Available online at www.sciencedirect.com

ScienceDirect

Journal of the Chinese Medical Association 81 (2018) 31−36

www.jcma-online.com

Original Article

Intraprocedural arterial perforation during neuroendovascular therapy: Preliminary result of a dual-trained endovascular neurosurgeon in the neurosurgical hybrid operating room

Yuang-Seng Tsuei [a,b,c], Chih-Hsiang Liao [c], Chung-Hsin Lee [c], Yea-Jiuan Liang [c], Wen-Hsien Chen [d,*], Shun-Fa Yang [a]

[a] Institute of Medicine, Chung Shan Medical University, Taichung, Taiwan, ROC
[b] Department of Neurosurgery, Tri-Service General Hospital, National Defense Medical Center, Taipei, Taiwan, ROC
[c] Department of Neurosurgery, Taichung Veterans General Hospital, Taichung, Taiwan, ROC
[d] Department of Neuroradiology, Taichung Veterans General Hospital, Taichung, Taiwan, ROC

Received December 27, 2016; accepted April 24, 2017

Abstract

Background: Intraprocedural arterial perforation (IPAP) is a potentially dismal complication of neuroendovascular therapy with high mortality and morbidity rates. The management of IPAP with the techniques described has been well established, but rescue results from the dual-trained endovascular neurosurgeon in the neurosurgical hybrid operating room (OR) are rarely reported. Here, we report five cases of successful rescue of IPAP in the neurosurgical hybrid OR and compare them with other series.
Methods: Between December 2009 and December 2013, 146 intracranial neuroendovascular procedures were performed in the hybrid operating room of Taichung Veterans General Hospital. A total of five patients with IPAP were identified. Postoperative clinical outcome was evaluated by Glasgow Coma Scale scores and postoperative 3-month modified Rankin Scale.
Results: The causes of the IPAP were coil protrusion ($n = 3$), microcatheter perforation ($n = 1$), and microwire penetration ($n = 1$). Two cases involved emergent ruptured aneurysms, while three cases occurred during elective procedures. Salvage treatment with emergent external ventricular drainage (EVD) was applied in all five cases. The average time-to-first-EVD was 16.25 min, and the average time-to-patent-EVD was 32.5 min. Postoperative 3-month outcome was good recovery (mRS ≤ 2) in all five cases. The zero mortality rate in our series is the most encouraging result in the published literature.
Conclusion: IPAP can be rescued successfully with an aggressive approach and quick conversion to backup surgery by a dual-trained endovascular neurosurgeon in the hybrid OR. The value of the hybrid OR in neuroendovascular therapy should be further investigated in the future.

Keywords: Hybrid operating room; Intraprocedural arterial perforation; Neuroendovascular

1. Introduction

Intraprocedural arterial perforation (IPAP) is a potential complication of major concern which can result in fatal intracranial hemorrhages during neuroendovascular therapy.[1] Although management of IPAP with the techniques described has been well established, the inherent risks of morbidity, mortality and clinical outcome are still not satisfactory.[1−11]

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

* Corresponding author. Dr. Wen-Hsieh Chen, Department of Neuroradiology, Taichung Veterans General Hospital, 1650, Section 4, Taiwan Blvd., Taichung 407, Taiwan, ROC.
E-mail address: chenws.tw@gmail.com (W.-H. Chen).

http://dx.doi.org/10.1016/j.jcma.2017.05.012

Most neuroendovascular procedures are traditionally performed in a remote neuroradiology suite, where a full range of surgical equipment is not readily available. The theoretical advantage of the hybrid operating room (OR), where neurosurgical operation, angiographic cone-beam computed tomographic (CT) scan, and digital subtraction angiography (DSA) can be performed by a dual-trained endovascular neurosurgeon (a neurosurgeon with training in both open neurosurgery and endovascular therapy) on the same operating table without moving the patient, is to prevent a prolonged state of increased intracranial pressure. However, whether the use of a hybrid OR can improve neurological outcome of IPAP has not been well established in the literature. We present herein a brief report on the clinical course of five patients who were successfully rescued from IPAP after emergent EVD management in the hybrid OR.

