Management of incidentally discovered intracranial vascular abnormalities

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With the widespread use of brain imaging studies, neurosurgeons have seen a marked increase in the number of incidental intracranial lesions, including vascular abnormalities. Specifically, the detection of incidentally discovered aneurysms, arteriovenous malformations, cavernous angiomas, developmental venous anomalies, and capillary telangiectasias has increased. The best management strategy for most of these lesions is controversial. Treatment options include observation, open surgery, endovascular procedures, and radiosurgery. Multiple factors should be taken into account when discussing treatment indications, including the natural history of the disease and the risk of the treatment. In this article, the authors focus on the natural history of these lesions and the risk of the treatment, and they give recommendations regarding the most appropriate management strategy based on the current evidence in the literature and their experience with intracranial vascular abnormalities. (DOI: 10.3171/2011.9.FOCUS11200)

KEY WORDS • aneurysm • arteriovenous malformation • cavernous angioma • developmental venous anomaly • capillary telangiectasia • incidental finding

BRAIN vascular abnormalities including aneurysms, AVMs, CAs, DVAs, and capillary telangiectasias are common incidental findings on imaging studies. With brain imaging becoming available ubiquitously, these common lesions are expected to be discovered more and more in an asymptomatic stage. The management of most of these vascular abnormalities is still controversial. As a general rule, the natural history of these lesions should be balanced against the risk of morbidity and mortality that may result from treatment. With the conflicting results of recent studies, uncertainty remains concerning the natural history and the risk of treatment, further complicating the neurosurgeon's task. This article reviews the current evidence in the literature regarding the management of incidentally discovered aneurysms, AVMs, CAs, DVAs, and capillary telangiectasias and provides neurosurgeons with a decision-making paradigm for each of these lesions.

Abbreviations used in this paper: ARUBA = A Randomized Trial of Unruptured Brain AVMs; AVM = arteriovenous malformation; CA = cavernous angioma; DVA = developmental venous anomaly; ISUIA = International Study of Unruptured Intracranial Aneurysms; SAH = subarachnoid hemorrhage.

Aneurysms

The management of unruptured intracranial aneurysms has been a very controversial topic in neurosurgery. There is no clear consensus today as to when an incidental aneurysm should be treated and when it should be observed. Moreover, the magnitude of this problem is expected to increase in the future commensurate with increased detection due to advances in imaging quality and availability. The prevalence of aneurysms in the general population is thought to be somewhere between 1% and 7%.^{63,67,102,118} However, aneurysmal SAH remains a rare event with an incidence of 6–20 cases per 100,000 persons per year.^{49,60,92} This underscores the importance of patient selection for treatment. Because most aneurysms remain asymptomatic throughout the patient's life, it is crucial to weigh the risks of treatment against the natural history of these lesions. Treatment should only be offered to patients whose risk of SAH exceeds the risk of surgical or endovascular intervention.

Natural History

The natural history of intracranial aneurysms continues to be a controversial topic mainly because of the con-

flicting results of the different studies. The largest study to date that evaluated the risk of rupture of intracranial aneurysms is the ISUIA (International Study of Unruptured Intracranial Aneurysms).^{58,147} This prospective study involved 1692 patients and reported 5-year rupture rates for anterior circulation aneurysms with respect to their size as follows: 0% for lesions smaller than 7 mm in diameter, 2.6% for those 7–12 mm, 14.5% for those 13–24 mm, and 40% for those larger than 25 mm. The annual rate of SAH was 0.05% for aneurysms less than 10 mm in diameter and 1% for those 10 mm or greater. The 5-year rupture rates for posterior circulation aneurysms (including posterior communicating artery aneurysms) were 2.5% for those less than 7 mm, 14.5% for those 7–12 mm, 18.4% for those 13–24 mm, and 50% for those larger than 25 mm. Results also showed that the relative risk of rupture was 11.6 for aneurysms 10–24 mm in diameter and around 13 for posterior circulation aneurysms. Thus, the size and the location of the aneurysms are 2 important factors in predicting the risk of rupture of these lesions. Patients with a history of SAH from another aneurysm were found to have an annual risk of rupture of 0.5%, which is substantially higher than the risk for patients with no history of SAH (0.05%). Despite being heavily criticized by many authors for the flaws in the design, as well as a significant selection bias, the ISUIA has challenged the reports of previous studies and has had an enormous impact on the contemporary management of intracranial unruptured aneurysms. Based on the results of this study, the Stroke Council of the American Heart Association published guidelines for the management of unruptured aneurysms favoring observation over treatment for aneurysms less than 10 mm in diameter.¹⁹ They also recommended special consideration for treatment of small aneurysms approaching the 10-mm-diameter size, those with daughter sac formation, patients with a positive family history for aneurysms or aneurysmal SAH, and if changes in aneurysmal size or configuration are observed.¹⁹

