Endovascular Treatment of Intracranial Aneurysms

Current Status

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In a recent systematic review and meta-analysis, the overall prevalence of unruptured intracranial aneurysms (IAs) is estimated as 3.2%.1 The prevalence of IAs is higher in patients with autosomal dominant polycystic kidney disease or a positive family history of IAs of subarachnoid hemorrhage (SAH).1 From the same review, the size of unruptured IAs is <5 mm in 66%, 5 to 9 mm in 27%, and ≥10 mm in 7%; the site of IAs is internal carotid artery, including posterior communicating artery in 42%, middle cerebral artery in 35%, and anterior cerebral artery and anterior communicating artery in 18%.

Most IAs are clinically silent until rupture, which is unpredictable and sometimes associated with SAH, intraparenchymal hematoma, and an intraventricular hemorrhage. The case fatality of IA rupture is high (from 27% to 44%), but has decreased during the past 3 decades because of the introduction of improved management strategies, including neurocritical care.2 The International Study of Unruptured Intracranial Aneurysms (ISUIA) showed an increased risk of IA rupture with aneurysm size and for posterior circulation aneurysms.3

Although treatment of a ruptured aneurysm is accepted as an emergency, indication for treatment of unruptured IAs is still being discussed. Decision for treatment is based on clinical and anatomic factors; among them, the most important being patient’s age, family history of IAs(s), associated conditions (autosomal dominant polycystic kidney disease), symptomatic aneurysms, aneurysm size, and location. The randomized International Subarachnoid Aneurysm Trial (ISAT) study has clearly demonstrated the superiority of endovascular treatment (EVT) of ruptured aneurysms using coil technology over surgery.4 Since the publication of these results, EVT has rapidly evolved. Although for unruptured aneurysms a direct comparison between EVT and surgery is not available, EVT has been widely used in this subgroup as well.5

In fact the population presenting with IAs is quite heterogeneous, regarding their status at presentation (ruptured versus unruptured), aneurysm shape (fusiform versus saccular) and location (aneurysm geometry in relationship to parent artery), their size (small/large/giant), the size of their neck (small/ large), and other factors. The heterogeneity illustrates that various approaches have to be considered to treat all types of IAs by EVT. During the past >2 decades, different therapeutic modalities were developed for EVT of IAs, and the goal of the present review is to describe them and to analyze their role in the management of IAs.

Coiling

EVT of IAs was introduced by use of detachable latex balloons and pushable coils. Because their use was cumbersome and associated with high incidence of periprocedural complications, they were applied in a relatively limited number of patients who were difficult to treat with standard surgery. The development of coils with controlled detachable system was clearly the first important step for widespread use of EVT.6,7 Initial large series showed acceptable mortality (≈2%) and morbidity (between 4% and 9%), related mostly to thromboembolic complications and intraoperative rupture.8,9 Further larger series confirmed the feasibility of aneurysm coiling (96.9% in ruptured aneurysms and 94.0% in unruptured aneurysms), with acceptable procedural mortality (1.4% in ruptured aneurysms and 1.7% in unruptured aneurysms) and morbidity rates (8.6% in ruptured aneurysms and 7.7% in unruptured aneurysms).10,11

The 2 most frequent complications of aneurysm coiling are thromboembolic complications and intraoperative rupture that were analyzed in 2 large, prospective, multicenter series.5,12 In unruptured aneurysms, the rates of thromboembolic complications and intraoperative rupture associated with coiling were reported 7.3% and 2.0%, respectively.5 For both types of complications, no clinical worsening was observed in approximately half the cases, but the mortality rate was higher after intraoperative rupture (16.7%) than thromboembolic complications (4.1%). In ruptured aneurysms, the rates of thromboembolic complications and intraoperative rupture were higher: 13.3% and 3.7%, respectively.12 Because thromboemboli are the most common complication of aneurysm coiling, operators have adapted perioperative use of intravenous heparin for anticoagulation and aspirin as an antiplatelet agent for unruptured and in some instances for ruptured aneurysms as well.13