2. Methods

A total of 146 intracranial endovascular procedures were performed in the hybrid OR equipped with the robotic Artis Zeego system (Siemens AG, Forchheim, Germany) between December 2009 and December 2013. All medical charts were reviewed, and five patients with IPAP were identified. All five patients were consented for this report.

IPAP was determined by imaging findings, including immediate cerebral angiography and intraoperative cone-beam CT-like images (DynaCT). We were able to start rescue management immediately without moving the patient to another room by performing the following procedures: (1) quick and complete coiling until there was no further extravasation; (2) reversal of anticoagulation with protamine and fresh frozen plasma; (3) aggressive decompression using either immediate EVD insertion for bloody cerebrospinal fluid (CSF) drainage if the patient had not received EVD previously in elective surgical cases, or immediate opening of EVD drainage if EVD had already been inserted before the neuroendovascular procedure in previously ruptured cases. Revision of the EVD was necessary if there was clotting in the EVD drainage system; and (4) delicate post-operative care. Final clinical outcome was evaluated by Glasgow Coma Scale (GCS) and postoperative 3-month modified Rankin Scale (mRS).

3. Results

Of the 146 consecutive neuroendovascular procedures, including intracranial artery stenting and coiling of aneurysms, five patients (3.42%) had IPAP. There were two men and three women, with an age range of 55−66 years (mean: 59.2 years).

The causes of the IPAPs were coil protrusion ($n = 3$), microcatheter perforation ($n = 1$), and microwire penetration ($n = 1$). Two cases involved emergently ruptured aneurysms, and the other three cases (2 non-ruptured aneurysm cases and 1 intracranial BA stenting case) occurred during elective procedures. The location of IPAP was posterior cerebral artery in one case, basilar artery in two, and anterior communicating artery in two. Salvage treatment with emergent EVD were applied in all five cases. Insertion after stenting was performed in case 1. Cases 2 and 3 had already received EVD before IPAP so EVD was opened when IPAP occurred which was converted to large-bore EVD at 30−45 min due to clotting. Cases 4 and 5 involved emergent insertion at 15−30 min after IPAP. Time-to-first-EVD (time from IPAP to immediate EVD insertion for bloody cerebrospinal fluid (CSF) drainage if the patient had not received EVD previously in elective surgery or immediate opening of EVD drainage if EVD had already been inserted before the neuroendovascular procedure in previously ruptured cases) was from 0 to 40 min (mean: 16.25 min) and time-to-patent-EVD (the time of newly patent bilateral large-bored EVD placement in the cases of elective surgery, or revision into bilateral large-bored EVD for occlusion of previous EVD placement in the cases of ruptured aneurysm) was from 15 to 45 min (mean: 32.5 min). The open pressure of EVD was around 10−20 mmHg in 4 cases and was extremely high, over 40 mmHg, in one case. The average ICP in the first week was 5−20 mmHg. All five patients were discharged with clear consciousness (GCS: E4M5V6), and the analysis of the post-operative 3-month outcomes showed that all five cases were without significant additional deficits (mRS ≤ 2) (Table 1).

3.1. Illustrative case

3.1.1. Case 3 (rupture case; with EVD before IPAP)

A 61-year-old woman presented with E1VtM2 in the emergency room. Brain CTA and DSA showed bilobular aneurysm at the top of the basilar artery with diffuse SAH

Table 1
Summary of 5 IPAP cases.

Case	Age/Sex	Perforation location	Perforation mechanism	Timing of first-EVD	Time to first-EVD	Time to patent-EVD	Intra-op/Post-op ICP (mmHg)	Pre-op/immediate Post-op GCS	Post-op 3-month mRS/GOS
1	66/F	Distal PCA	Microwire	After IPAP	40 min	40 min	15/5-10	15/6	2/4
2	55/M	Acom aneurysm	Coil	Before IPAP	0 min[a]	30 min	20/10-15	14/5	1/4
3	61/F	BA aneurysm	Microcatheter	Before IPAP	0 min[a]	45 min	20/10-20	5/4	2/4
4	58/M	Acom aneurysm	Coil	After IPAP	15 min	15 min	>40/10-20	15/6	1/5
5	56/F	BA aneurysm	Coil	After IPAP	30 min	30 min	10/5-15	15/15	1/5

Acom = anterior communicating artery; BA = basilar artery; EVD = external ventricular drainage; GCS = Glasgow Coma Scale; GOS = Glasgow Outcome Scale; ICP = intracranial pressure; IPAP = intraprocedural arterial perforation; mRS = modified Rankin Scale; PCA = posterior cerebral artery.

