A Novel Aneurysm Clip Design for Atheromatous, Thrombotic, or Previously Coiled Lesions: Preliminary Experience With the "Compression Clip" in 6 Cases

Eric S. Nussbaum, MD

National Brain Aneurysm Center,
St. Joseph's Hospital,
St. Paul, Minnesota

Leslie A. Nussbaum, MD, PhD

National Brain Aneurysm Center,
St. Joseph's Hospital,
St. Paul, Minnesota

Reprint requests:
Eric S. Nussbaum, MD,
3033 Excelsior Blvd.,
Suite 403,
Minneapolis, MN 55416.
E-mail: lnussbaum@comcast.net

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BACKGROUND: Large and giant lesions often have thicker, atheromatous walls as well as intra-aneurysmal thrombus that combine to prevent traditional clips from closing properly in some cases.

OBJECTIVE: To report the development and use of a novel clip design specifically tailored to treat atheromatous, thrombotic, or previously coiled aneurysms.

METHODS: We retrospectively reviewed the records of 6 patients with complex aneurysms not amenable to simple neck clipping and not considered appropriate for endovascular therapy who were treated using a novel "compression" clip design. We describe the development and use of a novel aneurysm clip design with blades that are not opposed at rest to allow direct clipping of atheromatous, thrombotic, and previously coiled aneurysms.

RESULTS: Four patients had recurrent, previously coiled aneurysms; one of these also had a large thrombotic component. Two patients had complex lesions with heavy atheroma involving a portion of their aneurysms. There were no complications related to the use of the clip, and all patients did well without neurological complications. In every case, the clip allowed straightforward obliteration of the aneurysm without the need for temporary vascular occlusion, aneurysmorrhaphy, or removal of an intra-aneurysmal coil mass. All patients underwent intraoperative angiography to confirm obliteration of the aneurysm with preservation of the normal vasculature.

CONCLUSION: Atheromatous, thrombotic, and previously coiled aneurysms may not be treatable with simple neck clipping and may not be curable with endovascular therapy. For such cases, we designed a novel "compression" clip that has been used safely and successfully in our experience with good short-term follow-up.

KEY WORDS: Aneurysm, Atheroma, Brain, Clip, Coil, Compression, Design

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Traditional aneurysm clips rely on the ability of their blades to close the neck of an aneurysm to obliterate the lesion. Although this is effective for most thin-walled aneurysms, large and giant lesions often have thicker, atheromatous walls as well as intra-aneurysmal thrombus that combine to prevent traditional clips from closing properly in some cases.[1-5] Similarly, aneurysms that have undergone previous endovascular treatment often contain a thick coil mass that can preclude aneurysm clip blades from closing.[6-15] In these cases, standard clips tend to slip down toward the parent artery, potentially occluding efferent branches, dislodging embolic material, or even rupturing the lesion. The authors describe a novel clip design specifically tailored to address this problem that has been used safely and successfully in 6 patients treated over a 1-year period.

ABBREVIATION: MCA, middle cerebral artery

PATIENTS AND METHODS

We retrospectively reviewed the records of all patients undergoing treatment of an intracranial

aneurysm at our center from January 2008 to December 2008. During this period, our neurovascular service treated 350 aneurysms; 180 underwent open microsurgical treatment, and 170 were treated using endovascular techniques. Of those patients treated surgically, we identified 6 complex aneurysms that were occluded using a novel clip designed to address the inability of traditional aneurysm clips to close in these cases. The first "compression" clip that we used was developed by modifying intraoperatively a bayoneted fenestrated Sugita (Mizuho) clip so that the blades were no longer opposed at rest, leaving an interblade aperture of 3 mm to address the specific needs of the case (Figure 1).

Based on this design, a set of custom "compression" clips with varying blade lengths and aperture sizes was subsequently produced and supplied by Mizuho for our use. This set consisted of clips with 5 distinct blade lengths of 3, 5, 7, 9, and 11 mm. For each blade length, clips with interblade apertures of 2, 3, and 5 mm were produced. As described, these clips are similar in appearance to conventional clips of comparable blade lengths with the major exception being the fact that the clip blades remain unopposed at rest. Traditional clip appliers without modification are used to open and release the clips in standard fashion.

Hospital records, neuroimaging studies, operative reports, and follow-up clinic notes were available in all cases. Follow-up review ranged from 6 to 9 months, and no patient was lost to follow-up review. All patients were evaluated by a multidisciplinary neurovascular service that included a team of interventional neuroradiologists and a neurovascular surgeon. In every case, endovascular options were thought to be either contraindicated, to have a high likelihood of repeated coil failure, or to carry a higher risk than microsurgery.