Soon experience showed 2 main challenges for aneurysm coiling: (1) some aneurysms were not easy to treat because of their shape (large and giant aneurysms, fusiform aneurysms, large neck aneurysms, aneurysms with unfavorable size...
relationship between aneurysm dome, neck, and parent artery). This led to development of new techniques and technologies, including balloon-assisted coiling (known as the remodeling technique), aneurysm coiling supported by stenting, and more recently introduction of flow diversion/disruption. (2) The durability of aneurysm coil embolization was not achieved in all aneurysms. A systematic review of a large number of studies showed that aneurysm recanalization occurred in 20.8% of cases, requiring retreatment in 10.3%. Several factors were identified to be associated with an increased risk for recanalization and regrowth, including recent rupture, high blood pressure, smoking, aneurysm diameter and neck size, and quality of immediate postoperative aneurysm occlusion, for example, coil packing density. To reduce the recanalization rate, surface-modified coils, including polyglycolic-lactic acid coils and Hydrocoils (Microvention, Tustin, CA), were developed, but their evaluation in large multicenter series showed that they were not more efficacious than bare platinum coils. The clinical significance of aneurysm recanalization is not known very well. Albeit Cerebral Aneurysm Rerupture After Treatment (CARAT) study showed that the degree of aneurysm occlusion after the initial treatment was a strong predictor of the risk of subsequent rupture in patients presenting initially with an SAH. Because aneurysm recanalization can occur, anatomic follow-up with digital subtraction angiography and magnetic resonance imaging is mandatory (Figure 1).

**Balloon-Assisted Coiling**

Moret et al initially described the balloon-assisted coiling (BAC; aka remodeling technique) for expansion of EVT to wide-neck IAs. A nondetachable balloon is temporarily inflated in front of the neck of the aneurysm during each coil placement (Figures 2 and 3). In sidewall aneurysms, the balloon is simply placed in the parent vessel in front of the aneurysm neck. In bifurcation aneurysms, the approach is more complex. Several options are available, including use of 2 balloons, use of a hyper-compliant balloon, use of a round-shaped balloon, or use of a double lumen balloon. At the end of the procedure, the balloon is deflated and removed, and no device is left in place unless a stenting is performed subsequently (see below).

Several points about BAC are important. Is it associated with a higher rate of procedural complications as compared with standard coiling? Are anatomic results improved by the use of balloons? What is the current place of BAC in EVT of IAs?

In 2006, a single-center, retrospective series of ruptured and unruptured aneurysms suggested that BAC was associated with a high complication rate. The rates of thromboembolic events and intraoperative rupture were higher in the BAC group, 9.8% and 4.0%, respectively, as compared with the coiling alone subgroup, 2.2% and 0.8%, respectively. The rate of complications was recently re-evaluated in 2 large multicenter prospective series using BAC in unruptured (Analysis of Treatment by Endovascular approach of Non ruptured Aneurysms [ATENA]) and ruptured (Clinical and Anatomical Results in the Treatment of Ruptured Intracranial Aneurysms [CLARITY]) aneurysms. In unruptured aneurysms, the rate of thromboembolic events was not higher in the BAC group as compared with coiling alone (5.4% versus 6.2%) with a similar clinical outcome in both groups. The rate of intraoperative rupture was 3.2% in the BAC group and 2.2% in the coiling alone group, with clinical worsening (permanent deficit or death) in 0.6% in the coiling group and 1.4% in the BAC group. The treatment morbidity was 2.2% in the coiling group and 2.3% in the BAC group, whereas treatment mortality was 0.9% in the coiling group and 1.4% in the BAC group. In ruptured aneurysms, the rate of thromboembolic events was also similar in both groups (12.7% in the coiling group and 11.3% in the BAC group).
as well as the rate of intraoperative rupture (4.4% in both groups).\textsuperscript{37} The treatment morbidity was 3.9% in the coiling group and 2.5% in the BAC group, and treatment mortality 1.2% in the coiling group and 1.3% in the BAC group.