[a] Conversion to bilateral EVD using large-bore tubing due to being totally obstructed by blood clot.

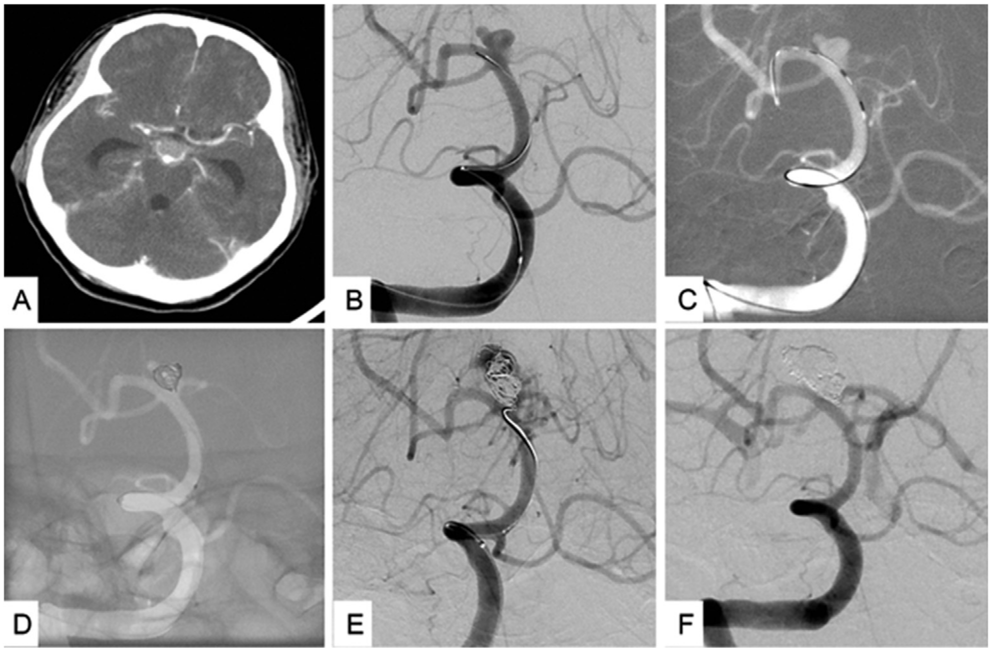

Fig. 1. Brain CTA and DSA showed bilobular aneurysm at the top of the basilar artery with diffuse SAH (Fig. 1A,B). Stent-jailed technique for coiling with an Enterprise stent (Cordis Neurovascular, Miami Lakes, FL, USA) placement from right posterior cerebral artery to basilar artery trunk (Fig. 1C). The first coil was deployed well (Fig. 1D). Profound extravasation secondary to the dome of aneurysm torn by migration of the microcatheter while placing the second coil was found by angiography (Fig. 1E). One-year angiographic follow-up showed no recurrent aneurysm (Fig. 1F).

(Fig. 1A and B). We performed EVD implantation first in the hybrid OR and then attempted stent-assisted coiling of the aneurysm. An Enterprise stent (Cordis Neurovascular, Miami Lakes, FL, USA) was deployed from the right posterior cerebral artery to the basilar artery trunk first (Fig. 1C). The first coil was then deposited with good placement (Fig. 1D). During coiling with the second coil, the dome of the aneurysm was torn by migration of the microcatheter. Profound extravasation was found by angiography (Fig. 1E). We opened the EVD (pressure = 20 mmHg), and fresh blood escaped rapidly. We reversed anticoagulation with 50 mg protamine. We attempted to seal the bleeding by further coiling. A total of 15 coils were used until there was no further extravasation. The sizes of the bilateral pupils were now 5 mm/5 mm with sluggish light reflex, and the previous EVD was totally obstructed by blood clot. We converted the unilateral EVD to bilateral EVD with large-bore tubing immediately in the hybrid OR. Postoperative ICP was around 10–20 mmHg and her GCS was E1VtM2 for 1 months. The patient was discharged three months later with status of mRS = 2. Regular follow-up revealed good recovery to E4V5M6 and mRS = 1 after one-year of continuous rehabilitation in the out-patient department. One-year follow-up angiography showed good flow in the basilar artery and bilateral posterior cerebral arteries (Fig. 1F) without recurrence of aneurysm.

