CLINICAL EXPERIENCE AND RESULTS OF MICROSURGICAL RESECTION OF ARTERIOVENOUS MALFORMATION (AVM) IN THE PRESENCE OF SPACE-OCCUPYING INTRACEREBRAL HAEMATOMA (ICH)

D.G. BARONE[1*], H.J. MARCUS[1*], J.N.P. HIGGINS[2], N. ANTOUN[2], T. SANTARIUS[1], R.A. TRIVEDI[1], R.W. KIROLLOS[1]

*Equal contribution

[1] *Department of Neurosurgery, Addenbrooke's Hospital, Cambridge, UK*

[2] *Department of Neuroradiology, Addenbrooke's Hospital, Cambridge, UK*

Corresponding author:

Mr Damiano G. Barone

Addenbrooke's Hospital, Cambridge, UK, CB2 0QQ

Email: baronedg@gmail.com

ABSTRACT

Objective: To evaluate the clinical outcome and obliteration rates of microsurgical resection of Arteriovenous Malformation (AVM) when performed concomitantly with evacuation of an associated space-occupying Intracerebral Haematoma (ICH).

Methods: Data on the presentation, management, and outcome of patients with AVM were collected prospectively. Cases were identified in which an AVM was resected and an associated space-occupying ICH was evacuated at the same time. Cases with only small associated intraparenchymal haemorrhage, or those in which an AVM was resected following previous evacuation of an ICH, or after the ICH had completely resolved, were excluded. Remaining cases were divided into: "Group 1" in which the surgery was performed acutely within 48 hours of presentation due to signs of elevated intracranial pressure; and "Group 2" in which selected patients were operated upon in the presence of a liquefying ICH in the "sub-acute" stage. Technically, the ICH cavity provided an operative trajectory to a deep AVM, or facilitated the deep dissection of the nidus. Clinical outcomes were assessed using the modified Rankin Scale (mRS), with a score of 0-2 considered a good outcome. Obliteration rates were assessed using post-operative angiography.

Results: Between 2001 and 2014, 126 patients underwent microsurgical resection of an intracranial vascular malformation, of which 61cases were included. In "Group 1" (n=20; Spetzler-Martin Class A in 13, Class B in 4, and Class C in 3), 10/20 (50%) had a good outcome and in 17/18 (94%) of those who had a postoperative angiogram the AVMs were completely obliterated. In "Group 2" (n=41; Spetzler-Martin Class A in 30, Class B in 9, and Class C in 2), 37/41 (90%) had a good outcome and 39/41(95%) were obliterated with a single procedure. For supratentorial AVMs the ICH cavity was utilised to provide an operative trajectory to a deep AVM in 11 cases and in 23 cases the ICH cavity was deep to the AVM and hence facilitated the deep dissection of the nidus.

Conclusions: In selected patients the presence of a liquefying ICH cavity may facilitate the resection of AVMs when performed in the subacute stage resulting in a good neurological outcome and obliteration rate.

INTRODUCTION

Incidental diagnosis of intracranial vascular lesions is on the increase due to the recent wide availability of imaging [1-4]. However, haemorrhage remains the most common presentation of intracranial arteriovenous malformation (AVM), accounting for approximately 2% of all haemorrhagic strokes [5]. Mass-producing intracerebral haematoma (ICH) are the most common type of haemorrhage associated with intracranial vascular malformations, followed by intraventricular haemorrhage (IVH) and subarachnoid haemorrhage (SAH) [6]. Despite new evidence [7] and treatment guidelines for cerebral AVMs having been proposed [8], the management of patients presenting with intracerebral mass-producing haematomas remains contentious.

In terms of management, AVMs may represent one of the most complex lesions encountered by the vascular neurosurgeon. The aim of treatment is the total obliteration of the AVM, thus eliminating the risk of subsequent lesion-related haemorrhage and long-term neurological sequelae. Available modalities for treating AVMs include operative microsurgery, stereotactic radiotherapy, and endovascular therapy, with several of these often employed in combination. Success in treating AVM relies on a detailed knowledge of their natural history, and a thorough understanding of the principles and risks of these aforementioned therapeutic modalities [9, 10]. In doing so, evaluation of the angio-architecture is necessary for preoperative planning and a number of grading systems have been developed [11-14]; the most widely used of these is that of Spetzler and Martin [15-17].

Current evidence on the outcome of patients with AVM presenting with haemorrhage exists largely in the form of case series that are heterogeneous in terms of case-mix, modality of treatment, and operator experience [18]. The mortality in AVMs associated with symptomatic haemorrhage is 4% to 29% [5, 19-26], depending on location and type of haemorrhage [20, 27]. This and the emergence of Endovascular Therapy (ET) and Stereotactic Radiotherapy (STRT) as alternatives to surgery means that the choice of when and how best to treat AVMs remains controversial. Although it is generally recommended that surgical excision of AVMs presenting with haemorrhage be deferred to an elective setting [10], the optimal timing for surgical intervention remains debatable [28]. The presence of a liquefying ICH may provide an operative trajectory to a deep AVM, or facilitate deep dissection of the nidus for microsurgical resection of an AVM in the presence of a mass-producing haematoma (Figure 2). However, these potential benefits must be balanced against the risks and the potential concern regarding morbidity due to operating on a swollen brain and the difficulty in defining the nidus in the presence of an adjacent ICH

The objective of this study was to evaluate the clinical outcome and obliteration rates of microsurgical resection of AVM when performed concomitantly with evacuation of an associated space-occupying ICH and whether the timing of microsurgical resection of AVMs after intracerebral haematoma presentation, affect the results of surgery.

.

Methods

Data on the presentation, structural details, management and outcome of patients undergoing microsurgical resection of intracranial vascular malformations was collected prospectively on a database. From November 2001 and until November 2014 there were 126 surgical procedures involving a single neurovascular surgeon.

All cases of elective AVM resection were excluded. Cases were identified in which the microsurgical AVM resection was performed concomitantly with evacuation of a space-occupying ICH. Cases were excluded if there was only small associated intraparenchymal haemorrhage, or the AVM was resected following previous evacuation of an ICH, or after the ICH had completely resolved.

All cases included in the study had a preoperative Digital Subtraction Angiography (DSA)-proven intracranial AVM. Some had Computed Tomography Angiogram (CTA) as well, but at the time the study was conducted CTA alone was not felt to be accurate enough to fully characterise the anomaly. AVMs were classified according to their angio-architecture using the Spetzler-Martin grading system into Class A, B or C [17].

All patients were assessed for postoperative neurological deficits and the modified Rankin Scale (mRS) was used to assess the outcome, with a score of 0-2 was considered a good outcome. Deficits in motor power, sensation, visual fields, speech and ataxia were correlated with the corresponding eloquent locations of the lesions. Post-operative DSA was used to evaluate AVM obliteration.

