Chapter 11
Balloon-Assisted Treatment of Intracranial Aneurysms: The Conglomerate Coil Mass Technique

David Fiorella and Henry H. Woo

Endovascular techniques for the treatment of intracranial aneurysms have rapidly evolved over the past 20 years since the introduction and subsequent US Food and Drug administration approval of the Guglielmi detachable coil (GDC). During this interval, a number of different coil designs and adjunctive devices have been developed to facilitate the treatment of more complex and challenging cerebral aneurysms. One such adjunctive device, the hypercompliant occlusion balloon, can be temporarily inflated during the delivery of embolization coils to prevent their prolapse into the parent vessel. This technique, known as balloon-assisted treatment (BAT), remains somewhat controversial as many operators do not incorporate this approach into their practice favoring stent-supported techniques instead. Moreover, those operators who do practice BAT use a variety of different approaches. In this review, we discuss the theoretical concepts underlying BAT, the potential advantages and disadvantages of this approach, and finally the technical evolution of BAT in our endovascular practice.

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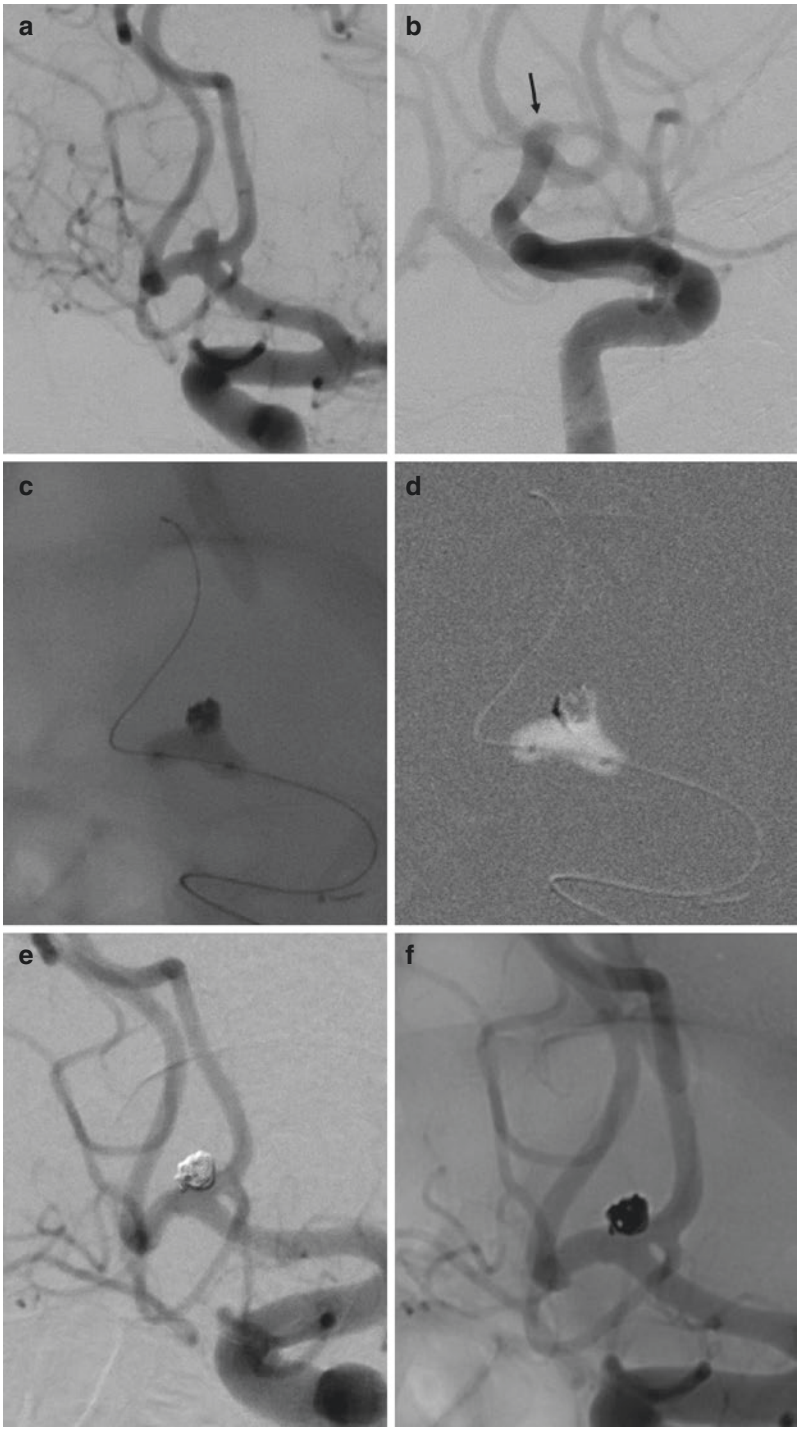
What Are the Major Anatomical Limitations of Endovascular Aneurysm Treatment?

In general, the primary anatomical limitations faced during the coil embolization of cerebral aneurysms are those which make it difficult to densely fill the aneurysm with coils without having those same coils prolapse into the parent artery. The aneurysms which most often present these challenges fall into several (related) anatomical categories:

1. *Wide neck*: The definition of a "wide-necked" aneurysm varies considerably but has been described in absolute terms as having a neck measuring more than 4 mm in any dimension or, more accurately, in relative terms as having a dome/neck ratio of <1.5 [1]. The geometry of these aneurysms is such that the neck is often insufficient to stably retain a spherically shaped three-dimensional coil within the aneurysm fundus (Fig. 11.1). Moreover, once detached, an apparently "stable" coil can subsequently prolapse out of the aneurysm into the parent artery and on occasion even embolize into the distal cerebrovasculature.
2. *Complex anatomy at the parent artery-aneurysm interface*: On occasion the morphology of the aneurysm fundus is such that it wraps around or otherwise obscures the parent artery and precludes visualization of the parent vessel-aneurysm neck interface on one or both of the standard angiographic views. As the aneurysm fundus is densely packed with embolization coils, the parent artery becomes increasingly more difficult to visualize, and it becomes progressively more difficult to determine whether the embolization coils are being retained within the aneurysm or are extending into the parent artery. In this scenario, the inflated balloon(s) can often be used to assist in defining an optimized view of the parent artery (Fig. 11.2).

Fig. 11.1 Patient with subarachnoid hemorrhage attributed to a ruptured anterior communicating artery aneurysm (ACOMM). Conventional angiography in the working angles for coil embolization (**a**, **b** (arrow)) demonstrates a 2.5 mm broad-based aneurysm arising from a 2.5 mm neck. The height of the aneurysm measured perpendicular to the ACOMM complex is less than 2 mm. The aneurysm is so shallow that it is difficult to perceive on the lateral projection (**b**, arrow). The dome: neck ratio is approximately 1.0, and given the configuration of the aneurysm, in particular the shallow nature of the dome, it seems highly unlikely that coils would be retained within the aneurysm sac. A 4 × 7 mm "ball-shaped" balloon was manipulated across the aneurysm neck and the aneurysm was catheterized with a standard 0.017" ID microcatheter. A native image in the frontal working projection (**c**) shows the balloon inflated after the completion of coil embolization. A blank fluoroscopic roadmap obtained after balloon deflation (**d**) in the frontal working angle shows a "negative defect" corresponding to the volume filled by the previously inflated balloon. The coil mass remains almost perfectly subtracted on the blank map, indicating that no coils have prolapsed and the conglomerate mass within the aneurysm fundus is stable. Subtracted (**e**) and native (**f**) images from the completion angiography performed in the working angles for coil embolization show complete embolization of the aneurysm with the exception of a tiny defect within the medial aspect of the aneurysm coil mass corresponding to the location of the microcatheter tip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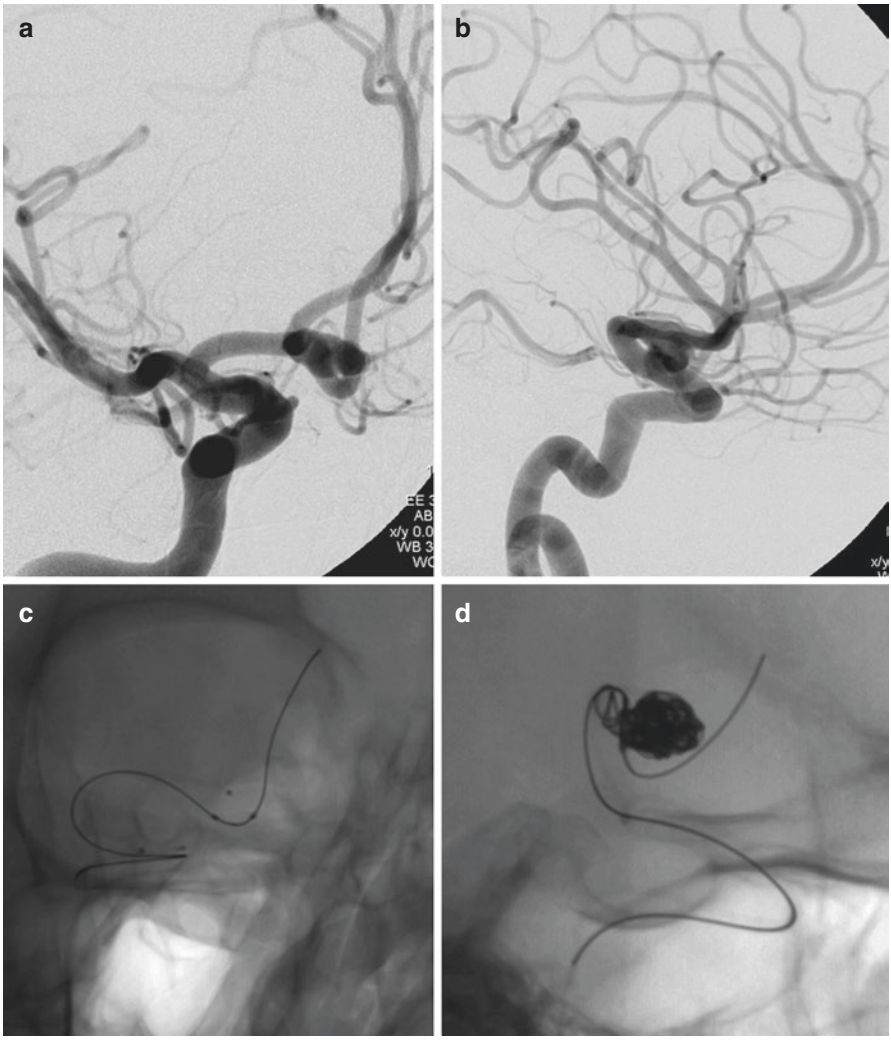


