Clipping on Crossed Wrapping Method for Ruptured Blood Blister-Like Aneurysm of the Internal Carotid Artery: Technical Note and Long-Term Results

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■ BACKGROUND: **We have been performing the clipping on crossed wrapping (COCW) method using 2 strips of cotton on patients with an internal carotid artery blood blister-like aneurysm (IC-BLA). This method is reliable in preventing the clips from slipping off and the aneurysm walls from being damaged during clipping, and it enables more appropriate and safer clipping. Here we report the technical details of this method and the long-term outcomes of patients receiving this procedure.**

■ METHODS: **Fifteen of 1275 (1.5%) patients with a ruptured cerebral aneurysm who received treatment at the Saiseikai Kumamoto Hospital during the period from January 1, 1999, to December 31, 2016, had an IC-BLA. All 15 patients were treated with COCW, except for the first patient, who was treated using a single strip of cotton. The long-term outcome of the treatment was analyzed.**

■ RESULTS: **The mean follow-up period was 74 months. The first patient experienced rerupture of an aneurysm 10 days after the operation. No complications or regrowth of an aneurysm were observed in the remaining 14 patients during the follow-up period, except for 1 patient who received a reoperation for the regrowth of an aneurysm. As the final outcome, the numbers of patients with a Modified Rankin Score of 0, 3, and 6 were 13, 1, and 1, respectively.**

■ CONCLUSIONS: **It is suggested that COCW is a treatment that enables safe and long-term management of lesions in IC-BLAs.**

INTRODUCTION

A blood blister-like aneurysm (BBA) found in the internal carotid artery (ICA) is relatively rare. It has been reported that BBAs account for 0.3% to 2.7% of intracranial aneurysms and 0.9% to 9.4% of ICA aneurysms.[1-7] The BBAs of the ICA (IC-BBAs) have been characterized by frequent reruptures and regrowth during and after surgery, generally resulting in poor outcomes.[4,5,8-11] This type of aneurysm appears to involve a process of arterial dissection for its formation, judging from some of the pathologic examinations.[12,13] Although diverse options have been proposed for the treatment of BBAs, including the endovascular method, as yet a unified standard treatment for BBA has not been established.[14] The interventional approach was deemed be a better prospect because of a recent technological innovation;[15-23] however, its long-term durability remains open

Key words
- Blood blister-like aneurysm
- Clipping on crossed wrapping
- Clipping on wrapping
- Direct surgery
- Internal carotid artery aneurysm

Abbreviations and Acronyms
3D-CTA: Three-dimensional computed tomographic angiography
AchA: Anterior choroidal artery
BBA: Blood blister-like aneurysm
COCW: Clipping on crossed wrapping
COW: Clipping on wrapping
CT: Computed tomography
IC: Internal carotid
ICA: Internal carotid artery
IC-BBAs: BBAs of the ICA
mRS: Modified Rankin Scale
PcomA: Posterior communicating artery
SAH: Subarachnoid hemorrhage

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Table 1. Characteristics, Treatment, and Outcome of 15 Patients with IC BBA

No.	Gender	Age (Years)	Location		Size of PcomA	H&K	Operation Date	Surgery	Rebleeding	Reoperation	mRS on Discharge.	GOS on Discharge.	Follow-Up Period (Months)	Final mRS
			Vertical	Horizontal										
1	M	53	C2 distal segment	Anterolateral	Large	Grade II	0	COW	+	–	6	DE	0	6
2	F	52	C1 communicating segment	Anterior	Large	Grade II	27	COCW	–	–	1	GR	205	0
3	F	53	C1-C2	Anterior	Small	Grade II	40	COW	–	–	2	MD	96	0
4	F	39	C1-C2	Anterolateral	Small	Grade II	7	COCW	–	–	1	MD	116	0
5	F	28	C1 communicating segment	Anterolateral	Small	Grade III	2	COCW	–	–	0	GR	174	0
6	F	52	C2 distal segment	Anterior	Small	Grade II	2	COCW	–	–	0	GR	71	0
7	F	62	C1-C2	Anterior	Small	Grade I	2	COCW	–	–	1	MD	87	0
8	F	50	C2 distal segment	Anterolateral	Small	Grade II	2	COCW	–	+	0	GR	50	0
9	M	39	C1 communicating segment	Lateral	Large	Grade I	8	COCW	–	–	0	GR	105	0
10	M	52	C1 communicating segment	Anteromedial	Small	Grade II	2	COCW with LFB	–	–	0	GR	60	0
11	F	57	C2 distal segment	Medial	Large	Grade III	3	COW with LFB	–	–	1	MD	70	0
12	F	41	C2 distal segment	Anterior	Small	Grade III	1	COCW with LFB	–	–	1	MD	25	0
13	F	30	C1 choroidal segment	Medial	Large	Grade I	3	COCW with LFB	–	–	2	MD	4	0
14	F	51	C1-C2	Medial	Large	Grade II	1	COCW with LFB	–	–	4	SD	2	3
15	F	42	C2 distal segment	Anterior	Large	Grade III	2	COCW with LFB	–	–	1	MD	8	0

The size of the posterior communicating artery was classified as "large" if it was drawn over the entire length in the 3D-CTA; otherwise it was classified as "small".

BBA, blood blister-like aneurysm; COCW, clipping on crossed wrapping; COW, clipping on wrapping; DE, dead; GOS, Glasgow Outcome Scale; GR, good recovery; H&K, Hunt & Kosnik; IC, internal carotid; LFB, low flow bypass; MD, moderate disablity; mRS, Modified Rankin Scale; SD, severe disablity; 3D-CTA, 3-dimensional computed tomographic angiography.

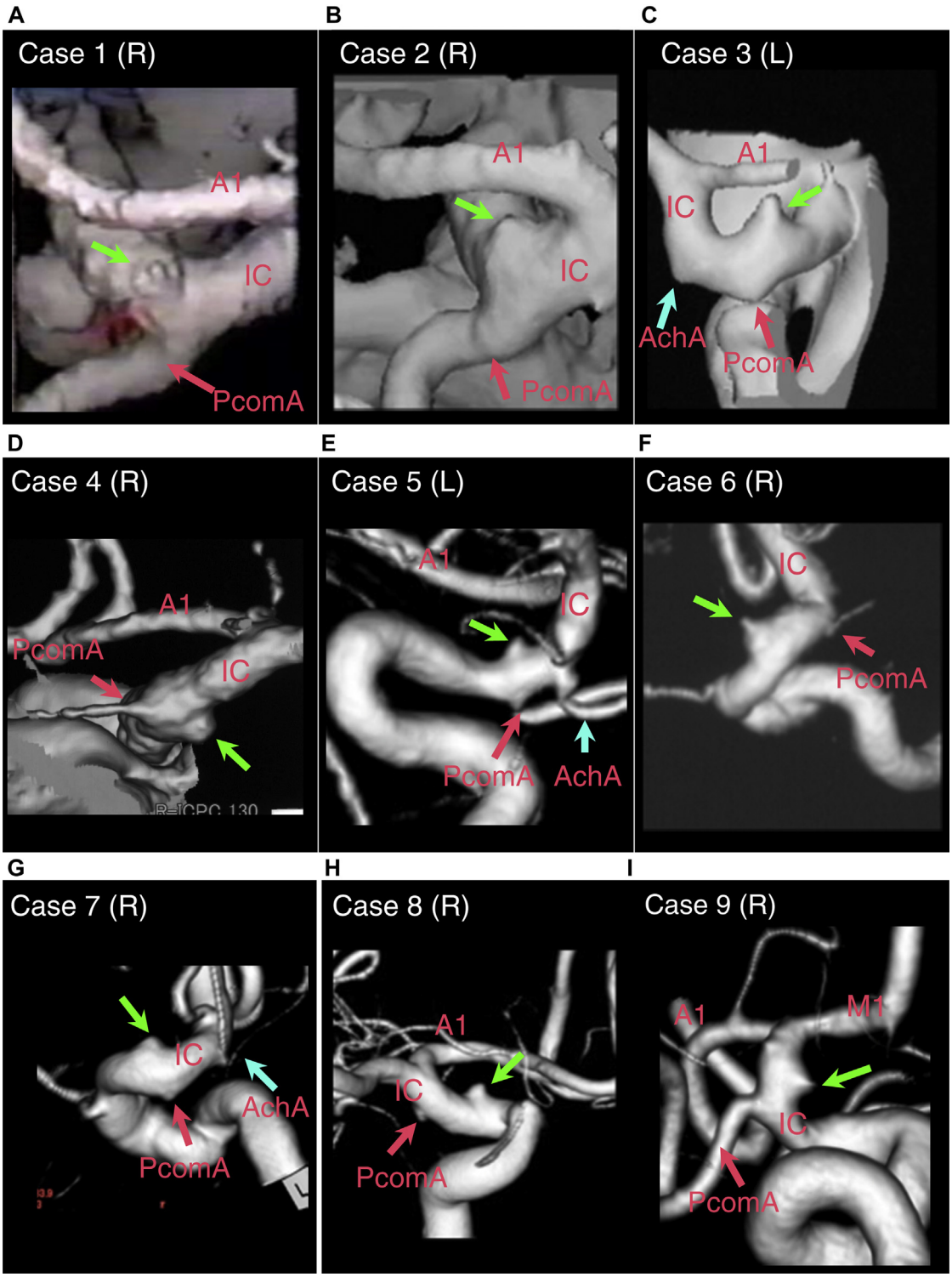

Figure 1. (**A**–**O**) Images of 3D-CTA or 3D-DSA of case 1 to case 15. A *green arrow* in each image indicates a blood blister aneurysm (BBA). The *red arrow* indicates the posterior communicating artery (PcomA), and the *blue arrow* indicates the anterior choroidal artery (AchA). (**P**) A schematic illustration of the left internal carotid artery (ICA) viewed from the left lateral side. Each *green thin, long arrow* indicates the site of a BBA in the individual case. A *bright red wizard-hat-like shape* indicates a BBA at the anterior or lateral wall of the ICA, whereas a *darker flat shade* indicates a BBA at the medial wall of the ICA. A1, first segment of the anterior cerebral artery.