Cases were divided into: “Group 1”, in which surgery was performed in the acute phase within 48 hours due to signs of elevated intracranial pressure (ICP); and “Group 2” in which surgery was performed in the sub-acute phase in the presence of a liquefying ICH, in order to provide an operative trajectory to a deep AVM, or to facilitate deep dissection of the nidus.

Results

Between 2001 and 2014, of the 126 patients who underwent microsurgical resection of an intracranial vascular malformation, 61cases were included in the present analysis (Figure 1).

Group 1

20 patients underwent microsurgical resection of AVM in addition to evacuation of the ICH at the same procedure within 48 hours of presentation. In all cases, patients had reduced or deteriorating GCS due to elevated ICP from the mass producing ICH.

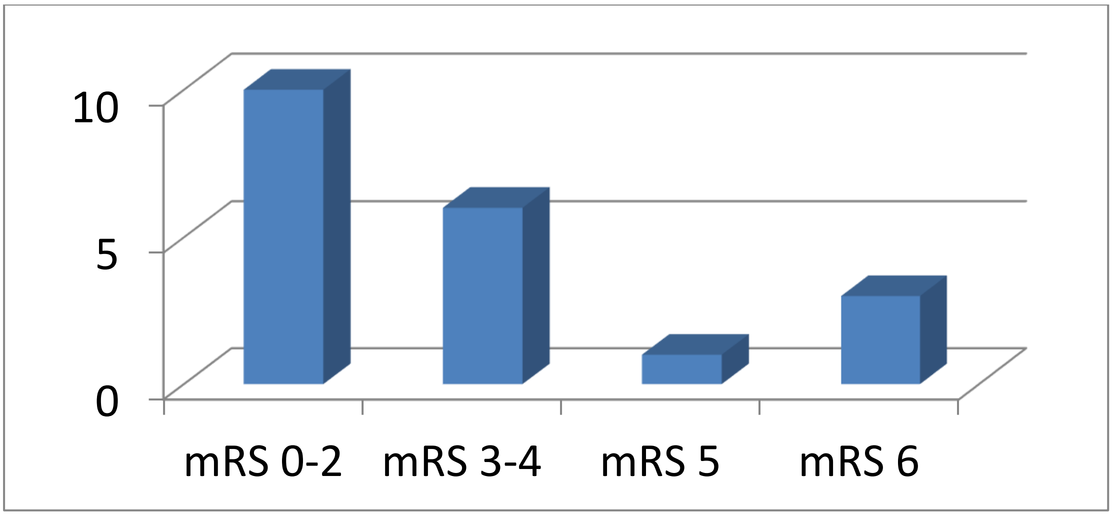
The age range was 3-73 years with 7 (35 %) being under the age of 18 years. There were 11 male and 9 female patients. Three cases were located infratentorially in the cerebellum. The AVMs were classified as Spetzler-Martin Class A in 13 cases, Class B in 4 cases and Class C in 3 cases. Therefore 7/20 (35 %) were Class B or C.

In 16 patients the resection of the AVM with the evacuation of the ICH was planned, as the AVM was felt to be well defined and surgically favourable. However, in 4 patients (Spetzler-Martin Class B in 3 cases, and Class C in 1 case), the decision to resect the AVM after evacuation of the ICH was made intraoperatively due to need to control active bleeding from the nidus. Overall in 15 cases of the 20 the ICH was deep to the nidus. In 3 patients associated flow aneurysms were identified on the proximal feeder and were obliterated at surgery.

In all, 10/20 (50%) patients had a good outcome, with a mRS score of 0-2 (Table 1). The outcome was correlated to the GCS at the time of intervention and to the Spetzler grade, 7 patients had no neurological deficits whereas the rest were left with combinations of deficits. Three patients were left with a permanent shunt. Three patients died at 10 days, 3 months and 4 months following surgery; one of these was discharged with a mRS of 3 but subsequently died from undiagnosed lung cancer.

Total obliteration of the nidus after first procedure was achieved in 17 out of 18 (94%) patients who underwent a postoperative angiogram (Table 1). An angiogram was not performed in the patient who died on the 10th postoperative day and in another who remained very disabled following surgery. There was a 5-year-old boy who had residual temporal AVM requiring further surgery and STRS to achieve complete obliteration.

Within this group there were 3 patients who developed an acute life-threatening large mass-producing ICH during planned endovascular embolization and underwent emergency evacuation of the haematoma. However, resection of the AVM was necessary to achieve full haemostasis. These were complex AVMs with deep extensions (Spetzler-Martin Class C in 2 cases, and Class B in 1 case). The ICHs were large and deep to the nidus in all cases. One patient (Spetzler-Martin Class C) remained very disabled (mRS 5) and due to the poor recovery the post-resection DSA was not performed and only had a postoperative CTA. In the other two a complete resection was confirmed by DSA. One of these patients had pre-existing hemiparesis but very good cognitive function (mRS 4). The other patient regained excellent cognitive function and was left with upper limb paresis (MRC grade >3) and moderate dysphasia (mRS 2).



Deficit	
None	7
Hemiparesis	5
Visual defect	1
Dysphasia	1
Ataxia	2
Un-assessable	5

GCS		Good Outcome – mRS 0-2	Mortality
<8	n=14	7 (50%)	3
>8	n=6	3 (50%)	0

Table 1. Summary of the angio-architecture, clinical outcome, and obliteration rate in cases that underwent microsurgical resection of Arteriovenous Malformation (AVM) with concomitant evacuation of Intracerbral Haematoma (ICH) in the acute stage.

Angio-architecture (Spetzler-Martin classification)	**Number of cases**	**Good clinical outcome (Glasgow Outcome Score 0-2)**	**Obliteration rate**
Class A	13	8 (66%)	12/13 (92.3%)
Class B	4	1 (25.0%)	4/4 (100%)
Class C	3	1 (33.3%)	1/1 (100%)
TOTAL	20	10 (50%)	17/18 (94.4%)

Group 2

41 patients underwent microsurgical resection of AVM in the subacute phase in the presence of a resolving but persistently space-occupying ICH. The timing of surgery was 5-10 days in 18 cases, 11-20 days in 18 cases, and over 21 days in 5 cases. Nine patients had other surgical interventions in the acute phase: 4 cases underwent a decompressive craniectomy with the ICH left *in-situ*; 5 cases had an External Ventricular Drain inserted for relief of hydrocephalus.