All patients underwent a standard pterional craniotomy. The superficial temporal vessels were carefully preserved for possible revascularization in patients with middle cerebral artery aneurysms. Aggressive drilling of the sphenoid wing and orbital roof was supplemented by an orbitozygomatic osteotomy in 2 cases. Mild hypothermia (34°C) and barbiturate anesthesia were used in all cases. Intraoperative angiography was used to confirm aneurysm obliteration and preservation of all major vessels in each case.

FIGURE 1. *Modified "compression" clip (left) and original clip as supplied by manufacturer (right). Note the aperture between the blades, which are no longer opposed at rest.*

RESULTS

Information about the patients and surgical results are detailed in the Table. All patients were women, ranging in age from 42 to 68 years. All patients were treated on an elective basis. Three patients had originally presented with a subarachnoid hemorrhage 1 to 3 years earlier, and 3 had aneurysms that were discovered incidentally. Three patients had undergone 2 coiling procedures, 1 had undergone 3 coiling procedures, and 2 had not had any previous treatment.

All patients underwent 4-vessel digital subtraction angiography as well as 3-dimensional rotational angiography. External carotid angiography was also performed to evaluate the caliber of the superficial temporal artery for possible revascularization. There were 2 aneurysms located at the anterior communicating artery and 4 at the middle cerebral artery (MCA) bifurcation (Table). In all cases, endovascular options were thought to be inferior to open microsurgery. Four patients had already failed repeated coiling procedures, suggesting an ongoing hemodynamic stress that would predispose the patients to repeated coil failure. In the other cases, the incorporation of the M2 branches into the base of large, wide-necked MCA bifurcation aneurysms was thought to be most appropriately suited to microsurgical treatment.

In each case, a thorough discussion of treatment options was conducted with the patient, and microsurgical exploration was recommended. The patients were told that if their aneurysms could not be clipped directly, potential options would include distal revascularization with proximal occlusion or temporary vascular occlusion with evacuation of thrombus and/or coils followed by clip reconstruction. Simple wrapping was also presented as a less preferred alternative.

All aneurysms were clipped primarily using the modified clip design. No intraoperative complications were encountered with the use of the clip. In each case, intraoperative angiography confirmed obliteration of the aneurysms with normal filling of all parent and associated branches. All patients awoke without new deficit, and no patients experienced complications related to the use of the novel clip design. A deep venous thrombosis developed in 1 patient 1 week postoperatively, which was treated with anticoagulation. The first 2 patients underwent delayed angiography 1 week to 1 month postoperatively, confirming a stable clip construct.

ILLUSTRATIVE CASES

Patient 1

Our first use of the current clip design represented a response to an apparent operative misadventure. A 52-year-old woman with a large MCA aneurysm had undergone endovascular coiling at an outside facility after presenting with a mild subarachnoid hemorrhage. She recovered fully, but her aneurysm recurred and

TABLE. Patient Details, Aneurysm Characteristics, and Complications in 6 Patients Undergoing Primary Clipping Using the Novel Compression Aneurysm Clip[a]

Patient	Age, y/Sex	Aneurysm Location	Size	Complicating Factors	Complication	Outcome
1	59/F	MCA	Large	Previous coil, atheroma	—	No deficit
2	48/F	MCA	Large	Previous coil, atheroma, thrombus	Deep venous thrombosis	No deficit
3	42/F	AComA	Small	Previous coil	—	No deficit
4	55/F	AComA	Large	Previous coil	—	No deficit
5	68/F	MCA	Large	Atheroma, thrombus	—	No deficit
6	53/F	MCA	Large	Atheroma, thrombus	—	No deficit

[a]MCA, middle cerebral artery; AComA, anterior communicating artery.

was treated with additional coil placement. Unfortunately, the aneurysm recurred again, and the patient sought surgical treatment for her aneurysm (Figure 2A).

At the time of surgical exploration, we identified a typical aneurysm of the MCA bifurcation (Figure 2B). The neck appeared compliant enough to close below the coils with a traditional, large aneurysm clip, and we attempted simple neck clipping of the lesion. Unfortunately, the clip blades did not close properly because of the coil mass, and the clip began to slip down onto the parent artery junction with the aneurysm and the M2 branches. The clip was removed. At this point, we could see an area on the aneurysm neck that had been injured by the clip. This area was thin walled and thought to be at high risk of future growth and rupture as a pseudoaneurysm. We contemplated temporary vascular trapping to allow coil removal, but the coils that had been used in this case were coated (Matrix) coils, and we have previously encountered difficulty removing these coils because of associated scarring to the aneurysm wall in some cases. As a result, we elected to modify a fenestrated, bayoneted aneurysm clip to create a novel clip design with parallel blades that were no longer opposed in the resting position.

