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ORIGINAL RESEARCH

Intraprocedural Aneurysmal Rupture during Coil Embolization of Brain Aneurysms: Role of Balloon-Assisted Coiling

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BACKGROUND AND PURPOSE: Intraprocedural aneurysmal rupture is a feared complication of coil embolization of intracranial aneurysms and is associated with high rates of morbidity and mortality. We report the incidence, endovascular management, and clinical outcome of patients with IAR, with emphasis on the role of the balloon-assisted technique.

MATERIALS AND METHODS: We conducted a retrospective analysis of all intracranial aneurysms treated by coil embolization between September 2001 and June 2011. All patients with IAR were studied. Comparison of immediate clinical outcomes was performed by using univariate analysis (Fisher exact test).

RESULTS: Of 652 intracranial aneurysms treated with coil embolization, an IAR occurred in 22 (3.4%). Rupture occurred during placement of coils in 18 cases, microcatheters in 2 cases, and a guidewire in 1 case, and during induction of anesthesia in 1 case. Before treatment, 15 of 22 (68%) patients were in good clinical condition (WFNS grade I). There were fewer patients with worsening of the WFNS grade following an IAR when the balloon-assisted technique was used (7.7%) compared with when it was not (55.5%) ($P = .023$). Death occurred in 2 (9.1%) patients.

CONCLUSIONS: IAR is a potentially serious complication of coil embolization. If IAR occurs, balloon-assistance is helpful in obtaining rapid hemostasis resulting in better short-term outcomes.

ABBREVIATIONS: EVD = external ventricular drainage; GCS = Glasgow Coma Score; GOS = Glasgow Outcome Scale; HH = Hunt and Hess; IAR = intraprocedural aneurysmal rupture; *n*-BCA = *n*-butyl cyanoacrylate; WFNS = World Federation of Neurological Surgeons

Intraprocedural aneurysmal rupture is one of the most feared complications during endovascular coil embolization, with associated high rates of morbidity and mortality, and it has been reported to occur in 1%–11% of coil embolization procedures.[1-18] Acute SAH and small aneurysm size represent well-known risk factors for IAR.[4,6,13,19,20] Balloon-assisted coil embolization of aneurysms, also known as balloon-assisted technique or balloon remodeling, is a controversial technique; some argue that it increases the risk of procedural complications,[21] while others argue that it allows better aneurysm packing without additional procedural risk.[22,23] In the present study, we review the IARs that took place in our institution and evaluate the impact of using balloon assistance on clinical outcome.

Materials and Methods

We reviewed a prospectively maintained data base of 652 aneurysms embolized with coils at our institution between September 2001 and June 2011. The balloon-assisted technique was used in 271 of 652 aneurysm-embolization procedures (41.2%). Twenty-two IARs were identified, which form the study population.

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Endovascular Treatment

The procedures were performed with the patient under general anesthesia. All acutely ruptured aneurysms were treated within 24 hours of admission to our hospital. Some patients, however, were treated >24 hours after the SAH because they were admitted to our hospital days after the onset of SAH, either because they were transferred from other hospitals or because they did not seek medical attention immediately after the onset of hemorrhage. Anticoagulation was obtained with heparin IV administered as a bolus, then by hourly maintenance doses to maintain the activated clotting time at twice the baseline. Anticoagulation was initiated after groin puncture in unruptured aneurysms and after intra-aneurysm placement of the first coil in ruptured aneurysms. Balloon assistance was used when the aneurysm had a wide neck (neck diameter > 4 mm or a dome-to-neck ratio < 2), to facilitate intra-aneurysmal coil packing without compromising the lumen of the parent artery and also for embolization of recently ruptured aneurysms when we judged that the risk of IAR was deemed significant, such as in aneurysms measuring <3 mm, located in the anterior circulation, and with associated daughter sacs. The balloons used in this series were compliant balloons, HyperForm or HyperGlide (ev3, Irvine, California), measuring 4 mm in maximal diameter and 7–20 mm in length. Various types of coils were used with the goal of packing the aneurysm by deploying as many coils as possible, except in small acutely ruptured aneurysms, in which safety rather than tight packing was prioritized.