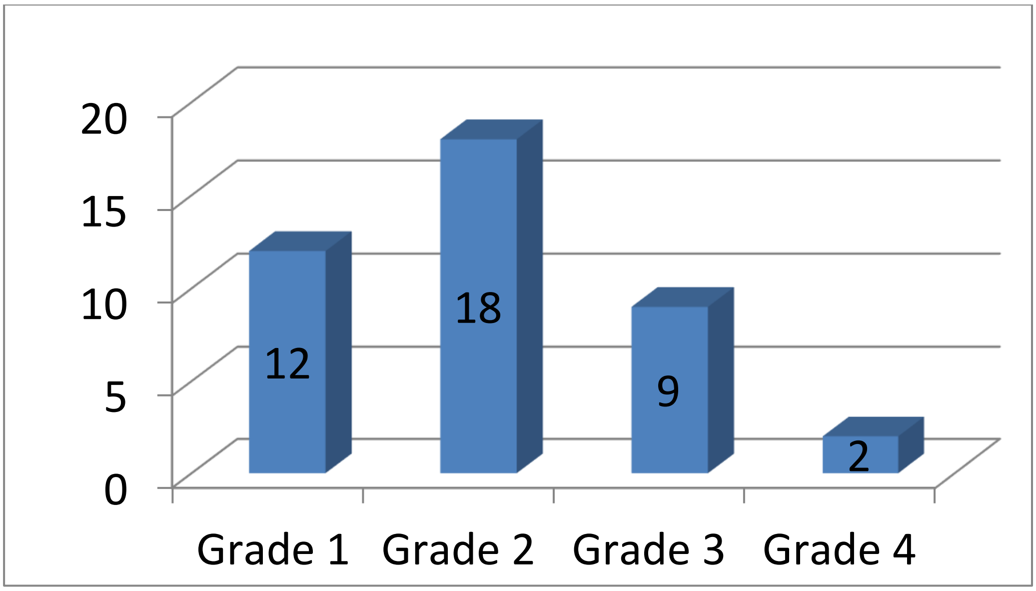
The age range was 5-73 years with 7 (17 %) being under the age of 18 years. There were 24 male and 17 female patients. Seven cases were located infratentorially in the cerebellum. The AVMs were classified as Spetzler-Martin Class A in 30, Class B in 9 and Class C in 2. Therefore 11/41 (27 %) were Class B or C.

The liquefying ICH cavity facilitated the approach to a deep AVM nidus by providing a corridor or trajectory in 11 cases, or by providing a dissection plane deep to the nidus in 23 cases (Figure 2 and 3 respectively). While this helped with the localisation of a relatively small nidus within the cerebellum in 7 cases. In 3 patients associated flow aneurysms were identified on the proximal feeder and were obliterated at surgery.

In all, 37/41 (90%) had a good outcome, with a mRS 0-2 and 76% had an mRS of 0-1(Table 2). The outcome was correlated to the Spetzler grade. Five patients required a permanent shunt. Three patients were left with well-controlled seizures. There were no mortalities.

Total obliteration of the nidus after the first procedure was achieved in 39/41 (95%) patients (Table 2). One case had a small residual AVM following microsurgical resection and was obliterated after STRS. Another patient, aged 5 years, with a diffuse cerebellar AVM, required STRS and multiple microsurgical procedures in order to achieve complete obliteration.

The neurological deficits where analysed in relationship to the presenting deficit and the eloquence of the AVM. Overall, 30 neurological deficits were noted preoperatively in this group (Table 3). Of these, the vast majority (22/30; 87%) either completely resolved or significantly improved post-operatively, and the remaining neurological deficits were stable. No new neurological deficits occurred post-operatively.



5-10	**n= 18**
10-20	n= 18
>20	n= 5

Table 2. Summary of the angio-architecture, clinical outcome, and obliteration rate in cases that underwent microsurgical resection of Arteriovenous Malformation (AVM) with concomitant evacuation of Intracerbral Haematoma (ICH) in the subacute stage.

Angio-architecture (Spetzler-Martin classification)	Number of cases	Good clinical outcome (Glasgow Outcome Score 0-2)	Obliteration rate
Class A	30	28 (93.3%)	29 (96.6%)
Class B	9	8 (88.9%)	9 (100%)
Class C	2	1 (50.0%)	1 (50.0%)
TOTAL	41	37 (90.2%)	39 (95.1%)

Deficits at presentation			**Postoperative deficit**			
Deficit		AVM eloquence	Improved (no/minor)	Same	Worse	New
Visual field defect	11	10*	10 (9)	1	0	0
Motor deficit	9	7	8 (6)	1	0	0
Speech dysfunction	6	4	6 (5)	0	0	0
Sensory deficit	0	1	-	-	-	-
Cerebellar ataxia	4	3**	2 (2)	2	0	0

- * = adjacent to primary visual cortex or optic radiation
- ** = adjacent to cerebellar peduncle
- Table 3. Summary of pre- and post-operative neurological deficits, accounting for AVM eloquence. *AVMs located adjacent to the primary visual cortex or optic radiations were considered to have eloquence (visual function), as were those located adjacent to the cerebellar peduncle (cerebellar function).

Function	**AVM eloquence***	**Pre-operative deficit**	**Post-operative deficit**				
			Resolved	**Improved**	**Stable**	**Worsened**	**New**
Visual	10	11	9	1	1	0	0
Motor	7	9	6	2	1	0	0
Speech	4	6	5	1	0	0	0
Cerebellar	3	4	2	0	2	0	0
Sensory	1	0	0	0	0	0	0
TOTAL	25	30	22 (73.3%)	4 (13.3%)	4 (13.3%)	0 (0%)	0 (0%)

DISCUSSION

In this case series we have shown that the subacute microsurgical resection of AVM with concomitant evacuation of ICH is safe and effective option in selected cases. Whenever possible we feel that the initial management of a vascular lesion presenting with an acute haemorrhage should be conservative; planned elective management, especially for complex lesions, is more likely achieve better outcome [10, 29]. Frequently relatively large haematomas can be tolerated and managed conservatively initially [29]. However, there are always situations where patients with a large space-occupying ICH and signs of raised intracranial pressure require acute surgical intervention. An angiogram should be obtained whenever possible prior to surgery. Vigilance is required on studying the imaging before surgery as the configuration of the nidus could be distorted by the presence of the ICH. Imaging would help to identify an associated aneurysm as the more probable cause of the haemorrhage and its management takes priority [36] { Turjman, *Correlation of the Angioarchitectural Features of Cerebral Arteriovenous Malformations with Clinical Presentation of Hemorrhage.* Neurosurgery, 1995. **37**(5): p. 856-862.]. In those situations when there is indication to urgently evacuate the ICH without having the opportunity to obtain an angiogram we strongly suggest not to tackle any vascular lesion encountered without prior angiographic knowledge. More recently with experience and good quality CTA studies very good definition of the AVM can be achieved. It is imperative to define whether the lesion is an AVM or a DAVF with cortical arterialised veins, as the wrong operative manoeuvre can result in disastrous consequences.

If emergency surgery is mandated and a technically simple malformation exists (Spetzler Class A), then microsurgical resection of the lesion, with simultaneous evacuation of the haematoma, may be considered. With complex lesions (Spetzler Class B and C), partial evacuation of the haematoma, or even a decompressive craniectomy alone, may be safer in the acute phase. However, even in these cases the surgeon should be aware that in the rare event where haemostasis cannot be achieved, resection of the lesion might still be necessary. In our case series, the decision to resect the AVM was made intraoperatively in 4 patients (all Spetzler-Martin Class B or Class C), due to need to control active bleeding from the nidus. The majority of AVMs resected in the acute phase together with ICH evacuation in this series were of low Spetzler grades, and many were paediatric patients.