This modified clip was easily applied across the neck of the aneurysm. Rather than trying to close the neck below the coils, the novel clip design, which we termed the compression clip, sandwiched the existing coil mass between the walls of the aneurysm, closing the open portion of the aneurysm without having any tendency to slip down or spring off the lesion (Figure 2C). The patient underwent intraoperative angiography confirming obliteration of the aneurysm with normal filling of all major branches (Figure 2D). She awoke without deficit. Angiography was repeated before discharge from the hospital and again 1 month later, confirming stability of the clip construct.

Patient 2

A 48-year-old woman initially presented to an outside facility with an acute SAH. She underwent partial coiling of a ruptured MCA aneurysm and made an excellent recovery. One year later, additional coils were added, but at 2-year follow-up, there was significant filling of the aneurysm, and the patient was referred to our center for additional treatment. At this point, angiography demonstrated a partially coiled aneurysm with coils well up in the aneurysm dome (Figure 3A, B). Microsurgical exploration and attempted clipping were recommended.

At surgical exploration, a partially thrombosed aneurysm with heavy atheroma that had only been partially visualized on preoperative angiography was encountered (Figure 3C). The wide, thickened neck could not be clipped primarily using standard clips. Instead, a modified compression clip was used to allow direct clipping of the thrombosed, atheromatous neck (Figure 3D). Intraoperative angiography and subsequent postoperative angiography demonstrated complete aneurysm occlusion with preservation of the parent and associated branch arteries (Figure 3E).

The patient did well without perioperative complications, but a deep venous thrombosis developed 1 week later. This was treated successfully with intravenous and then oral anticoagulation, which was continued for a period of 3 months. She had no neurological complication.

Patient 5

A 68-year-old woman with headaches and a family history of subarachnoid hemorrhage was found to have a large complex MCA aneurysm (Figure 4A). Microsurgical treatment was recommended. At the time of surgery, an atheromatous lesion was encountered (Figure 4B). Primary clip reconstruction was possible using 2 modified compression clips, and intraoperative angiography confirmed adequate obliteration of the aneurysm with preservation of the parent vessels (Figure 4C, D). Surgery was tolerated without complication.

DISCUSSION

The majority of intracranial aneurysms are thin-walled, saccular lesions that are well treated with either traditional clip or coil technology. Nevertheless, complex aneurysms that have atheromatous walls, intraluminal thrombus, or that have recurred after coiling may thwart attempts at standard clip occlusion. As more straightforward aneurysms are being treated using endosaccular coiling techniques, an increasing percentage of those aneurysms referred for open microsurgery are large or giant, wide-necked lesions.[16] In addition, the rapid evolution of endovascular

