MAEDICA – a Journal of Clinical Medicine
2021; 16(1): 117-124
https://doi.org/10.26574/maedica.2021.16.1.117

MÆDICA - a Journal of Clinical Medicine

CASE REPORT

Multimodality Treatment of Low-Grade Ruptured Brain Arteriovenous Malformations Presenting with Life-Threatening Intracranial Hematoma

Vasileios PANAGIOTOPOULOS[a, b], Parmenion P. TSITSOPOULOS[c], Petros ZAMPAKIS[b], Vasiliki ZOLOTA[d], Lambros MESSINIS[e], Constantine CONSTANTOYANNIS[a]

[a]Department of Neurosurgery, University Hospital of Patras, Greece

[b]Department of Neuroendovascular Surgery, University Hospital of Patras, Greece

[c]Department of Neurosurgery, Hippokratio General Hospital, Aristotle University School of Medicine, Thessaloniki, Greece

[d]Department of Pathology, University Hospital of Patras, Greece

[e]Department of Neuropsychology, University Hospital of Patras, Greece

ABSTRACT

Introduction: *Acute management of low-grade but life-threatening ruptured arteriovenous malformations (AVM) with simultaneous hematoma evacuation remains controversial. The current report aimed to present a case series of multimodality management of low-grade (Spetzler-Martin I-II) but life-threatening ruptured arteriovenous malformations.*

Methods: *A consecutive case series of six Spetzler-Martin (SM) grade I-II ruptured AVM patients with concurrent life-threatening hematoma initially treated with hematoma removal and, when possible, with simultaneous AVM extirpation is presented. Supplementary treatment was also applied when deemed necessary. Median clinical follow-up was 15.6 months. Neurological assessment was performed on admission (Glasgow coma scale score – GCS) and at final follow-up (modified Rankin scale score – mRS).*

Results: *Intraparenchymal hematoma was evacuated in all six cases, with simultaneous AVM extirpation in three cases. Preoperative embolization was done in one patient, whereas postoperative embolization was performed in three additional patients. Supplementary radiosurgery was applied in one patient. Complete AVM occlusion was achieved in all patients. At the final follow-up (15.6 months), 33.3% of patients were*

Address for correspondence:
Parmenion P. Tsitsopoulos
Department of Neurosurgery, Hippokratio General Hospital, Aristotle University School of Medicine, Thessaloniki, Greece
Tel: +3(0)2310992904; Fax: +3(0)2310992945
Email: ptsitsopoulos@auth.gr

Article received on the 15th of December 2020 and accepted for publication on the 18th of February 2021

asymptomatic, 50% had a non-significant or slight disability (mRS score 1-2), whereas one patient died. All patients with preoperative GCS score of 8 or higher had a favorable outcome.

Conclusions: *Acute surgical hemorrhagic clot evacuation as first step, followed by simultaneous AVM extirpation when feasible, may result in favorable clinical outcome in ruptured low-grade (SM I&II) brain AVMs with life-threatening hematoma. Embolization has a supplementary role in the acute phase of treatment either by either securing the bleeding source preoperatively or occluding the residual malformation especially in cases of technically demanding AVM removal.*

Keywords: brain arteriovenous malformation, life-threatening intracranial hematoma, surgical evacuation, embolization, radiosurgery.

INTRODUCTION

Brain arteriovenous malformations (AVMs) are the leading cause of spontaneous cerebral hemorrhage among patients aged below 45 years (1-3). The most common clinical presentation is hemorrhage with reported rates ranging between 32-82% (4-10). Mortality from the first hemorrhage is thought to range from 10-20% (6, 8, 11, 12) and morbidity is generally estimated at around 50% (12), with a long-term permanent disability rate of 10% to 20% (6). Although AVM acute rebleeding rate has been reported to be lower compared to intracranial aneurysms, this risk during the first year is usually 4-6% (3, 13-15).