Fig. 11.2 Patient with a ruptured ACOMM aneurysm and an aplastic left A1 segment of the anterior cerebral artery. Right internal carotid (ICA) angiography in a frontal (**a**) and lateral (**b**) projection demonstrates the aneurysm to be complex and wide necked, nearly circumferentially incorporating a segment of the anterior communicating artery. The demarcation between the aneurysm neck and parent artery was difficult to ascertain from the working projections and three-dimensional angiogram. Native image (**c**) demonstrates a balloon in position across the anterior communicating artery, extending from the right A1 into the left A2. After the first round of balloon inflation and coil placement, rotation of the imaging intensifier showed the ACOMM (demarcated by the uninflated balloon catheter) to be free of embolization coils which wrapped around the proximal aspect of the ACOMM complex inferiorly (**d**). The image intensifier was reoriented to demonstrate the proximal ACOMM in an approximately "down-the-barrel" projection, and coil embolization was completed. Subtracted (**e**) and native (**f**) images from the treatment angiogram demonstrate complete occlusion which remained stable at 6-month angiographic follow-up (**g**, **h**)

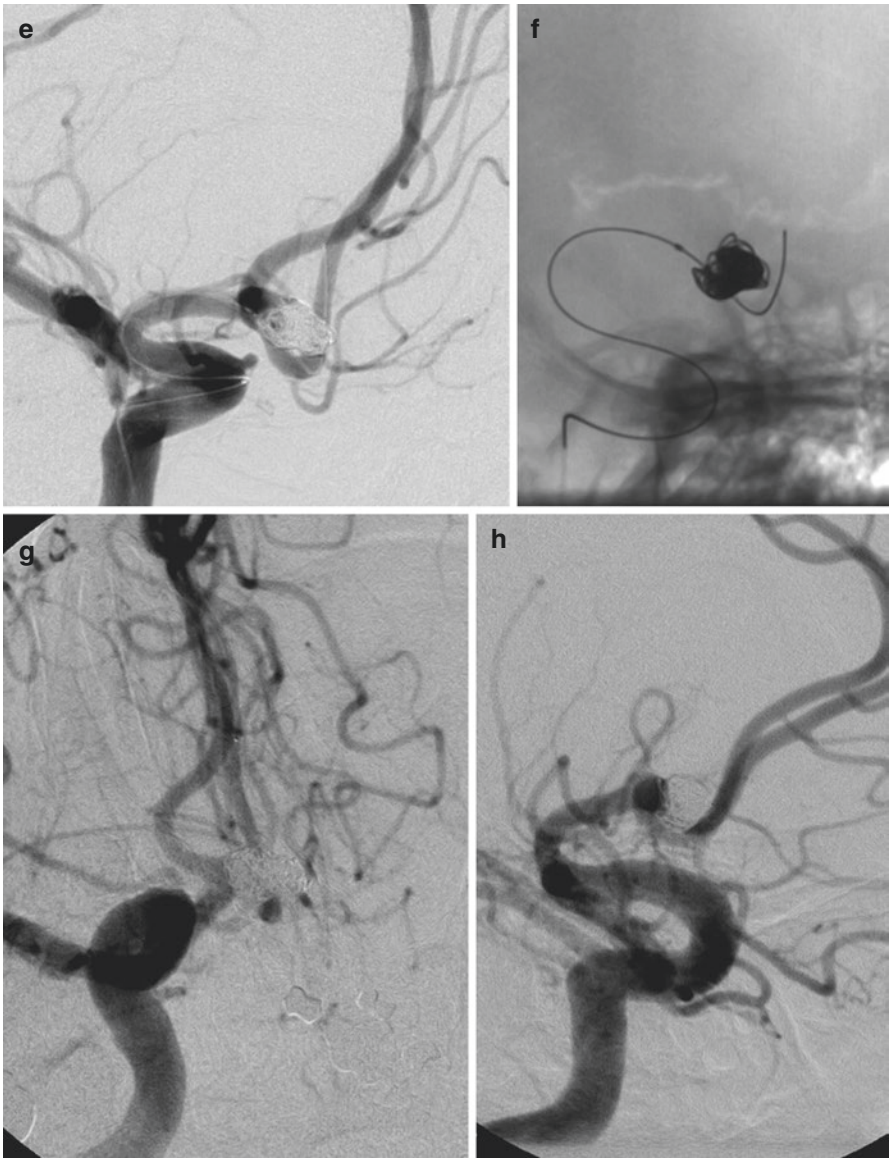


Fig. 11.2 (continued)

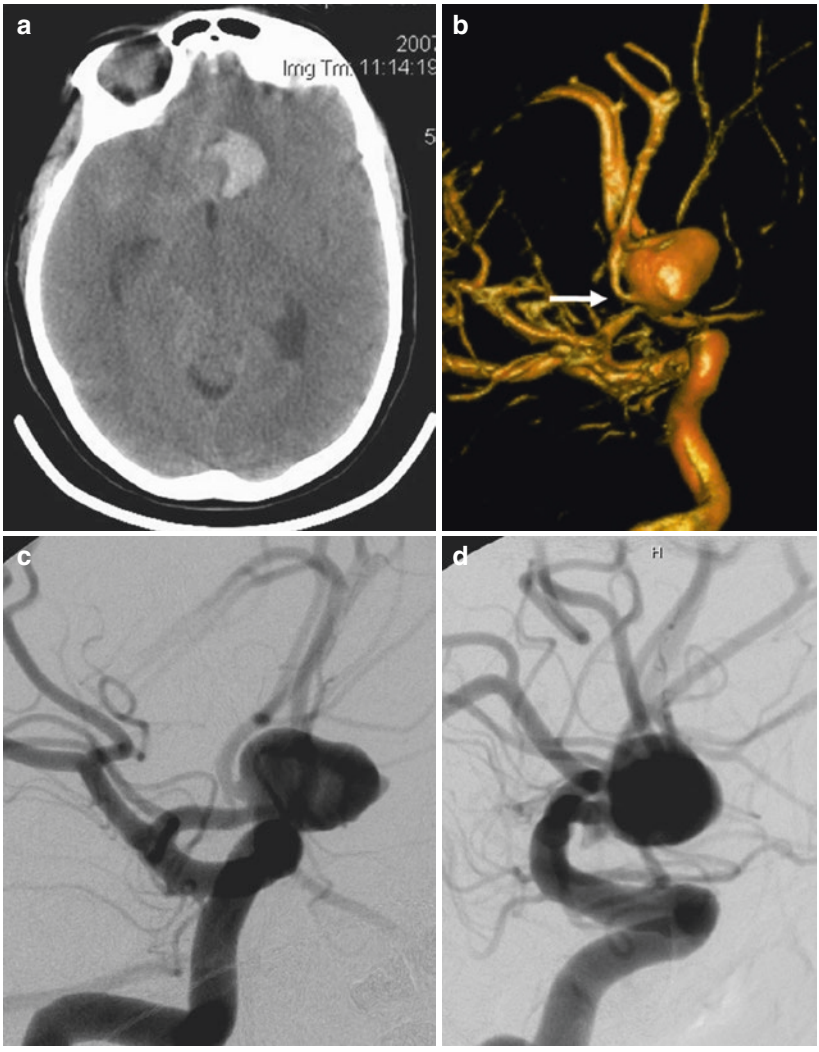
3. *Branch arteries are incorporated into the proximal aneurysm fundus*: Very wide-necked aneurysms (often those occurring at bifurcations) may actually incorporate the origins of important branch arteries which arise several millimeters into the aneurysm fundus. In these cases, it is exceedingly challenging to densely fill the aneurysm fundus with embolization coils without occluding the branch vessel arising from sac [2] (Fig. 11.3).