IAR

IAR was suspected on the basis of clinical criteria (Cushing reflex) or by direct fluoroscopic visualization of a device (coil, guidewire, or microcatheter) outside the limits of the aneurysm. Confirmation was obtained by injection of contrast showing extravasation. If the bal-

loon-assisted technique was used, the balloon was immediately inflated across the aneurysm neck to temporarily attain hemostasis, and time was then available to take the necessary steps to definitively seal the breach. If no balloon was used, we quickly took the following steps: reversal of heparin with IV injection of protamine sulfate, opening the ventricular drain when applicable, and endovascular sealing of the breach. Placement of a ventricular drain when one was not already present was performed if there were symptoms or signs of increased intracranial pressure and hydrocephalus.

Clinical and Angiographic Follow-Up

Immediate clinical and angiographic follow-up was available in all cases. Long-term clinical outcomes were evaluated by reviewing the patient's clinical notes and by phone interviews. Initial clinical status was graded according to the HH and WFNS classifications. Immediate clinical outcomes in the first 48 hours following an IAR were assessed by using the WFNS grades[24] and were defined as follows: grade I, GCS of 15 and no motor deficit; grade II, GCS of 13–14 and no motor deficit; grade III, GCS of 13–14 and motor deficit; grade IV, GCS of 7–12 and absence or presence of motor deficit; and grade V, GCS of 3–6 and the presence or absence of motor deficit. Clinical outcomes 1 month postcoiling were determined by using the following GOS scores[25]: 1 = death, 2 = persistent vegetative state, 3 = severe disability requiring daily support, 4 = moderate disability but independent, and 5 = good recovery. A favorable outcome was defined as a GOS score of 4 or 5, whereas an unfavorable outcome was defined as GOS score from 1–3. Immediate and long-term imaging follow-up were performed by using DSA and MRA, respectively. Procedure-related morbidity was defined as any clinical deterioration evidenced by worsening of the WFNS grade scale (ie, WFNS grade I to a WFNS grade II-V) within 48 hours of the IAR and the need for additional procedures such as craniotomy for hematoma evacuation or emergent aneurysm clipping or the placement of an EVD in the first 48 hours after an IAR. To determine the effect of balloon assistance on the clinical outcome of patients with IAR, we compared the percentage of patients with worsening score, WFNS score 48 hours posttreatment, with the WFNS score immediately before the embolization. We also reviewed the angiographic images, medical records, and postprocedure cross-sectional imaging to look for other procedure-related complications such as thromboembolic events, coil migration, or arterial injury.

Statistical Analysis

Comparisons between the immediate pretreatment WFNS scale and the 48-hour posttreatment WFNS scale in relationship to balloon use in the setting of an IAR were made by using univariate analysis with the 2-tailed Fisher exact test. A probability value of $P \leq .05$ was considered significant.

Results

There were 22 IARs (3.4% of 652 aneurysms). Nineteen patients (86.4%) were women and 3 (13.6%) were men. The mean age was 55 years (range, 24–92 years). Postprocedure clinical data were available in all patients. The mean clinical follow-up period was 27.1 months (range, 1–87 months). Of the 22 patients, 2 (9.1%) died, 2 (9.1%) were not be able to be contacted, and 18 (81.8%) were seen as having made a good recovery (GOS, 4 or 5) at the end of the study period. There were 19 patients who presented for coil embolization of acutely ruptured aneurysms with the following HH classifications: grade I or II in 11 patients, grade III in 5 patients, and grade IV and V in 3 patients. In the cohort of patients with IAR, the morbidity rate was 32% (7 of 22 patients) and the mortality rate was 9.1% (2 of 22 patients). IAR was more frequent in acutely ruptured aneurysms, defined as the occurrence of subarachnoid hemorrhage up to 4 weeks before treatment (19 of 352, 5.4%), than in nonacutely ruptured aneurysms (3 of 300, 1%). IAR was more frequent in the anterior circulation (21 of 543 aneurysms, 3.9%) compared with the posterior circulation (1 of 109 aneurysms, 0.9%) and was more frequent in small (<7 mm) aneurysms (19 of 383, 4.9%) than in larger (≥7 mm) aneurysms (3 of 269, 1.1%). In the anterior circulation, IAR was more frequent for anterior communicating artery aneurysms (8 of 153 aneurysms, 5.2%) compared with other locations (13 of 499 aneurysms, 2.6%).