The effect of BAC on anatomic result is still unclear. In 1 series, incomplete aneurysm occlusion was more frequently observed in aneurysms treated with BAC (27.7%) than with standard coiling (16.9%); retreatment was also more frequently performed in aneurysms treated with BAC (16.9% versus 9.0% for aneurysms treated with standard coiling).\textsuperscript{35} In another series, both initial and follow-up anatomic results were better with BAC.\textsuperscript{38} Postoperatively, a total occlusion was observed in 73% of patients in the BAC group and in 49% of patients treated with coiling alone. At follow-up, similar results were observed. A total occlusion was observed in 72% of patients using BAC and in 54% of patients treated with coiling alone. In the ATENA series (unruptured aneurysms only), postoperative anatomic results were not better in patients treated with BAC.\textsuperscript{36}

Balloon-assisted coil embolization was initially developed for the treatment of wide-neck aneurysms, but a recent series has demonstrated that, in the setting of intraoperative rupture, balloon assistance was associated with a higher probability of unchanged or improved clinical outcome as compared with standard coiling.\textsuperscript{39} The authors suggested that balloon assistance has not to be used only to enable coiling, but also as a sentinel in case of an intraoperative aneurysm rupture during coiling. The balloon stays deflated across the neck of the aneurysm and is inflated only in case of intraoperative rupture. Probably because of this sentinel use, a recent single-center study showed an increased use of BAC in the time period from 2008 to 2010 (from 23.9% in 2008 to 39.5% in 2009, and 43.9% in 2010).\textsuperscript{40} This study also showed that BAC was used in both ruptured and unruptured aneurysms of all locations as frequently and in aneurysms with small neck and large neck. However, it was more frequently used in aneurysms with unfavorable dome-to-neck ratio ($\leq$1.5).

### Stent-Assisted Coiling

Stent-assisted coiling (SAC) was introduced >10 years ago to overcome some limitations of standard coiling and to help for the treatment of some complex aneurysms, including wide-neck aneurysms, large and giant aneurysms, and fusiform aneurysms (Figure 4).\textsuperscript{41-44}

Initially, because of lack of availability of stents specifically designed for the neurovascular realm, stiffer coronary stents were used. Subsequently, several stents dedicated to the treatment of IAs became available making the treatment easier. The development of low-profile stents is a further interesting evolution that permits to combine both BAC and SAC.\textsuperscript{45}

SAC was also precociously used as rescue approach in case of coil herniation or migration of coils into the parent vessel. Because stents are implanted in the parent artery, bridging the aneurysm neck, risk of implant thrombosis is higher than with coiling alone. Thus, preoperative and postoperative antiplatelet treatment is mandatory. This initially limited SAC to unruptured aneurysms. However, with gaining experience during the past years, stenting has been used in ruptured aneurysms.

Stenting was also considered to prevent aneurysm recanalization. This contributed to increased use of SAC as well. The safety and efficacy of SAC as compared with standard coiling has been evaluated in a few and mostly retrospective single-center series. Only a few prospective, multicenter series have been performed and published. Currently, no prospective randomized clinical trials have been published comparing
standard coiling with SAC. One of the first publications on SAC reported a large retrospective single-center series of 1137 patients with 1325 aneurysms treated without (1109 aneurysms) and with stents (216 aneurysms).\textsuperscript{46} However, aneurysms were different in the nonstented and stented group based on anatomic features (bifurcation/sidewall, aneurysm size, neck size), limiting the value of clinical and anatomic results. Although not significant, SAC was associated with higher rates of permanent neurological complications (7.4\%) as compared with standard coiling (3.8\%; \(P=0.644\)). Procedure-related mortality in the nonstenting group was 4.6\% versus in the nonstenting group (1.2\%; \(P=0.006\)). Follow-up was available in ≈50\% of the patients, and angiographic recurrence was significantly higher in the nonstenting group (33.5\%) as compared with the stenting group (14.9\%; \(P=0.0001\)).