In contrast to the findings of the ISUIA, several studies have reported results showing that the majority of SAH resulted from aneurysms less than 10 mm in size.^{21,34,70} Winn et al.¹⁵⁰ found that 80% of aneurysmal SAH resulted from aneurysms that were smaller than 10 mm in their greatest diameter. They also suggested that the yearly rate of rupture of intracranial aneurysms falls between 1% and 2%. Similarly, in a study from Finland that followed 142 patients with 181 unruptured intracranial aneurysms for a period of 19.7 years, the overall annual incidence of SAH was found to be 1.3% in patients with prior SAH and 1% in those with incidental aneurysms.⁶⁸ A recent meta-analysis that included 19 studies with 4705 patients and 6556 unruptured aneurysms showed an annual risk of rupture ranging from 0.6% to 1.3%.¹⁴⁶ These results were significantly higher than the annual risk of rupture reported by the ISUIA. The meta-analysis also identified higher age, female sex, smoking, location at the posterior circulation, and increasing size of the aneurysm as risk factors for SAH. In our practice, most patients present with SAH harbor aneurysms smaller than 10 mm, and a significant proportion present with ruptured aneurysms less than 5 mm in diameter.

Risk Associated With Treatment

The 30-day rate of mortality from aneurysmal SAH approaches 50%.^{14,56} Preventive treatment of the aneurysm can avoid this deadly and profoundly disabling event. Treatment of unruptured aneurysms can be achieved either by surgical clipping or by endovascular means. In either case, the risk of the intervention should be weighed against the potential benefit because the rate of morbidity and mortality is substantial with these procedures.^{17,54,58,114,147} The ISUIA reported a combined morbidity and mortality rate at 1 year equal to 12.2% for surgery and 9.5% for coil embolization.^{58,147} Many studies have reported, however, a better benefit-risk profile for endovascular techniques than for surgery.^{54,64,65} In a series of 2069 patients with unruptured aneurysms, Johnston and colleagues⁶⁵ found that adverse outcomes were more frequent in patients treated with surgery (25%) than in those treated with endovascular procedures. In a recent large study that evaluated 2535 unruptured aneurysms, endovascular treatment was associated with fewer adverse outcomes (6.6% vs 13.2%) and decreased mortality (0.9% vs 2.5%) than surgical treatment.⁵⁴ Many studies published recently have noted a very low rate of complications or death related to aneurysm treatment. Moroi et al.⁹⁷ reported a remarkable 0.3% mortality and 2.2% morbidity after treating 549 unruptured aneurysms. In a recent report Benes and colleagues²⁰ suggested that unruptured aneurysms can be treated with coil embolization with low rates of complication (6-month combined morbidity and mortality rate of 1.5%), justifying offering treatment to most patients with unruptured aneurysms. Along similar lines, surgical treatment has produced low rates of morbidity and mortality in patients with unruptured aneurysms in expert hands.^{5,108,109,123,141} Tuffiash et al.¹⁴¹ demonstrated no cognitive effects of craniotomy for unruptured aneurysms. Furthermore, the unparalleled team of Dr. Charles Drake and colleagues was able to clip unruptured basilar bifurcation aneurysms smaller than 12.5 mm in diameter with a 3.6% risk of poor outcome and no mortality.¹⁰⁸ Later in their monumental series, the combined risk of morbidity and mortality was reduced below 3%. Therefore, it is clear that the rate of morbidity and mortality of microsurgery or endovascular techniques is largely dependent on the experience of the neurosurgical team.

Management of Incidentally Discovered Aneurysms

Neurosurgeons should consider many factors before deciding whether to treat or watch an incidentally discovered aneurysm. If the risk of SAH is substantial, treatment should be considered. Two important factors that help predict the risk of rupture are the size and the location of the aneurysm. Aneurysms larger than 10 mm and those located in the posterior circulation are at increased risk of rupture.^{58,147} Conversely small intracavernous internal carotid artery aneurysms are less prone to rupture and do not lead to SAH; observation is therefore recommended for these lesions.¹⁹ Many studies also showed that multilobed aneurysms are at increased risk of hemorrhage compared with single-lobed lesions.^{14,122} Another parameter that showed association with the risk of rupture is the aspect ratio (height/neck width).^{55,99} In a study by Nader-Sepahi and