Intraprocedural aneurysmal rupture was due to perforation of the aneurysm during placement of coils in 18 cases, advancement of the microcatheter into the aneurysm in 2 cases, and advancement of the guidewire in 1 case. In the last case, the IAR was diagnosed only when the patient awoke from anesthesia after an apparently uneventful procedure. This patient was treated for an acutely ruptured aneurysm and there was a new SAH after the procedure evaluated by CT scanning but no clinical or imaging findings of aneurysm rupture during the procedure. Thus, we believe that this patient re-bled during induction of anesthesia due to fluctuations in blood pressure. Complete aneurysm obliteration was achieved in 17 (77.3%) aneurysms, and a neck remnant was seen in 5 (22.7%) lesions. An EVD had been placed before the procedure in 8 patients. Of the 14 patients in whom an EVD was not present before the embolization, 7 patients did not require placement of an EVD after the IAR, 6 patients required EVD placement after developing signs and symptoms of acute hydrocephalus, and 1 patient required EVD placement 22 days after the IAR because of mental status changes due to hydrocephalus.

We separated the patients with IAR into 2 groups: patients treated with balloon-assisted coil embolization ($n = 13$) and patients treated with coils only ($n = 9$). In the balloon-assisted group, 10 of 13 patients (77%) presented with SAH. An EVD was placed before the coiling procedure in 5 of 13 patients (38%). In this group of patients, hemostasis was obtained with immediate inflation of the balloon in all patients. Unchanged or improved clinical grades were seen in 12 of 13 (92.3%) patients treated with balloon assistance. Of these 12 patients, 2 required the use of *n*-BCA to seal the defect. One patient with HH grade V with an IAR caused by microcatheter perforation died, despite having a balloon in place. None of the patients treated with balloon assistance required emergent hematoma evacuation or aneurysm clipping. Three patients (23%) required EVD placement after the IAR. Therefore, the immediate morbidity rate in this group was 23% (3 of 13 patients), and the mortality rate was 7.7% (1 of 13 patients). Long-term follow-up was obtained in 11 patients because 1 patient could not be contacted. Good recovery (GOS, 4 or 5) was seen in all patients contacted.

In the group of patients in whom no balloon assistance was used, all patients presented with SAH. An EVD was placed before an IAR in 3 of 9 patients (33.3%). In this group of patients, unchanged or improved clinical grades were seen in 5 of 9 (44.4%) patients. Of these 9 patients, coils were deployed

in a timely fashion in 4 patients, resulting in an unchanged clinical grade (WFNS grade I) in 3 patients and a fair clinical grade (WFNS grade II) in 1 patient. Two of 9 patients with IAR caused by coils required emergent surgical evacuation of the hematoma and surgical clipping of the aneurysm, which resulted in a poor clinical grade (WFNS grade IV) in 1 patient and a fair clinical grade (WFNS grade II) in the other.

In 1 of 9 patients with an IAR caused by coils during which we attempted to control the hemorrhage with more coils, a massive SAH that dissected through the corpus callosum caused transuncal herniation and death (WFNS grade V). In 1 of 9 patients, the IAR occurred during the induction of anesthesia, and the aneurysm was quickly embolized with coils. The patient then went on to surgical evacuation of the hematoma and had a poor clinical grade (WFNS grade IV). Finally, 1 of 9 patients with a pre-WFNS clinical grade of 4 presented with an IAR caused by the microcatheter, which was treated with parent vessel occlusion of the left PICA with *n*-BCA, which resulted in a fair clinical grade (WFNS grade II). The patient developed a left cerebellar infarct as a result of the PICA occlusion, requiring a suboccipital craniectomy for decompression. Four patients (44%) required EVD placement after the IAR. In this group of patients, the morbidity rate was 44.4% (4 of 9 patients) and the mortality rate was 11.1% (1 of 9 patients). Long-term follow-up was obtained in 7 patients. One patient could not be contacted. Good recovery (GOS, 4 or 5) was seen in all patients. In these 22 patients with IAR, there were no other procedure-related complications.