Shapiro et al\textsuperscript{47} provided in 2012 a literature review showing that the overall complication rate was 19\% with an overall death rate of 2.1\%. Thromboembolic and hemorrhagic complications were observed in 10\% and 2.2\%, respectively. Technical complications associated with stenting were seen in 9\% of the cases. After stenting, 45\% of aneurysms were immediately and completely occluded. On follow-up angiograms, the occlusion rate increased to 61\%, and in stent-stenosis and stent occlusion were observed in 3.5\% and 0.6\% of cases, respectively. There was a learning curve with complication rate being higher in the first 10 cases treated. Although an increased risk of thromboembolic events and parenchymal hemorrhage was observed, the literature survey showed that stents could be used as an adjunctive device with endosaccular coiling, resulting in improved rate of complete occlusion in a subset of more complex aneurysms.

Similar results were reported in recently published larger series.\textsuperscript{48,49} Lee et al\textsuperscript{48} studied stenting in 289 patients and showed procedure-related complications of 13.8\% with permanent neurological sequelae in 1.5\% of patients. Follow-up imaging showed minor and major recanalization in 7.4\% and 12.7\%, respectively. In-stent stenosis was observed in 12.7\%, stent migration in 4.5\% of cases, and delayed infarction was observed in 4.2\% of patients. Gao et al\textsuperscript{49} in a large series of 232 patients with 239 wide-neck aneurysms treated with SAC also reported a high rate of procedural complications (34/232, 14.7\%), high procedure-related morbidity and mortality, 4.2\% and 1.3\%, respectively, and recanalization rate of 14.5\%.

Recent multicenter studies show contradictory results.\textsuperscript{50,51} A retrospective study involving 9 centers in the United States enrolled 229 patients with 229 aneurysms, including 32 ruptured aneurysms. The authors reported death in 3.5\% of treated patients (16\% for all patients with SAH and 1.5\% for electively treated patients), nonfatal intracranial hemorrhages in 1.0\%, and immediate or delayed thromboembolic events in 4.4\%.\textsuperscript{50} In the group of patients with angiographic follow-up, complete occlusion was observed in 59\% of patients, and retreatment was needed in 8.3\% of patients. In-stent stenosis was observed in 3.4\%. In a French multicenter registry, a total of 107 patients with 107 aneurysms were enrolled that were treated with SAC.\textsuperscript{52} The complete occlusion rate after the procedure was 66.4\%. An additional 14\% of the treated aneurysms showed a progressive occlusion at 12 to 18 months follow-up; aneurysm recurrence rate was 9.7\%. Subsequently, 4\% of the aneurysms were retreated. The periprocedural thromboembolic rate was 3.7\%; delayed thromboembolic events were observed in 3\%. The overall mortality rate at 12 to 18 months was 1\%, and the permanent morbidity rate was 1\%.

Only a few published series are comparing directly the safety and efficacy of SAC and standard coiling (or BAC). Most of them are single-center, retrospective series with a limited number of patients and significant differences about the aneurysms treated with both techniques. Piotin et al\textsuperscript{46} showed a higher mortality rate and less recanalization in patients treated with stents (see above). Jahshan et al\textsuperscript{52} reported different results in a single-center series. A total of 489 aneurysms were treated. The authors observed similar permanent morbidity in the nonstenting arm as compared with the stenting group. However, a higher rate of complete occlusion was seen in the stented group. Hwang et al,\textsuperscript{53} however, found in a retrospective single-center study, in a small group of 86 aneurysms treated with coils alone and 40 aneurysms treated with stent and coils, similar rates of progressive aneurysm occlusion (42.5\% in stenting group and 39.5\% in nonstenting group) and a recanalization of 17.5\% in stenting group and 21.0\% in nonstenting.