What Is Balloon-Assisted Treatment of Cerebral Aneurysms?

Balloon-assisted aneurysm treatment (BAT; i.e., balloon remodeling, balloon protection), first described concurrently by Dr. Peter Kim Nelson (in the USA) and Pr. Jacques Moret (in Europe), is a technique in which a temporary occlusion balloon is positioned within the parent artery across the aneurysm neck and inflated, while coils are introduced into the aneurysm fundus through a second parallel catheter [3, 4]. The inflated balloon prevents the coil loops from herniating into the parent artery

Fig. 11.3 Patient with a large ruptured ACOMM aneurysm. An image from the presenting head CT shows subarachnoid hemorrhage surrounding a large ACOMM aneurysm (**a**). A selected reconstructed three-dimensional projection from rotational angiographic source data shows the aneurysm to be extremely wide necked incorporating the right aspect of the ACOMM complex and right A2 (**b**). While the contralateral left A2 arose from the left aspect of the ACOMM complex and was essentially free of the aneurysm neck, the right A2 segment arose from the proximal aspect of the aneurysm fundus (arrow, **b**). The working angles for coil embolization (**c**, **d**) confirm the complex anatomy at the aneurysm neck. The subtracted frontal (**c**) working angle shows the ipsilateral A2 arising from the aneurysm fundus several millimeters away from the ipsilateral A1. The lateral working angle (**d**) was chosen to display a "down-the-barrel" view of the ACOMM and proximal A2 segment; however, this anatomy is almost impossible to perceive due to vascular superimposition. After diagramming the "volume at risk," it was determined that the most efficient means by which the right A2 and ACOMM complex could be protected was to place a single balloon catheter from the contralateral A1 into the ipsilateral A2. Given the very large interface between the planned coil mass and the "volume at risk" to be protected, we felt that it was essential to introduce multiple coils without losing microcatheter access to the aneurysm and thereby construct the most stable "conglomerate mass" possible. For this reason, two microcatheters were manipulated into the aneurysm via the right internal carotid artery guiding catheter. A subtracted image in the working projection (**e**) schematically demonstrates the microcatheter positioning. The solid lines indicate the position of the two microcatheters placed into the aneurysm for embolization. The dotted line depicts the trajectory of the 4 × 7 mm balloon catheter which was placed via the left A1 to lie across the right aspect of the ACOMM and extend into the proximal right A2. A total of 14 embolization coils (40 cm of Presidio-18, 151 cm of Cashmere-14 (Micrus Endovascular, San Jose, CA), and 36 cm of Hydrocoil-10 (Microvention/Terumo, Alisa Viejo, CA)) were placed during three balloon inflations. The blanked roadmap in the lateral working projection (**f**) demonstrates the "negative defect" of the deflated balloon demarcating the "down-the-barrel" projection of the proximal A2 and ACOMM complex. The coils surrounds nearly 180 degrees of the ACOMM complex and right A2 segment and remains nearly perfectly subtracted after balloon deflation indicating stability of the conglomerate mass. Frontal (**g**, subtracted; **h**, native) and lateral (**i**, subtracted; **j**, native) projections in the working angles following coil embolization show adequate occlusion of the aneurysm with a small amount of residual filling at the right A1–A2 junction. The residual area of filling corresponds to the intra-aneurysmal volume which was protected by the balloon to allow continued patency of the right A2 segment as it arose from the proximal aneurysm fundus. Although there is essentially no anatomical "neck" to prevent the prolapse of coils into the orifice of the right A2, the stability of the conglomerate mass allowed the coil reconstruction of the A1–A2 junction around the outside of the balloon. The lateral working angle (**i**, **j**) depicts the patent proximal right A2 and ACOMM (white circle) in the "down-the-barrel projection." The ACOMM anatomy is now better appreciated with the aneurysm fundus being filled with embolization coils

during delivery into the aneurysm. During the delivery of the framing coil, the balloon technique essentially "forces" the coil to achieve its complex or spherical configuration within the confines of aneurysm fundus. During the placement of the subsequent filling coils, the balloon again prevents prolapse of the new coil during deployment, but also prevents the displacement of the other previously detached coils by the new coil. Thus, the balloon essentially "forces" these filling coils to "nest" somewhere within the structure of the preexisting intra-aneurysmal coil mass. After a coil has been placed completely within the aneurysm, the balloon can then



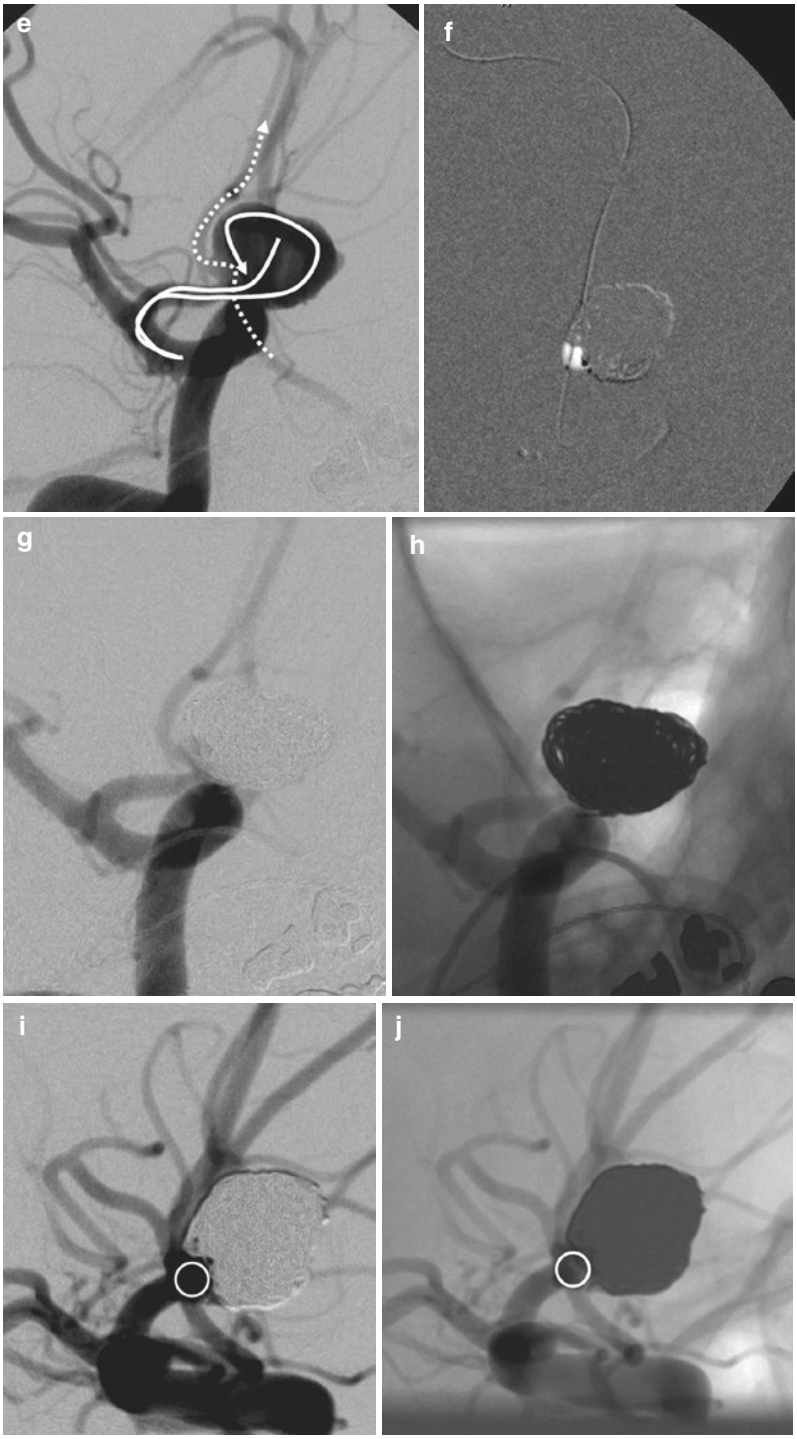


Fig. 11.3 (continued)