Surgical removal of brain AVMs remains controversial in the acute phase of rupture due to brain swelling that may require retraction and manipulation of healthy brain parenchyma. In the current report, we present our case series of multimodality management of low-grade (Spetzler-Martin I-II) but life-threatening ruptured arteriovenous malformations including hematoma removal with simultaneous AVM surgical excision when possible, assisted by pre- or postoperatively by endovascular techniques and radiosurgery. ❑

MATERIALS AND METHODS

A consecutive case series of six patients with life-threatening hematoma due to cerebral AVM (Spetzler-Martin grade I and II) (16) rupture were retrospectively analyzed. Preoperative computed tomography angiography (CTA) and/or digital subtraction angiography (DSA) was performed in order to identify the location and angioarchitecture of brain AVM. Patients' demographics as well as their clinical features, management data, complications and radiological imaging were recorded. Neurological assessment was performed on admission using the Glasgow coma scale score (GCS) and at final follow-up, using the modified Rankin scale score (mRS) (17). The treatment protocol was individualized, emphasizing primarily on the acute management of this life-threatening condition.

This study did not require ethics approval, as it was a retrospective analysis of already existing and anonymized data extracted from our medical archives.

RESULTS

A total of six patients with Spetzler & Martin (SM) grade I (n=4) and II (n=2) AVMs were operated in the acute stage of bleeding or rebleeding within 12 hours from ictus (range 2-12 h, average 7.3 h). There were three male patients and three female patients with an average age of 33.7 years (range 8-57 years). All but one case (No. 2) underwent preoperative CTA, while cases No. 4, 5 and 6 had preoperative DSA as well. Case No. 2 neither underwent CTA nor DSA due to rapid neurological deterioration and need for emergent open surgery.

Surgical treatment included intraparenchymal hematoma removal in all six cases with simultaneous AVM extirpation in three cases. Preoperative embolization was performed in one patient, whereas postoperative embolization followed in three patients. Intranidal AVM aneurysms were diagnosed and endovascularly occluded in two cases (33.3%) and clipped in one case (16.7%). One patient underwent stereotactic radiosurgery after hematoma removal and postoperative partial embolization of a small

TABLE 1. Patients' demographical and clinical data, summary of cases

Pt	Sex	Age (y)	GCS	Location	SM grade	Time to surgery (h)	Surgical AVM occlusion	Embolization	AVM occlusion	Final mRS
1	M	22	10	Left temporal	2	6	N/A	Postop	Complete	1
2	M	8	9	Right parietal	2	6	Partial	Postop	Complete	0
3	M	51	8	Right frontal	1	12	Complete	N/A	Complete	2
4	F	57	9	Cerebellar	1	2	Complete	N/A	Complete	0
5	F	50	11	Cerebellar	1	6	Partial	Postop	Complete	1
6	F	32	3	Cerebellar	1	12	Complete	Preop	Complete	6

AVM=arteriovenous malformation; GCS=Glasgow coma scale score; h=hours; mRS=modified Rankin scale score; N/A=not applicable; Pt=patient; SM=Spetzler-Martin grade; y=years.

AVM. Complete AVM occlusion was achieved in all occasions.

Table 1 summarizes the patients' demographic and clinical data. The preoperative GCS score was 8 or less in two (33.3%) patients and 9-11 in four (66.7%) patients. In half patients, the acute bleeding/AVM was located in the posterior fossa. Early rebleeding occurred within 12 hours from hospital admission in one patient.

At a median follow-up of 15.6 months, two (33.3%) patients were symptom-free (mRS 0), three (50%) patients presented with a non-significant or slight disability (mRS score 1-2), whereas one (16.7%) patient died (mRS 6). All patients with preoperative GCS score ≥ 8 had a favorable outcome (mRS 0-2). ❑

CASES PRESENTATION

Case No. 1

A 22-year-old male presented with a decreased level of consciousness following an acute headache. On the emergency department, he was evaluated as GCS 10. Brain CT scan showed an intraparenchymal hemorrhage on the left temporal lobe, while CTA scan revealed an SM grade II AVM with arterial feeders from the middle cerebral artery. He underwent immediate hematoma removal without AVM extirpation, mainly due to limited information regarding the AVMs detailed characteristics. Postoperatively, the AVM was successfully occluded with embolization. The patient had eventually a good recovery (mRS: 1).