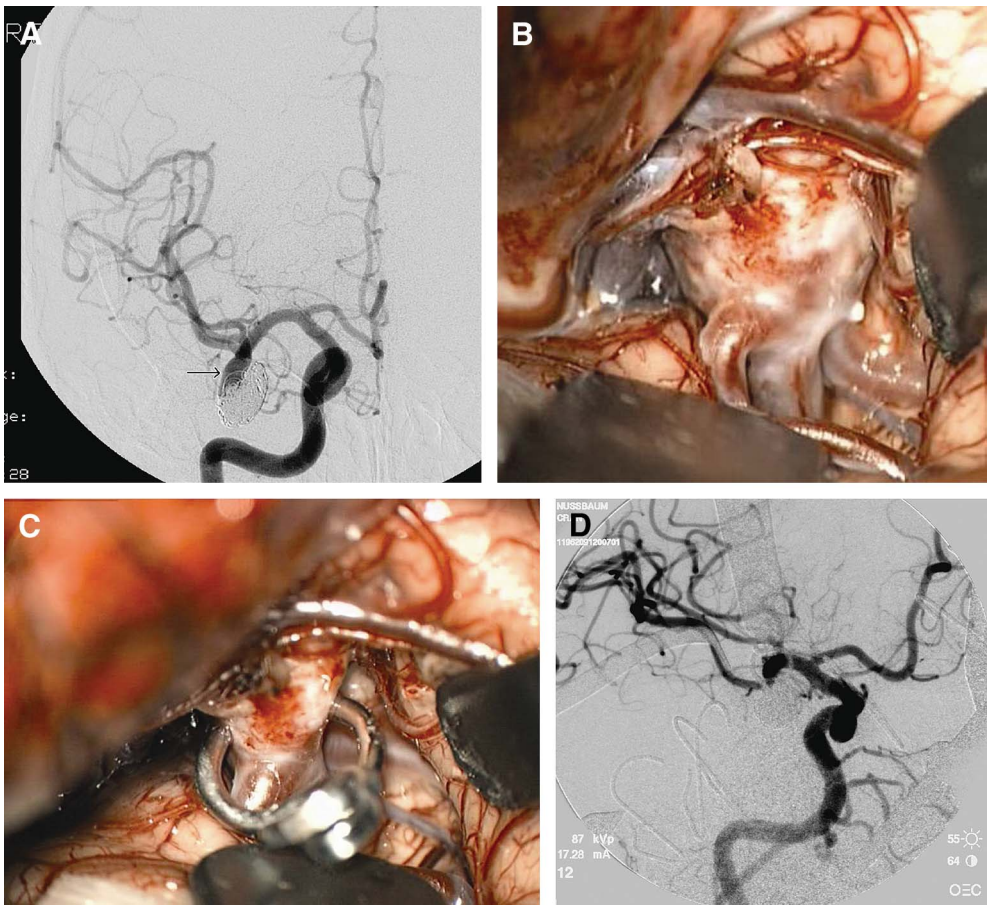

FIGURE 2. *Preoperative anteroposterior digital subtraction right internal carotid arteriogram (A) demonstrating the coil mass and filling portion of the middle cerebral artery (MCA) aneurysm (arrow). Note that the coil mass extends up to the neck region of the aneurysm, which ultimately precluded treatment with a conventional aneurysm clip. Intraoperative photomicrographs obtained after complete dissection of the aneurysm (B) and after application of the modified clip (C). The compression clip occludes the open, filling portion of the aneurysm without disturbing the coil mass. Intraoperative right internal carotid arteriogram (D) demonstrates obliteration of the aneurysm with preservation of the MCA vessels.*

technology coupled with growing evidence of its safety and efficacy has produced an expanding number of aneurysms previously treated with coils that have recanalized or recurred, often repeatedly.[8,14,15,17-19] These patients are now being referred for or are independently seeking definitive microsurgical treatment. In these cases, simple clipping may be difficult or impossible because the coil mass within the aneurysm may preclude traditional aneurysm clips from closing.

Although some of these lesions may be treatable with simple clipping, many require complete temporary vascular occlusion with opening of the aneurysms for evacuation of thrombus, coils, or local endarterectomy, before definitive clipping.[2,5,8,15,20-22] Alternatively, we and others have used bypass with proximal occlusion or trapping as a reasonable treatment option in many of the most complex cases.[3,5,14,15,20,23-25] Nevertheless, these options all require some form of temporary or permanent vascular occlusion, increasing the associated surgical morbidity and mortality rates. In the past, large, heavy clips, at times supplemented by booster clips, were used in attempts to close atheromatous aneurysm necks.[2,20,22,26] Recently, Navratil et al[27] reported their experience with crushing the neck of these aneurysms using various hemostats. Although this maneuver may be successful in select cases, the technique can result in embolic complications, dissection or occlusion of the parent artery, and even rupture of the aneurysm.

Rationale Behind the Development of a Novel Clip Design

There are few experiences as disheartening for the neurovascular surgeon as watching what appeared to be a well-placed