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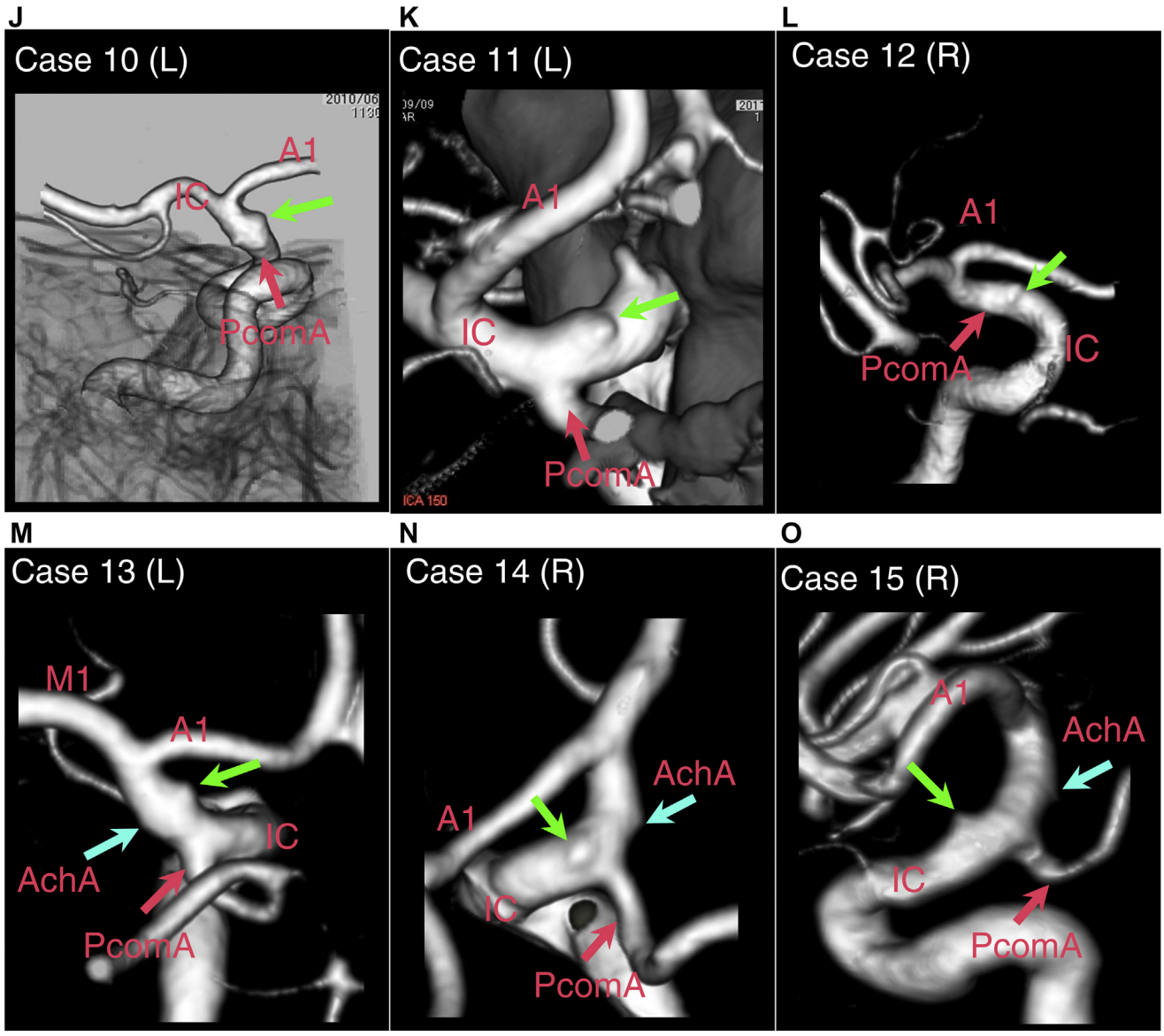


Figure 1. (Continued).

to debate. Several approaches to direct surgery have been proposed.[24-26] One of the procedures that use a metal clip to pinch the thin material wrapping the aneurysm is called clipping on wrapping (COW), or alternatively, the wrap-clip method.[25,27,28] Because the details of this procedure vary from institute to institute as to which material is used for wrapping,[29-32] it is difficult to evaluate accurate outcomes of this method as a single entity. Generally, the COW method that uses a single cotton strip to cover the aneurysm is widely accepted to provide adequate sealant effect for BBA while preserving blood flow in the ICA.[33] However, as this COW method relies on the indirect closure of the aneurysm, unlike direct clipping of the saccular form of aneurysm, a fear of regrowth and subsequent rerupture always remains. To improve the efficacy of this procedure, we have employed 2 strips of cotton, instead of 1, to cross-wrap the lesion, ultimately achieving a more robust and complete closure of the aneurysm. This procedure was given the unique name of "clipping on crossed wrapping" (COCW), and already the COCW method has been

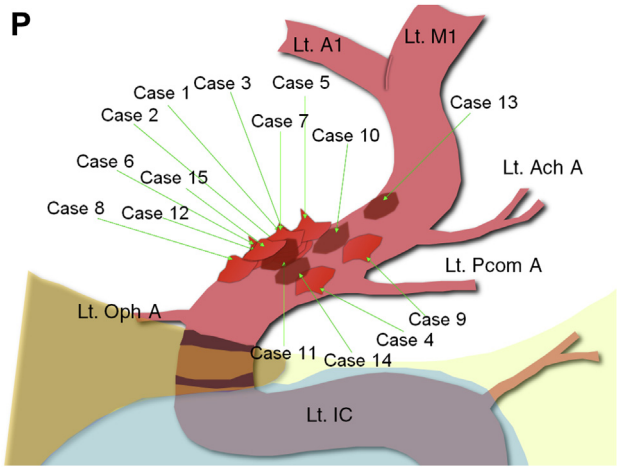


Figure 1. (Continued).

used for decades in our institution. Here, we report the technical details of COCW and the favorable long-term outcomes of the patients who received COCW.

MATERIALS AND METHODS

Patient Population

A total of 1811 patients, who presented with subarachnoid hemorrhage (SAH) at the Saiseikai Kumamoto Hospital during the period of 17 years from January 1, 1999, to December 31, 2016, were retrospectively analyzed. Among them, the source of bleeding was investigated and identified in 1347 patients (74.4%), and BBAs were identified as the bleeding source in 15 patients (1.5%). The male-to-female ratio was 1:4, and the mean patient age was 46.7 years, indicating that patients with BBA are younger than those with other types of aneurysm as shown previously.[34] All 15 patients were treated with the COCW method, except 1 patient who was treated with COW.

Table 1 shows the summary of general characteristics of each case, such as BBA location, size of the BBA, neurologic grade, method of surgery, and outcome. Figure 1 shows a series of 3-dimensional angiograms depicting the BBA on the ICA (green arrow: BBA). As for the vertical distribution, the cases involved the C1 choroidal segment (n = 1), the communicating segment (n = 4), the C1-C2 junction (n = 4), and the C2 distal segment (n = 6). As for the horizontal distribution, the cases involved the anterior wall (n = 6), the anterolateral wall (n = 4), the anteromedial wall (n = 1), the lateral wall (n = 1), and the medial wall (n = 3). With regard to the morphologic classification of IC-BBAs, 4 types (types I, II, III, and IV) have been reported.[28] According to this classification, all of the BBAs that we encountered were considered as either type I, II, or III; there was no type IV BBA in our group. The timing of surgery ranged from 0 to 40 days from the onset of SAH. The first patient was treated with the unmodified COW method using a single strip of cotton, and the subsequent 14 patients were treated with COCW using 2 strips of cotton sheet to wrap around the lesion. A combination of cross-wrapping with low-flow bypass was used in the 6 later cases.

RESULTS

Surgical Procedures

Figure 2A–G shows the detailed steps of the COCW method. The large diagram (Figure 2A) shows the lateral view of BBA at the anterior wall of the C1-C2 junction of the left ICA. A superficial temporal artery to middle cerebral artery anastomosis was performed following the transsylvian approach as a precaution for the unexpected obstruction of the ICA's blood flow. Furthermore, the ipsilateral cervical carotid bifurcation was surgically exposed in case of proximal control of IC flow for all cases except a case involving a BBA at C1. The subarachnoid spaces of the Sylvian fissure were dissected from distal to proximal segment as widely as possible to expose all the anatomical structures, including the ICA, the anterior cerebral artery, and the middle cerebral artery. Under proper proximal control, a whole aspect of the BBA was exposed by clearing the blood clot over the ICA/BBA (Figure 2B). If the BBA should rupture during the surgery, the bleeding could be controlled by severing the IC at the proximal and distal side of the