Case No. 2

An eight-year-old male patient presented with acute deterioration of the level of consciousness (initial GCS 9). Brain CT scan showed a large (6.3 cm maximum diameter) right frontoparietal intraparenchymal hematoma with intraventricular involvement (Figure 1 a). He underwent urgent right frontoparietal craniotomy with evacuation of the intraparenchymal hematoma within six hours from ictus. Partial clipping (arrows) of a deep located arteriovenous malformation (Figures 1 b, c), with arterial feeders from the right pericallosal artery and a single parietal draining vein towards the superior sagittal sinus was achieved. Further surgical treatment was not attempted in order to avoid brain damage from ischemic complications. Next, the patient underwent complete endovascular occlusion of the residual AVM with a single Onyx injection (Figure 1 d) through the single remaining arterial feeder of the pericallosal artery. Post-embolization DSA (Figure 1 e) confirmed complete AVM occlusion. Digital unsubtracted cerebral angiography (Figure 1 f) shows the clips (red arrow) and the Onyx (blue arrow) following treatment. The patient had an uneventful recovery without any neurological deficit (mRS 0) at the long term follow up.

Case No. 3

A 51-year-old man was transferred intubated to the emergency department in a comatose status (initial GCS 8). A CT scan of the brain (Figure 2 a)

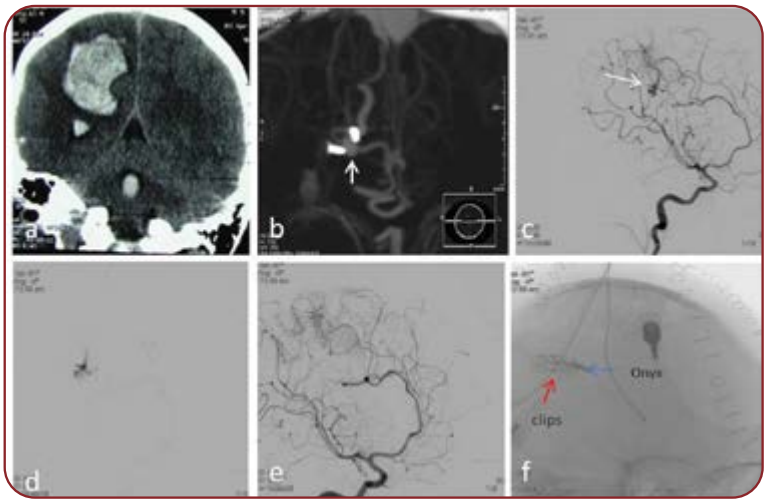

FIGURE 1. a) Computed tomography (CT) of the brain revealing a large right frontoparietal intraparenchymal hematoma with intraventricular expansion. b) Postoperative computed tomography angiography (CTA) showing a residual arteriovenous malformation (AVM) in the right frontoparietal area. c) Digital subtraction angiography (DSA) showing a residual deep located arteriovenous malformation with arterial feeders from the right pericallosal artery. d) A single parietal Onyx injection into the residual arteriovenous malformation (AVM) up to the origin of the draining vein. e) Post-embolization (DSA) confirmed the complete AVM occlusion after a combination of surgical and endovascular techniques. f) Digital unsubtracted angiography showing the surgical clips (red arrow) and the Onyx cast (blue arrow)