Balloon assistance was associated with a higher probability of unchanged or improved clinical grades in the immediate postprocedure period compared with when no balloon was used in the setting of an IAR, reaching statistical significance ($P = .023$).

Discussion

This article represents the largest published series of IAR to date, to our knowledge. We divided the patients with IAR into 2 groups, those treated with a balloon-assisted technique and those treated with coil embolization only, and showed that the immediate postprocedural morbidity rates were significantly better in the group with balloon-assisted technique. Even though our sample size was relatively small and the clinical course of patients with SAH and/or IAR depended on multiple factors, we believe that there is a strong correlation between improved clinical outcomes in the short-term after the procedure and the ability to control the IAR as early as possible.

Despite recent studies showing that the balloon-assistance technique is not associated with increased periprocedural complications such as thromboembolic events and intraoperative rupture,[22,23,26] this finding remains a matter of debate.[10,27] In our practice, we use balloon assistance in many cases and, therefore, have become very accustomed to this technique. In this cohort of patients with IAR, using the balloon-assisted technique was beneficial in the immediate postprocedure period, without increasing the risk of procedure-related morbidity or mortality from other complications such as thromboembolic events. These findings are in agreement with the ATENA[28] and CLARITY (Clinical and Anatomic Results in the Treatment of Ruptured Intracranial Aneurysms)[22] series, which showed that the balloon-remodeling technique is not associated with increased periprocedural complications. We recently retrospectively reviewed our coil embolization data in 491 aneurysms treated with coils alone or the balloon-assisted technique and found no increase of periprocedural complications (thromboembolic events, IAR, and device-related problems), morbidity, or mortality in patients with acutely ruptured and unruptured aneurysms (A. Santillan, Y.P. Gobin, J. Mazura, et al, unpublished data, 2011).

Other authors disagree with our opinion. For example, Levy et al,[10] in a retrospective analysis of 274 patients with intracranial aneurysms, postulated that the inflation of a balloon across the aneurysm neck may cause rupture. Sluzewski et al[9] reported 5 IARs (2.7%) during the endovascular embolization of 264 aneurysms. The 2 deaths were associated with the use of a temporary occlusion balloon. The authors postulated that there was a higher incidence of procedure-related rupture when a temporary occlusion balloon was used. We disagree with this opinion because in our experience, none of the IARs were due to balloon inflation. However, we recognize that balloon inflation across the aneurysm neck during coil embolization may push the microcatheter deeper inside the aneurysm or may prevent the microcatheter from recoiling when pushing coils. These factors may lead to aneurysm rupture, particularly in very small aneurysms (<3 mm).[18]

The good outcomes seen in our series confirm that balloon assistance is safe and effective when used by frequent operators, and if a perforation occurs, it can be controlled much faster than if no balloon is used. We are so comfortable with balloon assistance that we often place it not for neck remodeling but as a "sentinel." For example, during embolization of an acutely ruptured aneurysm, the sentinel balloon stays deflated across the neck of the aneurysm, and is inflated only in case of an IAR. According to Sluzewski et al,[9] the clinical outcome of intraprocedural aneurysmal rupture manifests as 2 extremes, patients either do well or death occurs. We found the same dichotomy of results in our series.