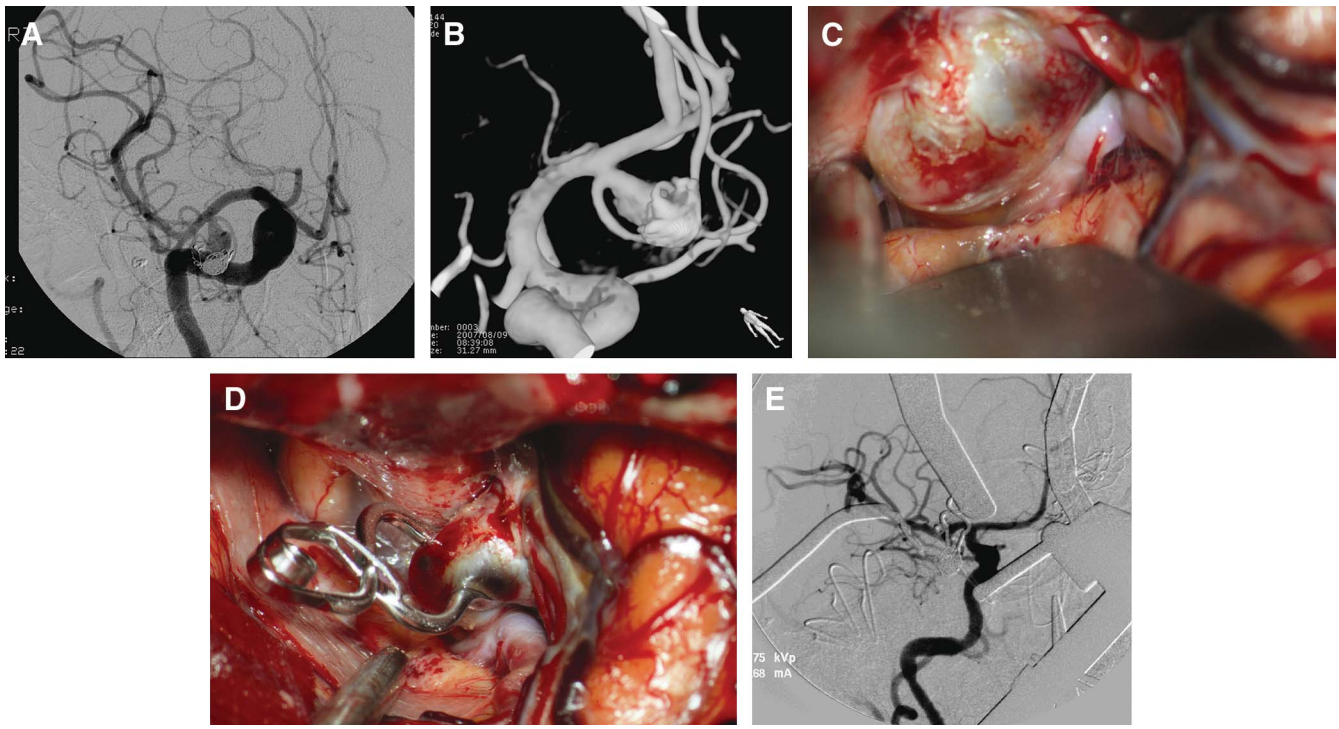

FIGURE 3. *Preoperative right internal carotid digital subtraction (A) and 3-dimensional rotational (B) angiographic images reveal the recurrent middle cerebral artery aneurysm with the associated coil mass and presumed intraluminal thrombus resulting in a filling defect within the aneurysm. Intraoperative photomicrographs obtained after exposure of the aneurysm (C) and after application of the modified compression clip (D) demonstrating an atheromatous partially thrombosed sac that would not accept a traditional aneurysm clip. Note the positioning of the clip well up on the neck aneurysm that resulted in obliteration of the lesion on intraoperative angiography (E) with preservation of all normal vessels including the branch that was originating from the aneurysm neck and wrapping around the aneurysm dome.*

aneurysm clip slip down onto the parent artery, scissor, spring back off, or perch precariously in a partially open position on the neck of a complex aneurysm. On careful intraoperative evaluation of these large, giant, and previously coiled aneurysms, it became clear to the authors that clip failure often appeared to result from the fact that traditional clips have 2 blades that, at rest in the closed position, are parallel and perfectly opposed. Thus, when faced with a noncompliant aneurysm wall, whether caused by coils, clot, atheroma, or simple wall thickness, the blades cannot close, and the clip "fails." As a result, we hypothesized that a novel clip design with nonopposed blades would eliminate the problems created by parallel opposed blades and would allow the clip to close properly in at least some of these cases.

In the setting of intra-aneurysmal coils, which, in our practice, has become the most common of the aforementioned conditions interfering with simple neck clipping, the very problem precluding traditional clips from closing (the coil mass) is used to advantage by the current compression clip design. Specifically, the clip blades are allowed to obliterate the remaining filling portion of the aneurysm by sandwiching or compressing the coil mass between the existing aneurysm walls (Figure 5). Because the blades are not opposed at rest, the clip has no impetus to either slide down or spring off, but rather rests comfortably in position with the mass of thickened wall, thrombus, and/or coils between its blades. Because the clip is now completely "closed" even though an "aperture" remains between the blades, there remains no potential energy to encourage immediate or delayed migration of the clip.

The intraoperative modification of aneurysms clips is not a novel concept. As a vascular fellow at the University of Western Ontario, the senior author routinely saw aneurysm clip blades shortened using a whetstone or drill to address the unique needs of a specific lesion. In practice, we have continued to shorten clips using a diamond drill when necessitated by the particular local anatomy. This has been required most often in the setting of a basilar apex aneurysm when clip blades of a very specific length are needed beyond a fenestration that incorporates the P1 segment of one of the posterior cerebral arteries. Based on this experience and given the inherent risks associated with treating these aneurysms using standard methods, the idea of modifying an existing clip to address this problem seemed reasonable, particularly given the circumstances associated with our first case as detailed previously.