A particularly difficult group to manage are those presenting with ICH as a complication resulting from an endovascular embolisation procedure. Evacuation of the ICH alone in the context may not be possible in many cases for several reasons, and the stage of embolisation and the configuration of both the residual and obliterated parts of the nidus have to be considered carefully. In all three of our cases the ICH was deep to the nidus and haemostasis after approaching the deep ICH was achieved with difficulty and only by resecting the AVM. The presence of Onyx as the embolisation material within parts of the AVM rendered the nidus non-compressible and increased the difficulty of dissecting the deeper parts for resection. Furthermore, it is suspected that the ICH may have occurred due to premature occlusion of the venous outflow and the reflected increased intranidal pressure further increased the difficulty of dealing with these during surgery.

For the majority of patients with AVM who are stable, several clinical and anatomical factors should be considered to dictate the further method and timing of management. The clinical considerations include the estimated risk of recurrent haemorrhage [30]. Following presentation with a haemorrhage, the risk of haemorrhagic recurrence in the first year from an AVM, is around 6% compared to 2-3% per annum in subsequent years [31]. Factors increasing the intranidal pressure such as increased feeding artery pressure, fewer draining veins, and stenosis of venous outflow, increase the risk of haemorrhage; small size and deep location are interrelated and may also increase the risk due to more limited venous outflow. Intranidal aneurysms also increase the risk of haemorrhage [32]. The increased risk of recurrent haemorrhage in the first year and the latent period for obliteration of AVMs following STRS may favour earlier microsurgical resection for lesions suitable for surgery after a haemorrhagic presentation. The presence and the course of neurological deficits that may have resulted from the haemorrhage have to be considered. These deficits often improve significantly in the weeks and months after the initial haemorrhage. Elective resection of complex vascular lesions in more favourable brain conditions would allow a better chance for continuous recovery [29].

In combination with the above considerations, the presence or absence of a mass-producing ICH may dictate the timing of intervention. We considered the period between the second and fourth week following haemorrhage as the “subacute” phase during which a haematoma, if present, is liquefying. The impact of this on the anatomical configuration of the AVM before the total resolution of the ICH would present a “window of opportunity” for surgical intervention. The morbidity of surgery for AVM resection correlates with the Spetzler grade. Practically the difficulty and morbidity of surgery is mostly related to a deep and/or eloquent location in particular [30]. Spetzler grading identifies a higher grade for an AVM on or adjacent to a sensorimotor, language or visual eloquent cortical region. Recent advanced neuroanatomical knowledge has emphasised the surgical importance of the different functional white matter tracts. In fact deep tract disruption may be associated with a more permanent deficit than a cortical lesion as there is plasticity in cortical function.

Naeser, M.A. & Palumbo, C.L., 1994. Neuroimaging and language recovery in stroke. *Journal of clinical neurophysiology : official publication of the American Electroencephalographic Society*, 11(2), pp.150–174.

Duffau, H., 2014. The huge plastic potential of adult brain and the role of connectomics: New insights provided by serial mappings in glioma surgery. *Cortex; a journal devoted to the study of the nervous system and behavior*, 58C, pp.325–337.

An ICH can act as a trajectory or a corridor to an otherwise deep AVM that facilitates the resection. Moreover, ICH adjacent to the deep surface of an AVM nidus not only facilitates the deep dissection but may also separate or push away eloquent white matter tracts and thus protected them from surgical manipulation. This of course is not always the case as the haematoma may well disrupt these tracts with a resulting permanent deficit. In the group of patients operated upon in our series in the presence of a subacute ICH adjacent to eloquent regions the initial severe deficit did improve in the majority of cases to a variable degree following surgery. This approach has facilitated the resection of otherwise more complex Spetzler Class B and C AVMs in our series. Although it may be argued that this approach may have contributed to some of the persistent deficits that would have recovered otherwise if a longer period of time were left prior to more elective surgery, nevertheless we did achieve reasonably good results. Furthermore, this approach did not seem to compromise the obliteration rate of AVMs.

Patients operated upon in the ”subacute” phase i.e. Group 2 where subjectively selected. The timing of surgery was mostly within the first 2-3 weeks. This provided optimum time during which the ICH is liquefying and the clots are easily evacuated without being adherent to the by then well formed surrounding cavity within the brain. Few were delayed beyond 20 days mainly to ensure that there neurological recovery has stabilised. In those, imaging prior to surgery ensured that the haematoma cavity was still large enough to facilitate the surgery. The haematoma was used as providing a “corridor” or trajectory to deep seated AVMs such as the mediobasal location within the hemisphere or in the periventricular areas. However, during planning in these cases especially for the more complex lesions, the ICH was deemed useful not only to provide access to the nidus but also to allow control of the deep arterial feeders. More commonly the ICH cavity facilitated the definition of the deep aspect of the nidus especially those adjacent to important tracts such as the internal capsule in those AVMs located in the insula, corona radiata and the optic radiation. In the posterior fossa the ICH cavity aided in localisation of the majority of cerebellar AVMs that were mainly small in size.

Delayed elective management is appropriate for complex lesions especially in the absence of a significant ICH to allow better recovery and possibly planning preoperative embolisation if deemed beneficial [10]. Pre-operative adjuvant endovascular therapy ideally should aim to obliterate a deep segmental volume of the AVM rather than patchy diffuse occlusion. This should be preserved for complex AVMs otherwise the morbidity of combined treatment modalities would add up unnecessarily [33-39]. Delay once a decision is made for surgical intervention should be avoided, considering the possible increased risk of recurrent haemorrhage, in particular within the first year [31]. Small deep lesions are suited for STRS treatment [40-43].

CONCLUSIONS

In selected patients with AVM the presence of a liquefying ICH cavity represents a “window of opportunity” and may provide an operative trajectory, or facilitate deep dissection of the nidus. In such cases, microsurgical resection of the AVM with concomitant evacuation of the ICH in the subacute stage may be associated with a good neurological outcome and an excellent obliteration rate.