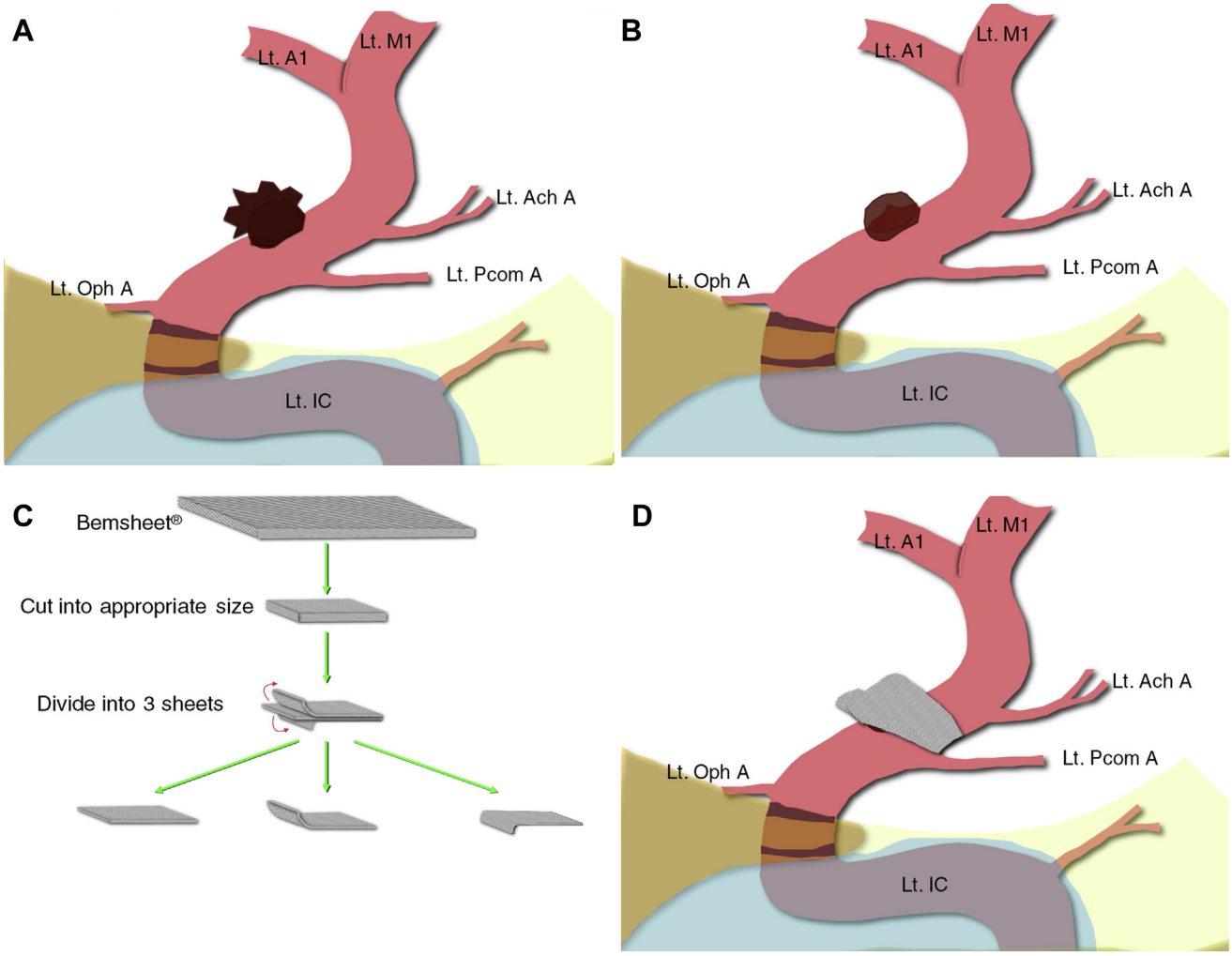


Figure 2. The procedures of clipping on crossed wrapping (COCW) are shown in a series of illustrations. (**A**) An imaginary blood blister aneurysm (BBA) is shown at the C1-C2 junction in the left internal carotid artery (ICA). The blood clot is seen on the BBA. (**B**) The blood clot was removed from the surface of the BBA as much as possible. (**C**) An illustration shows a preparation process of cotton strips used in COCW. First, a large sheet of cotton was cut into appropriate sizes; then each sheet was further separated into 3 layers to make a cotton strip for actual wrapping. (**D**) The BBA on the ICA was wrapped by a cotton strip starting from the distal side of the posterior communicating artery (PcomA). (**E**) The second strip of cotton is wrapped around the ICA from the proximal side of the PcomA. (**F**) After the entire lesion of ICA-BBA was covered with the 2 strips of cotton, a clip was used to pinch the over-wrapping cottons as well as the healthy portion of the arterial wall while the ends of the cotton strips were being pulled toward the direction of the *fat red arrow*. (**G**) A figure of the final step shows that the clip was placed in the appropriate position to include the right amount of the artery wall (notice: slightly shifted position of the clip), avoiding the constriction of the ICA. (Continues)

BBA by a couple of temporary clips, and if necessary, severing the cervical IC as well. Before wrapping the lesion, appropriately sized cotton sheets were separated into 2 to 3 layers for the actual usage (Figure 2C). Then, the BBA-bearing segment of the IC was enveloped by each cotton strip in a crossing manner. If the BBA was found at the contralateral side of the origin of the main arterial branch, such as the posterior communicating artery (PcomA) or the anterior choroidal artery (AchA), it was wrapped with the first strip of cotton from the distal side and a second strip of cotton from the proximal side. Thus, each cotton strip was crossed over between the distal side and the proximal side of the artery (Figure 2D and E). After the entire lesion had been wrapped around by 2 layers of the cotton, the 4 ends of 2 cotton strips were pulled together with an adequate strength so as not to loosen the knot. A metal clip was placed onto the cotton strips perpendicular to the ICA to fasten the knot (Figure 2F). During this step, the clip blades pinched a certain segment of cotton underneath which a small volume of healthy artery wall remained. Thus, it should achieve a minimal but tangible constriction of the ICA to tighten the seal of the BBA, to the extent that the flow of the

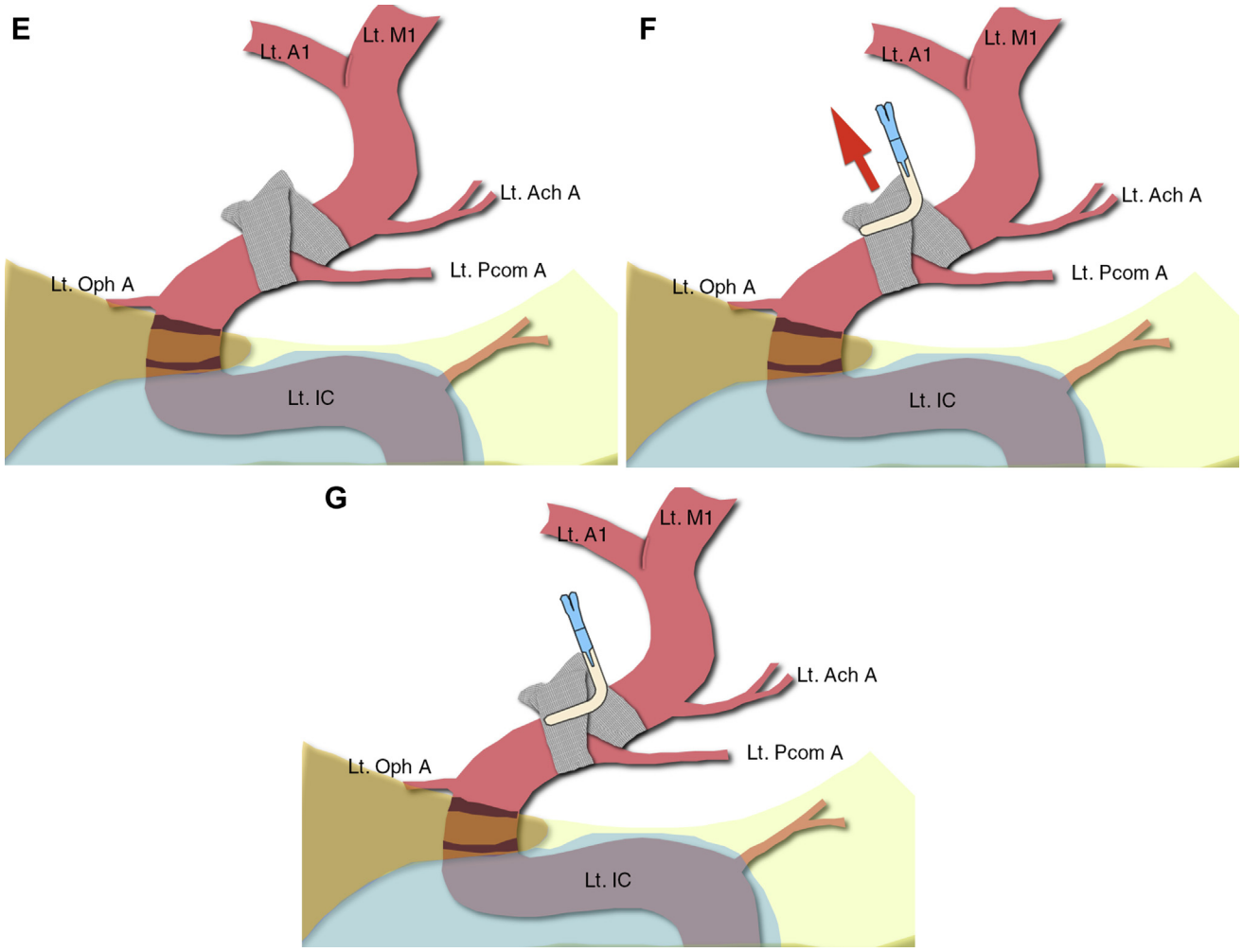


Figure 2. Continued

ICA was not too disturbed (Figure 2G). If a BBA faced the medial side, such as the backside of the ICA, the procedure became problematic, because the pulling action of the cotton had to be performed on the blind side (opposite direction from the view point). So, the closure necessitated a fenestrated clip. Because of those physical limitations, the maneuver required some special steps, such as follows: 1) the cross-wrapping cotton strips were pressed on the intact arterial wall at the far side of the BBA by the blades of the unfastened fenestrated clip, 2) the blades were gradually being slid toward the BBA-bearing side (medial side of the IC) with the adequate downward pressure to hold the tight adherence between the cotton and the arterial wall, and 3) the blades were finally closed at the adequate position under which a healthy volume of the intact arterial wall alongside the BBA remained (Figure 3, case 13). After successful clipping, an excess of cotton was cutoff as much as possible for negating its allergic effect. The absence of BBA regrowth was confirmed with either a 3-dimensional computed tomographic angiography (3D-CTA) scan or a cerebral angiography before discharge.