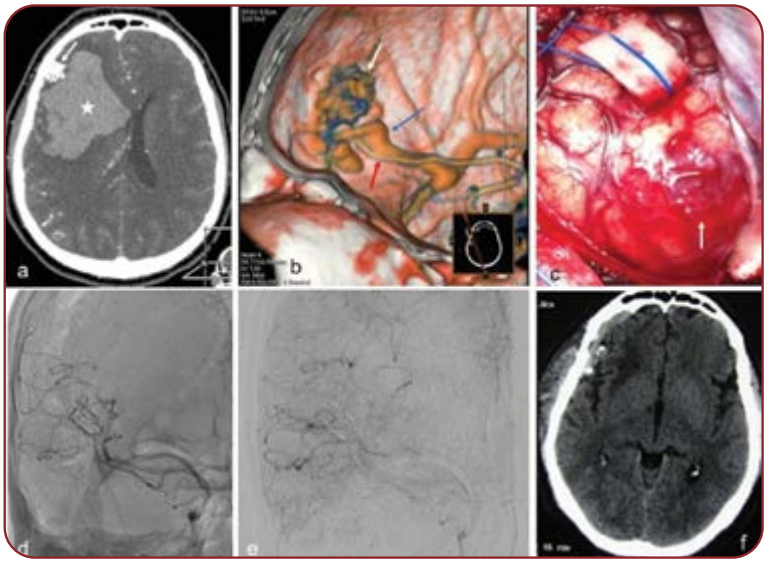

FIGURE 2. a) Brain computed tomography (CT) scan shows a 7 cm intraparenchymal hematoma (asterisk) with significant midline shift due to a superficial arteriovenous malformation (AVM) (white arrow). b) Computed tomography angiography (CTA) showing the AVM (white arrow), a single arterial feeder (red arrow) and a single draining vein towards the superficial middle cerebral vein (blue arrow). c) Intraoperative view of the AVM (white arrow). d, e) Postoperative digital angiography of the arterial and early venous phase confirmed the complete removal of the AVM without any residual lesion. f) Postoperative CT scan demonstrates the complete excision of the arteriovenous malformation without any brain hematoma or ischemic lesion

revealed a 7 cm intraparenchymal hematoma (asterisk) in the right frontal lobe with significant midline shift due a superficial AVM (white arrow). Computed tomography angiography (Figure 2 b) showed a single arterial feeder (red arrow) from the anterior cerebral artery and a single draining vein towards the superficial middle cerebral vein (blue arrow). He underwent immediate hematoma evacuation and simultaneous surgical extirpation of the AVM (Figure 2 c, white arrow). Postoperative angiography of the arterial and early venous phase and brain CT scan confirmed the complete removal of the AVM (Figures 2 d-f) without any brain hematoma or ischemic lesion. The patient recovered almost completely, having a minor cognitive deficit (mRS 2) at the final follow-up.

Case No. 4

A 57-year-old female patient, who had experienced a sudden neurological deterioration, was admitted to the Neurosurgical Department. The initial GCS score was 14. Cranial imaging showed a cerebellar hemorrhage (asterisk) with obstruction of the fourth ventricle (Figure 3 a) and a SM grade I AVM with arterial feeders from the right AICA (Figure 3 b, white arrow). After clinical deterioration to GCS 9, an urgent suboccipital craniectomy was performed, with evacuation of the cerebellar hematoma and simultaneous removal of the AVM. Postoperative CT (Figure 3 c) and DSA (Figure 3 d) confirmed the complete AVM extirpation. The patient recovered completely without any neurological deficits (mRS 0).

Case No. 5

A 50-year-old female presented with acute headache, nausea and decreased level of consciousness (GCS 11). Brain CT scan showed a right cerebellar hemorrhage. CTA and DSA revealed the presence of a SM grade I AVM. She was operated within 12 hours from ictus with hematoma removal and partial resection of the AVM. Postoperatively, the AVM was totally occluded with intravascular embolization. Neurological recovery was favorable (mRS:1).

Case No. 6

A 32-year-old female patient was admitted to our emergency department in a comatose status