REFERENCES

1. Stapf, *Invasive treatment of unruptured brain arteriovenous malformations is experimental therapy.* Current Opinion in Neurology, 2006. **19**(1): p. 63-68.
2. Rinkel, G.J., *Intracranial aneurysm screening: indications and advice for practice.* Lancet Neurol, 2005. **4**(2): p. 122-8.
3. Stapf, C., et al., *Invasive treatment of unruptured brain arteriovenous malformations is experimental therapy.* Curr Opin Neurol, 2006. **19**(1): p. 63-8.
4. Gabriel Je, R., *Intracranial aneurysm screening: indications and advice for practice.* The Lancet Neurology, 2005. **4**(2): p. 122-128.
5. Brown, R.D., et al., *Frequency of intracranial hemorrhage as a presenting symptom and subtype analysis: a population-based study of intracranial vascular malformations in Olmsted County, Minnesota.* Journal of Neurosurgery, 1996. **85**(1): p. 29-32.
6. Aoki, N., *Do intracranial arteriovenous malformations cause subarachnoid haemorrhage?* Acta Neurochirurgica, 1991. **112**(3): p. 92-95.
7. Mohr, J.P., et al., *Medical management with or without interventional therapy for unruptured brain arteriovenous malformations (ARUBA): a multicentre, non-blinded, randomised trial.* Lancet, 2014. **383**(9917): p. 614-21.
8. Starke, R.M., et al., *Treatment guidelines for cerebral arteriovenous malformation microsurgery.* British Journal of Neurosurgery, 2009. **23**(4): p. 376-386.
9. Riina, H.A. and Y.P. Gobin, *Grading and surgical planning for intracranial arteriovenous malformations.* Neurosurgical Focus, 2001. **11**(5): p. 1-4.
10. Ogilvy, C.S., 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**(21): p. 2644-2657.
11. Luessenhop, *AVM Grading in Assessing Surgical Risk.* Journal of Neurosurgery, 1987. **66**(4): p. null.
12. Pertiliset, B., et al., *Classification of supratentorial arteriovenous malformations. A score system for evaluation of operability and surgical strategy based on an analysis of 66 cases.* Acta Neurochirurgica, 1991. **110**(1): p. 6-16.
13. Spears, J., et al., *A Discriminative Prediction Model of Neurological Outcome for Patients Undergoing Surgery of Brain Arteriovenous Malformations.* Stroke, 2006. **37**(6): p. 1457-1464.
14. Shi, Y.-q. and X.-c. Chen, *A proposed scheme for grading intracranial arteriovenous malformations.* Journal of Neurosurgery, 1986. **65**(4): p. 484-489.
15. Spetzler, R.F. and N.A. Martin, *A proposed grading system for arteriovenous malformations.* Journal of Neurosurgery, 1986. **65**(4): p. 476-483.
16. Hamilton, *The Prospective Application of a Grading System for Arteriovenous Malformations.* Neurosurgery, 1994. **34**(1): p. 2-7.
17. Spetzler, R.F. and F.A. Ponce, *A 3-tier classification of cerebral arteriovenous malformations. Clinical article.* J Neurosurg, 2011. **114**(3): p. 842-9.
18. Ross, J. and R. Al-Shahi Salman *Interventions for treating brain arteriovenous malformations in adults*. Cochrane Database of Systematic Reviews, 2010. DOI: 10.1002/14651858.CD003436.pub3.
19. Wilkins, R.H., *Natural history of intracranial vascular malformations: a review.* Neurosurgery, 1985. **16**(3): p. 421-30.
20. Graf, C.J., G.E. Perret, and J.C. Torner, *Bleeding from cerebral arteriovenous malformations as part of their natural history.* J Neurosurg, 1983. **58**(3): p. 331-7.
21. Trumpy, J.H. and P. Eldevik, *Intracranial arteriovenous malformations: conservative or surgical treatment?* Surg Neurol, 1977. **8**(3): p. 171-5.

22. Ondra, S.L., et al., *The natural history of symptomatic arteriovenous malformations of the brain: a 24-year follow-up assessment.* J Neurosurg, 1990. **73**(3): p. 387-91.
23. Brown, R.D., et al., *The natural history of unruptured intracranial arteriovenous malformations.* Journal of Neurosurgery, 1988. **68**(3): p. 352-357.
24. da Costa, L., et al., *The natural history and predictive features of hemorrhage from brain arteriovenous malformations.* Stroke, 2009. **40**(1): p. 100-5.
25. Hernesniemi, J.A., et al., *Natural history of brain arteriovenous malformations: a long-term follow-up study of risk of hemorrhage in 238 patients.* Neurosurgery, 2008. **63**(5): p. 823-9; discussion 829-31.
26. Laakso, A., et al., *Long-term excess mortality in 623 patients with brain arteriovenous malformations.* Neurosurgery, 2008. **63**(2): p. 244-53; discussion 253-5.
27. Fults, D. and D.L. Kelly, Jr., *Natural history of arteriovenous malformations of the brain: a clinical study.* Neurosurgery, 1984. **15**(5): p. 658-62.
28. Kuhmonen, J., et al., *Early surgery for ruptured cerebral arteriovenous malformations.* Acta Neurochir Suppl, 2005. **94**: p. 111-4.
29. Thomas Kretschmer, R.H., *Microsurgical Management of Arteriovenous Malformations*, in *Youmans Neurological Surgery*, R. Winn, Editor. 2011, Elsevier. p. 4075.
30. Schaller, C., J. Schramm, and D. Haun, *Significance of factors contributing to surgical complications and to late outcome after elective surgery of cerebral arteriovenous malformations.* Journal of Neurology, Neurosurgery & Psychiatry, 1998. **65**(4): p. 547-554.
31. Weerakkody, R.A., et al., *Arteriovenous malformations.* British Journal of Neurosurgery, 2009. **23**(5): p. 494-498.
32. Meisel, *Cerebral Arteriovenous Malformations and Associated Aneurysms: Analysis of 305 Cases from a Series of 662 Patients.* Neurosurgery, 2000. **46**(4): p. 793-802.
33. Starke, R.M., et al., *Adjuvant Embolization With N-Butyl Cyanoacrylate in the Treatment of Cerebral Arteriovenous Malformations.* Stroke, 2009. **40**(8): p. 2783-2790.
34. Jafar, J.J., et al., *The effect of embolization with N-butyl cyanoacrylate prior to surgical resection of cerebral arteriovenous malformations.* Journal of Neurosurgery, 1993. **78**(1): p. 60-69.
35. Hartmann, A., et al., *Determinants of Staged Endovascular and Surgical Treatment Outcome of Brain Arteriovenous Malformations.* Stroke, 2005. **36**(11): p. 2431-2435.
36. Hartmann, A., et al., *Risk of Endovascular Treatment of Brain Arteriovenous Malformations.* Stroke, 2002. **33**(7): p. 1816-1820.
37. Haw, C.S., et al., *Complications of embolization of arteriovenous malformations of the brain.* Journal of Neurosurgery, 2006. **104**(2): p. 226-232.
38. Vi√±uela, F., et al., *Combined endovascular embolization and surgery in the management of cerebral arteriovenous malformations: experience with 101 cases.* Journal of Neurosurgery, 1991. **75**(6): p. 856-864.
39. Spetzler, R.F., et al., *Surgical management of large AVM's by staged embolization and operative excision.* Journal of Neurosurgery, 1987. **67**(1): p. 17-28.
40. Shin, M., et al., *Analysis of nidus obliteration rates after gamma knife surgery for arteriovenous malformations based on long-term follow-up data: the University of Tokyo experience.* Journal of Neurosurgery, 2004. **101**(1): p. 18-24.
41. Pollock, *Factors Associated with Successful Arteriovenous Malformation Radiosurgery.* Neurosurgery, 1998. **42**(6): p. 1239-1244.
42. Utiger, R.D., R.C. Heros, and K. Korosue, *Radiation Treatment of Cerebral Arteriovenous Malformations.* New England Journal of Medicine, 1990. **323**(2): p. 127-129.
43. Heros, R.C., *Treatment of arteriovenous malformations: gamma knife surgery.* Journal of Neurosurgery, 2002. **97**(4): p. 753-755.