3.1.2. Case 4 (non-rupture case; without EVD before IPAP)

A 58-year-old man presented with headache and a large aneurysm at the anterior communicating artery which was found by CTA (Fig. 2A). Elective trans-arterial embolization of aneurysm with stent-assisted coiling was attempted. As the first coil was being completed, unexpected rupture was found (Fig. 2B). Systolic blood pressure rapidly surged to over 200 mmHg. Angiography was performed and arrested intracranial blood flow secondary to profound increased intracranial pressure was detected (Fig. 2C). An ultra-emergent salvage EVD was inserted after performing burr-hole trephination within 15 min in the hybrid OR without moving the patient (Fig. 2D). The open pressure of EVD was over 40 mmHg. At the same time, we reversed anticoagulation with 50 mg protamine. In the following endovascular treatment, restoration of intracranial blood flow allowed the surgeons to finish coiling. A total of 10 coils were used to stop further bleeding. Final angiography showed patent flow in the bilateral anterior cerebral arteries (Fig. 2E–F). Bilateral pupils measured 3 mm/3 mm with light reflex and GCS was E1VtM4 after operation. Postoperative ICP was around 10–20 mmHg. Fortunately, the patient's consciousness became clear two days later. Eventually, he was discharged with status of mRS = 1 after ventriculoperitoneal shunt implantation. The 3-month postoperative follow-up in the outpatient department revealed mRS = 0.

4. Discussion

Previously reported prevalence rates of IPAP during embolization of cerebral aneurysms vary among studies, from approximately 1.4%–4.7%.[3–11] Among patients with IPAP, mortality and morbidity (defined as a change of ≥2 points on mRS at discharge compared to before treatment) rates have also varied considerably, ranging from 5% to 63%.[4,7,12–16] Elijovich

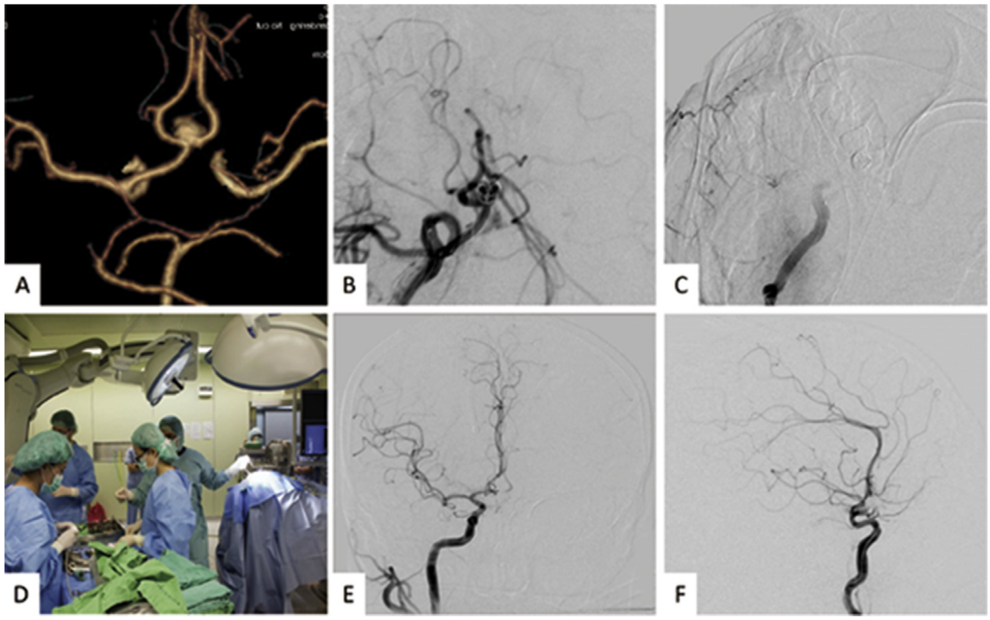

Fig. 2. CTA showed a large aneurysm at the anterior communicating artery (Fig. 2A). Unexpected rupture during the first coil placement was found (Fig. 2B). Arrested intracranial blood flow secondary to increased intracranial pressure was detected by the angiography (Fig. 2C). Photo showing dual-trained neurovascular surgeons can perform quick conversion from endovascular embolization to salvage EVD placement without moving the patient in the hybrid OR (Fig. 2D). Final angiography showed patent flow in the bilateral anterior cerebral arteries (Fig. 2E,F).