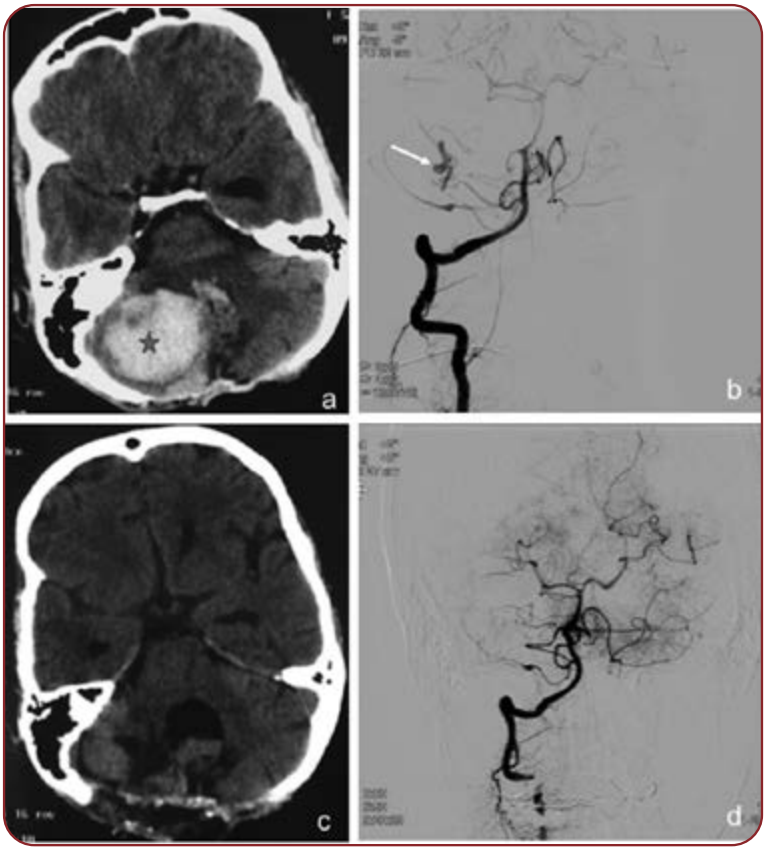

FIGURE 3. a) Brain CT scan showing a hemorrhage in the right cerebellar lobe with obstruction of the 4th ventricle and the aqueduct; b) DSA reveals a SM grade I AVM with arterial feeders from right AICA (white arrow); c, d) Postoperative CT and DSA confirmed the evacuation of the cerebellar hematoma and simultaneous complete removal of the AVM after an emergency suboccipital craniectomy

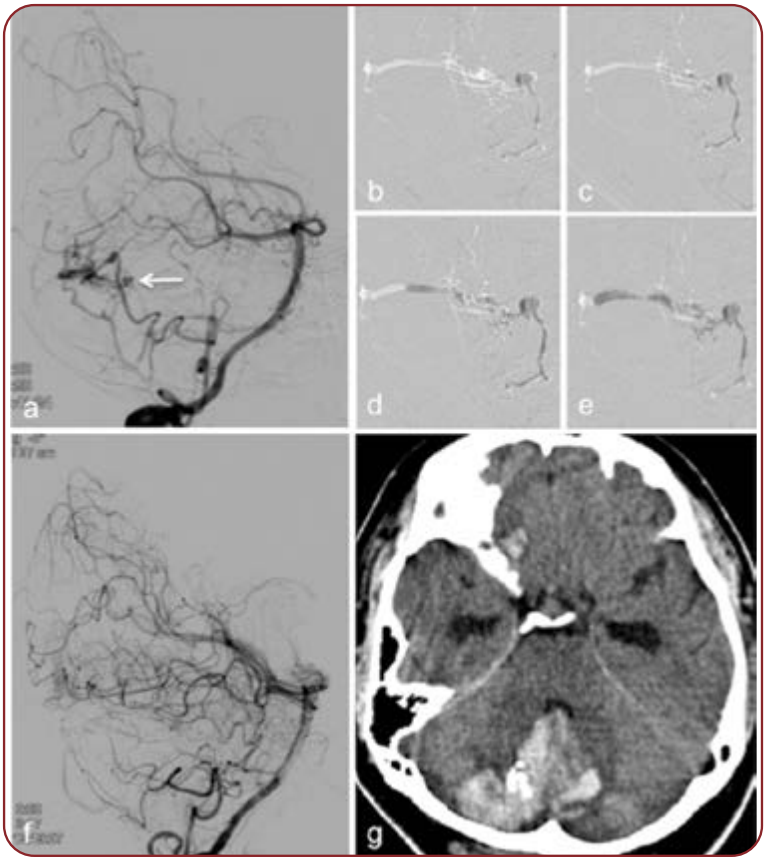

FIGURE 4. a) Digital subtraction angiography showing a SM grade I AVM with arterial feeders from right AICA and PICA with a low nidal aneurysm that was recognized as the source of cerebellar hemorrhage (white arrow); b-f) Superselective embolization of the ruptured nidal aneurysm was performed on an emergency basis; g) Post-embolization CT shows the cyanoacrylate cast used for embolization inside the extended cerebellar hematoma. The patient subsequently underwent surgical removal of the cerebellar hematoma and AVM, but finally died due to severe posterior fossa edema and initial brain stem injury

with initial GCS score of 3 and mid-size fixed pupils which indicated devastating midbrain injury, due to an extensive cerebellar hemorrhage. DSA revealed a SM grade I AVM with arterial feeders from the right AICA and PICA with a low nidal aneurysm that has been recognized as the source of cerebellar hemorrhage (Figure 4 a, white arrow). Superselective preoperative embolization of the ruptured nidal aneurysm was performed on an emergency basis with cyanoacrylate injection (Figure 4 b, c, d, e, f). She subsequently underwent surgical removal of the cerebellar hematoma (Figure 4 g) and the AVM but finally died due to excessive cerebellar edema and initial brain stem injury. ❑

DISCUSSION

It has been reported that acute surgical removal of ruptured brain AVMs may be contraindicated since it can be associated with serious persistent neurologic deficits (18, 19). The current treatment strategy, involving microsurgical excision, is to wait four weeks in order to allow for patient recovery, hematoma liquefication and inflammatory reactions to subside (20). In addition, the resulting hematoma cavity usually creates a well-defined dissection plane between the lesion and the normal brain parenchyma allowing for safer surgical excision (2, 21). Surgical removal of the AVM in the acute phase is governed by multiple factors such as AVM size, venous drainage, deep *vs* superficial location and location in an eloquent or an non-eloquent area (22).