Figure 1. Selection of cases that underwent microsurgical resection of Arteriovenous Malformation (AVM) with concomitant evacuation of Intracerbral Haematoma (ICH)

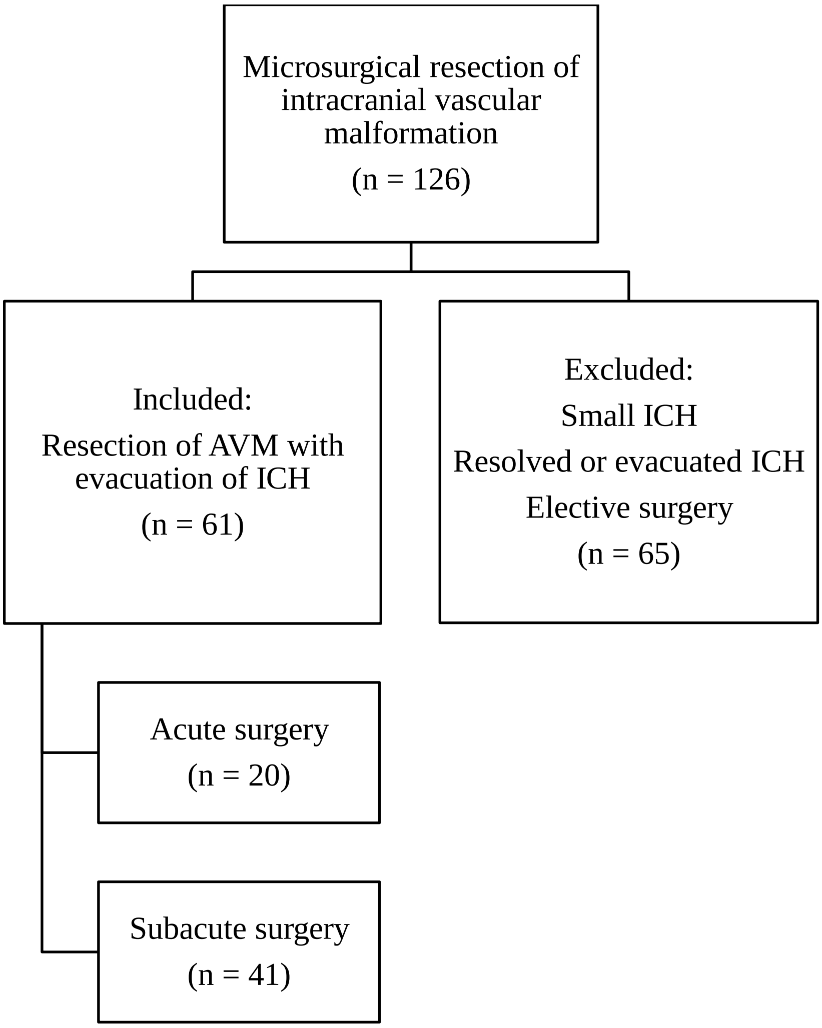
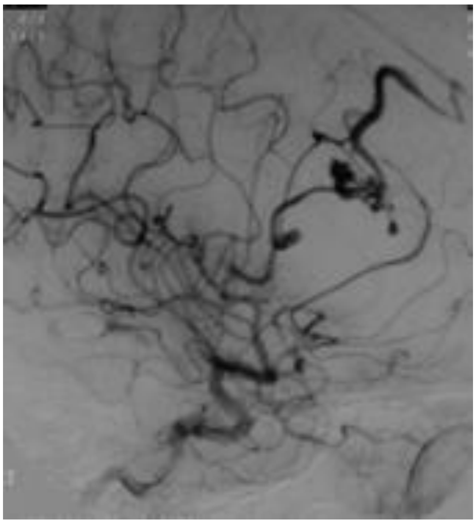


Figure 3

Figure 1

Examples of lesions operated upon in the acute phase with microsurgical resection of the AVM concomittantly with evacuation of ICH.

(a) small frontal AVM



(b) more complex AVM with haematoma formation post-partial stagged endovascular embolization