SAC is increasingly used in ruptured aneurysms.\textsuperscript{54} A review of the literature using SAC for acutely ruptured IAAs shows a high degree of technical success (93\%), but associated with a higher rate of clinically significant intracranial hemorrhage (up to 11\%) and thromboembolic events (up to 6\%).\textsuperscript{55} Fourteen percentage of patients had poor outcomes and up to 19\% died. SAC has enabled the treatment of more complex aneurysms with lower rate of recanalization and retreatment. However, the periprocedural risk of hemorrhage and thromboembolic events, especially in ruptured aneurysms, is higher than with standard coil embolization. Larger randomized studies comparing safety and efficacy of SAC with BAC or coiling alone are missing.\textsuperscript{56}

### Flow Diversion

Based on previous in vivo and in vitro studies performed during the past 2 decades, flow diverters (FDs) were introduced into the clinical armamentarium for aneurysm treatment only in the last 6 years.\textsuperscript{57–63}

FDs are low porosity tubular stent-like implants that have 2 main work mechanisms:

- **Flow redirection:** The FD bridges the aneurysm neck and reduces the blood flow into the aneurysm sac because of increased impedance created by the mesh of the implant, yet providing blood flow through adjacent perforators and side branches. This creates a redirection of the blood flow away from the aneurysm toward the distal parent artery. Reduction of blood circulation within the aneurysm leads to flow stasis and promotes formation of a stable aneurysmal thrombus.
- **Tissue overgrowth:** The FD provides a scaffold for neointimalization across the aneurysm neck.

Preclinical studies have shown the efficacy and safety of FDs in the treatment of aneurysms.\textsuperscript{64,65}

Initially 2 FDs were clinically available: Pipeline Embolization Device (EV3-MTI, Irvine, CA) and Silk (Balt, Montmorency, France). Other devices have recently been...
introduced, including Surpass (Stryker, Fremont, CA) and FRED (Microvention, Tustin, CA). Preliminary clinical experience with FDs was mostly reported in relatively small single-center or multicenter retrospective series. The results showed an excellent feasibility of the treatment with acceptable periprocedural complications as well as morbidity and mortality rates and a high efficacy. Recently, large retrospective and prospective single-center and multicenter series have confirmed these results. In most series, flow diversion was used for the treatment of complex aneurysms, including large and giant aneurysms, wide-neck aneurysms, fusiform aneurysms, and recanalized aneurysms after previous coiling (Figure 5). A recent prospective, international multicenter series focused on treatment of complex aneurysms. The results confirmed the high efficacy of FD with acceptable safety profile. This series included the treatment of large and giant, wide-necked aneurysms located in the intracranial internal carotid artery in 108 patients. The treatment was technically feasible in 99.1%, with a high efficacy (73.6% of aneurysms met the study’s combined primary effectiveness end point of complete occlusion at day 180 without major stenosis of the parent vessel; no adjunctive coils were used) and acceptable safety (5.6% of patients had major ipsilateral stroke or neurological death, which was the primary safety end point).

Albeit the indications for flow diversion are still not completely established, the cumulated clinical experience shows that FDs are mainly used in large and giant aneurysms (including fusiform), wide-neck aneurysms, multiple aneurysms within a segmental diseased artery, and recurrent aneurysms. Because dual antiplatelet is recommended, most aneurysms treated are unruptured (see below). However, a small series has suggested the value of flow diversion treatment in very small aneurysms untreatable by standard coiling technique, including blister-like aneurysms.

With the increasing use of FD in clinical practice, more information on potential complications is available. As for any EVT of aneurysms, thromboembolic events and intraoperative rupture can occur. Although the risk of intraoperative rupture is reduced because of lack of endosaccular manipulations, the risk of thromboembolic events is higher as compared with standard coiling or BAC, because the FD is placed in the parent artery. To prevent thromboembolic events, the use of preoperative and postoperative single or dual antiplatelet treatment is currently recommended.