CASE PRESENTATIONS

Case 1 (Figure 4): A 53-year-old man, whose initial 3D-CTA had shown SAH and a BBA at the C1-C2 junction of the right ICA, received surgery on the same day of onset. First, the right ICA and then the BBA on which a blood clot was left unremoved (red arrow) were exposed. The COW method was performed using a single strip of cotton. Initially, the postoperative clinical course had been favorable, but the patient died of a recurrent SAH on day 10. Neither a postmortem brain scan nor an autopsy was performed. The intraoperative video raised some technical issues that might have been the culprits: 1) the removal of the blood clot over

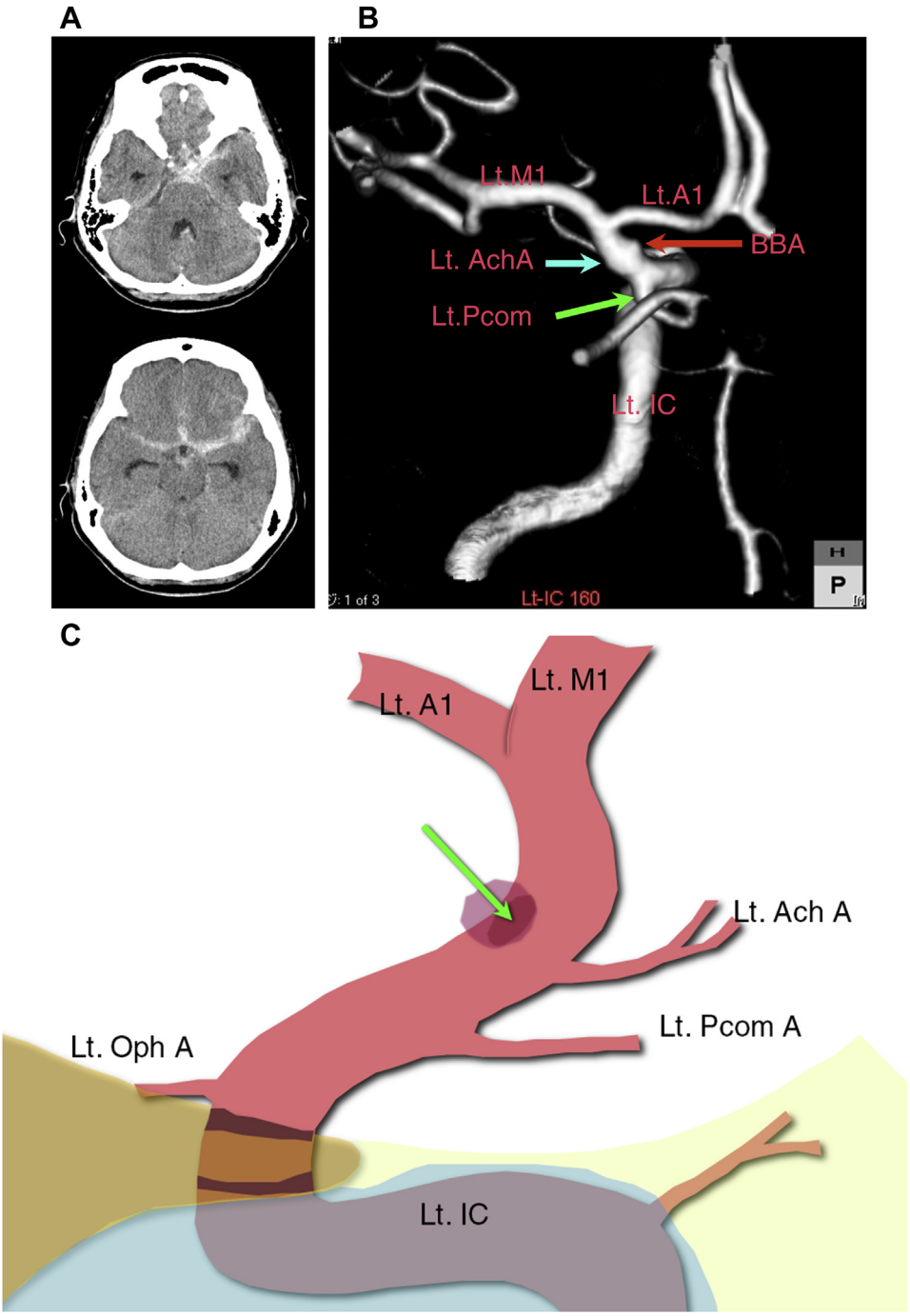


Figure 3. *Case 13.* A 30-year-old woman had a rupture of a blood blister aneurysm (BBA) on the medial side of the internal carotid artery (ICA). (**A**) An initial computed tomography scan showed diffuse subarachnoid hemorrhage. (**B**) A 3D-DSA image showed a BBA (*red arrow*) on the medial side of the left ICA at the contralateral side of the origin of the left anterior choroidal artery (AchA) (*blue arrow*). The origin of the left posterior communicating artery (Pcom) is also indicated (*greeen arrow*). (**C**–**G**) The schematic figures depict the left ICA viewed from the lateral side, where an orifice of BBA is located at the medial side of ICA (**C**: *green arrow*). The BBA was wrapped with cotton strips at (**D**) proximal and (**E**) distal sides of the AchA. Using a (**F**) fenestrated clip, (**G**) clipping on crossed wrapping was performed. (**H**) A temporary clip was placed at C2 portion of the left ICA (*green arrow*), and then a first cotton strip (*green arrow head*) was wrapped over the IC-BBA (*red arrow*) at the proximal side of the AchA. (**I**) Another cotton strip was wrapped over the IC-BBA at the distal side of the AchA (*green arrow head*) to cover the entire BBA; then, the blades of a fenestrated clip (*green arrow*) were placed on the crossed wrapping. (**J**) Completion of COCW is shown. (**K**) Blood flow of the posterior communicating artery (PcomA) (*green arrow head*) and AchA (*green arrow*) was confirmed. (**L**) Four months after surgery, a 3-dimensional computed tomographic angiography image showed no recurrence. A1, first segment of the anterior cerebral artery; COCW, clipping on crossed wrapping; M1, first segment of the middle cerebral artery; Oph A, ophthalmic artery; 3D-DSA, Three-dimentional digital subtraction angiography. (Continues)