Incidental vascular abnormalities

colleagues,⁹⁹ the mean aspect ratio was 2.70 for ruptured aneurysms, compared with 1.8 for unruptured aneurysms. It is currently accepted that the risk of hemorrhage is high when the aspect ratio is greater than 3.⁷⁸

Active cigarette smoking has been shown to be an important risk factor for aneurysm growth^{39,66} and therefore should be considered in the decision whether to treat or watch an aneurysm.³⁹ Patients should also be strongly advised to quit smoking. Although female sex has been cited in 1 article as a potential risk factor for aneurysm growth,⁶⁶ more evidence is needed before including this factor in the decision-making algorithm for these lesions. Hypertension is the most obvious risk factor for aneurysm growth and rupture in the brain and elsewhere in the body.^{39,101,106} A recent article that linked arterial hypertension to cerebral aneurysm growth and rupture strongly recommended that hypertension be considered when treatment indications for small unruptured aneurysms are discussed.³⁹

The ISUIA showed that patients with prior SAH have a greater risk of rupture of intracranial aneurysms. Similarly, a family history of SAH is a significant risk factor for aneurysm growth and rupture.^{27,94,126} In a study that followed 130 patients with unruptured aneurysms using serial magnetic resonance angiography, a family history of SAH was found to be an independent risk factor for aneurysm growth.⁹⁴

According to the recommendations of the Stroke Council of the American Heart Association, any changes in aneurysm size or configuration should lead to special consideration for treatment.

A recent study showed that growth and rupture risks of aneurysms in the autosomal dominant polycystic kidney disease group are not higher than those in the general population.⁵⁹

Finally the patient's age (and life expectancy) is a crucial factor when discussing treatment indications. A defined cutoff age, however, has not been determined. Mitchell et al.⁹³ concluded in their study that patients with remaining life expectancy of less than 20 years should be informed that from a statistical point of view the benefits of treatment do not outweigh the risks. Additional data are necessary to more clearly determine the impact of age and establishment of a potential age cutoff. An absolute cutoff age is unlikely to be established as many other factors play into the decision-making process.

Treatment decisions should obviously be individualized to every patient, and the choice between surgical clip placement and endovascular treatment should take into consideration the configuration and location of the aneurysm, as well as the patient's age and preferences. In patients managed conservatively, periodic follow-up (every 6–12 months) with noninvasive imaging studies (MR angiography or CT angiography) is recommended.

Based on the current evidence in the literature, the recommendations of the Stroke Council of the American Heart Association, and our institutional experience with aneurysms, we suggest the following paradigm in the decision-making process with respect to incidentally discovered intracranial aneurysms (Fig. 1).

We grouped risk factors of growth and rupture of intracranial aneurysms into 2 categories:

The Type A category represents risk factors that favor intervention over observation. These factors include active smoking, arterial hypertension, posterior circulation aneurysm, prior SAH, history of familial SAH, and an aspect ratio greater than 3.

The Type B category represents risk factors that warrant strong consideration for treatment regardless of the size of the aneurysm. These include young patient age, change in the size or configuration of the aneurysm, and the presence of multiple, multilobed, or symptomatic aneurysms.

We recommend that aneurysms larger than 7 mm in diameter be treated because of their propensity to rupture, except in older patients and those with significant medical comorbidities and short life expectancy. Aneurysms less than 5 mm in diameter should only be treated in the presence of 2 or more Type A risk factors or in the presence of any of the Type B risk factors. Finally, aneurysms that are 5–7 mm in diameter should be treated if any risk factor (Type A or Type B) is present.

Arteriovenous Malformations

Brain AVMs are the leading cause of intracerebral hemorrhage in the young population. They are responsible for 3% of strokes in young adults and 9% of SAHs.⁸ The prevalence of these lesions is 1 per 1000 adults,¹⁴⁴ and their incidence is 1 per 100,000 per year.⁷ The most common manifestation of an AVM is an intracranial hemorrhage, accounting for as many as 50% of initial presentations.¹⁴⁵ AVMs may also cause headaches, seizures, or focal neurological deficits. More recently, however, more AVMs are being incidentally discovered with noninvasive imaging techniques. At present there is a paucity of high-quality evidence in the literature. Consequently, the optimal management of these lesions is not clear, and neurosurgeons are left to make difficult clinical decisions with respect to the management of incidental brain AVMs.