In our series, IAR was more frequent in acutely ruptured aneurysms, small aneurysms, and aneurysms in the anterior circulation, especially the anterior communicating artery. These intuitive risk factors for IAR have been described in the literature[9,17] as well for aneurysms with associated daughter sacs.[11,14] Small cerebral aneurysms pose specific treatment challenges due to the difficulty of deploying coils without perforating the fragile aneurysm wall and causing an IAR.[10,29] In a recent meta-analysis by Brinjikji et al,[18] which included 422 very small aneurysms (≤ 3 mm), the rate of IAR was 5% for unruptured aneurysms compared with 10.7% for ruptured aneurysms. Several studies have shown that IAR rates are higher in smaller and ruptured aneurysms compared with larger and unruptured aneurysms,[3,16,19] with high rates of an IAR particularly in acutely ruptured cerebral aneurysms of <3 mm.[2,6] In our series, 5 of 22 IARs (22.7%) were associated with aneurysms <3 mm and 8 of 22 IARs (36.3%) were associated with anterior communicating artery aneurysms.

Timing of intervention after SAH is important for the occurrence of an IAR. Cognard et al[3] reported perioperative ruptures in 5 of 6 cases when treatment was performed within 9 days after SAH. Our series confirmed that most IARs (19/22) occur when treating acutely ruptured aneurysms.

IAR may be related to the coils, microcatheter, or the guidewire itself.[4,6,8,18] Overpacking the aneurysm, oversizing the coils, or using stiff 3D coils[4,10,13,15] has been reported to be associated with an IAR. Even the deployment of a single coil inside an aneurysm may increase the intraluminal pressure and result in an IAR.[11] Li et al[15] observed 10 ruptures during the treatment of 284 aneurysms. Three of the 10 patients died, and the remaining 7 had good outcomes. Of the 3 patients who died, 2 were as the result of overpacking the ruptured aneurysms and death occurred during the last stage of embolization.

When an IAR results from coil perforation and the tip of the microcatheter remains inside the aneurysm, further delivery of coils usually stops the hemorrhage.[8,10,15,17] A coil can be placed at least partially outside the aneurysm sac, within the subarachnoid space, to occlude the defect. Additional coils can then be delivered into the aneurysm sac after withdrawing the microcatheter tip. Other embolic agents can be used to seal the breach in the setting of an IAR, such as *n*-BCA. In our series, we report 9 patients with IARs caused by coil perforation without balloon assistance. Of this group of patients, the deployment of coils was performed in a timely manner in 4 patients, resulting in good clinical grades in all of these patients. Two patients with an IAR caused by coils were taken emergently to the operating room for surgical clipping, resulting in a poor clinical grade (WFNS grade IV) in 1 patient and a fair clinical grade (WFNS grade II) in the other. In 1 patient, the perforation could not be controlled with the placement of coils and resulted in a massive subarachnoid hemorrhage leading to death (WFNS grade V).

IARs that are caused by aneurysm perforation with the microcatheter are generally more difficult to control due to the larger size of the defect.[10,18] To avoid such IARs, extreme care must be taken when positioning the microcatheter into the aneurysm, especially when braided microcatheters are used because of the potential risk of rapid catheter movements.[13] McDougall et al[4] reported 4 IARs during the embolization of 200 aneurysms, and the only death was the result of perforation of the aneurysm by the microcatheter. In another article,[30] a microcatheter-associated aneurysm perforation was treated by leaving the microcatheter in place while coils were deployed by using a second microcatheter, resulting in a good clinical outcome. We had 2 cases in which the IAR resulted from microcatheter perforation: One patient was a 57-year-old woman who presented with HH grade V from a ruptured anterior communicating artery aneurysm. Despite having a balloon in place, the IAR resulted in the patient's death (WFNS grade V). The other IAR required parent vessel occlusion with *n*-BCA to achieve rapid hemostasis, which resulted in a fair clinical grade (WFNS grade II). As demonstrated by this case, parent vessel occlusion is another technique that can be used to safely control the hemorrhage after an IAR.[10] However, when performed emergently and without proper preocclusion testing, parent vessel occlusion is associated with a high risk of stroke.