et al.[12] also reported in the CARAT study that IPAP during coil embolization had an even greater impact on risk of periprocedural death/disability, with a four-fold increased risk among those with IPAP (63%) compared to those without (15%). However, these IPAP data comprised cases treated using the traditional neuroendovascular suite, rather than the hybrid neuroendovascular OR. Yamakawa et al.[17] reported the only study of cases treated using the hybrid neuroendovascular OR. There were 5 IPAP cases among 602 patients who underwent coil embolization: two died (Glasgow Outcome Scale, GOS = 1), and there was severe disability (GOS = 3) in one, moderate disability (GOS = 4) in one, and good recovery (GOS = 5) in one. In our series, we observed IPAP in 3.42% (5/146) of our intracranial neuroendovascular procedures performed in the hybrid OR, with a mortality rate of 0% and postoperative 3-month mRS $\leq$2 and GOS $\geq$4 in all five cases after our rescue management in the hybrid OR environment. To our knowledge, this is the most encouraging outcome in comparison to other IPAP reports in the literature[3,5,7,10,11,13–19] (Table 2).

Regarding the rescue procedure and time to emergent rescue management, two craniotomies and three EVD were performed in cases treated by Yamakawa et al., with the average time to emergent rescue management being 69.4 min (from 35 to 112 min). In our series, rescue management involved just EVD in all five cases, and average time-to-first-EVD was 16.25 min (from 0 to 40 min) and the average time-to-patent-EVD was 32.5 min (from 15 to 45 min). Surgical decompression that can be quickly performed in-situ without moving the patient is not routinely in used except when a neurosurgeon is already standing by. Therefore, the management process or strategy of IPAP is currently diverse.

Table 2
A comparative summary of the results from 12 published retrospective reports of IPAP.

Paper	Published journal, year	First author	IPAP case numbers/(%)	Mortality cases (%)	Operators'subspeciality	Operating suite
1	NS, 1997	Raymond J	6 (8%)	3 (50%)	Neuroradiologist	Angiographic suite
2	NS, 2001	Tummala RP	10 (1.4%)	4 (40%)	Neuroradiologist	Angiographic suite
3	NS, 2001	Levy E	6 (2.2%)	2/(33%)	Neuroradiologist	Angiographic suite
4	JNS, 2001	Sluzewski M	7 (2.7%)	2 (29%)	Neuroradiologist	Angiographic suite
5	AJNR, 2001	Doerfler A	5 (3%)	1 (20%)	Neuroradiologist	Angiographic suite
6	NS, 2005	Brisman JL	6 (1%)	1 (13%)	Neuroradiologist	Angiographic suite
7	AJNR, 2006	Van Rooij WJ	8 (1.2%)	5 (63%)	Neuroradiologist	Angiographic suite
8	NR, 2006	Li MH	10 (4.5%)	3 (30%)	Neuroradiologist	Angiographic suite
9	JNS, 2008	Vinuela F	11 (2.7%)	6 (55%)	Neuroradiologist	Angiographic suite
10	JCMA, 2012	Luo CB	10 (2.4%)	3 (30%)	Neuroradiologist	Angiographic suite
11	J Anes, 2012	Yamakawa K	5 (0.8%)	2 (40%)	Dual-trained neurosurgeon	Hybrid OR
12	The present study	Tsuei YS	5 (3.4%)	0 (0%)	Dual-trained neurosurgeon	Hybrid OR

AJNR = American Journal of Neuroradiology; J Anes = Journal of Anesthesia; JCMA = Journal of Chinese Medicine Association; JNS = Journal of Neurosurgery; NR = Neuroradiology; NS = Neurosurgery.

Theoretically, the faster the hemostasis, the more rapidly ICP can be controlled, and the better the neurological outcome. Therefore, any effort or workflow with the potential to improve IPAP outcome should be further studied.