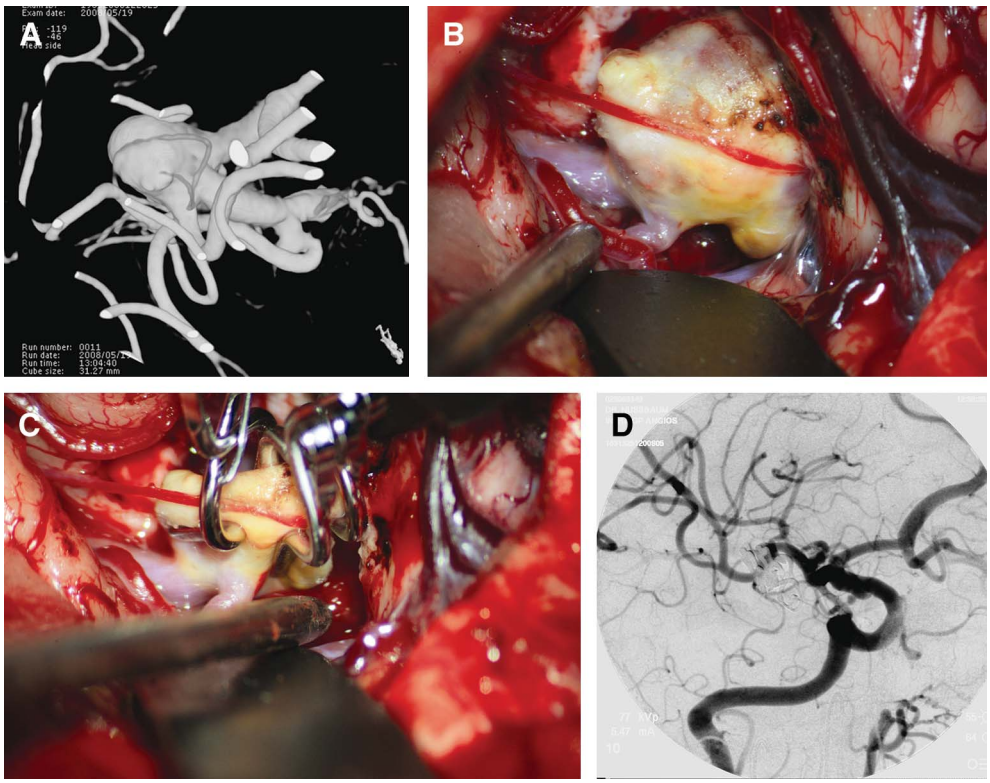

FIGURE 4. *Preoperative 3-dimensional rotational angiographic image (A) demonstrating a wide-necked middle cerebral artery aneurysm. Intraoperative photomicrographs obtained after exposure of the aneurysm (B) and after modified clip application (C) reveal an atheromatous sac not amenable to closure with traditional clips that repeatedly slipped back off the aneurysm. Using several modified clips, the aneurysm was obliterated, as seen on the intraoperative arteriographic image (D). Note the preserved arterial branch that was densely adherent to the aneurysm dome running through the clip fenestrations.*

Clinical Experience

After our original successful experience, we suspected that the use of similarly modified clips might enable us to treat other aneurysms that would otherwise have been unclippable in our hands. Given the real morbidity associated with the alternative options described, we had Mizuho produce a set of custom clips and began to discuss this option with patients as one potential treatment choice that might be used intraoperatively if their aneurysm could not be clipped using an existing clip pattern. As a result, we have now used the modified clip in 6 cases with a minimum follow-up period of 6 months.

In our experience using the modified compression clip design, it can be extremely difficult to assess the adequacy of aneurysm obliteration and to exclude the possibility of vascular compromise using simple visual inspection. In our series, intraoperative angiography was considered invaluable in confirming proper clip placement. In 3 of our 6 patients, intraoperative angiography resulted in clip repositioning to properly occlude the aneurysm.