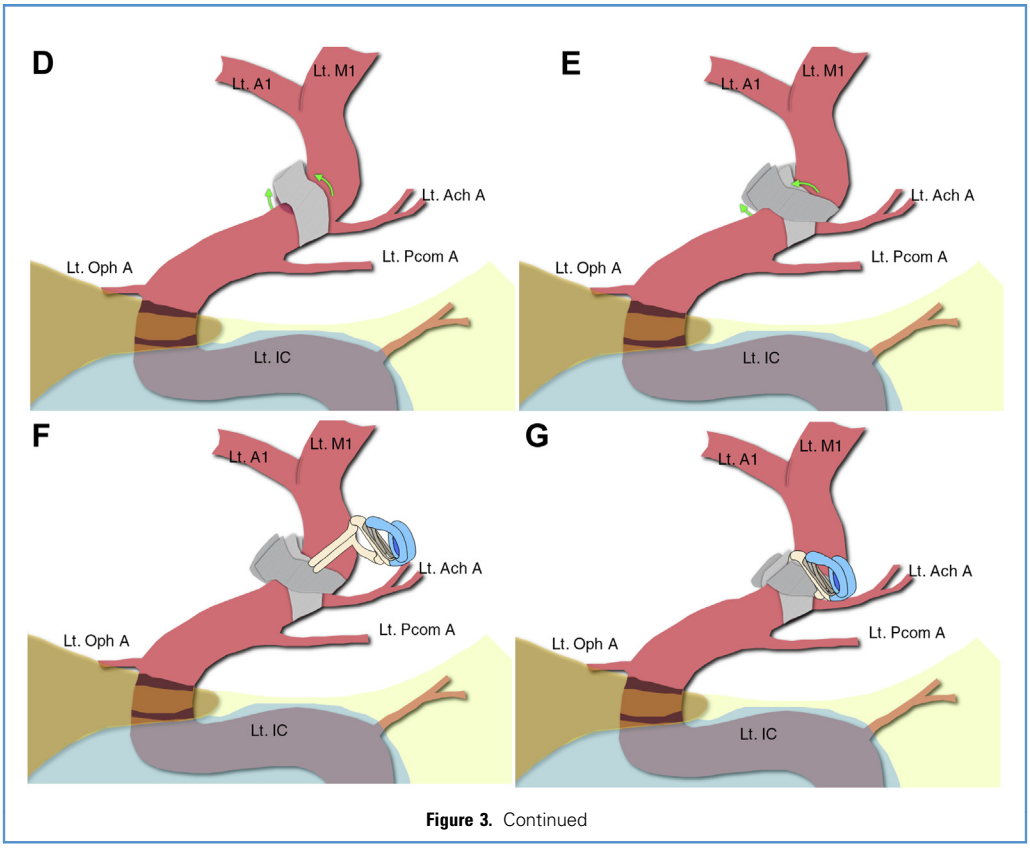


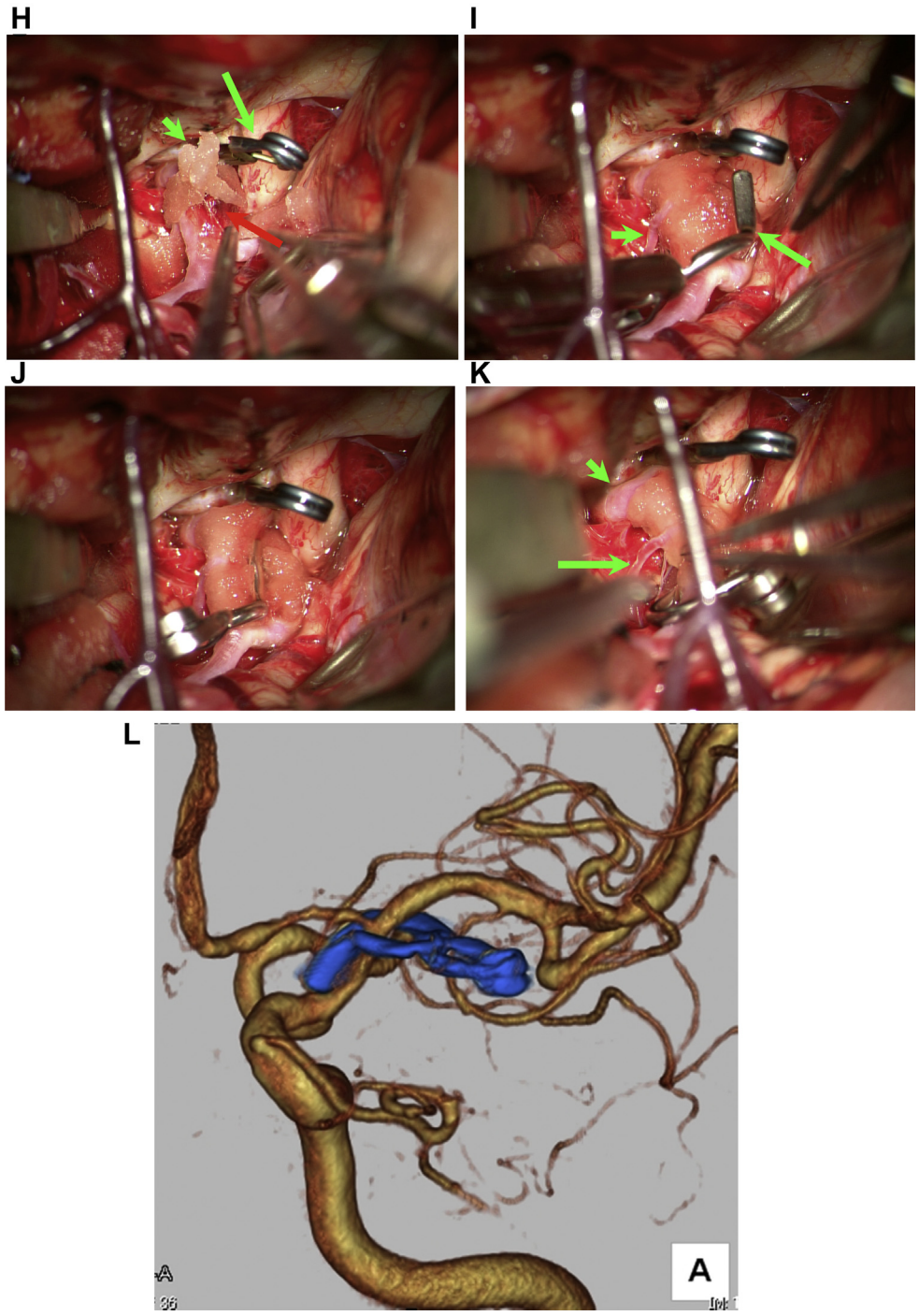
Figure 3. Continued

the BBA seemed inadequate, 2) the single cotton strip might not have been large enough for the complete wrapping of the entire BBA, and 3) the clip seemed to have pinched only the cotton but not enough artery wall, which might have resulted in the incomplete closure of the BBA. This unfortunate case provided an invaluable experience; therefore, we decided to adopt an improvised version of COW, the COCW method, for the subsequent cases.

Case 2 (**Figure 5**): A 52-year-old woman, whose initial CT/3D-CTA had demonstrated severe SAH in the right basal cistern (A) and a BBA at the contralateral side of an origin of PcomA (B), received surgery on day 27 from the onset. The BBA was exposed, but the blood clot on the BBA was left (C: red arrow). The 2 strips of cotton were crossed around the origin of the PcomA to wrap the IC/BBA, first at the proximal side (D: green arrow), and then at the distal side (E: green arrow). Hence, the entire lesion of BBA was covered with the 2 "cross-wrapping" strips of cotton. Then, a Sugita straight clip was applied at the ideal position on the cotton strips that were being pulled with a constant force by forceps (F). The postoperative clinical course has been good, as a 3D-CTA at 205 months from the onset showed no recurrence of BBA (G).

Case 8 (**Figure 6**): A 50-year-old woman, whose initial CT/Three-dimentional digital subtraction angiography had demonstrated diffuse SAH (A) and a BBA at the anteroexterior wall of the C2 level of the right IC (B: red arrow), received surgery using the COCW method on day 2 from the onset (C). The postoperative clinical course was uneventful, but a 3D-CTA on day 16 showed a regrowth of the BBA (D: red arrow). The initial COCW appeared to be insufficient for the closure of the entire BBA, especially at the proximal side of the BBA (E). Thus, the patient underwent an additional surgery with COCW. First, the previous clip was removed, and then an additional strip of cotton was applied to wrap the proximal side of PcomA to cover the entire BBA. Then, a clip pinched the 3 layers of the cotton as an additional COCW procedure (F). Her clinical course has been favorable, as a 3D-CTA at 50 months after the reoperation showed no recurrence of the BBA (G).

Case 13 (**Figure 3**): A 30-year-old woman, whose initial CT/3D-CTA had demonstrated severe SAH in the left basilar cistern (A) and a BBA facing the medial side at the C1 portion of the left IC (B: red arrow) with a fetal type PcomA (B: green arrow), received surgery on day 3 after onset. Simple schematic drawings show the step-by-step procedures of the surgery for the BBA, including the relationship between the BBA and the main branches of the PcomA/AchA (**Figure 3C–G**). First, a left transsylvian approach was performed to expose the whole structures around the ICA including the BBA (H: red arrow), AchA (I: green arrow head), and PcomA (K: green arrow head). The orifice of the BBA was located on the contralateral side of the origin of the left AchA (C: green arrow, H: red arrow). A temporary clip was applied to the proximal side of the ICA (H: green arrow). COCW was performed for the BBA by crossing the 2 strips of cotton over



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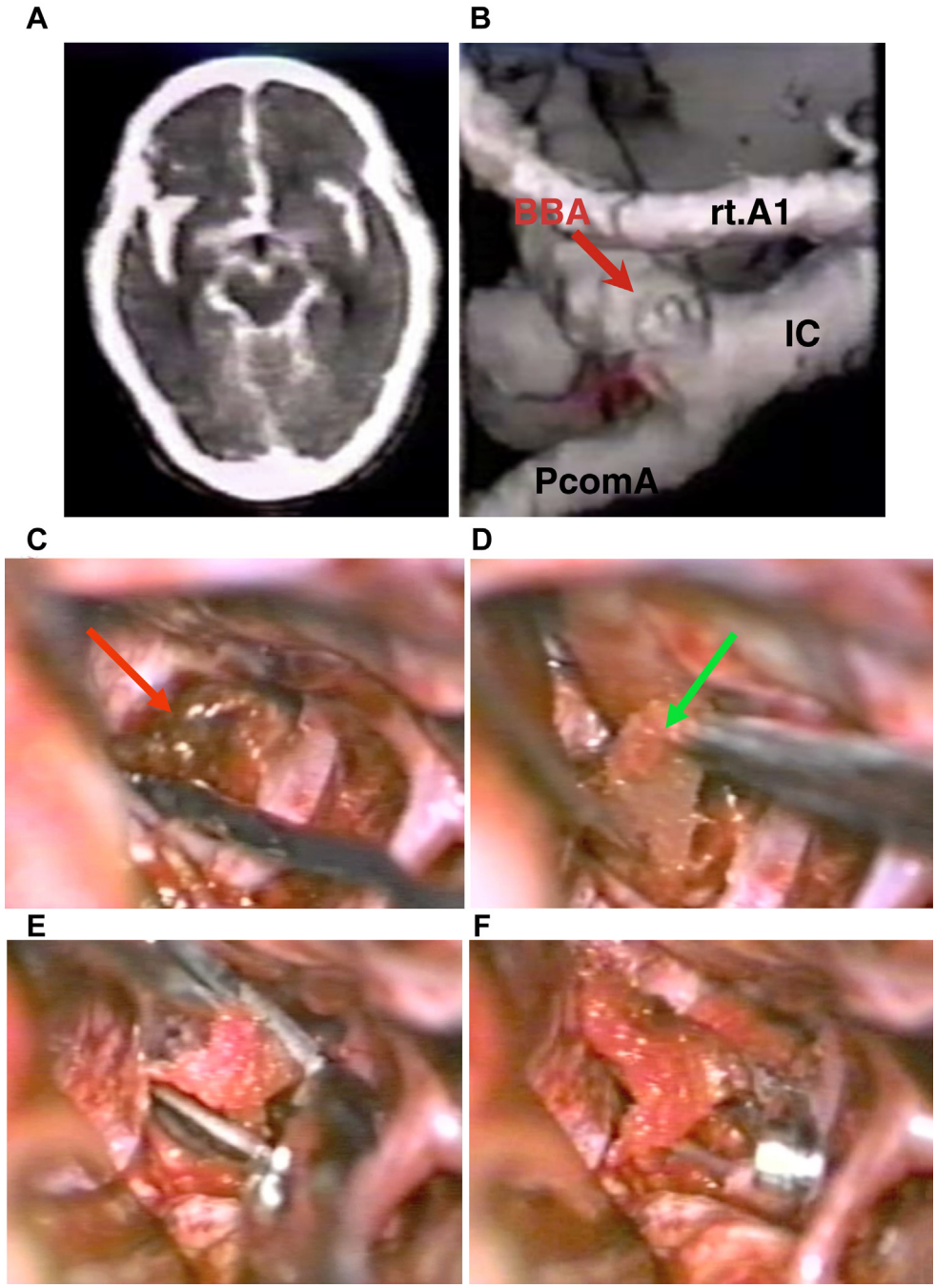