Although life-threatening hematomas due to AVM rupture represent a more complex pathogenetic entity than spontaneous intracerebral hematomas, they should be considered for acute surgical removal when rapid clinical deterioration exists, as early surgery for intraparenchymal brain hemorrhage can quickly reduce mass effect and potentially spare healthy neuronal tissue from prolonged exposure to toxic blood degradation products (23). Early surgery for ruptured AVMs with associated hematomas has been reported in a number of small series (21, 24-29), involving predominantly patients with massive hematomas and rapid clinical deterioration.

Among these series, Kuhmonen et al. (24) reported the largest experience on early surgery for ruptured AVMs in 49 patients (42 with SM grade I-III), mostly in a poor clinical condition on arrival (two thirds were Hunt & Hess grade 4–5). All patients were operated within four days and in 92% the AVM was acutely extirpated. Over 55% of patients had a good functional outcome at 2–3 months after the initial bleeding. Factors that predicted outcome included initial neurological status and age. Further, the presence of IVH correlated with Glasgow outcome scale. The authors showed that the outcome was predicted by the primary severity of bleeding rather than SM grade, location of AVM, and size of intracerebral hematoma. Pavesi et al. (29) presented their experience concerning the acute surgical treatment of 27 patients with ruptured brain AVMs (SM grade I and II) within six days (78% operated within the first day); 85% of all subjects had a favorable functional outcome and mortality was low (7.4%), which was similarly to the current series. The authors concluded that early surgical management of grade I-II hemorrhagic AVMs led to favorable results, minimizing the risk of re-bleeding, reducing thus hospital stay and allowing faster rehabilitation.

Surgery is considered the preferred treatment option for low grade (SM I and II) brain AVMs due to low surgical risk of 0.7% (30). Nevertheless, operative management in the acute phase of rupture may increase the risk for neurological complications due to brain swelling and technical difficulties concerning surgical excision. Our small cohort included only patients with low grade AVMs (SM I and II) presented with life-threatening hematoma which caused initially comatose status or significant clinical deterioration due to bleeding or re-bleeding. All six patients were acutely operated within 12 hours from admission. Management included a multidisciplinary treatment strategy consisting mainly of initial intraparenchymal hematoma removal in order to reduce mass effect and brain edema and potentially spare healthy neuronal tissue from a prolonged exposure to toxic blood degradation products. Simultaneous removal of the arteriovenous malformation was not the primary issue but was extirpated when it was deemed technically possible with relatively low risk for further neurological complications. Preoperative embolization of a flow associated nidal aneurysm that was recognized as the source of cerebellar hemorrhage was performed in one comatose patient with initial GCS score of 3 and mid-size fixed pupils who eventually died.

On the other hand, postoperative embolization was applied in 50% of our cohort, whereas one patient was subjected to additional radiosurgery. Our stepwise management of ruptured brain AVMs with life-threatening hematoma showed that hyperacute surgical removal of intraparenchymal hematoma within 12 hours proved to be a life-saving procedure in all patients (5/6) initially admitted with a GCS score ≥8. Moreover, all surviving patients (5/6) reached a good clinical outcome of mRS score ≤ 2 at the median follow-up of 15.6 months. Non-aggressive strategy including straightforward extirpation of 2/4 SM grade I AVMs and additional embolization or radiosurgery in half of patients resulted in complete AVM occlusion in all five surviving patients.