Natural History

The most dreaded complication of an AVM is an intracerebral hemorrhage. The annual rate of hemorrhage varies widely and depends on the number of risk factors. In most series, a previous hemorrhage, a central location, a deep venous drainage, and the presence of intranidal aneurysms greatly increase the risk of future hemorrhage.^{30,38,132,134} In unruptured lesions not deeply located and without deep venous drainage, the annual risk of bleeding is as low as 0.9%, according to the Columbia AVM database.¹³² Conversely, in AVMs with all the previously mentioned risk factors, the annual rate of hemorrhage can reach 34.4%. The strongest risk factor for subsequent AVM bleeding is an intracranial hemorrhage at initial presentation.¹³² A small AVM size was also associated with hemorrhage in 3 series,^{35,46,132} but several other studies failed to demonstrate this association.^{30,48} Furthermore, Stefani et al.¹³⁴ reported that large and deep-seated AVMs were more prone to hemorrhage during prospective follow-up of 390 patients with brain AVMs at the University of Toronto (Toronto Brain Vascular Malfor-

Fig. 1. Management of incidental aneurysms.

mation Study Group). Studies have also shown that the presence of venous stenosis on angiography increases the rate of intracranial hemorrhage.^{85,104} It is estimated that for unruptured AVMs, regardless of the other risk factors, the average annual rate of bleeding ranges from 2% to 4%.^{13,107} Kondziolka et al.⁷³ proposed the following formula taking into account the patient's age to estimate the lifetime risk of hemorrhage for an AVM:

$$\text{risk of hemorrhage} = 1 - (\text{risk of no hemorrhage})^{\text{expected years of remaining life.}}$$

Based on a 3% annual risk of hemorrhage, Brown²⁸ proposed a simple and reasonable approximation of the above formula:

$$\text{lifetime risk of hemorrhage} = 105 - \text{patient's age in years.}$$

It is also estimated that the average annual case fatality rate is around 1% for AVMs.¹³² A hemorrhage from the AVM remains a deadly and extremely morbid event; the mortality rate is around 10%–15% and the morbidity rate can be as high as 53–81%.⁴¹ Such morbidity and mortality rates could prompt neurosurgeons to offer treatment to all incidentally discovered AVMs. However, the low rate of hemorrhage of unruptured AVMs and the mild clinical syndrome from such rupture reported in the Columbia database raise doubt about the benefit of interventional therapy for AVMs that have not been associated with any hemorrhage.¹³³ The results of the Columbia database provided impetus for ARUBA (A Randomized Trial of Unruptured Brain AVMs).¹³¹ This ongoing project is a prospective, multicenter, randomized, controlled trial

that enrolls 800 patients with unruptured brain AVMs and aims to determine whether medical management improves long-term outcomes of patients with unruptured AVMs compared with interventional therapy.

At present, there are limited data in the literature about the natural history of AVMs. Additional information may become available from studies such as ARUBA.

Management of Incidentally Discovered AVMs

The management of incidentally discovered AVMs aims to prevent an intracranial hemorrhage. Arteriovenous malformations are classically treated by open surgery, radiosurgery, endovascular techniques, or a combination of the three. It is not clear, however, if an intervention improves the outcome of incidentally discovered AVMs. A recent study by Wedderburn et al.¹⁴⁵ in Scotland compared the 3-year outcome for adults who received interventional treatment for their unruptured AVMs (63 patients) with those who did not (51 patients). They found no difference in the functional outcome between the 2 groups. Moreover, interventional treatment was found to be an independent predictor of progression to poor outcome, as was AVM size. The results of this study should be interpreted with much caution for 2 main reasons. First, the 2 groups were not comparable at baseline, which means that confounding factors were not neutralized and have probably biased the study. Second, the follow-up was limited to only 3 years, which greatly underestimates any long-term benefits from interventional treatment and partly explains why the 2

Incidental vascular abnormalities

groups had comparable outcomes. Another study by Lawton et al.⁷⁹ compared the benefits from resection in 224 patients with ruptured or unruptured AVMs. The condition of patients with ruptured AVMs improved after surgery, whereas patients with unruptured AVMs were susceptible to slight worsening of their neurological status. However, again the mean follow-up period was just 1.3 years, so no meaningful conclusions can be drawn from this study regarding the benefit of treatment. A recent analysis of the Columbia database showed that the initiation of any invasive treatment strategy was associated with a 3-fold increased risk of AVM hemorrhage and an increased risk of clinical impairment, raising questions about the benefit of treating unruptured AVMs.¹³³ Conversely, in a study involving 623 patients harboring AVMs, with a median follow-up of 11.9 years, Laakso et al.⁷⁵ found that active treatment of these lesions improved outcome and that even partial treatment enhances survival, but this benefit is not apparent until 6 years after the intervention. This may explain why the previously cited studies reported no benefit from treatment of unruptured AVMs. We hope that ARUBA, discussed above, will help solve the dilemma, although we are concerned that the planned follow-up period may be too short.