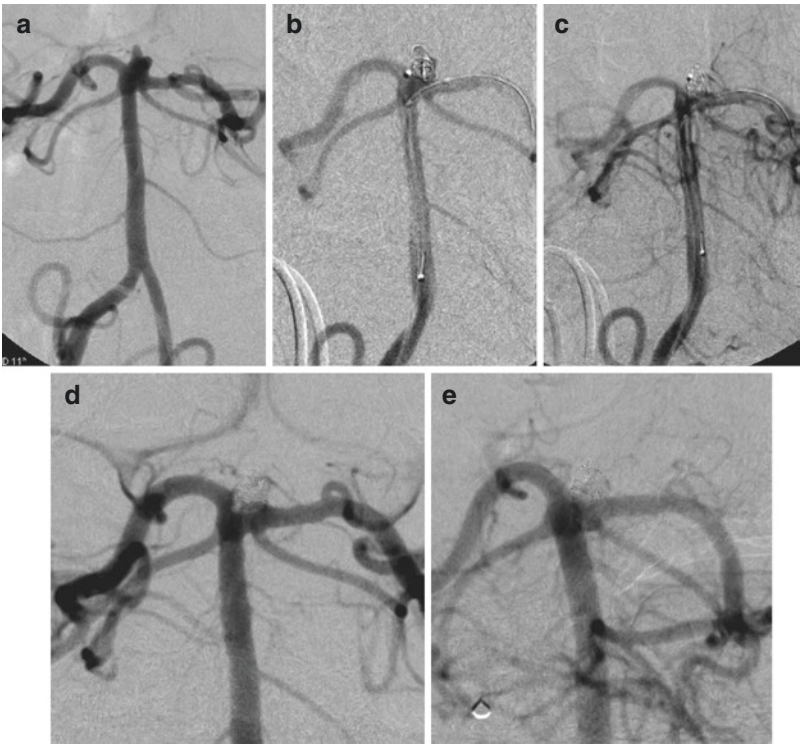


Fig. 11.4 Young female with subarachnoid hemorrhage. The initial angiographic image (**a**) in the frontal working angle for coil embolization shows a small, very wide-necked basilar artery apex aneurysm with a dome/neck ratio ~1.0. It is difficult to envision creating a stable coil mass within the aneurysm without an adjunctive device. Given that the aneurysm was ruptured, treatment was performed using a traditional balloon-assisted technique (BAT). A number of attempts were required to achieve a stable configuration of the framing coil within the aneurysm. During each of the preceding attempts, the introduced coil would prolapse out of the aneurysm with deflation of the balloon. Finally, after multiple cycles of balloon inflation and deflation with coil introduction and removal, a stable configuration of the framing coil was finally achieved (**b**). Then, additional coils were introduced into the aneurysm under balloon protection (**c**). The aneurysm was effectively coiled to complete occlusion (**d**) which was demonstrated to be durable (**e**) at 1-year angiographic follow-up. While this technique was ultimately successful, it was very time-consuming; it involved extensive manipulation of a framing coil within a small ruptured aneurysm and required a number of inflation-deflation cycles of the occlusion balloon

be deflated to "test" the coil for stability. If stable, the coil can be detached. If the coil begins to prolapse after the balloon is deflated, it can be removed and repositioned. Not uncommonly, several balloon inflations and attempted deliveries are required to achieve a stable configuration of a given coil within the aneurysm (Fig. 11.4). Thus, during traditional BAT these serial inflation-deflation cycles are repeated (occasionally multiple times) for each coil until the embolization is completed.

What Are the Arguments in Favor of BAT?

The balloon is in many aspects an optimal adjunctive device for aneurysm coil embolization for the following reasons:

1. *Reliable parent artery protection*: While inflated, the balloon provides a much more reliable and robust parent artery protection than do the available Nitinol, self-expanding, intracranial microstents (Neuroform, Boston Scientific, Fremont, CA; Enterprise, Codman Neurovascular, Warren, NJ). First, the contrast-inflated balloon can be unambiguously visualized to demonstrate the location of the parent artery. The self-expanding stents are radiolucent, and as such, the exact anatomy of the interface between the parent artery and aneurysm fundus sometimes remains unclear. As such, during the embolization of aneurysms with complex anatomy, it is sometimes difficult to confidently ascertain whether coils are completely free of the parent artery. Second, the interstices of the self-expanding stents are large enough (2 French) to accommodate the unimpeded passage of a microcatheter into the aneurysm. These interstices may become even larger when the stent is deployed across an aneurysm which arises from a curved segment of the cerebrovasculature [5]. The area of these interstices is sometimes sufficient to allow the prolapse of coils through the stent and into the parent artery (Fig. 11.5).

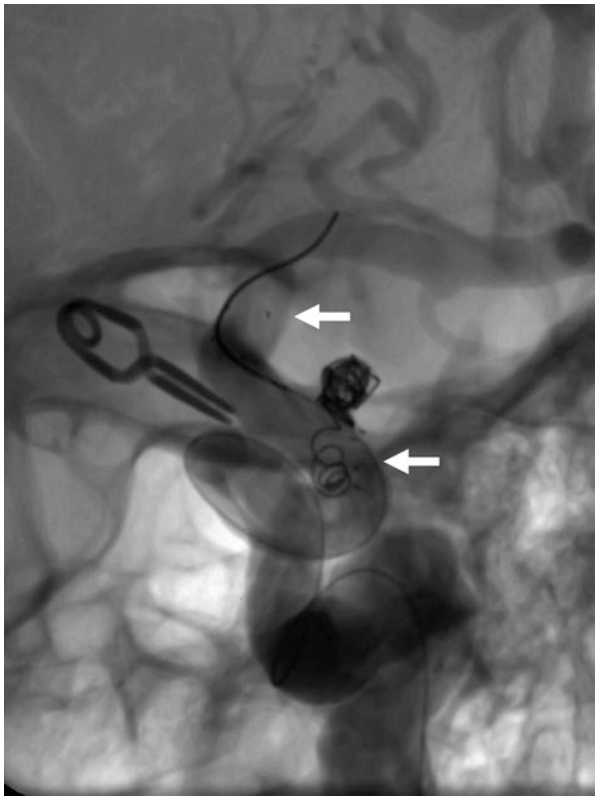


Fig. 11.5 Coil prolapse through an intracranial self-expanding stent. Native image from a trans-stent coiling of a small carotid-ophthalmic segment aneurysm depicts a stent in position across the aneurysm neck (arrows demarcate the stent end markers). The intra-aneurysmal coil mass shows a vivid stent effect with a flat edge at the aneurysm-parent vessel interface. However, an immediately following detachment, a coil herniated through the interstices of the stent. A second stent was subsequently deployed across the aneurysm to secure the coil and prevent further prolapse or distal embolization

In contrast to the stent, the balloon provides a completely continuous, radio-opaque barrier along the aneurysm neck. As such, unless the coiling microcatheter gets pushed out of the aneurysm or coils prolapse around the outside of the balloon (which typically indicates that the balloon is underinflated or improperly sized/shaped), there is no way that coils can come into the parent artery while the balloon is inflated.

2. *Unambiguous parent artery visualization*: Once positioned across the neck of the aneurysm, the balloon can often times provide invaluable assistance with respect to pre- (or more appropriately stated intra-) treatment planning. With the balloon inflated, the framing coil can be placed within the aneurysm but not detached. If optimally sized, the framing coil then provides a radio-opaque demarcation of the boundaries of the aneurysm. At this point, with the balloon inflated and the framing coil in place, the image intensifiers/detectors can be manipulated under fluoroscopic visualization to best depict the parent artery (demarcated by the contrast filled balloon) free of the aneurysm fundus (demarcated by the framing coil). This technique is very useful to determine the most optimal working angles for coil embolization. This is particularly useful in achieving a perfect "down-the-barrel" projection of the parent artery in the region of the aneurysm neck. This "down-the-barrel" projection is usually the most reliable demonstration of the parent artery boundaries during complex cases (Fig. 11.6).
3. *Rupture protection*: Intra-procedural aneurysm rupture is a potentially catastrophic complication which can often be managed and considerably mitigated using with a balloon-assisted technique. In the absence of an occlusion balloon, procedural aneurysm perforation usually results in immediate extravasation which can be controlled only by reversing heparinization, lowering blood pressure, and quickly placing additional embolization coils. Aneurysm perforation is particularly difficult to manage in the setting of stent-assisted coiling since these procedures are usually performed with the patient on dual antiplatelet therapy in addition to full procedural heparinization.

   During BAT, an occlusion balloon is inflated across the aneurysm neck, and the lesion is essentially isolated from the cerebral circulation. Correspondingly, the inflated balloon actively prevents or minimizes any extravasation from the aneurysm should it re-rupture during the introduction of coils. If there is evidence of aneurysm rupture during coiling (e.g., the coil passes outside of the confines of the aneurysm roadmap), the balloon can be left inflated, while the heparinization is reversed, and additional coils are introduced into the aneurysm fundus. In this way the amount of extravasation which occurs after rupture can be minimized or eliminated altogether. The occlusion balloon in this scenario functions similarly to the temporary surgical clips used to control intraoperative aneurysm rupture during surgery.
4. *Temporary device*: The absolute requirement for dual antiplatelet medications represents one significant potential drawback of the application of intracranial stents for aneurysm treatment. This is particularly an issue in the setting of acute subarachnoid hemorrhage in which platelet inhibition represents a significant hazard during subsequent intensive care management [6]. In contrast to stenting, BAT can be performed with heparinization alone in patients with subarachnoid