Figure 4. *Case 1*. A 53-year-old man underwent surgery for a blood blister aneurysm (BBA) on day 10 of subarachnoid hemorrhage (SAH). (**A**) A brain computed tomography image on admission showed diffuse SAH. (**B**) The 3-dimensional computed tomographic angiography image before surgery indicated a BBA just proximal to the origin of the posterior communicating artery (PcomA) (*red arrow*). (**C**) The BBA is exposed, but a blood clot is still sitting on the surface (*red arrow*). (**D**) The BBA is being wrapped with a single cotton strip (*green arrow*). (**E**) The BBA is being clipped over the cotton strip. (**F**) A picture taken after completion of the clipping operation. (**G**) An illustration explained the cause of the rerupture as a postoperative analysis of the surgical video showed that a single strip of cotton seemed insufficient to wrap the whole BBA, especially for the extreme proximal end of the BBA in this case (*green arrow*). A1, first segment of the internal cerebral artery; IC, internal carotid artery. (Continues)

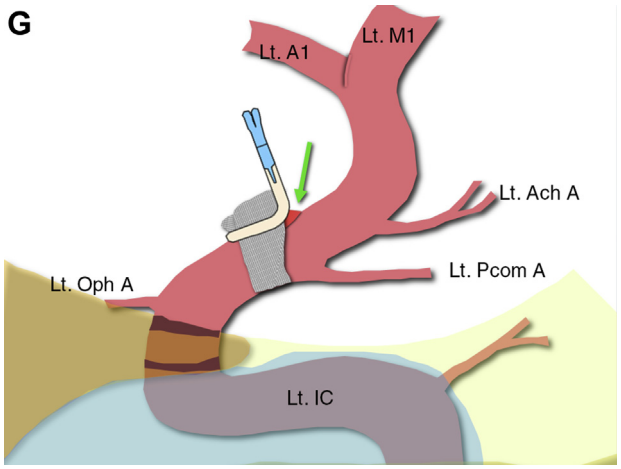

Figure 4. Continued

the proximal side (D, H: green arrow head) and distal side (E, I green arrow head) of the AchA. The BBA was pinched over the main trunk of the ICA (G, I: green arrow head) using a fenestrated clip with sideward bended blades (F, I: green arrow). The complete closure of the BBA was achieved, whereas the blood flows of the PcomA (K: green arrow head) and the AchA (K: green arrow) were adequately preserved. The postoperative clinical course has been favorable, and a 3D-CTA at 4 months after the surgery showed no recurrence of a BBA (L).

Surgical Outcomes

A mean follow-up period was 74 months with a range of 7 to 204 months (Table 1). A patient (case 1) who received a COW surgery using a single strip of cotton died after rerupture of the BBA 10 days after the initial surgery. Another patient (case 8) received a reoperation of COCW after the regrowth of BBA was noticed before discharge. Despite this incident, the patient has been in good condition (Modified Rankin Score [mRS]: 0) for 50 months without any recurrence of BBA. A regrowth of a BBA was not observed in other patients, and no patient showed symptomatic stenosis or obstruction of the ICA. Furthermore, no patient showed granulation or cerebral edema in and around the vicinity of the lesion, which suggested that no, or a negligible, allergic reaction had occurred to the cotton used in the COCW method. The outcomes of those patients were assessed by the Glasgow Outcome Scales (good recovery, moderate disability, severe disability, dead) and the mRS (mRS: 0–6). The following GOS and mRS at hospital discharges were noted (good recovery: n = 6; moderate disability: n = 7; severe disability: n = 1; dead: n = 1/mRS 0: n = 5; mRS 1: n = 6; mRS 2: n = 2; mRS 4: n = 1; mRS 6: n = 1) with comparison with the improved outcomes at the end of the follow-up period (mRS 0: n = 12; mRS 3: n = 1; mRS 6: n = 1).

DISCUSSION

There are several reasons for the difficulties with the treatment of IC-BBA.[9,12] The prime reason lies in the strenuous physical properties of BBAs. Because most IC-BBAs are associated with a dissection-related disorder, the angiography of BBAs tends to show a barely noticeable small bulge,[3,7] and the shape of the BBA often lacks the neck-like segment that allows for conventional clipping.[3,12] Also, the ICA itself, a parental artery of the BBA, has difficult properties such as a torturous curved course, which creates cramped workable space surrounded by important brain structures. In addition, the BBAs often involve the bifurcation of the indispensable but fragile PcomA or AchA, and the BBAs are widely distributed both vertically and horizontally. Those technical difficulties have impeded a unified therapy scheme to be implemented for the treatment of BBAs.[3,6,14]

There are 2 approaches to treat BBAs, such as endovascular or direct surgery (Table 2).[7,18,22,35] The number of reports using the endovascular method have been increasing because of the recent improvement of medical equipment such as a flow diverter.[11,15-17,19-21,36-43] Previous studies comparing the 2 approaches found higher risk in the direct surgeries including accidental IC occlusions, albeit higher recurrence rate and more frequent reoperation in the endovascular treatment.[18,22,37,44-46] Despite those reports, because the technical details of direct surgery vary widely by institution,[22,25,27] it seemed to be unrealistic to compare the treatment efficacy of these methods collectively.

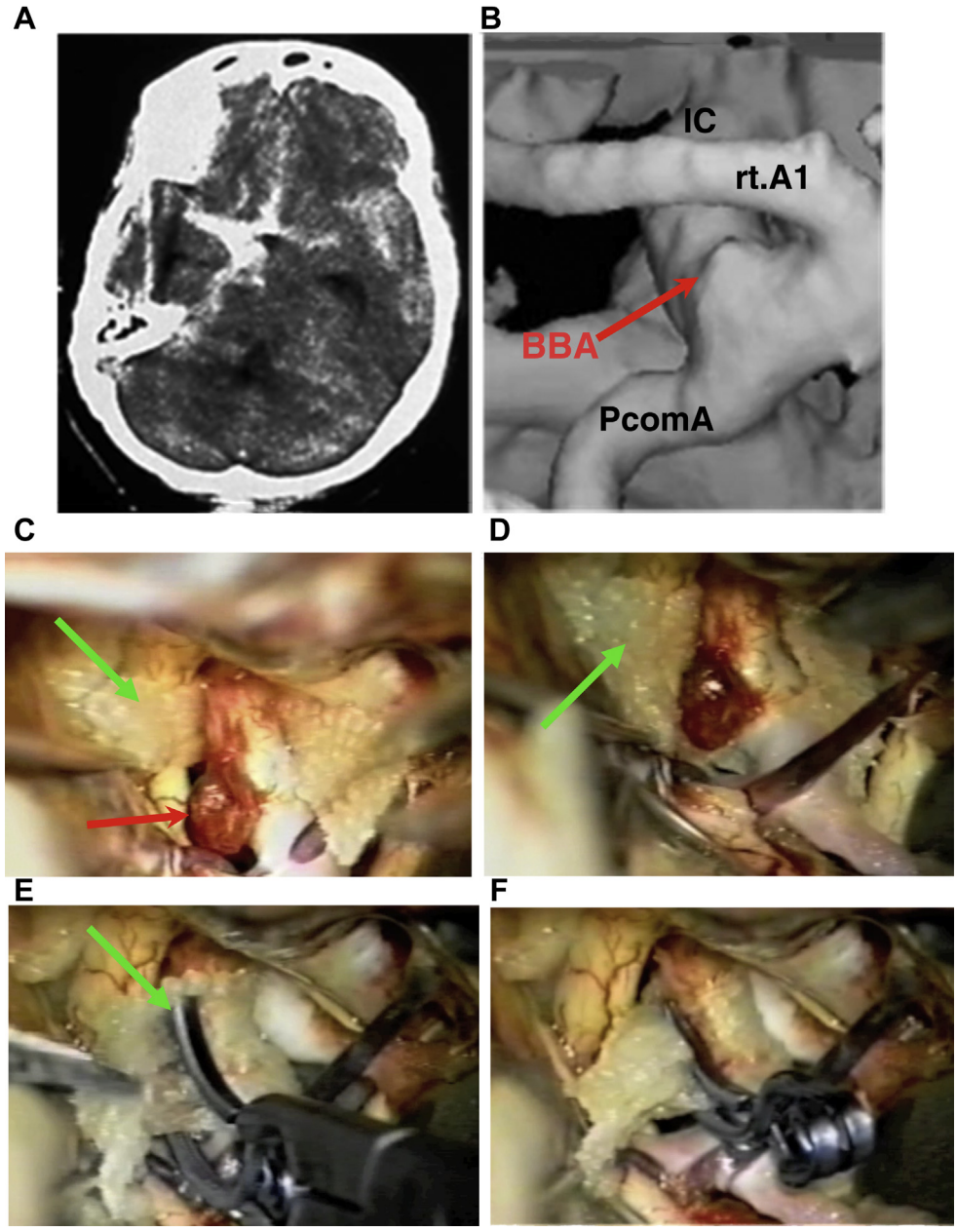

Figure 5. *Case 2.* A 52-year-old woman was the first patient who received a clipping on the cross-wrapping cotton (COCW). (**A**) A head computed tomography scan on admission showed diffuse subarachnoid hemorrhage. (**B**) A 3-dimensional computed tomographic angiography (3D-CTA) image showed a BBA in the right internal carotid artery (ICA) just proximal to the origin of the posterior communicating artery (PcomA) (*red arrow*). (**C**) The blood blister aneurysm (BBA) was exposed and the blood clot was left on its surface (*red arrow*). The BBA was wrapped with the first strip of cotton from the proximal side of the PcomA (*green arrow*). (**D**) The BBA was wrapped with a second strip of cotton from the distal side of the PcomA (*green arrow*). (**E**) The vessel wall is being pinched with a clip blade (*green arrow*) while pulling the 4 ends of cotton strips by forceps. (**F**) The COCW procedure is completed. (**G**) Two hundred and five months after the surgery, a 3D-CTA image showed a slight stenosis of the ICA, but no recurrence of BBA. A1, first segment of the anterior cerebral artery. (Continues)

