

F.I. Wanke MD<sup>1</sup>  
M. Forsting MD<sup>2</sup>

## Imaging of Intracranial Hemorrhage: A Review Article

This review gives an overview about pathophysiology, pathology and imaging findings in patients with intracranial hemorrhage and illustrates typical and common findings.

### General Remarks

**I**ntracranial hemorrhage (ICH) is a frequent indication for emergent neuroimaging. To understand the appearance of clots on CT and MR it is mandatory to know some details of clot formation.

Initially, an intracerebral hematoma is composed of 95% to 98% oxygen-saturated hemoglobin, mainly containing erythrocytes. Over the first 4-6 hours the protein clot retracts, still containing intact biconcave red blood cells with oxygenated hemoglobin. During the next 48 hours the RBC shrinks and hemoglobin desaturation occurs. During this period the hematoma contains predominantly deoxygenated intracellular (remember: the RBCs are still intact!) hemoglobin. In the early subacute phase (a few days after the initial hemorrhage) oxidative denaturation of the hemoglobin progresses and deoxyhemoglobin is gradually converted to methemoglobin (MetHb). These changes first occur around the periphery of the hematoma and then progress centrally. RBCs continuously lyse and release MetHb into the extracellular space. After that the hematoma starts to shrink and finally there is a slitlike cavity, containing CSF-like fluid and – as a long-standing marker for the bleeding – ferritin- and hemosiderin- laden macrophages.

### CT Imaging

Fresh intracerebral blood typically appears hyperdense on CT due to the high protein concentration and its high mass density. However, occasionally acute intracerebral hematoma can appear isodense or even hypodense on CT. This occurs with extreme anemia, i.e., when the hemoglobin concentration drops to 8 g/dl. Another reason for primary isodense clots on CT can be a coagulation disorder. Failure of clot retraction results in a relatively isodense acute ICH.

Within 1 to 6 weeks hemorrhage becomes virtually isodense with adjacent brain and due to the breakdown of the blood-brain barrier it can mimic an abscess on contrast enhanced studies.

### MR Imaging

MR imaging of intracerebral hemorrhage is complex and requires a lot of knowledge about the pathophysiology of blood degradation. The signal is mainly influenced by the hemoglobin oxidation state and the protein concentration.

1. Associate Professor of Radiology and Neuroradiology, Institute of Diagnostic and Interventional Radiology and Neuroradiology, University of Essen, Germany.

2. Professor of Radiology and Neuroradiology, Institute of Diagnostic and Interventional Radiology and Neuroradiology, University of Essen, Germany.

Corresponding Author:

Michael Forsting  
Address: Institute of Diagnostic and Interventional Radiology and Neuroradiology, University of Essen, Hufeland Strasse 55, D 45147 Essen, Germany.  
E-mail: michael.forsting@uni-due.de

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Extrinsic factors are the pulse sequences and the field strength of the MR system. As a rule of thumb: Deoxy-Hb appears isointense with brain on T1-weighted images and hypointense on T2-weighted images. Extracellular methemoglobin (subacute clots) appears bright on T1- and T2- weighted images. Hemosiderin (chronic state) is dark on T2 and T1. However, this is only a rough summary.

## Hemorrhagic Diseases

### Hypertensive Intracranial Hemorrhage

Hypertensive hemorrhage is the most common cause of intracranial hemorrhage and has a predilection for areas supplied by penetrating branches of the middle cerebral and basilar arteries. Two thirds of these bleedings are located in the basal ganglia, in 50% of them associated with intraventricular hemorrhage. Other relatively common sites of hypertensive ICH are the cerebellum and the pons. Additionally to the location of the bleeding, findings of lacunar stroke or white matter disease may further enhance the suspicion of a hypertensive cause.

Patients usually get a CT scan first. If the hypertensive character of the hematoma was in doubt, MR may be a second step. Finally, the majority of these patients, specifically if they are below 70 years old and do have a bleeding in a so-called atypical location need angiography (Figures 1a,b).