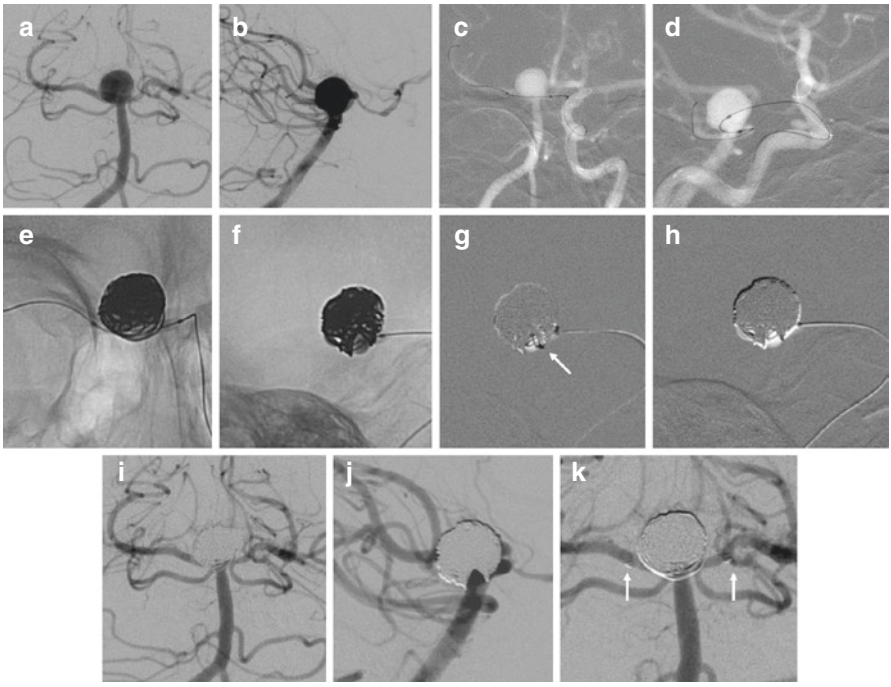


Fig. 11.6 Patient with an incidental basilar apex aneurysm. Initial frontal (**a**) and lateral (**b**) working angles show a very wide-necked aneurysm wrapping around the anterior and posterior aspects of the basilar apex and incorporating both proximal P1 segments into the neck. On the frontal working angle (**a**), it is difficult to visualize the origins of either P1 as they are obscured by the aneurysm. On the lateral view (**b**), the anatomy is difficult to assess due to superimposition of many branch vessels and the aneurysm. Fluoroscopic roadmap images in the frontal (**c**) and lateral (**d**) projections show a 4 × 15 cylindrical balloon in position across the basilar apex via the left PCOMM. This balloon position allows the protection of the entire "volume at risk" with a single balloon catheter. Once coils have been placed in the aneurysm, the detectors were manipulated to optimize the working angles. While the frontal (**e**) angle cannot show the parent artery due to superimposition, the lateral (**f**) angle has been manipulated into an exact "down-the-barrel" projection, viewing the balloon and its central microwire on axis. The lateral blank roadmap (**g**) following balloon deflation after the first round of coiling demonstrates some coil prolapse along the anterior aspect of the basilar apex (arrow). At this point, this compartment of the aneurysm lacked a sufficient number of coils to create a stable conglomerate mass. Fortunately, reinflation of the balloon displaced these coils back into the aneurysm. The microcatheter was reoriented into this anterior compartment, the balloon was reinflated, and a number of additional coils were placed. During the second balloon deflation, the blank roadmap in the lateral working projection (**h**) shows that the prolapsed coils which were displaced into the fundus by the balloon became enmeshed with the new coils introduced during the second round of coiling. Now, after the second balloon deflation, the basilar (demarcated by the "negative defect" of the deflated balloon) remains free of coils, indicating that conglomerate mass is now completely stable. Completion angiography in the frontal (**i**) and lateral (**j**) working angle shows complete aneurysm occlusion. The lateral working angle (**j**) demonstrates the coil reconstructed basilar apex, with 270° of its circumference surrounded by embolization coils. At the conclusion of coiling, the balloon catheter was exchanged for a stent delivery system and a self-expanding microstent was placed from the right to the left P1. A magnified frontal (**k**) view at the end of the procedure shows the coil mass within the basilar apex and the stent end markers (arrows) in the left and right P1's

hemorrhage. In some elective BAT cases, we do pretreat patients with aspirin or sometimes both aspirin and clopidogrel. These antiplatelet medications provide prophylaxis against procedural thromboembolic complications and to allow the accommodation of a stent if one is ultimately deemed necessary at some point during the procedure. However, if an elective patient is pretreated with both antiplatelet agents and no intracranial stent is used, we typically discontinue clopidogrel immediately after the procedure and stop aspirin after 2–4 weeks.

5. *Improved microcatheter access (stability and reaccess)*: The temporary occlusion balloon can often function to stabilize the microcatheter at the aneurysm neck, preventing excessive kickback during coiling. This augmentation of microcatheter stability can facilitate dense aneurysm packing with coils. If the microcatheter should get pushed out of the aneurysm during coiling, the balloon can be deflated, and it presents no barrier to aneurysm reaccess. In contrast, an in situ stent frequently impairs microcatheter access into the aneurysm and also provides no additional support for the stability of the microcatheter once it is navigated into the aneurysm.
6. *Packing density*: The improved access to the aneurysm as well as the more robust nature of the parent artery protection offered by the balloon may contribute to a more aggressive coiling of the aneurysm and a higher packing density in some cases.
7. *Dynamic parent artery protection*: Initially, the balloon is sometimes inflated to the point that it herniates slightly into the aneurysm neck during coil placement. As the coiling is completed, the balloon can be inflated less aggressively to allow the coil mass to form an interface with the parent artery that exactly approximates the aneurysm neck (Fig. 11.7).

What Are the Potential Disadvantages of BAT?

1. *Temporary protection may be unreliable*: The overriding belief which discourages some operators from using a balloon remodeling technique is the absence of a permanently implanted device to secure the coil mass in place. This raises the concern that the entire coil mass could spontaneously begin to prolapse into the parent artery at some point during the case. Once the operator gains sufficient experience with the technique, particularly when applied using the "conglomerate mass" approach, it becomes evident that this is not a common or unmanageable problem. In some cases, when a very wide-necked aneurysm has been densely packed down to the parent artery, the operator may elect to place a stent at the conclusion of coiling to definitively stabilize the coil mass. With this approach, one gains all of the above advantages of BAT while alleviating any concerns that the coil mass could begin to prolapse after the procedure is complete (Fig. 11.6). Similarly, if any coil prolapse is noted during the procedure, the operator retains the ability to exchange the balloon catheter for a stent delivery system.
2. *Time*: When applied using a traditional approach (i.e., an inflation-deflation cycle with each coil introduction), the BAT approach can consume a considerable

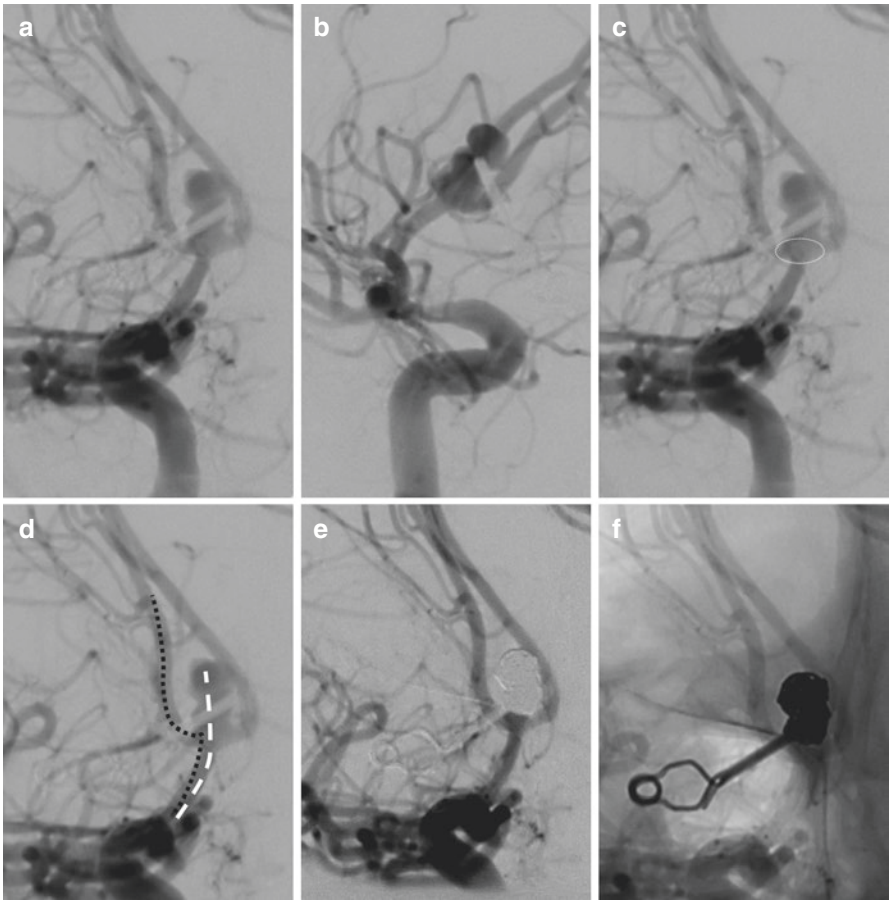


Fig. 11.7 Patient with wide-necked ruptured ACOMM aneurysm originally clip-wrapped at an outside institution after direct clipping was unsuccessful. The left A1 segment was aplastic, with both A2 segments filling from the right anterior circulation. Angiography in the frontal (**a**) and lateral (**b**) working projections demonstrates a wide-necked ACOMM aneurysm incorporating the entire ACOMM complex and proximal right A2 segment. The "volume at risk" (dotted line) is depicted schematically on the frontal (**c**) working projection. The more difficult branch to protect and catheterize is clearly the ipsilateral (right) A2. As such, a 4 × 7 mm balloon was manipulated into position within the ACOMM and proximal right A2. The position of the microcatheters is diagrammatically depicted on the subtracted frontal working projection (**d**). The balloon catheter position is marked by a black dotted line, while the microcatheter position is demarcated by a white dashed line. Eleven coils were introduced during two 5-min balloon inflations (38 cm of Cashmere-14, 20 cm of Ultipaq-10 (Micrus Endovascular) and 4 cm of Hydrosoft-10 (Microvention/Terumo)). Subtracted (**e**) and native (**f**) images following coil embolization demonstrate complete, dense occlusion of the aneurysm with the coil mass forming a homogeneous flat interface with the ACOMM complex. Both A2 segments remain widely patent

amount of time and require extensive manipulation of the coiling microcatheter and embolization coils. The deflation times for the balloons can last up to 15–30 s in some cases, adding a significant amount of additional time to each coil placement and detachment cycle.