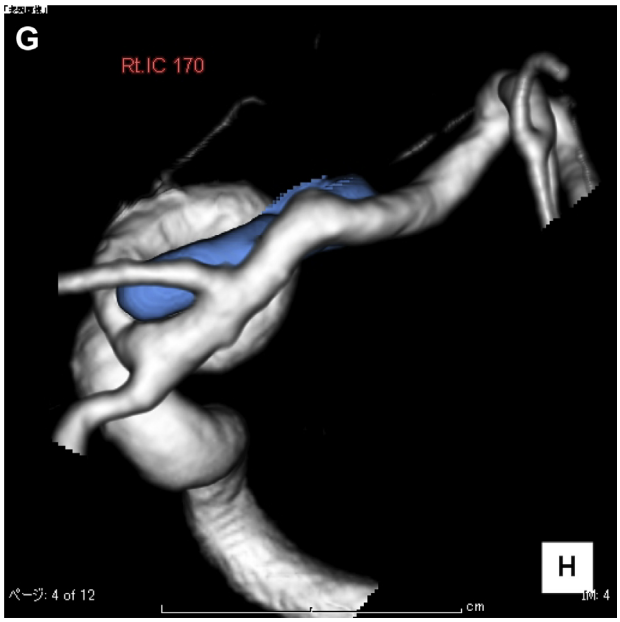

Figure 5. Continued

Direct surgeries are roughly classified into the following 2 groups: one that prevents rerupture by occlusion of the ICA together with the BBA or one that seals the BBA without compromising the ICA's blood flow.[3,47] If treatment involves occlusion of the ICA, often a high-flow bypass is required.[48-52] Although the bypass surgeries involve complex maneuvers with considerable risks, the trapping of the BBA itself is a straightforward and simple procedure. However, it should be noted that the retrograde blood flow from the bypass has to be able to maintain sufficient blood supply to the vital PcomA and AchA (**Figure 7A**). If the PcomA originating from the distal side of the trapped segment of the ICA was large enough to allow the retrograde flow, blood supply to the AchA territory would be sufficient (**Figure 7B**). On the other hand, if the PcomA was hypoplastic, trapping might create insufficient blood supply in the AchA to cause catastrophic infarction (**Figure 7C**).[52] In fact, a study reported that a higher rate of ischemic complications often occurred during the surgery with trapping, especially if the operation was performed at the concurrent period of vasospasm.[50] There has been a general consensus that occlusion of large vessels in the acute phase of SAH is not recommended in any situation because of the expected poor prognosis.[5] Furthermore, the actual clinical experiences showed that it was indeed difficult to perform trapping of IC and simultaneously maintain good blood flow of the branching arteries, if the BBA was located at the C1 portion of the ICA involving the origin of the PcomA and AchA.[27,52]

In our cases, analysis of sizes of PcomAs and distributions of BBAs showed that the PcomAs were hypoplastic in 8 patients, and the BBAs were found at C1 in 5 patients (**Table 2**). These findings indicated that a combination of trapping with adequate bypass surgery might have been suitable for only 4 of the 15 patients, which suggests the limitation of the trapping method for preserving the flow of branching arteries.

Hence, the core of a method that enables durable closure of the BBA as well as preserving ICA flow has to be clipping. When a BBA is treated with clipping, it is necessary 1) to pull intact vessel walls close to each other by pinching them over the fragile aneurysm dome and neck and 2) to prevent clip blades from slipping off after pinching.[2,3,8,28] If these 2 conditions were satisfied, a BBA could be repaired by a simple clipping without the procedure of wrapping as reported in several studies.[4,7,25,26,28,53-56] There have been reports of other methods, including a method of directly suturing a BBA alone[57] or a method of suturing the BBA followed by clipping to augment the closure.[53,58,59] Bojanowski et al[28] classified the IC-BBAs into 4 types based on their morphology, and then chose an appropriate method, either a clipping only or a COW, according to its classification.

Such a clipping method requires removal of the blood clot adhering to the ruptured site as much as possible to make the

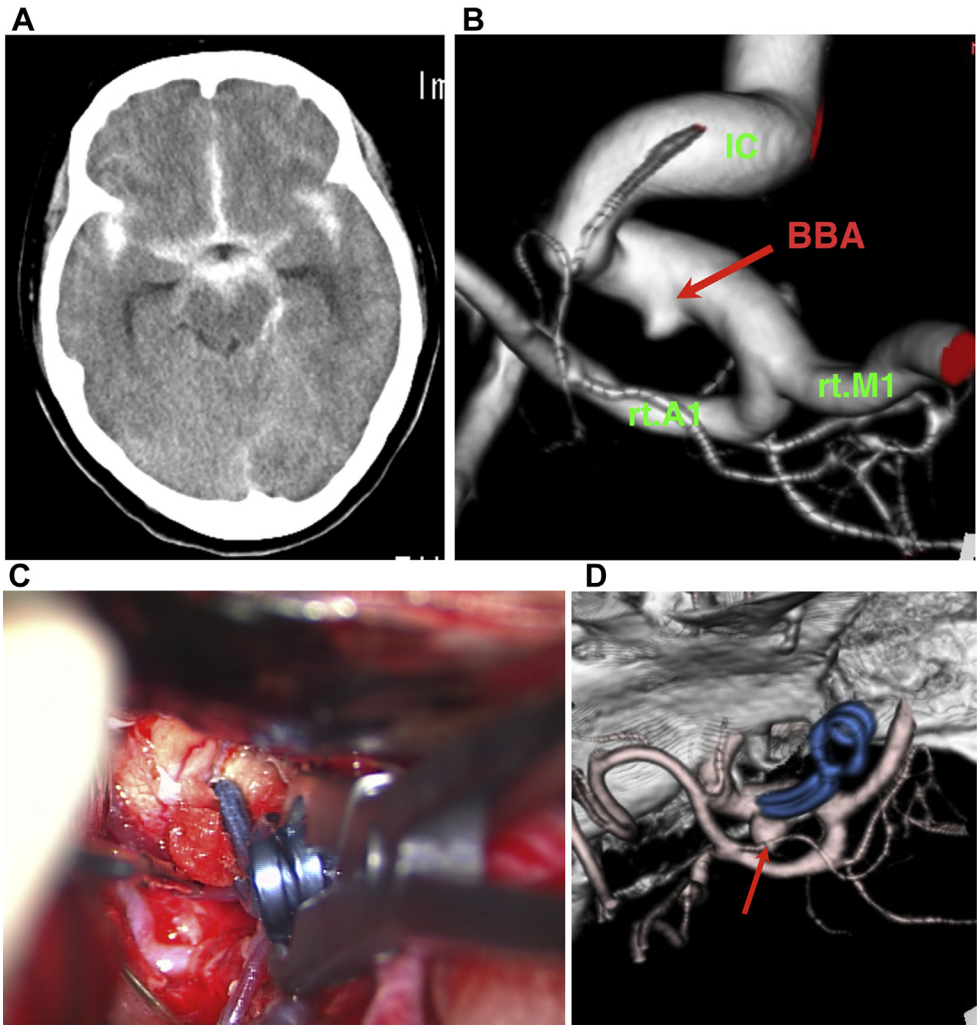

Figure 6. *Case 8.* A 50-year-old woman required reoperation. (**A**) A head computed tomography scan on admission showed diffuse subarachnoid hemorrhage. (**B**) A 3D-DSA image showed a blood blister aneurysm (BBA) on the anterior side of the C2 portion of the right internal carotid artery (ICA) (*red arrow*). (**C**) Clipping on crossed wrapping (COCW) was performed by wrapping the BBA from the proximal and the distal sides of the posterior communicating artery (PcomA). (**D**) A 3D-DSA image on day 16 showed a regrowth of the BBA beside the tip of a clip blade (*red arrow*). (**E**) A schematic figure of the regrown BBA (*red arrow*) shows insufficient wrapping of the BBA at the proximal side. (**F**) An additional COCW was performed in the reoperation; the first clip was removed, and then an additional strip of cotton was wrapped around the ICA/BBA at the proximal side of the PcomA, and the vessel wall was pinched with a larger clip to complete the closure of the BBA. (**G**) Fifty months after the surgery, a 3-dimensional computed tomographic angiography image showed no recurrence of BBA. A1, first segment of the anterior cerebral artery; M1, first segment of the middle cerebral artery; 3D-DSA, Three-dimentional digital subtraction angiography. (Continues)

entire lesion and a whole aspect of the BBA directly observable. To do so, both considerable expansion of the operative field and proper proximal control are required to safely exfoliate the thick clot to expose the ruptured BBA.[28] Also, it is imperative to achieve difficult tasks to avoid stenosis/occlusion of the ICA and not to rupture the BBA at the same time during this type of clipping. Although pinching a substantial portion of the intact artery wall may cause stenosis or occlusion of the ICA, pinching too shallowly for fear of stenosis may increase the risk of rupturing the BBA by letting the clip slide off.[3,4,9,26,55]

Therefore, the idea of combining clipping and wrapping arises. An array of techniques to perform COW have been