Potential Envisioned Uses

We used the current clip design to occlude the neck of aneurysms that were not amenable to simple clipping. In rare cases of aneurysms with particularly wide necks, when complete surgical occlusion is impossible, one could envision the use of a compression clip to significantly narrow an aneurysm neck to allow subsequent endovascular coiling of a now narrower necked lesion. In addition, in theory, this clip design could be used as a "pilot" clip to allow the surgeon to partially occlude and then see around the far side of a large, very wide-necked aneurysm. This might allow dissection of perforators or other adherent critical structures before final application of a more standard clip, which, if used at the outset, might have caught and injured these structures. The authors have considered the use of such a clip as an initial pilot clip for a large basilar apex lesion, allowing one to more safely inspect the far back wall of the aneurysm for any perforators that had been missed on initial inspection. These fine and critical vessels can be damaged irreparably by a traditional

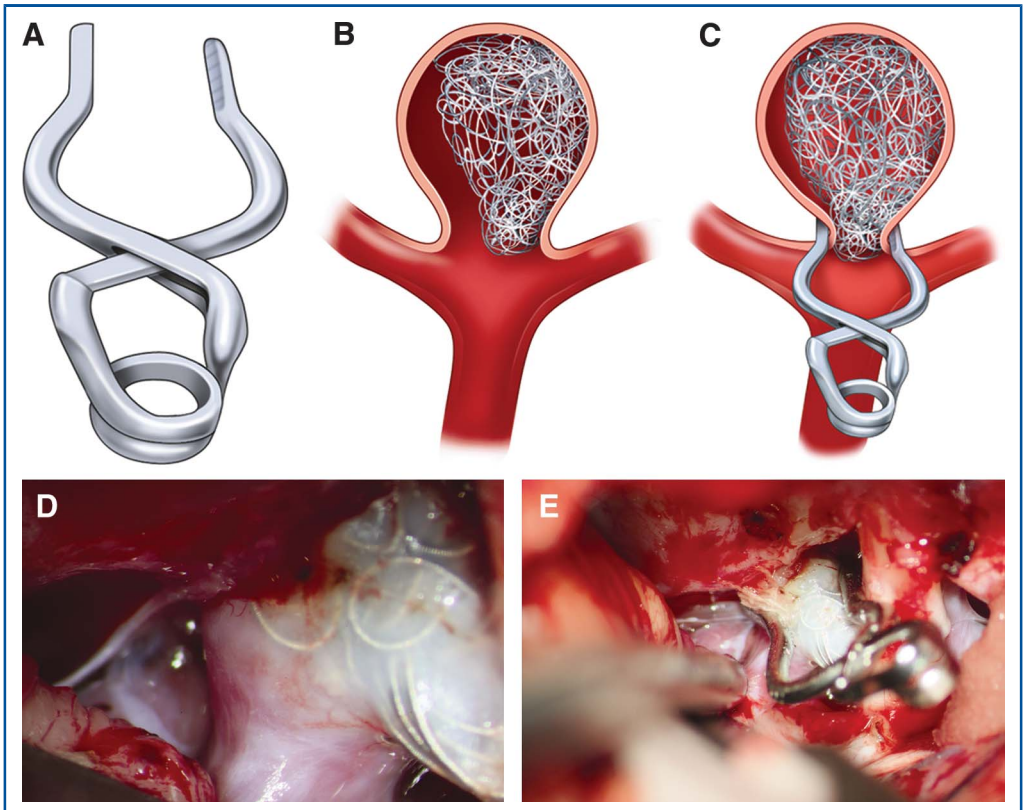

FIGURE 5. *Artist's drawing depicting the resting position of the novel compression clip design used in our series (A). Accompanying illustration showing a previously coiled, recurrent aneurysm (B) with the coil mass extending down to the aneurysm neck as encountered in several patients in this report and occlusion of the aneurysm with the modified clip sandwiching the coil mass and the open portion of the aneurysm between the clip blades (C). Intraoperative photomicrographs from patient 3 (Table) demonstrating a highly magnified view of a recurrent anterior communicating artery aneurysm (D) with coils extending to the aneurysm neck and treatment of the aneurysm with a modified clip occluding the open portion of the aneurysm against the large coil mass (E).*

aneurysm clip if they are inadvertently occluded even temporarily along with the aneurysm.

Study Limitations

This study describes a small series of patients treated with a novel clip design to circumvent the limitation of traditional clips bearing parallel blades that are perfectly opposed at rest. The small size of this series will necessitate a larger experience before the technique can be considered reliably successful. In addition, our patients have all been treated over the past year. Although all patients underwent intraoperative angiography and some had early follow-up angiography as well, careful, long-term follow-up will be necessary to confirm stability in these cases. We would caution that surgeons treating these complicated lesions should be comfortable with the full spectrum of traditional revascularization and aneurysmorrhaphy techniques should the presented option fail and/or injure the aneurysm wall.