3. *Brain ischemia*: While the balloon is inflated, the parent artery is completely occluded, resulting in reduced blood flow (and depending on the status of the collateral circulation) and potentially ischemia of the region of brain supplied by that vessel. For this reason, it is useful to assess very closely the patterns of collateral circulation which are in place during balloon inflation. For aneurysms of the carotid artery, the balloon should be positioned specifically to avoid inducing unnecessary ischemia by occluding these collaterals. Specifically, one should avoid when possible having the balloon extend into the ICA terminus if the ACOMM provides collateral flow or occluding the PCOMM when that vessel could otherwise provide perfusion to the hemisphere. The repetitive inflation and deflation of the balloon with each coil introduction may also raise the risk of thromboembolic events by repeatedly agitating the forming coil mass and also potentially resulting in small amounts of blood being aspirated into the balloon and ultimately embolized during the procedure.
4. *Durability of coil embolization*: While BAT may allow the embolization of very wide-necked aneurysms, the results may not be durable, given the propensity of these lesions to recur [7]. Some operators have suggested that the application of a stent may in fact improve the durability of coil embolization by providing some degree of flow redirection and neoendothelial/overgrowth at the aneurysm-parent artery interface [8]. However, there are several arguments which can be made against using a stent primarily. First, the BAT likely allows a more meticulous and complete packing of the aneurysm which might lessen the risk of recanalization. Second, following BAT, if the operator believes that either the coil mass is unstable or otherwise requires a stent, one can be placed at that time. The balloon catheter can be exchanged over a 0.010″ 300 cm exchange microwire (e.g., Xcelerator-10, eV3, Irvine, CA) for a microcatheter, then a 0.014″ exchange wire, and ultimately a stent delivery system.

Balloon-Assisted Coiling in Our Practice: The Conglomerate Coil Mass Technique

What Is the "Conglomerate Coil Mass Technique" of BAT?

Having recognized that the potential and practical limitations of balloon-assisted coiling are primarily related to the repetitive cycles of inflation and deflation associated with the introduction of each coil, we began to place multiple embolization coils (3–7 coils) during each balloon inflation (typically lasting 5–10 min).

Several observations led to the evolution of this technique. First, we noticed that during traditional BAT occasionally a newly introduced coil would lead to the prolapse of a formerly placed and previously detached coil. Often times, we would continue embolization with the idea that a stent would be required at the conclusion of the coiling to secure the prolapsed coil. However, we often found that if the prolapsed loop(s) were pushed back into the aneurysm during subsequent balloon inflations and additional coils were introduced and detached, the prolapsed loops actually enmeshed within the newly introduced coils, ultimately forming a stable intra-aneurysmal "conglomerate mass" and obviating the need for a stent (Fig. 11.6).

Second, in some very wide-necked aneurysms, we found that the original framing coil was unstable despite multiple attempts at repositioning. Moreover, even when stable within the aneurysm, the coil would frequently shift during balloon deflation. In contrast, when multiple coils were introduced and detached during the initial balloon inflation, they formed a stable intra-aneurysmal "conglomerate mass" which did not appreciably shift or prolapse when the balloon(s) were ultimately deflated.

Third, continuous occlusion times of between 5 min and 10 min with intermittent perfusion seemed very well tolerated in most patients. In the setting of adequate direct collateral circulation (e.g., robust ACOMM collateral which remains patent during BAT), much longer occlusion times are acceptable. The duration of acceptable occlusion times during endovascular procedures can be extrapolated from the literature describing the application of temporary aneurysm clips during surgery. During aneurysm surgery, temporary clip occlusion times of between 10 min and 20 min are routinely necessary and typically well tolerated by most patients [11–13]. As opposed to the placement of temporary aneurysm clips, the application of an occlusion balloon as an endovascular "temporary clip" is performed with full heparinization (often times with adjunctive antiplatelet medications in patients with unruptured aneurysms), does not require manipulation of the parent artery or regional perforator vessels, and is not performed in conjunction with brain retraction. For these reasons, it would seem that endovascular balloon occlusion would be at least as well tolerated as temporary clip application when applied over similar time intervals.

Fourth, during the occasional procedural rupture using traditional BAT, the conglomerate technique was used by default in an attempt to achieve complete aneurysm occlusion and halt any further hemorrhage. In these cases, it became evident that very dense packing could be achieved quite quickly using this technique.

Arguments in Favor of the "Conglomerate Mass" Technique Versus a Traditional Approach to BAT

We find in our practice that this BAT technique provides several potential advantages over the traditional approach.

1. The conglomerate mass created with the introduction of multiple coils was more stable than individually placed coils and allowed the coil embolization of very wide-necked aneurysms without the use of an adjunctive stent (Fig. 11.1).

2. This approach allowed the dense packing of small, soft, finishing coils at the level of the aneurysm neck, facilitating very high packing densities and more homogeneous coil reconstructions of segmental neck defects (Fig. 11.7).
3. The rapid placement and detachment of multiple coils in succession shortened the overall procedural time for aneurysm coiling in comparison to the standard BAT approach (Fig. 11.8).
4. Placing multiple coils during a single balloon inflation allowed for fewer overall balloon inflations and less coil manipulation/repositioning. This technique likely results in shorter cumulative total balloon occlusion times in many cases.
5. Unexpected procedural aneurysm perforation becomes more manageable, as many coils are introduced quickly and the aneurysm is typically very well occluded at the time of the initial balloon deflation (i.e., the time when procedural perforation becomes evident).

The Conglomerate Coil Mass Technique: Technical Points, Equipment, and Procedural Details

Key Technical Points

Anticoagulation/Antiplatelet Regimen: Full Anticoagulation Is Required for BAT Using the Conglomerate Coil Mass Technique

For these cases, it is required that patients, regardless of their rupture status, are completely heparinized (activated clotting time of 250–300 s) prior to balloon inflation. The application of complete heparinization can be deferred until the microcatheters are in appropriate position for the initiation of coiling. Patients with unruptured wide-necked aneurysms undergoing elective embolization with BAT are pretreated with aspirin (81–325 mg per day given the morning of the procedure) and sometimes clopidogrel (75 mg per day for 5–7 days or 600 mg the day prior to the procedure with 75 mg the morning of the procedure) particularly if stent use is anticipated. If stenting is not performed, in most cases, the clopidogrel can be discontinued immediately after the procedure and the aspirin stopped at 2–4 weeks.

Balloon Selection, Positioning, and Navigation

Strategies for balloon selection and positioning are based upon a thorough understanding of the anatomy of the aneurysm, the parent artery, and the relevant adjacent branch vessels. Two general factors govern these decisions.