Although the current study needs further evaluation in larger clinical series, it still indicates that multidisciplinary stepwise treatment, including acute surgical hemorrhagic clot evacuation as first step, followed by AVM simultaneous extirpation when feasible, may result in favorable clinical outcome (mRs 0-2) in cases of ruptured low-grade brain AVMs with life-threatening hematoma in patients with a GCS score ≥8. This strategy is in agreement with previous studies as it decreases the risk of intra/postoperative uncontrollable hemorrhage due to residual arteriovenous malformation (22, 25-27). Our small cohort study also introduces the complementary role of preoperative embolization in case of nidal or flow-related aneurysms, especially when they are recognized as the bleeding source. Moreover, in case of potential neurological complications due to intraoperative technical difficulties during AVM removal, such as excessive brain edema, incomplete intraoperative recognition of the AVM angio-architecture and deep location, minimally invasive treatment methods like postoperative endovascular embolization in the acute phase (preferably within the first days) should be considered. ❑

CONCLUSIONS

Multidisciplinary stepwise management of ruptured low-grade brain AVMs with life-threatening hematoma, with acute surgical hemorrhagic clot evacuation as first step followed by AVM simultaneous extirpation when feasible, may result in favorable clinical outcome. Less invasive treatment methods such as preoperative or postoperative endovascular embolization can provide an additive effect. This approach may decrease further potential neurological complications when a complete occlusion of the AVM is attempted. ❑

Conflicts of interest: none declared.

Financial support: none declared.

Data handling: Data were handled according to the Helsinki and the Health Insurance Portability and Accountability (HIPAA) Acts.

References

1. **Gonzalez-Duarte A, Cantu C, Ruiz-Sandoval JL, et al.** Recurrent primary cerebral hemorrhage: frequency, mechanisms, and prognosis. *Stroke* 1998;29:1802-1805. 10.1161/01.str.29.9.1802.
2. **Ashley WW Jr, Charbel FT, Amin-Hanjani S.** Surgical management of acute intracranial hemorrhage, surgical aneurysmal and arteriovenous malformation ablation, and other surgical principles. *Neurol Clin* 2008;26:987-1005, ix. 10.1016/j.ncl.2008.06.006.
3. **Gross BA, Du R.** Natural history of cerebral arteriovenous malformations: a meta-analysis. *J Neurosurg* 2013;118:437-443. 10.3171/2012.10.JNS121280.
4. **Steiger HJ, Schmid-Elsaesser R, Muacevic A.** *Neurosurgery of arteriovenous malformations and fistulas. A multimodal approach*. Springer-Verlag, Wien, 2002.
5. **Starke RM, Komotar RJ, Hwang BY, et al.** Treatment guidelines for cerebral arteriovenous malformation microsurgery. *Br J Neurosurg* 2009;23:376-386. 10.1080/02688690902977662.
6. **Ogilvy CS, Stieg PE, Awad I, et al.** Recommendations for the management of intracranial arteriovenous malformations: a statement for healthcare professionals from a special writing group of the Stroke Council, American Stroke Association. *Circulation* 2001;103:2644-2657. 10.1161/01.cir.103.21.2644.
7. **Stapf C, Mast H, Sciacca RR, et al.** Predictors of hemorrhage in patients with untreated brain arteriovenous malformation. *Neurology* 2006;66:1350-1355. 10.1212/01.wnl.0000210524.68507.87.
8. **Hartmann A, Mast H, Mohr JP, et al.** Morbidity of intracranial hemorrhage in patients with cerebral arteriovenous malformation. *Stroke* 1998;29:931-934. 10.1161/01.str.29.5.931.
9. **Panagiotopoulos V, Gizewski E,**

Asgari S, et al. Embolization of intracranial arteriovenous malformations with ethylene-vinyl alcohol copolymer (Onyx). *AJNR Am J Neuroradiol* 2009;30:99-106. 10.3174/ajnr.A1314.