With the recent advances in endovascular techniques, embolization has become a safe and effective primary treatment modality for AVMs. In a series of 387 patients with a brain AVM, Valavanis and Yaşargil¹⁴² achieved a 40% angiographic cure with morbidity and mortality rates as low as 1%. Endovascular embolization can completely cure an AVM, especially small lesions with limited arterial feeders, which were reported to have a cure rate close to 85% according to a recent series.¹² It can also be used before surgery to decrease the size of the nidus and occlude surgically inaccessible feeders, reducing the amount of blood loss and shortening operative time.^{29,87} In addition, embolization decreases the target size of the AVM; this reduction in target size has been associated with less morbidity and higher cure rates following radiosurgery,⁴⁵ although it remains the subject of controversy. Finally, embolization can be palliative for patients with large nonresectable AVMs, intractable seizures, or progressive neurological deficits.^{42,82} A variety of embolic materials are currently used for the treatment of AVMs. N-butyl cyanoacrylate (NBCA) and Onyx (ev3, Inc.) are nonabsorbable embolic agents that can achieve complete obliteration of an AVM. Due to its nonadhesive nature, Onyx allows longer, slower, and more controlled injections with subsequent embolization of a larger percentage of the AVM from a single catheter position. In a very recent article, Saatci et al.¹²¹ reported achieving complete obliteration in more than 50% of brain AVMs using prolonged intranidal Onyx injection. The authors concluded that this technique leads to higher rates of anatomical cures than previously reported with other embolic agents. In addition, the more effective intranidal penetration of the embolic agent with this technique allows high-grade AVMs to be made radiosurgically treatable.

In radiosurgical treatment of AVMs, the goal is obliteration of the vessels in the nidus. It is known to provide high cure rates and low morbidity rates, especially in small lesions.^{88,136} It is also useful in treating small deeply

located AVMs that are otherwise challenging to surgical treatment or embolization.^{11,89} Maruyama et al.⁸⁹ reported a 66% obliteration rate for brainstem AVMs after radiosurgery (at 3-year follow-up). However, as the size of the AVM increases, the cure rate decreases and the complication rate increases.^{33,47,105} Another major disadvantage of radiosurgery is the risk of hemorrhage until the AVM is totally obliterated.^{103,111} In a retrospective study of 500 patients with AVMs who were treated with Gamma Knife surgery, Maruyama et al.⁸⁸ reported that 23 patients had a hemorrhage during the first 2 years following radiosurgery, and 6 patients had a hemorrhage even after angiographic obliteration. The risk of hemorrhage declined by 54% after 2 years and by 88% after obliteration of the lesion. In a recently published article, Blamek and colleagues²⁶ reported that annual hemorrhage rates after radiosurgery were 3.4% and 1.1% during the 1st and 2nd year of follow-up, respectively. The authors also concluded that a 3-year follow-up period is required to accurately assess the outcome after radiosurgery for brain AVMs.

Surgical excision of AVMs has long been considered the mainstay of treatment, with the advantage of completely removing the lesions. However, potential morbidity and mortality rates associated with the procedure warrant careful patient selection especially for incidentally discovered AVMs. The Spetzler-Martin classification takes into account the AVM size, eloquence of the adjacent brain, and the pattern of venous drainage of the AVM to estimate the surgical risk.¹²⁹ The initial classification (1986) included 5 categories¹²⁹ (Table 1). In a prospective evaluation of the classification system, morbidity rates for Grades I, II, and III were 0%, increasing to 21.9% in patients with Grade IV and 16.7% in patients with Grade V AVMs.⁵⁰ Similarly, Heros and Tu⁵³ reported good surgical results in 100%, 94.3%, 88.6%, 61%, and 28.6% of patients with Grade I, II, III, IV, and V AVMs, respectively. It is therefore clear that Grades I and II and even Grade III lesions (low-grade AVMs) can totally be excised with a low rate of observed morbidity. Conversely, Grade IV and V AVMs (high-grade AVMs) are associated with a high rate of complications, and surgery should therefore be avoided in patients with these lesions. A few studies have assessed the risk of hemorrhage of AVMs based on the Spetzler-Martin grade with conflicting results. A high annual risk of bleeding for high-grade AVMs (10.4%) was