First, the operator must define the exact volume of the parent artery and regional branch vessels (i.e., the parent artery-aneurysm complex) which is at risk for coil prolapse and therefore must be protected with the balloon(s) – the “volume at risk.” Sometimes it is helpful to actually trace this volume out on the image or on a sheet of paper. This volume will then determine which balloon(s) should be selected and

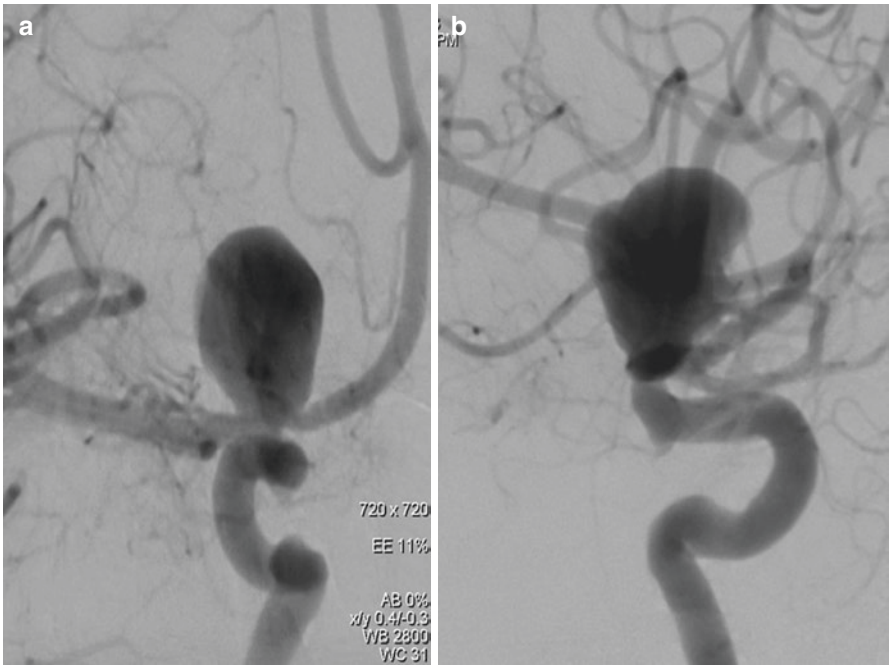


Fig. 11.8 Very large ruptured ICA terminus aneurysm presenting with subarachnoid and a right frontal parenchymal hemorrhage. Angiography in the initial frontal (**a**) and lateral (**b**) working projections demonstrates a large, wide-necked ICA terminus aneurysm incorporating a short segment of the proximal right M1. The right A1 essentially arises from the aneurysm fundus. While there were two patent and equally sizes A1s, the ACOMM complex was tiny. As such, it was decided that patency of the right A1 had to be maintained during treatment. Coronal (**c**) and surface-shaded three-dimensional (**d**) reconstructions of computed tomographic angiography (CTA) source images show the right A1 arising at an acute angle just distal to the neck of the aneurysm. The planned microcatheter positions are schematically superimposed upon the frontal working projection (**e**) with the dash-dotted line representing a 4 × 15 mm balloon extending from the ICA into the right M1, a dotted line representing a 4 × 7 mm balloon extending from the ICA terminus into the right A1, and a solid line representing a microcatheter wrapped around the dome of the aneurysm with the tip positioned near the A1 outflow zone. A native (**f**) image in the frontal working projection demonstrates the simultaneously inflated balloons with the microcatheter in position wrapping around the dome of the aneurysm. During 3 balloon inflations lasting 12, 8, and 8 min, respectively, a total of 25 coils were introduced. Subtracted (**g**) and native (**h**) images in the frontal working projection for coil embolization demonstrate a dense coil mass within the aneurysm forming a flat interface with the parent arteries. A tiny defect at the medial aspect of the coil mass corresponds to the intra-aneurysmal portion of the ACOMM-proximal right A2 segment junction, the patency of which was preserved by the 4 × 7 mm balloon to allow continued filling of the right A2. A tiny focus of thrombus at the lateral aspect of the coil mass, seen as a tiny lucent defect within the right M1, was prophylactically treated with several milligrams of IA abciximab and post-procedural aspirin

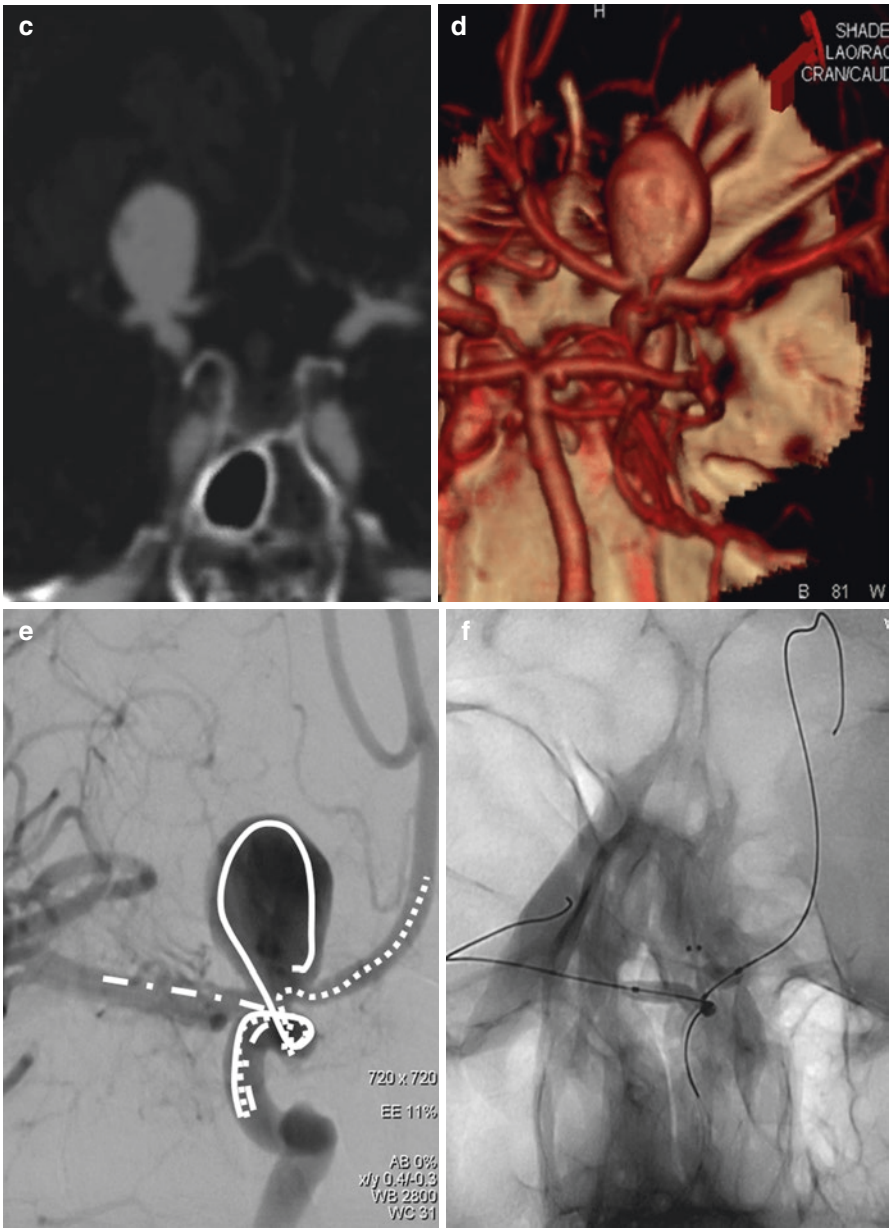


Fig. 11.8 (continued)

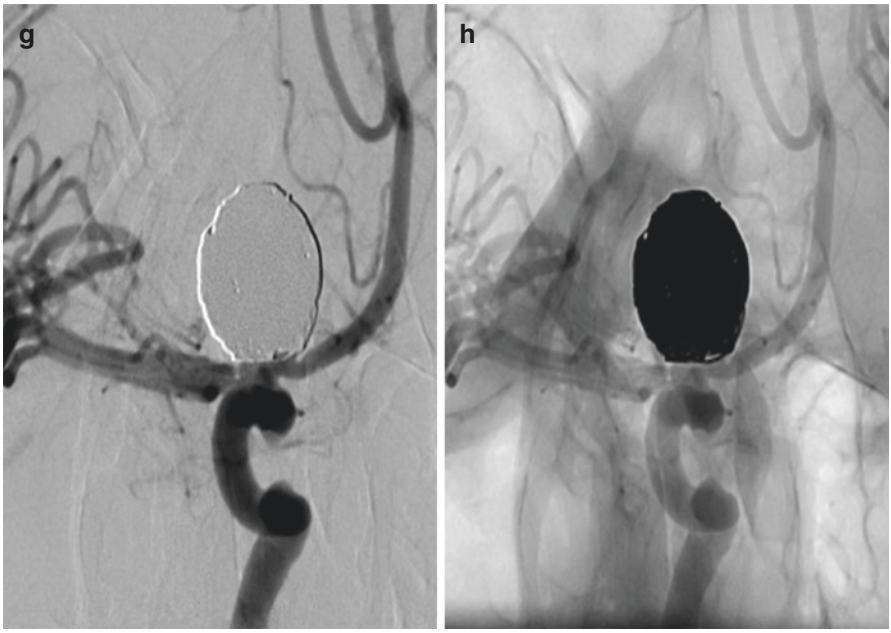


Fig. 11.8 (continued)

where it/they should be positioned such that the required space can be completely filled during the inflations (Figs. 11.3, 11.6, and 11.7).

Second, for bifurcation aneurysms, the operator must determine which branch(es) is(are) most likely to be occluded by the prolapse of an individual coil or the forming coil mass. This can often be done by visualizing the aneurysm completely filled by a symmetric spherical or elliptical coil mass, since the favored configuration of implanted coils typically conforms to this shape. The branch vessel most likely to be occluded by the coil mass is the one which will require not only balloon protection but control via catheterization with the balloon microwire. This microwire control allows the operator to seamlessly exchange the balloon catheter for a stent delivery system in the case that coils prolapse into the orifice of the vessel during or after treatment.