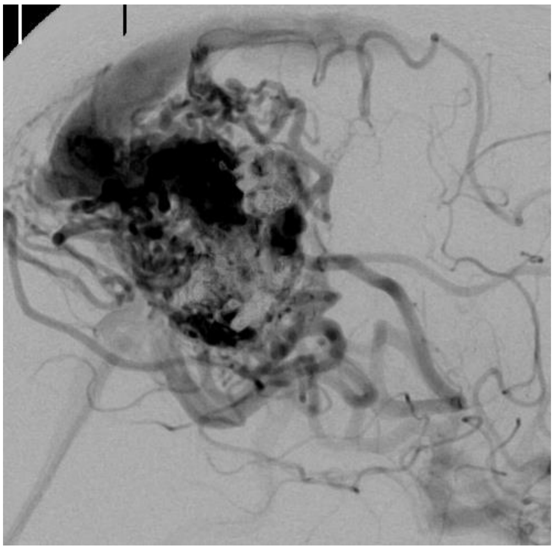


Figure 2

A CT sacn of a liquefying ICH within 2 weeks from presentation

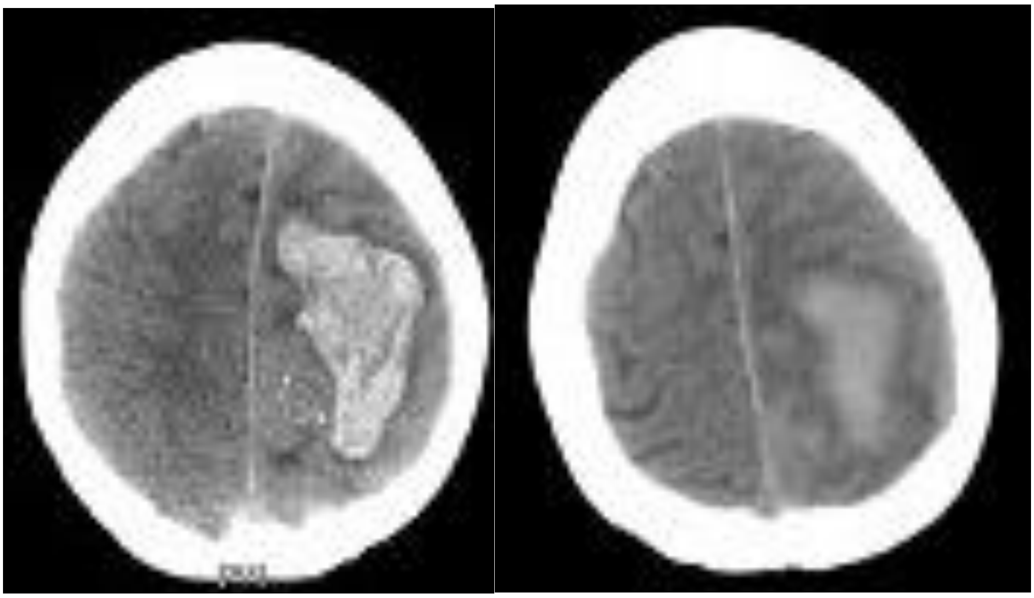
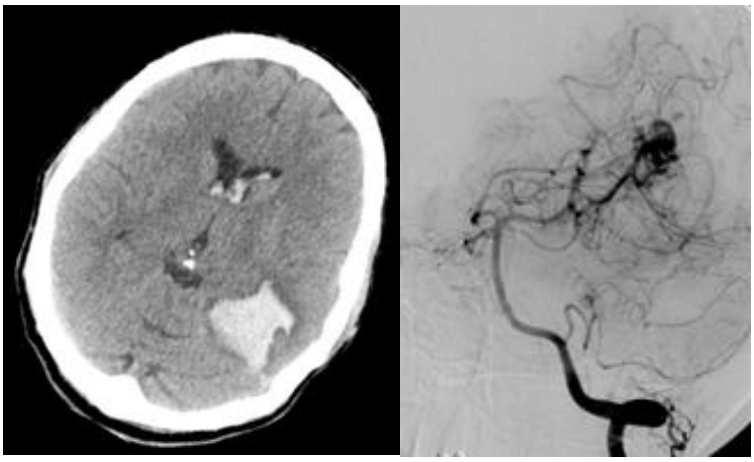


Figure 3

Exmaples demonstrating the use of the ICH cavity during planning of microsurgical resection of the underlying AVM in the "subacute" phase.

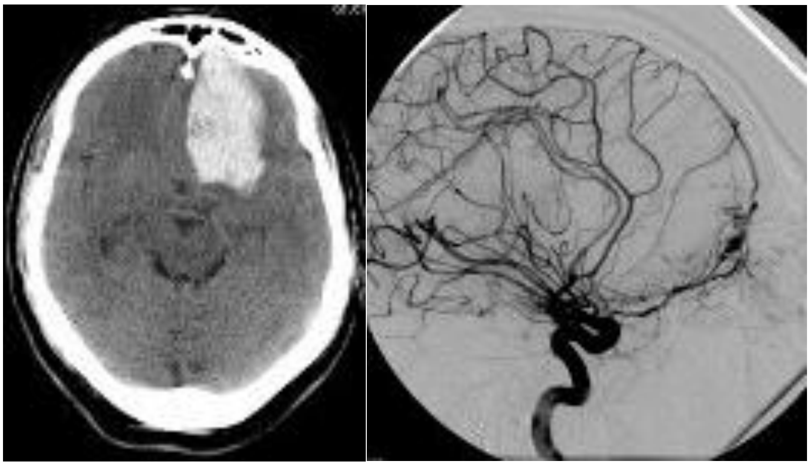
(a) ICH cavity serving a trajectory to the AVM

(i) Deep periventricular

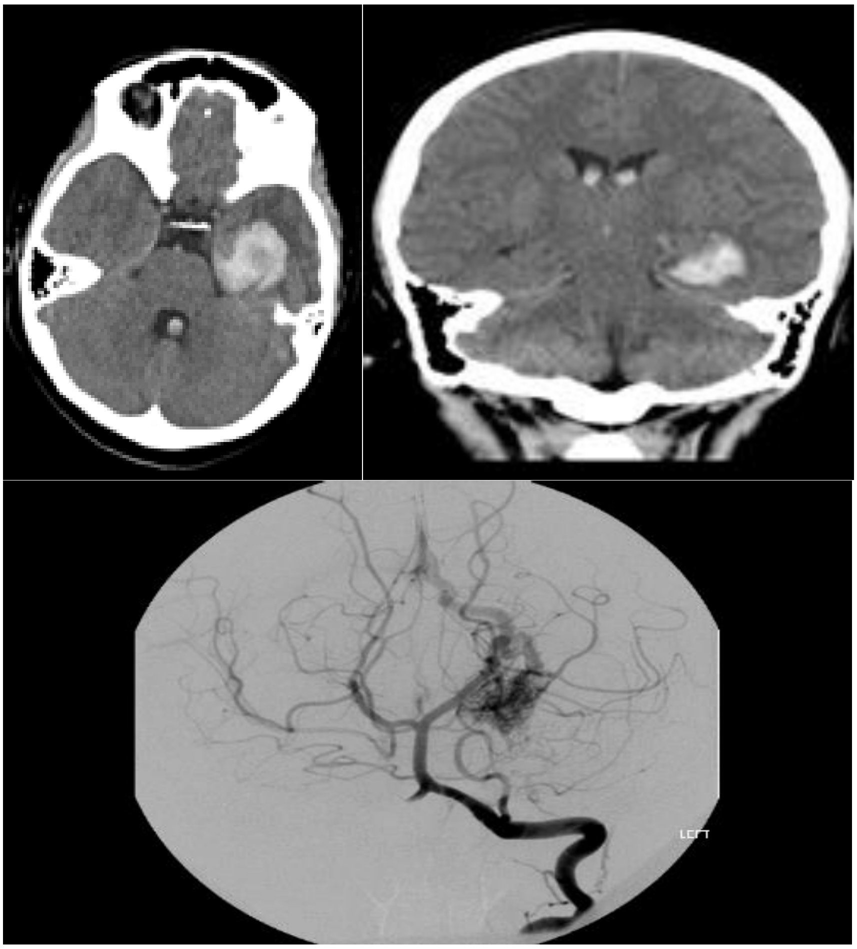


(ii) Cortical to basal

Figure . Example of Intracerebral Haematoma (ICH) being used to guide the operative trajectory to an Arteriovenous Malformation (AVM) during subacute surgery. (a) Axial CT scan demonstrating a left frontal ICH (b) Lateral DSA demonstrating an underlying AVM.