With gaining larger clinical experience, complications with FDs are not observed with standard coiling or BAC, such as delayed aneurysm ruptures and remote parenchymal hematomas. However, most of those complications have occurred in large and giant aneurysms that have a high natural incidence of bleeding or were previously neither surgically or otherwise endovascularly treatable. From the Retrospective Analysis of Delayed Aneurysm Ruptures (RADAR) study analysis, delayed aneurysms rupture after FDs use occurred in 1.0% of patients. Turowski et al reported 13 delayed ruptures after use of Silk implant. Patients were separated into 2 groups with early (<3 months) and late (≥3 months) ruptures after FD implantation. Early ruptures were more frequent (10/13 patients) and occurred 2 to 48 days after the treatment (mean time to rupture: 16 days). In this group, patients were usually still receiving aspirin and clopidogrel treatment. Late rupture occurred in 3/13 patients (receiving aspirin alone), at 110 to 150 days (mean: 132 days) after treatment. As suggested by the authors and confirmed by RADAR analysis, delayed rupture is frequently observed in symptomatic aneurysms (11/13 patients), large and giant aneurysms (13/13), and aneurysms with a large aspect ratio (aneurysm dome-to-neck ratio). Mechanisms of delayed rupture are not well understood and remain speculative at this point. Hemodynamic mechanisms can play a role, for example, the sudden change in flow pattern leading to increased or focal stress within the aneurysm wall that was not previously encountered. Another potential mechanism involves intraneurysmal thrombus created by flow reduction, which can be associated with an inflammatory aneurysm wall reaction. Large aneurysm clot burden may release inflammatory markers and via upregulation of matrix metalloproteinases leads to breakdown of the aneurysm wall. As suggested by Turowski et al, FD treatment can be associated with the formation of a nonorganized red thrombus, which is not stable and has a high content of proteolytic enzymes that can weaken the wall of the aneurysm. Use of antiplatelet may also play a role in preventing platelet aggregation before and during aneurysm rupture. To prevent delayed rupture after use of FDs, especially in large and giant aneurysms, several suggestions have been proposed: use of a few coils before placement of an FD and use of steroids after aneurysm treatment in large and giant aneurysms.

Another potentially severe complication after use of FD is a delayed ipsilateral parenchymal hemorrhage. The incidence is not precisely known. In the small series of Cruz et al (66 patients), it was observed in 8.5% of patients. In RADAR analysis, delayed parenchymal hemorrhage was reported.

Figure 5. Unruptured internal carotid artery aneurysm with very wide neck. A, Digital subtraction angiography (lateral view) and B 3-dimensional views show the aneurysm (arrow). C, Treatment with flow diverter (arrows). D, The control angiogram 6 months later shows a complete occlusion of the aneurysm and no stenosis of the parent vessel.
in 1.9% of patients. In Cruz et al series, this complication occurred in 4 patients with small (3 patients) or large (1 patient) aneurysms. The delay of occurrence was between 1 and 6 days. In this series, clinical outcome was quite variable (mRS 0, 2, 4, and 6), but no decompressive craniotomy was performed. In a recently published small series (4 patients), surgical evacuation of the hematoma was performed in all cases after platelet transfusion with favorable clinical outcome at midterm follow-up (L. Pierot; personal communication). Several mechanisms are proposed to explain the occurrence of this delayed parenchymal hematoma, including hemorrhagic transformation of ischemic lesions, modification of intracranial blood pressure singularly in the distal territories, loss of arterial autoregulation of the distal arteries. Dual antiplatelet treatment may also play a role not only to explain the size of hematoma, but also to be a reason for spontaneous parenchymal bleed as seen infrequently after carotid artery stenting.