The available single lumen, hypercompliant temporary occlusion balloons accommodate only a 0.010″ microwire. Given the limited torque response of the smaller 0.010″ microwires, the negotiation of complex cerebrovascular anatomy with the balloon catheter can be very challenging. In addition, the balloon catheters are larger and more rigid than the standard 0.017″ ID microcatheters and as such have a tendency to "override" the relatively soft 0.010″ microwire in the absence of excellent distal wire purchase. For this reason, we prospectively navigate predictably difficult anatomy with a standard microcatheter and 0.014″ microwire to achieve distal access within the targeted anatomy (foregoing any attempt at primary catheterization with the balloon). We then exchange the microcatheter for the

occlusion balloon of choice over a 300 cm, 0.010″ exchange length microwire (Xcelerator-10, eV3, Irvine, CA). After this exchange, we maintain the 300 cm microwire in place through the balloon catheter for the entire case, allowing for a seamless exchange to a stent delivery system should this be necessary at some point during the case.

Microcatheter Positioning

As the stability of the conglomerate mass is predicated upon the introduction of multiple coils during a single balloon inflation, it is important that the microcatheter does not get rejected from the aneurysm after only one or two coils are placed. For this reason, a stable and deep access into the aneurysm is preferable. In larger aneurysms, we have achieved this with a microcatheter position which courses around the aneurysm dome and/or through the introduction of a second microcatheter into the aneurysm for coiling (Figs. 11.8). Coils can then be introduced into the aneurysm until the microcatheter(s) is/are rejected.

Coils with Rapid Detachment

The rapid delivery and detachment of multiple coils requires a rapid detachment mechanism. The standard electrolytic detachment, which can require between 15 s and 45 s per coil, is not compatible with the conglomerate coil mass technique.

Soft Coils of Long Length

Softer coils work best with this technique as they do not reject the microcatheter from the aneurysm during their introduction. They also tend to fill the interstices within the developing coil mass, and in the region of the aneurysm neck, they "mold" around the outside of the balloon to form a more continuous interface at the parent artery-aneurysm neck interface (Fig. 11.8). The longer coils provide more length available to insinuate and enmesh within the forming coil mass. They also provide a greater volume of filling per coil, reducing the total number of coils introduced and thereby reducing the collective amount of time for coil preparation, loading, and delivery.

Efficient Coil Preparation and Delivery

The entire team must be fully engaged with the procedure while the balloon(s) is(are) inflated. The expected sequence of coils should be preselected and readily available from the technologist. During the introduction of one coil, the operator should be asking for the next coil which should be immediately ready for

introduction as soon as the preceding coil is detached and removed. The assistants to the primary operator must be familiar with the process of coil preparation and microcatheter loading so that this can be performed as efficiently as possible. These considerations are critical to limiting time required to prepare and introduce each coil. If the time allotted to place each coil can be reduced, more coils can be successfully introduced into the aneurysm during a given inflation, the overall number of inflations required can be reduced as can the overall collective procedural time.

Equipment

Balloon Catheters

The original temporary occlusion balloons (Endeavor, Boston Scientific, Fremont, CA) relied on flow direction and were subsequently limited in terms of navigability. A new generation of hypercompliant, wire-guided, temporary occlusion balloon catheters have been developed for use in the cerebrovasculature. These devices are now widely used for temporary vessel occlusion, angioplasty of cerebral vasospasm, mechanical disruption of thrombus in the setting of acute ischemic stroke, and balloon-assisted treatment of cerebral aneurysms.

In the USA, the Hyperglide and Hyperform (eV3, Irvine, CA) balloons are most frequently used for BAT. These balloons accommodate a 0.010″ microwire which occludes the distal end hole of the catheter when passed out the microcatheter tip. When a mixture of contrast-saline is injected into the proximal hub around the microwire through a rotating hemostatic valve, the injectate is directed into the balloon chamber resulting in balloon inflation. The hypercompliance of the balloon material allows for multiple inflations without a significant change in the profile of the distal catheter when the balloon is deflated (i.e., the material collapses around the distal catheter and does not form "wings" as would a semicompliant or noncompliant "wrapped" angioplasty balloon). Also, the hypercompliant inflation profile makes for a very soft, atraumatic, and "moldable" balloon which can be inflated such that it insinuates into adjacent vessels or the aneurysm neck.

The available balloons come in two general shapes, a conformable ball-shaped (e.g., Hyperform 4 × 7 mm and 7 × 7 mm) which is typically used for bifurcation and terminal aneurysms and a more cylindrically shaped tubular balloon (e.g., Hyperglide 4 × 10, 15, 20, 30 mm) which is most often used for side wall aneurysms. These two different shaped balloons can sometimes be used in combination to achieve more extensive and complex remodeling.

Microcatheters

Any standard 0.017″ internal diameter (ID) microcatheter (SL-10, Boston Scientific, Fremont, CA; Echelon-10, eV3, Irvine, CA; Prowler-10, Codman Neurovascular, Warren, NJ) can be used in conjunction with the available hypercompliant balloon

catheters through a standard 6F, 0.070″ ID guiding catheter system with the exception of the 7 × 7 mm Hyperform balloon. The 7 × 7 mm Hyperform balloon requires a larger guiding catheter (7F) to accommodate a parallel microcatheter.

Rotating Hemostatic Valve (RHVs)

There are a number of different options for managing the proximal aspect of the guiding catheter. The two microcatheters can be placed side by side through a single RHV port. We do not prefer this technique, as this setup makes the independent positioning of the two catheters more challenging. Two RHVs can be coupled together to provide two ports for microcatheter access; however, the additional RHV adds considerably to the dead space of the guiding catheter system. Finally, a W-shaped adapter (e.g., The Sequel, Cook Medical, Indianapolis, IN) with two valve ports and a one side arm integrated into a single RHV, in our opinion, represents an optimal solution by minimizing dead space and providing an independent access for both microcatheters.

Procedural Details

Diagnostic angiography is first performed to approximate the working angles for coil embolization and to obtain accurate measurements of the aneurysm fundus for coil selection. The framing coils and the anticipated filling/finishing coils are then removed from the stock and placed in an accessible position such that they may be opened and provided to the operators efficiently. The volume distribution which must be protected with the balloon(s) is determined at this point, and the appropriate balloon(s) are opened and prepared. Regardless of rupture status, full heparinization (ACT of approximately 250–300 s) is usually instituted at the time that the balloons are being inflated.

Once the balloons are in position and the aneurysm is catheterized, it is sometimes useful to inflate the balloons and partially deploy the framing coil into the aneurysm. The coil outlines the confines of the aneurysm, while the contrast opacified balloon(s) demarcate the parent artery. Then under live native fluoroscopy, the image detectors can be manipulated to demonstrate the parent arteries (demarcated by the contrast-inflated balloon(s)) to best advantage as separate from the aneurysm fundus (demarcated by the aneurysm coil). This technique can be used to optimize the working angles for embolization.

At this point, the coil can be removed and the balloons deflated and to allow cerebral reperfusion. A new angiographic run is performed in these optimized working angles and if possible displayed as a reference image which can be viewed throughout the case. The balloons can then be reinflated and coils delivered into the aneurysm. During the initial inflation, typically between three and seven coils can be deployed over 5–10 min depending on the aneurysm size. Following placement of these coils, a blank roadmap image can be created with the balloon(s) inflated.

Then the balloon(s) can be deflated with fluoroscopic visualization on a blank roadmap. The balloons deflate to form a negative defect in the region of the parent artery (Figs. 11.1, 11.3, and 11.6). On the blank map, even the most subtle shift of the coil mass or an individual coil loop will be evident. An angiographic run is performed at this time to confirm the patency of the parent arteries and branches. Additional rounds of balloon inflation and embolization are then performed as needed. Usually the endpoint of the case is indicated when the microcatheter has been rejected from the aneurysm during the introduction of small diameter, short finishing coils (e.g., 2 mm Ultipaq or DeltaPlush (Micrus Endovascular, San Jose, CA); 2 mm Hydrosoft or Hypersoft (Microvention/Terumo, Alisa Viejo, CA)). For smaller aneurysms (<7 mm), it is not uncommon that the entire embolization can be completed during a single balloon inflation.

Limitations

The occlusion times accepted using this technique are longer than those traditionally used during balloon-assisted coil embolization. However, certain subsets of patients may not tolerate these lengths of occlusion, and caution should be exercised in these cases. The literature describing occlusion times with temporary surgical clips have indicated that older patients and those with subarachnoid hemorrhage may be at a higher risk of ischemia with temporary occlusion [9–15]. Further work with procedural neuromonitoring and anesthetic optimization may make this approach safer and more effective in the future.

The technique described in the present manuscript has been derived *solely* from our collective clinical experience. To date, beyond our empirical observations from individual cases, there are no studies which support the conglomerate coil mass technique as a general approach to aneurysm coil embolization.

Summary

The balloon-assisted treatment (BAT) of aneurysms offers several theoretical and practical advantages over unassisted or stent-supported coil embolization. By introducing a number of coils during a single balloon inflation, the procedures may be completed more quickly with fewer balloon inflations. In addition, our clinical experience suggests that when a number of coils are placed during a single balloon inflation they form a “conglomerate mass” which is more stable than any individually placed aneurysm coil. Using this “conglomerate mass” technique, we have (in some cases) been able to achieve a very dense packing of wide-necked and complex aneurysms without adjunctive stents.

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