Based on our results, we propose a rescue paradigm comprising five important factors that are closely related to IPAP outcomes: (1) Rapidly initiate all subsequent rescue processes without moving the patient in the hybrid OR environment; (2) Anesthesiologists in the hybrid operating room can help to control blood pressure within a favorable range and reverse the anticoagulation status with protamine effectively; (3) Stop the bleeding as quickly as possible by further embolization with coils or other devices; (4) Surgeons should note the patency of the original EVD or start to prepare a new EVD insertion to relieve increased intracranial pressure; (5) Obtain a relatively good angiographic flow in the final round of DSA, which has been shown to be correlated with a good outcome. These factors are described in more detail below.

(1) Rapidly initiate the rescue process in the hybrid OR environment:

When a complication occurs during a neuroendovascular procedure performed in the traditional neuroendovascular suite, the patient is usually transported emergently from the angiography suite to the nearest CT scanner to determine a diagnosis or must be transported emergently to the nearest OR for further neurosurgical rescue management.[5] This workflow may endanger the patient not only due to the transport itself but also because of the delay in further rescue management. These phenomena may explain, at least in part, the high mortality and high morbidity found in the CARAT study.[12] The hybrid OR equipped with a high-end angiographic system can provide both CT-like images for immediate detection of intracranial hemorrhage and quick surgical decompression without moving the patient. Theoretically, this workflow has more potential to improve outcome because it obviates the need for transportation, which is associated with increased risk and longer duration of increased intracranial pressure.

(2) Anesthesiologists in the hybrid OR can help to stabilize hemodynamics effectively:

Once IPAP has occurred, the hemodynamic situation usually becomes unstable, often with high blood pressure and bradycardia, especially in cases without previous EVD placement.[2] In our series, only case 4 had profound hemodynamic change, with blood pressure surging to more than 200 mmHg and arrested intracranial blood flow. The anesthesiologist can help to control blood pressure within a relatively higher range to maintain brain perfusion immediately. Quick reversal of anticoagulants with protamine should then be performed. Nussbaum et al.[19] reported on salvage surgery after endovascular complications and noted the importance of rapid reversal of heparinization. In general practice, this management is a standard rescue procedure and the first recommended step.[20] In our series, case 1 had a Wingspan stent (Stryker, Kalamazoo, Michigan) implanted and cases 3, 4, and 5 had Enterprise stents (Cordis Neurovascular, Miami Lakes, FL.) placement. Rescue management with reversal of heparinization did not cause any thrombus-related complications in any of the four cases.

(3) Stop the bleeding by further coiling:

Closure of the perforation can be achieved by several techniques or devices, including further embolization with coils, liquid adhesives, or a tamponade with balloons.[2,13] Willinsky and ter Brugge[21] reported the use of a specific technique to manage a vessel perforated by the microcatheter, which involved leaving the catheter in place and introducing a second microcatheter without disturbing the first catheter. Vessel sacrifice is the choice of last resort to be used for control of aneurysmal hemorrhage in IPAP. In our five cases, we stopped the bleeding successfully using further coiling regardless of whether vascular perforation was caused by coil or microcatheter. We attempted to deliver smaller-sized coils inside the aneurysm, and this approach usually succeeded in the cases with smaller perforation, i.e., cases 2, 4, and 5. In the case of a larger perforation torn by a microcatheter, as in case 3, coil deposition within the aneurysm is impossible, so having a part of the coil's loop start from outside of the aneurysm is an unavoidable and reasonable treatment approach for this complication.[11] The 7-day, 3-month, and 1-year follow-up imaging studies revealed no pseudoaneurysm or recurrent aneurysm, even in case 3, in which most coils were placed outside the aneurysm within the subarachnoid space. We found that continuous coiling was the most rapid and effective method to stop bleeding. An intact arachnoid membrane and reflective contraction of vessel wall seem to be helpful for the sealing of IPAP and obliteration of a ruptured aneurysm.