IAR occurring in the early phase of aneurysm coiling may involve a different mechanism and result in different patient outcomes compared with ruptures that occur in the later phase of coiling. According to Murayama et al,[13] aneurysm perforation has a higher tendency to be fatal if it occurs during the early phase of embolization. Cognard et al[3] reported 6 IARs in 182 patients with ruptured and unruptured aneurysms treated by endovascular coiling. In our series, of the 3 IARs occurring during placement of the first coil without balloon assistance, 1 patient died, and 2 patients had a fair clinical grade (WFNS grade II). In 1 patient, the IAR occurred during induction of anesthesia; thus, control of the hemorrhage with coils was delayed and the patient had a poor clinical outcome (WFNS grade IV). This adds to the concept that IARs that cannot be controlled immediately are associated with worse outcomes.

Another critical time is during the late phase of embolization, when the aneurysm is almost completely occluded, because a high risk of rupture occurs at the junction of the aneurysm neck with the parent artery. For this reason, some have postulated that for patients with subarachnoid hemorrhage with aneurysms at high risk for IAR, it may be safer to leave a small aneurysm neck remnant during the first embolization procedure instead of attempting to achieve complete aneurysm obliteration.[11,31] The neck remnant may be occluded later by a second embolization procedure or by surgical clipping when the patient presents with a better clinical status.[15,31] We report 10 cases, in which the IAR occurred in the late phase of embolization. Although we do not agree with intentionally leaving a neck remnant, we find it safe not to overpack an acutely ruptured aneurysm with coils.

Patient outcomes after an IAR also seem to be related to the pre-existing neurologic condition of the patient. Guglielmi et al[32] reported 5 IARs (3.9%) during the coiling of 127 aneurysms. The 2 deaths reported were in patients who presented with HH grades IV or V. Vinuela et al[31] reported 6 IARs (2.7%) in 403 aneurysms treated. In that study, the 6 patients who died postprocedure presented with HH IV or V. Tummala et al[11] reported 10 IARs (1.4%) in 734 aneurysms treated. The 4 deaths reported in this study were in patients who presented with HH grade III or IV. Debrun et al[5] reported 4 IARs after the treatment of 152 aneurysms. In our series, 1 death occurred in a patient with HH grade V, and the other death occurred in a patient with HH grade III.

Conclusions

Small acutely ruptured aneurysms of the anterior circulation appear to be at highest risk for IAR. Management of an IAR includes prompt recognition of the hemorrhage, heparin reversal with protamine, rapid continued occlusion of the aneurysm, control of intracranial pressure and blood pressure, and placement of ventricular drainage either at the time of rupture or emergently after the rupture.[4,8,10,11] Our comparison of morbidity and mortality rates related to IAR among patients treated with balloon assistance versus coils only shows that the presence of a balloon across the aneurysm neck at the time of rupture not only allows immediate and effective control of the hemorrhage but is also associated with better clinical outcome. On the basis of this finding, we propose using a balloon in assisting the embolization of aneurysms with high risk of IAR. We consider the balloon-assistance technique in the endovascular treatment of aneurysms to be analogous to the use of temporary clips in the neurosurgical treatment of aneurysms: both indispensable tools.

Disclosures: Yves Pierre Gobin—*UNRELATED*: *Board Membership*: The Lazarus Effect, *Comments*: Company makes embolectomy devices for treatment of acute stroke (I have stock); *Consultancy*: NFocus Neuromedical, *Comments*: Company makes an intra-aneurysmal flow diverter (I have stock), *Patents (planned, pending, or issued)*: Merci retriever, *Royalties*: Merci retriever, *Stock/Stock Options*: The Lazarus Effect, NFocus, *Comments*: See above. Howard Riina—*UNRELATED*: *Grants/Grants Pending*: Helmsley Charitable Trust,* *Patents (planned, pending, or issued)*: Weill Cornell Medical College, *Stock/Stock Options*: e-Vision Medical Systems, *Travel/Accommodations/Meeting Expenses Unrelated to Activities Listed*: Siemens, Brainlab. *Money paid to the institution.

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