Another important issue about the use of FDs is the patency of the perforating arteries and side branches covered by the device. In a small case series of basilar artery aneurysms published by Kulcsar et al (12 patients), all but one of the angiographically visible vessels covered by the device was patent at the end of the procedure. One P1 segment that was covered by the FD was no longer opacified immediately after device implantation. As frequently seen with covered ophthalmic arteries and because of existing demand, the posterior cerebral artery was collateralized via the posterior communicating artery. Follow-up studies in this series showed small symptomatic lesions in 2 patients, one located in the thalamus and the other in the pons, most probably related to occlusion of perforators.

Finally, late thrombosis of FDs in certain aneurysms has been described and, thus, long-term follow-up is indicated.

**Flow Disruption**

Intrasaccular flow disruption is an endovascular approach similar to the intraluminal FD technology; however, the mesh of the flow disruptor is placed within the aneurysm pouch and creates blood flow stasis with subsequent thrombosis (Figure 6).

Preclinical studies have shown the feasibility of this approach as well as its safety and efficacy. In a preliminary, retrospective, multicenter series of 20 patients treated with the WEB device (Sequent Medical Inc, Aliso Viejo, CA), the technical success of the treatment was high (100.0%) with no mortality and low morbidity (4.8%). A subsequent, prospective, single-center series showed similar results.

From this preliminary experience, the WEB device seems to be well suited for the treatment of wide-neck bifurcation aneurysms of the basilar artery, the middle cerebral artery, the anterior communicating artery, and the internal carotid artery. Because the flow disruptor device is placed wholly within the aneurysm, the need for antiplatelet therapy is eliminated. Taken together, this intrasaccular treatment is potentially valuable in ruptured aneurysms. Limited successful experience with ruptured aneurysms has been reported. WEB treatment of recanalized aneurysms also seems feasible.

**Embolization With Liquid Embolic Material**

Attempts have been made to use Liquid Embolic Agents for the treatment of IAs. Onyx (Covidien/EV3, Irvine, CA) was the product whose development was the most important and clinical evaluation the largest. Under the control of a remodeling balloon (see above), the product is progressively injected in the aneurysm to fill all the aneurysm from the dome to the neck. Initial results in uncoilable IAs were acceptable with good safety and efficacy. However, increasing safety concerns (mass effect of large and giant IAs increased after filling of IAs with Onyx, stenosis of the parent vessel attributable to leaks of Onyx) rapidly interrupted the development of this technique.

In summary, several endovascular approaches are now available for the treatment of IAs, including standard coiling, BAC, SAC, and flow diversion. Ruptured aneurysms have to be treated on an emergency base to avoid rebleeding and minimize further complications associated with SAH-associated vasospasm and hydrocephalus. Treatment of ruptured aneurysms remains with standard coiling or BAC. Flow disruption has currently not been sufficiently evaluated for emergency use. Because antiplatelet medication is needed for SAC and flow diversion, these approaches should be used in ruptured aneurysms only if not treatable with standard coiling or BAC. Indications for treatment of unruptured aneurysms are still discussed on a case-by-case basis, taking into account clinical presentation of the age of the patients and comorbidities as well as aneurysm location and size. For small aneurysms with small neck, treatment with standard coiling or BAC is probably appropriate, and SAC as well as FDs have probably a limited value unless aneurysms are prone to recurrence. For large and giant, fusiform, and wide-neck aneurysms, because of the potentially high rate of recanalization, a more sophisticated approach probably has to be used, including SAC, flow diversion, and flow disruption. Progress in imaging and device manufacturing
is providing more sophisticated tools that have expanded EVT to aneurysms that were previously neither surgically or endovascularly treatable. Randomized trials will be necessary to evaluate the safety and efficacy of various emerging new technologies for aneurysm treatment.

Disclosures
Dr Pierot is a consultant for Johnson & Johnson/Codman, Covi�en/EV3, Microvention/Terumo, Penumbra, and Sequent. Dr Wakhloo is a consultant for Stryker Neurovascular, Boston Biomedical Associates, and has received research grant from Philips Healthcare.

References


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