(4) External ventricular drainage (EVD):

In patients presenting with diffuse subarachnoid hemorrhage secondary to ruptured aneurysm, there is a potential risk of developing hydrocephalus requiring EVD followed by aneurysm coiling with heparinization. Ross et al.[22] notes the importance of considering the risk of hemorrhage when anticoagulation or antiplatelet therapy is applied in patients requiring EVD. Hoh et al.[23] reported asymptomatic EVD-related hemorrhage rates of 9.2% and 8.8%, respectively, in heparinization and non-heparinization groups. The symptomatic EVD-related hemorrhage rates were 0.8% and 1.2%, respectively, in the heparinization and non-heparinization groups. Therefore, ventriculostomy seems to be not obviously increasing EVD-related hemorrhage rates for patients who have received or are about to receive heparinization during endovascular treatment.

Moreover, Doerfler et al.[5] recommend performing ventriculostomy before endovascular treatment because the outcome after IPAP is better in patients with EVD. In the present series, our results were consistent with the aforementioned findings. Cases 2 and 3 presented with subarachnoid hemorrhage and underwent EVD insertion before endovascular treatment. The previously placed EVD was capable of temporarily controlling ICP by immediate drainage of blood and saved time, thereby allowing the surgeon to focus his efforts on stopping the bleeding with further coiling. In addition, a good outcome could be obtained after salvage surgery by EVD insertion alone in all five of our cases. Thus, our results indicate that EVD is an effective and safe backup modality for critical management of IPAP.

Although Ricolfi et al.[9] point out that emergent EVD should be directly performed in the angiographic suite, setup for neurosurgical procedure is not convenient in the traditional angiographic suite, and it is also necessary to have a neurosurgeon stand by to perform an immediate neurosurgical decompression. In the hybrid neuro-endovascular suite, EVD insertion is readily available and can be effectively performed by a dual-trained endovascular neurosurgeon.

(5) Good angiographic flow may result in good outcome:

Aneurysmal perforation during embolization may be accompanied by severe intracranial hypertension, which causes either a decrease in perfusion or arrest of cerebral flow. The duration of compromised cerebral perfusion is an absolute determinant of clinical outcome. Some investigators have asserted that shortening the duration of normalization of IICP was related to a good outcome.[11] Based on our observations of the five cases in our series, we postulate that a near-normal flow pattern in the final round of post-rescue angiography, which is suggestive of relief of severe IICP, is positively related to a good outcome. This phenomenon may therefore be a simple predictor of outcome in IPAP.

The primary limitation of this study is its limited case number from a single institution and not being a case-controlled study. This report provides just a small series of the preliminary experience of IPAP from a dual-trained endovascular neurosurgeon in the neurosurgical hybrid operating room. Our experience of the potential pitfalls involved in the endovascular treatment of intracranial aneurysm and results of rescuing IPAP may be of value to neurosurgeons in this field.

In conclusion, for IPAP cases, shorter time of aggressive conversion to neurosurgical salvage procedures may have better outcome, especially without moving the patient in the well-equipped hybrid OR. The value of the hybrid operating room in neuroendovascular therapy should be further investigated in the future.