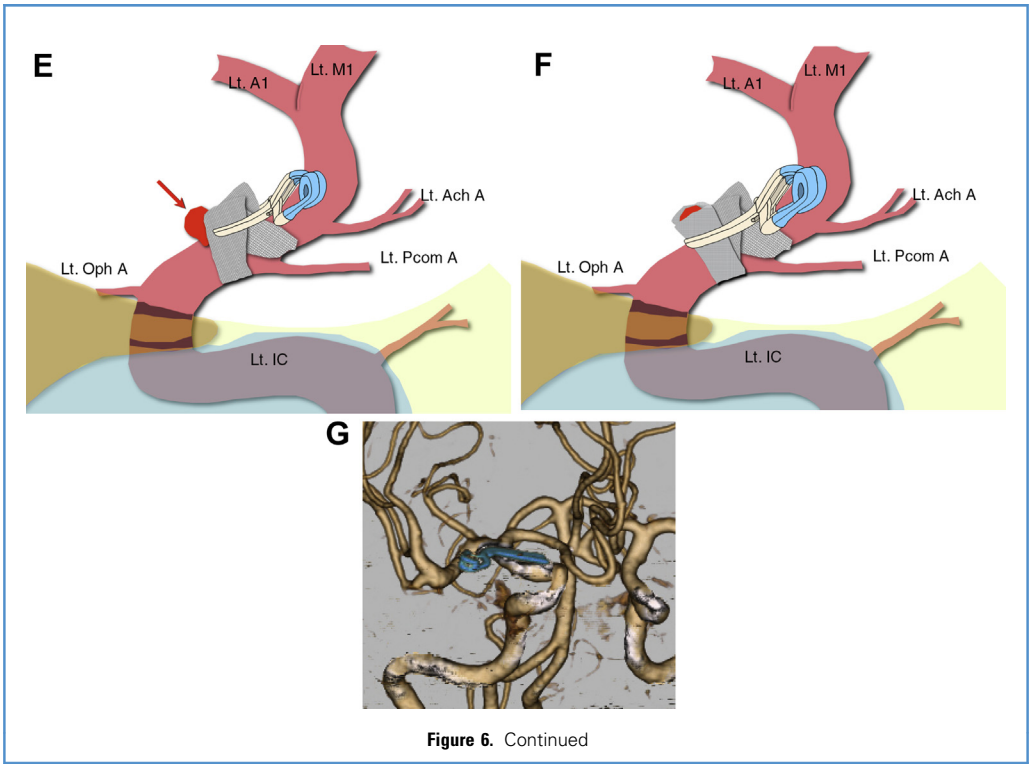

Figure 6. Continued

proposed;[9,10,25,27-30,33,44,60-64] however, it is difficult to evaluate the efficacy and outcomes of these methods as a single entity. For example, some groups used clipping to fixate only wrapping material covering the BBA without including the artery wall.[30,32] It is not ideal to use an elastic material such as fascia, cotton, or polyglycolic acid sheet (Neoveil; Gunze, Osaka, Japan) to cover a fragile BBA, which is being constantly stressed by a high pressure of ICA, without a strong physical pressure.[9,30,63] It might be better, strength-wise, if a less elastic material such as an expanded polytetrafluoroethylene sheet (Gore-Tex; W.L. Gore and Associates, Inc., Flagstaff, Arizona, USA) was used for wrapping.[25,65] However, the ICA is not straight, and as its diameter varies as it ascends, it is difficult to adhere a nonelastic material tightly to the lesion. Even a slight gap between the BBA's wall and the wrapping material may allow the BBA to regrow.[63] Furthermore, it is technically very difficult to wrap a rigid material around a lesion that involves a complex shape where the origin of the PcomA or AchA arises. Therefore, the ideal treatment has to involve a fine-tuned clipping to create just enough adherence between the wrapping material and the BBA.[27] To satisfy all of the demanding issues mentioned here, we incorporated many tweaks into our own COCW procedure. By using 2 strips of cotton, instead of a single strip, and also crossing them over the proximal origin of PcomA or AchA to envelop the entire BBA on the ICA, the procedure permits less deformation of the ICA that may disrupt the flow of the branching arteries. Also, it allows the end of the strips to be pulled much harder for a better closure, and it enables the clip blades to land in a more appropriate location without fear of slipping off or obstructing their blood flow. The most difficult BBAs for this method are the ones occurring at the medial aspect of the ICA, where the tight cisternal space impedes the pulling action of cotton necessary to maintain a tight grip of the ICA during the closure of the clip. Despite this limitation, as shown in the presentation of case 13, COCW was safely performed for this type of BBA with the help of a fenestrated clip. Likewise, Garrett and Spetzler[27] reported a modified COW by making a cut to the wrapping material to facilitate preserving blood flow to the branching artery while achieving robust closure of the BBA.

The biggest concern about the use of cotton strips is a possible allergic reaction that induces granulation around the ICA to

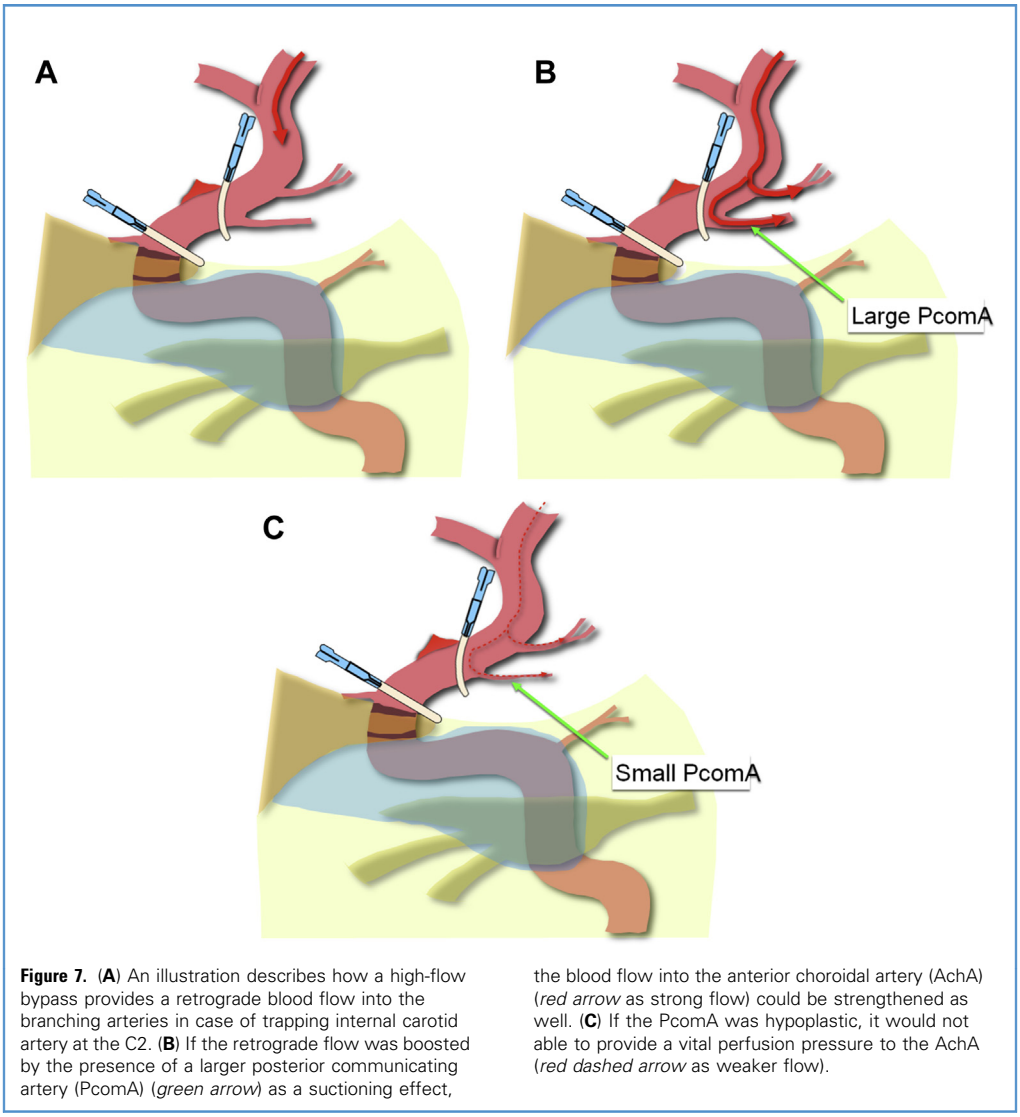

Figure 7. (**A**) An illustration describes how a high-flow bypass provides a retrograde blood flow into the branching arteries in case of trapping internal carotid artery at the C2. (**B**) If the retrograde flow was boosted by the presence of a larger posterior communicating artery (PcomA) (*green arrow*) as a suctioning effect, the blood flow into the anterior choroidal artery (AchA) (*red arrow* as strong flow) could be strengthened as well. (**C**) If the PcomA was hypoplastic, it would not able to provide a vital perfusion pressure to the AchA (*red dashed arrow* as weaker flow).

cause stenosis or occlusion.[66] In our experiences of COCW, however, no patient has shown granulation or cerebral edema in the vicinity of the treated BBAs as an allergic reaction, and also no consequential stenosis or obstruction of the ICA was encountered.

Limitations

It should be noted that this study is a retrospective study with a small number of patients. In addition, significant technical alterations, such as the introduction of new monitoring devices including indocyanine green video angiography and motor-evoked potential, were made during the study period. However, the 3 of our surgeons have performed COCW surgery with the same

Table 2. Treatment Options for IC BBAs

1. Direct surgery
■ Direct simple clipping
■ Clipping on wrapping ± low flow bypass
■ Trapping + low or high flow bypass
2. Endovascular surgery
■ Simple coiling
■ Coiling through stent
■ Flow diverter

BBA, blood blister-like aneurysm; IC, internal carotid.

scheme, and the basic surgical procedures have been consistent throughout this study.

CONCLUSIONS

Although concerns over allergic reactions and granulation to the cotton material remain as issues, this COCW method deserves consideration as a novel method that enables the safe and effective long-term control of IC-BBAs.

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