To limit the potential for "weakening" of the clip by intraoperatively bending an existing clip pattern, we had a set of custom clips produced. In general, severe bending of a standard clip may result in a possible increased risk of delayed clip failure, which should be considered when considering performing such a modification. Because the blades of our clips are unopposed at rest, it is not possible to measure the clip "closing force," as traditionally defined. We have been working with the clip manufacturers to address this important issue. Finally, we would caution that most truly giant aneurysms have such firm, thickened walls that our clip (like more traditional clips) would likely fail to close the aneurysm neck. It is only those rare giant aneurysms that have a thinner section of wall down near the aneurysm neck that might be well suited for clipping using the current design.

CONCLUSION

We describe the development and use of a novel aneurysm clip designed specifically to allow clipping of complex and previously coiled aneurysms. The modification consisting of blades that are

not opposed at rest prevents the problem of clips tending to slip down on or spring off of thickened aneurysm necks. Given the significant complication rates associated with traditional reconstructive methods used to treat these lesions, this option appears to be a reasonable addition to the neurovascular surgeon's armamentarium when addressing these complex lesions.

Disclosure

The authors currently have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article. The authors are working together with a clip manufacturer towards the potential development of the ''compression clip'' described in this paper.

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COMMENTS

The Nussbaums have developed a new aneurysm clip called the compression clip. It is a fenestrated clip whose blades are unopposed at rest, allowing it to close aneurysm neck around coils, thrombus, or atherosclerotic tissue. This design is ingenious because a closed compression clip can squeeze solid material between its blades without undue potential energy causing clip migration down the neck or springing off the aneurysm. The clip was used in 6 patients with good results. It seems to have addressed the problem of the sliding clip, and the use of intraoperative angiography addressed the completeness of aneurysm obliteration. This experience contains no long-term angiographic follow-up data, and it will be important to confirm that these clips are not prone to delayed aneurysm recurrences. I applaud the authors' creativity in dealing with a vexing clinical problem. Any clip that might reduce the need to remove coils from an aneurysm or perform a bypass to exclude a recurrent aneurysm is a welcome addition to our armamentarium.

Michael T. Lawton
San Francisco, California

The authors present their preliminary experience using a modified clip designed to treat aneurysms containing coil mass or atheroma. Such aneurysms can be challenging to obliterate without placing the parent vessel or perforators at risk. This report describes 6 patients in which the authors placed a ''compression clip,'' in which the blades are not fully opposed at rest, to treat complex aneurysms. All cases included aneurysms with coil mass or atheroma that precluded simple clip occlusion of the neck. In each case, the authors demonstrated aneurysm occlusion and parent vessel patency with angiography in the perioperative period.

Although the number of patients treated and the length of follow-up are limited, the ''compression clip'' holds intuitive appeal. Theoretically, by leaving an open aperture in the closed position, the modified clips are less likely to migrate when clipping aneurysms with associated coil mass or atheroma. Although the authors reported good clinical and angiographic results in the perioperative period, long-term follow-up is required to establish the durability of this novel clip design. Without longer follow-up, the suitability of these clips cannot be established. However, as a preliminary experience with a modified clip design, this

article describes an original approach in addressing a challenging neurosurgical problem.

David A. Wilson
Robert F. Spetzler
Phoenix, Arizona

This is an interesting, innovative approach to a vexing technical problem that complicates the life of every surgeon who deals with very large and giant intracranial aneurysms. As the authors succinctly point out, the almost inevitable presence of expansive necks, thick atheromatous walls, and intra-aneurysmal thrombus (and or coils) frequently render atraumatic apposition of these aneurysmal necks extremely difficult without threatening the patency of the parent or efferent arteries. Judicious use of temporary proximal occlusion, trapping, aneurysmorraphy, and a variety of bypass procedures serves to reduce the percentage of ''unclippable'' lesions, but the initial angiographic and clinical results reported in this impressive small series may ultimately shunt these more risky procedure into the second rank of treatment options.

For caveats, the authors are quick to mention that the durability of these results remains to be confirmed. They emphasize the absolute requirement for intraoperative angiography, and one wonders whether the resolution of indocyanine green–based imaging will be of sufficient quality to permit its substitution for more invasive intra-arterial injections. Furthermore, intraoperative Doppler studies of the distal vasculature might be of benefit in analyzing the incidence of distal microembolization at the moment of clip closure, a theoretical consequence of incomplete approximation of the clip blades.

This is a thoughtful, well-balanced approach to a very difficult surgical problem, and we congratulate the authors on both their ingenuity and technical skill.

Kim Rickert
Duke Samson
Dallas, Texas