References

1. McDougall CG, Halbach VV, Dowd CF, Higashida RT, Larsen DW, Hieshima GB. Causes and management of aneurysmal hemorrhage occurring during embolization with Guglielmi detachable coils. *J Neurosurg* 1998;**89**:87−92.
2. Halbach VV, Higashida RT, Dowd CF, Barnwell SL, Hieshima GB. Management of vascular perforations that occur during neurointerventional procedures. *AJNR Am J Neuroradiol* 1991;**12**:319−27.
3. Brisman JL, Niimi Y, Song JK, Berenstein A. Aneurysmal rupture during coiling: low incidence and good outcomes at a single large-volume center. *Neurosurgery* 2005;**57**:1103−9.
4. Cloft HJ, Kallmes DF. Cerebral aneurysm perforations complicating therapy with Guglielmi detachable coils: a meta-analysis. *AJNR Am J Neuroradiol* 2002;**23**:1706−9.
5. Doerfler A, Wanke I, Egelhof T, Dietrich U, Asgari S, Stolke D, et al. Aneurysmal rupture during embolization with Guglielmi detachable coils: causes, management, and outcome. *AJNR Am J Neuroradiol* 2001;**22**:1825−32.
6. Henkes H, Fischer S, Weber W, Miloslavski E, Felber S, Brew S, et al. Endovascular coil occlusion of 1811 intracranial aneurysms: early angiographic and clinical results. *Neurosurgery* 2004;**54**:268−80.
7. Luo CB, Teng MH M, Chang FC, Lin CJ, Guo WY, Chang CY. Intraprocedure aneurysm rupture in embolization: clinical outcome with imaging correlation. *J Chin Med Assoc* 2012;**75**:281−5.
8. Murayama Y, Nien YL, Duckwiler G, Gobin YP, Jahan R, Frazee J, et al. Guglielmi detachable coil embolization of cerebral aneurysms: 11 years' experience. *J Neurosurg* 2003;**98**:959−66.
9. Ricolfi F, Le Guerinel C, Blustajn J, Combes C, Brugieres P, Melon E, et al. Rupture during treatment of recently ruptured aneurysms with Guglielmi electrodetachable coils. *AJNR Am J Neuroradiol* 1998;**19**:1653−8.
10. Sluzewski M, Bosch JA, van Rooij WJ, Nijssen PC, Wijnalda D. Rupture of intracranial aneurysms during treatment with Guglielmi detachable coils: incidence, outcome, and risk factors. *J Neurosurg* 2001;**94**:238−40.
11. Tummala RP, Chu RM, Madison MT, Myers M, Tubman D, Nussbaum ES. Outcomes after aneurysm rupture during endovascular coil embolization. *Neurosurgery* 2001;**49**:1059−66.
12. Elijovich L, Higashida RT, Lawton MT, Duckwiler G, Giannotta S, Johnston SC. Cerebral Aneurysm Rerupture after Treatment (CARAT) Investigators: predictors and outcomes of intraprocedural rupture in patients treated for ruptured intracranial aneurysms: the CARAT study. *Stroke* 2008;**39**:1501−6.
13. Levy E, Koebbe CJ, Horowitz MB, Jungreis CA, Pride GL, Dutton K, et al. Rupture of intracranial aneurysms during endovascular coiling: management and outcomes. *Neurosurgery* 2001;**49**:807−11.
14. Vinuela F, Duckwiler G, Mawad M. Guglielmi detachable coil embolization of acute intracranial aneurysm: perioperative anatomical and clinical outcome in 403 patients. *J Neurosurg* 1997;**86**:475−82.
15. Raymond J, Roy D. Safety and efficacy of endovascular treatment of acutely ruptured aneurysms. *Neurosurgery* 1997;**41**:1235−46.
16. Van Rooij WJ, Sluzewski M, Beute GN, Nijssen PC. Procedural complications of coiling of ruptured intracranial aneurysms: incidence and risk factors in a consecutive series of 681 patients. *AJNR Am J Neuroradiol* 2006;**27**:1498−501.
17. Yamakawa K, Kiyama S, Murayama Y, Uezono S. Incidence and neurological outcomes of aneurysm rupture during interventional neuroradiology procedures in a hybrid operating suite. *J Anesth* 2012;**26**:592−4.
18. Li MH, Gao BL, Fang C, Cheng YS, Li YD, Wang J, et al. Prevention and management of intraprocedural rupture of intracranial aneurysm with detachable coils during embolization. *Neuroradiology* 2006;**48**:907−15.
19. Nussbaum ES, Defillo A, Janjua TM, Zelensky A, Tatman P, Stoller R, et al. Emergency surgical salvage for severe intracranial aneurysm rupture during endovascular coiling procedures not amenable to additional coiling. *Surg Neurol Int* 2011;**2**:87.
20. Nguyen TN, Raymond J, Guilbert F, Roy D, Bérubé MD, Mahmoud M, et al. Association of endovascular therapy of very small ruptured aneurysms with higher rates of procedure-related rupture. *J Neurosurg* 2008;**108**:1088−92.
21. Willinsky R, ter Brugge K. Use of a second microcatheter in the management of a perforation during endovascular treatment of a cerebral aneurysm. *AJNR Am J Neuroradiol* 2000;**21**:1537−9.
22. Ross IB, Dhillon GS. Ventriculostomy-related cerebral hemorrhages after endovascular aneurysm treatment. *AJNR Am J Neuroradiol* 2003;**24**:1528−31.
23. Hoh BL, Nogueira RG, Ledezma CJ, Pryor JC, Ogilvy CS. Safety of heparinization for cerebral aneurysm coiling soon after external ventriculostomy drain placement. *Neurosurgery* 2005;**57**:845−9.