10. **Morgan MK, Davidson AS, Assaad NNA, et al.** Critical review of brain AVM surgery, surgical results and natural history in 2017. *Acta Neurochir* (Wien) 2017;159:1457-1478. 10.1007/s00701-017-3217-x.
11. **Lawton MT, Kim H, McCulloch CE, et al.** A supplementary grading scale for selecting patients with brain arteriovenous malformations for surgery. *Neurosurgery* 2010;66:702-713; discussion 713. 10.1227/01.NEU.0000367555.16733.E1.
12. **Schmid-Elsaesser R, Steiger HJ, Yousry T, et al.** Radical resection of meningiomas and arteriovenous fistulas involving critical dural sinus segments: experience with intraoperative sinus pressure monitoring and elective sinus reconstruction in 10 patients. *Neurosurgery* 1997;41:1005-1016; discussion 1016-1008. 10.1097/00006123-199711000-00001.
13. **Graf CJ, Perret GE, Torner JC.** Bleeding from cerebral arteriovenous malformations as part of their natural history. *J Neurosurg* 1983;58:331-337. 10.3171/jns.1983.58.3.0331.
14. **Fults D, Kelly DL, Jr.** Natural history of arteriovenous malformations of the brain: a clinical study. *Neurosurgery* 1984;15:658-662. 10.1227/00006123-198411000-00003.
15. **Mast H, Young WL, Koennecke HC, et al.** Risk of spontaneous haemorrhage after diagnosis of cerebral arteriovenous malformation. *Lancet* 1997;350:1065-1068. 10.1016/s0140-6736(97)05390-7.
16. **Spetzler RF, Martin NA.** A proposed grading system for arteriovenous malformations. *J Neurosurg* 1986;65:476-483. 10.3171/jns.1986.65.4.0476.
17. **Wilson JT, Hareendran A, Grant M, et al.** Improving the assessment of outcomes in stroke: use of a structured interview to assign grades on the modified Rankin Scale. *Stroke* 2002;33:2243-2246. 10.1161/01.str.0000027437.22450.bd.
18. **Luessenhop AJ, Rosa L.** Cerebral arteriovenous malformations. Indications for and results of surgery, and the role of intravascular techniques. *J Neurosurg* 1984;60:14-22. 10.3171/jns.1984.60.1.0014.
19. **Troupp H, Marttila I, Halonen V.** Arteriovenous malformations of the brain. Prognosis without operation. *Acta Neurochir* (Wien) 1970;22:125-128. 10.1007/bf01401164.
20. **Martinez JL, Macdonald RL.** Surgical Strategies for Acutely Ruptured Arteriovenous Malformations. *Front Neurol Neurosci* 2015;37:166-181. 10.1159/000437121.
21. **Jafar JJ, Rezai AR.** Acute surgical management of intracranial arteriovenous malformations. *Neurosurgery* 1994; 34:8-12; discussion 12-13.
22. **Derdeyn CP, Zipfel GJ, Albuquerque FC, et al.** Management of Brain Arteriovenous Malformations: A Scientific Statement for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke* 2017;48:e200-e224. 10.1161/STR.0000000000000134
23. **Endo S, Kuwayama N, Takaku A, et al.** Direct packing of the isolated sinus in patients with dural arteriovenous fistulas of the transverse-sigmoid sinus. *J Neurosurg* 1998;88:449-456. 10.3171/jns.1998.88.3.0449.
24. **Kuhmonen J, Piippo A, Vaart K, et al.** Early surgery for ruptured cerebral arteriovenous malformations. *Acta Neurochir Suppl* 2005;94:111-114. 10.1007/3-211-27911-3_17.
25. **Liang X, Liu Z, Wang B, et al.** Surgical strategy for cerebral arteriovenous malformation with acute surgery. *Neural Regen Res* 2007;2:416-420.
26. **Purdy PD, Batjer HH, Samson D.** Management of hemorrhagic complications from preoperative embolization of arteriovenous malformations. *J Neurosurg* 1991;74:205-211. 10.3171/jns.1991.74.2.0205.
27. **Puzzilli F, Mastronardi L, Ruggeri A, et al.** Early surgical treatment of intracerebral hemorrhages caused by AVM: our experience in 10 cases. *Neurosurg Rev* 1998;21:87-92. 10.1007/bf02389310.
28. **Steudel WI, Lorenz R, Berkefeld J.** Acute operation on arteriovenous malformation with hematomas--report on six cases. *Neurochirurgia* (Stuttg) 1992;35:26-30. 10.1055/s-2008-1052241.
29. **Pavesi G, Rustemi O, Berlucchi S, et al.** Acute surgical removal of low-grade (Spetzler-Martin I-II) bleeding arteriovenous malformations. *Surg Neurol* 2009;72:662-667. 10.1016/j.surneu.2009.03.035.
30. **Davidson AS, Morgan MK.** How safe is arteriovenous malformation surgery? A prospective, observational study of surgery as first-line treatment for brain arteriovenous malformations. *Neurosurgery* 2010;66:498-504; discussion 504-495. 10.1227/01.NEU.0000365518.47684.98.