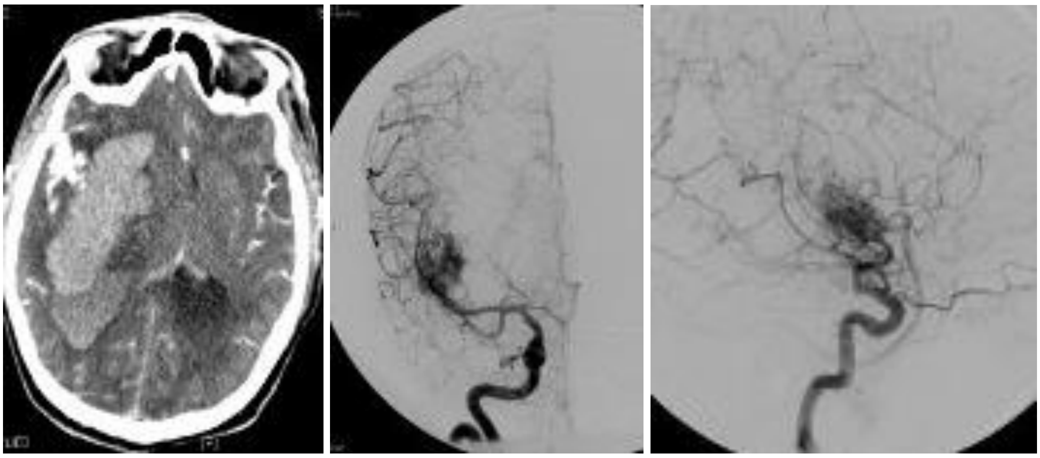
(iii) Lateral to medial



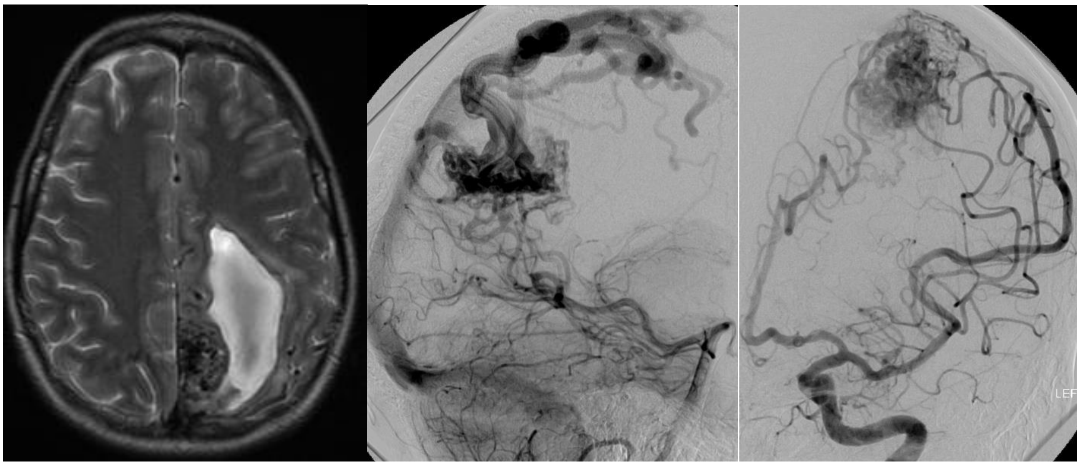
(b) ICH cavity providing a deep dissection plane for the nidus of the AVM

(i) Internal capsule

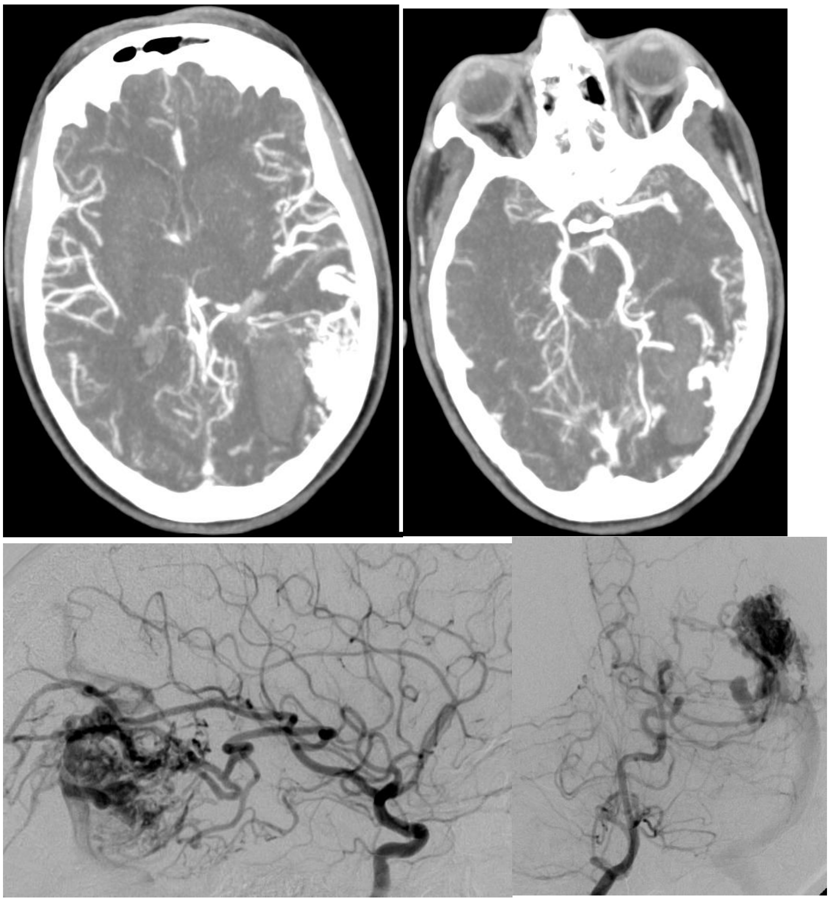
. Example of Intracerebral Haematoma (ICH) being used to facilitate the deep dissection of an Arteriovenous Malformation (AVM) during subacute surgery. (a) Axial CT scan demonstrating a right ICH of the internal capsule (b-c) A-P and Lateral DSA demonstrating underlying an AVM.



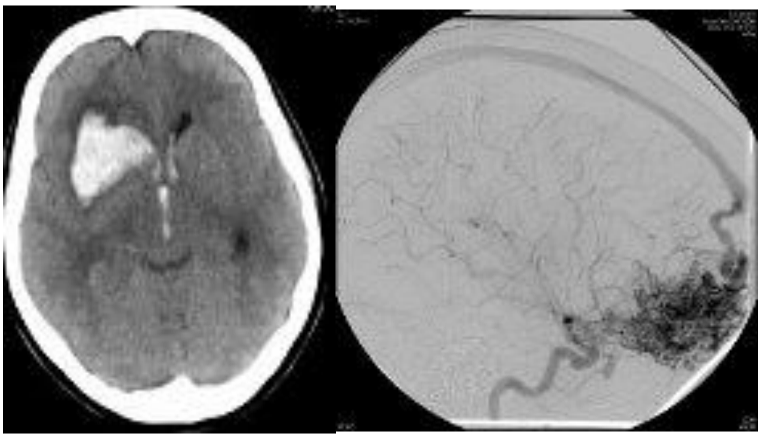
(ii) Corona radiate



(iii) Optic radiation



(iv) Basal ganglia



© ICH cavity assisting in localisation of relatively small nidus of cerebellar AVMs