TABLE 1: The Spetzler-Martin classification for AVMs

Lesion Characteristics	Points
size	
small (<3 cm)	1
medium (3–6 cm)	2
large (>6 cm)	3
eloquence of the adjacent brain	
noneloquent	0
eloquent	1
pattern of venous drainage	
superficial only	0
deep	1

reported in a study by Jayaraman and coworkers.⁶² Elsewhere, the risk was found to be even lower (1.5%) than that for all AVMs on average (3%).⁵¹ In a recently published article, Spetzler and Ponce¹³⁰ proposed a new classification for AVMs (2011) that consists of 3 classes: Spetzler-Martin Grades I and II AVMs were combined into Class A and Grades IV and V lesions into Class C; Grade III AVMs became Class B (Table 2). This was justified by the finding that surgical outcomes in 1476 cases from 7 surgical series were similar for Grades I and II AVMs (Class A) and for Grades IV and V AVMs (Class C).¹³⁰ The new classification system also offers a paradigm for management of AVMs; surgical excision is recommended for Class A, multimodality therapy for Class B, and observation for Class C. Treatment of Class C AVMs is only recommended in the presence of recurrent hemorrhages, progressive neurological deficits, steal-related symptoms, and AVM-related aneurysms.¹³⁰

In our institution, we perform endovascular embolization for some Grade IV AVMs even in the absence of the previously cited factors, especially in cases involving young patients. Embolization can safely decrease the size and the grade of the lesion, allowing for surgical excision or radiosurgery.^{84,121,148,149} Blackburn et al.²⁵ recently evaluated endovascular therapy followed by radiosurgery in 21 patients with high-grade AVMs (12 lesions were Spetzler-Martin Grade IV or V). Interestingly, they found an obliteration rate close to 80% and a major neurological complications rate as low as 0%. In the previously discussed study by Saatci et al.,¹²¹ which involved 350 patients with brain AVMs, including high-grade lesions, the authors reported complete obliteration by endovascular means in 50% of the population, with 38% and 6% of the patients referred to radiosurgery and surgical excision, respectively. It is also well known that the Spetzler-Martin classification is not applicable for embolization procedures because deep venous drainage is not associated with increased risk of complications for this treatment modality. Furthermore the classification system does not take into account important factors for embolization like the number of vessels feeding into the AVM and the presence of fistulous components.⁴⁰

Based on the current evidence in the literature and our experience, we suggest the following algorithm (Table 3).

We recommend surgical excision for Spetzler-Martin Grade I and II AVMs. Grade III AVMs should be treated with a combination of surgery, endovascular techniques, and radiosurgery. Grade IV AVMs should be strongly considered for endovascular therapy followed whenever

TABLE 2: The 3-tier classification of cerebral AVMs

Spetzler-Martin Class	Grade	Management
A	I & II	resection
B	III	multimodality treatment
C	IV & V	no treatment*

* Exceptions for treatment of Class C AVMs include cases characterized by recurrent hemorrhages, progressive neurological deficits, and steal-related symptoms, as well as AVM-related aneurysms.

TABLE 3: Management of incidental AVMs

Spetzler-Martin Grade	Management
I & II	surgery
III	multimodality treatment
IV	endovascular treatment followed by surgery/radiosurgery, or observation
V	observation or endovascular treatment followed by radiosurgery (especially for young patients)

possible by surgery or radiosurgery. Observation is also an option in the latter group. Finally, we recommend observation in cases of Grade V AVMs because of the high morbidity rate associated with treatment. In some cases, especially those involving young patients, Grade V AVMs can be considered for endovascular therapy followed by radiosurgery.

Cavernous Angiomas

Cavernous angiomas, more commonly known as cavernomas, are low-flow vascular abnormalities of the brain composed of clusters of dilated, thin-walled capillaries filled with thrombus.⁴⁴ These lesions account for 15% of all vascular malformations^{18,86} and have an estimated prevalence approaching 0.6% in the general population.^{18,37,120} Up to 50% of CAs are familial⁷⁷ and follow an autosomal dominant pattern of inheritance linked to the *CCM1*, *CCM2*, and *CCM3* genes on 7q, 7p, and 3q, respectively.^{22,61,77} Patients with familial CAs typically harbor multiple lesions, unlike those with a sporadic form who usually present with a single lesion.^{77,152} Cavernous angiomas are typically located supratentorially; brainstem lesions account only for 8%–22% of all cases.

Patients with CAs usually present in the 4th or 5th decade of life, although in 25% of cases, patients present in childhood.⁹⁸ Depending on their location, the lesions can manifest with seizures, headaches, progressive neurological deficits, or intracranial hemorrhage. The most common presentation in patients with supratentorial CA is a new-onset seizure (40%–70% of cases).^{4,71,151} Seizures are due to recurrent microhemorrhages and hemosiderin deposition in the perilesional area.¹⁵² Headaches are also a common presentation and occur in 30%–50% of cases.^{74,151,152} Infratentorial CAs are rarely clinically silent and typically produce progressive neurological deficits.^{52,143} Intracranial hemorrhages are seen in both supratentorial and infratentorial lesions and are typically mild in severity, but severe and fatal hemorrhages do occur. With the increased use of MR imaging for brain imaging, it is now estimated that almost 40% of CAs that are identified represent incidental findings.¹⁸

Cavernous angiomas are known as angiographically occult vascular malformations because they do not appear on angiography, which therefore has little value in the diagnosis or management of these lesions except for detecting the presence of an associated atypical venous drainage.²⁴ Magnetic resonance imaging is the most sensitive and specific imaging modality for the diagnosis and

Incidental vascular abnormalities

follow-up of CAs.^{57,116} Typically, the lesions appear as areas of mixed signal intensity on T1- and T2-weighted images and are surrounded by a peripheral area of hypointensity (representing a hemosiderin ring) on T2-weighted images.¹¹⁹ According to recent reports, the highly sensitive T2-weighted gradient-echo imaging has become the gold standard MR imaging sequence for visualization of CAs.^{31,81}

Natural History and Management of Incidentally Discovered CAs

The annual rate of symptomatic hemorrhage from a CA ranges from 0.7% to 6% according to multiple studies and varies with a number of factors.^{76,113,120,152} The risk of significant bleeding is higher in patients with a prior history of hemorrhage.^{6,72} In a study involving 122 patients with CAs, Kondziolka et al.⁷² reported an annual hemorrhage rate of 0.6% in patients with no hemorrhagic presentation versus 4.5% for patients with hemorrhagic presentation. It is worth noting that the risk of rebleeding is particularly high in the 2 years following the initial hemorrhage but seems to significantly decrease thereafter. This phenomenon is known as “temporal clustering” and has been reported in several series.^{16,143} Deeply located CAs, especially those in the brainstem, have been found to carry a worse prognosis than superficial lesions.¹¹² Porter et al.¹¹² reported that the risk of bleeding for infratentorial CAs is 3.8% compared with 0.4% for supratentorial CAs. Female sex also appears to negatively impact the outcome for patients with CAs.^{6,113} Seizures and a familial form have been proposed as potential risk factors for hemorrhage, but there is not enough evidence in the literature to support this hypothesis.

The treatment of symptomatic CAs is image-guided resection. If a DVA is associated, it is recommended not to excise the DVA, as doing so would pose an unnecessary risk of venous infarction.³ Surgery is classically performed in patients with repetitive episodes of hemorrhage, intractable seizures, and progressive neurological deficits, especially when the CA is located in noneloquent areas of the brain.^{24,36,115} Conversely, in deep and eloquent areas, the risk of complications is substantial and the threshold for surgery is even higher.^{10,23,135} There is a recent tendency in some institutions to extend surgical indications to mildly symptomatic CAs, even in the brainstem. In a recent study involving 300 patients with surgically treated brainstem cavernomas, Ablat et al.² reported that surgery markedly improved the risk of rehemorrhage and related symptoms. They concluded that surgery should be considered in patients with accessible lesions. However, new or worsening neurological symptoms developed in 53% of patients after the procedure, 36% had permanent new deficits, and perioperative complications developed in 28%.² Due to the significant potential morbidity associated with resection of CAs in eloquent areas like the brainstem, we have adopted a more conservative approach. More evidence is needed to ascertain whether patients with mildly symptomatic but accessible brainstem CAs actually benefit from surgery.

Finally, the role of radiosurgery in the treatment of CAs is still controversial despite encouraging reports. In

a recent study involving 68 patients with brainstem CAs treated with Gamma Knife surgery, Monaco et al.⁹⁵ found that radiosurgery decreased the annual hemorrhage rate from 32% before treatment to 1.3% after 2 years of follow-up. However 11.8% of patients experienced new neurological deficits as a result of adverse radiation effects. Lunsford et al.⁸³ were also able to demonstrate that radiosurgery reduced the risk of bleeding from 32% to just 1% after 2 years of follow-up. The rate of morbidity was 13.5% in this series. There are concerns about the high risk of complications associated with radiosurgery for CAs, particularly in the brainstem and deep locations.^{9,69,95} It is also known, as discussed above, that the risk of bleeding of a CA significantly decreases by itself beyond 2 years after the initial hemorrhage. Consequently, the positive results associated with radiosurgery in the previously cited studies could simply reflect the natural history of these lesions. The utility of radiosurgery in the treatment of CAs remains unproven and continues to be a subject of debate.

Purely incidental CAs should be managed conservatively and followed with yearly MR imaging. We recommend treating cavernous angiomas only in the following situations: intractable seizures, progressive significant neurological deficit, after the first clinically significant hemorrhage in noneloquent areas, and after the second clinically significant hemorrhage in eloquent areas including the brainstem.

Developmental Venous Anomalies

Developmental venous anomalies, formerly known as venous angiomas, are enlarged venous vessels that drain into a large-caliber vein with a characteristic appearance of caput medusae on angiography. They are congenital malformations of the brain that are viewed as a normal variant of the cerebral venous system. Their prevalence is 2.5% according to autopsy studies.^{43,125} Developmental venous anomalies are the most commonly diagnosed intracranial vascular malformation and are typically discovered incidentally on brain MR imaging studies or CT scans.¹³⁹ They are associated with a CA in 13%–18% of cases,^{124,139} and it is thought that there is a causative link between these 2 lesions. It has been postulated that the recurrent microhemorrhages from a DVA induce angiogenesis in the surrounding brain, leading to CA formation.¹¹⁰

Developmental venous anomalies have a benign natural history with an extremely low morbidity rate and a mortality rate of 0%.^{91,100} The annual risk of hemorrhage is negligible (0.25%–0.34%),^{37,91} and it is thought that a hemorrhage in the setting of a DVA is due to an associated CA.¹¹⁷ Nevertheless, DVA thrombosis can lead to a venous infarct with a secondary hemorrhagic transformation, although this remains a rare event.⁹⁰ No relationship has been established to date between DVAs and headaches or seizures.^{96,137}

A DVA is primarily visualized on MR images as a signal-void linear structure especially on T2-weighted sequences.¹⁴⁰ Magnetic resonance imaging also offers the possibility of detecting an associated cavernoma. Contrast-enhanced MR imaging is the sequence of choice and shows the classic caput medusae appearance.¹⁴⁰ Similar

findings are seen on contrast-enhanced CT. Angiography is performed only in patients with an ischemic or hemorrhagic presentation and in those in whom an AVM should be ruled out.

Surgical obliteration of a DVA can lead to venous thrombosis, venous congestion, and infarct with a secondary hemorrhagic conversion.^{1,128} This is due to the fact that a DVA drains normal brain tissue. Developmental venous anomalies should always be left untreated, even when associated with a CA.¹ Given their benign natural history, DVAs do not require follow-up imaging studies.

Capillary Telangiectasias

Capillary telangiectasias are dilated thin-walled capillaries surrounded by normal brain parenchyma and associated with other vascular abnormalities.¹⁵ They are relatively common and account for 4%–12% of all vascular malformations.¹²⁷ Capillary telangiectasias are incidental findings on imaging studies and are frequently misdiagnosed as glial tumors. Patients typically remain typically asymptomatic throughout life, although the lesions may occasionally cause seizures, vertigo, cranial nerve dysfunction, visual changes, and dizziness.^{80,138} In a recent study, Sayama et al.¹²⁷ reported that 28.6% of large capillary telangiectasias (> 1 cm) were symptomatic, whereas none of the small ones were.

Capillary telangiectasias are visualized as small enhancing lesions on contrast-enhanced MR imaging sequences and demonstrate a signal intensity loss on gradient-echo sequences.³² They are angiographically occult and are not usually seen on CT scan.

Capillary telangiectasias are benign lesions that do not require any treatment or follow-up.

Conclusions

Incidentally discovered intracranial vascular abnormalities are increasingly coming to the attention of neurosurgeons with the ubiquitous availability of high-quality, noninvasive imaging studies. Lesions such as intracranial aneurysms, AVMs, CAs, DVAs, and capillary telangiectasias may be incidentally discovered on brain imaging studies. Each pathological entity is associated with its own unique natural history, and management must be tailored to the type of lesion and individual circumstances of a given patient. In the present article we have attempted to provide an evidence-based resource to guide neurosurgeons in the management of these incidentally discovered intracranial vascular abnormalities. The quality and quantity of evidence, however, remains limited, and further studies are needed to elucidate the most appropriate management strategy in many situations.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Jabbour, Chalouhi. Acquisition of data: Chalouhi. Drafting the article: Jabbour. Critically

revising the article: Jabbour, Chalouhi, Dumont, Randazzo, Tjoumakaris, Gonzalez. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Jabbour. Administrative/technical/material support: Chalouhi. Study supervision: Jabbour.

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