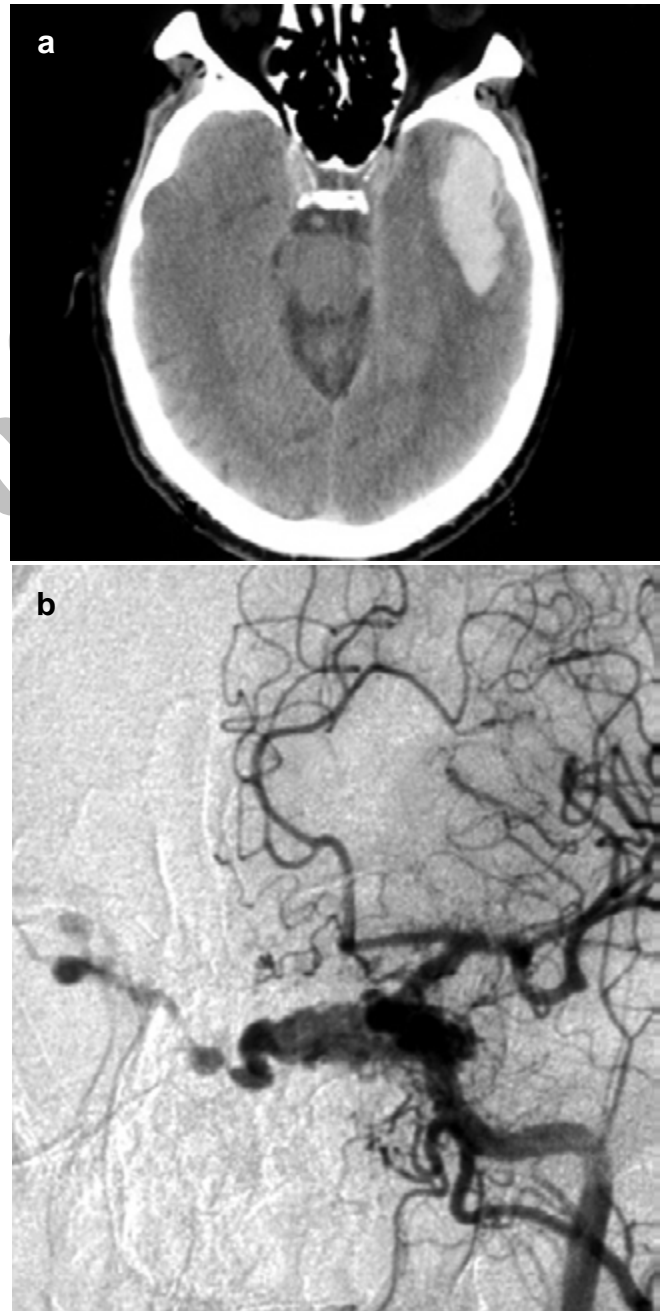
### Vascular Malformations and Aneurysms

If the hemorrhage is not hypertensive – no specific history of the patient and atypical location of the hematoma – a vascular malformation or an intracranial aneurysm is the most likely cause of the ICH<sup>1</sup> The purpose of this summary is not to fully cover the large field of these diseases, but to give a short overview about pathology, clinical presentation, imaging findings and treatment options.

### Intracranial Aneurysms

Usually, intracranial aneurysms are divided into three basic types: saccular, fusiform and dissecting. They can arise as solitary (70-75%) or multiple (25-30%) vascular lesions, usually located at the circle of Willis. The vast majority of aneurysms (85%) are lo-

cated in the anterior and only 15% are located in the posterior circulation. The majority of saccular aneurysms are not considered to be congenital and develop during life. The most common location (30% to 35%) is the anterior communicating artery (AcomA). Many of AcomA aneurysms do have their origin at the A1 / A2 junction of the anterior cerebral artery and do not involve the anterior communicating artery. Internal carotid and posterior communicating



**Fig 1. a,b;** CT with atypical left temporal lobe hemorrhage (a) DSA (b) reveals an arteriovenous dural fistula as the cause of the hematoma.

artery aneurysms account for 30% and middle cerebral artery (MCA) bifurcational aneurysms for 20%. Around 10% - 15% of intracranial aneurysms arise at the vertebrobasilar circulation. Half of them develop at the basilar tip (with various involvement of the P1 segments) and the other 50% from other posterior fossa vessels. Extremely rare are aneurysms of the anterior inferior cerebellar artery (AICA) and vertebral artery aneurysms without involvement of the VA-PICA junction or the vertebrobasilar junction.

Most intracranial aneurysms remain undetected until the time of rupture. SAH, a medical emergency, is by far the most common initial clinical presentation. A history of abrupt onset of a severe headache of atypical quality ("the worst headache in my life") is typical of SAH. Headache onset may or may not be associated with brief loss of consciousness, nausea and vomiting, focal neurologic deficits, or meningism. Despite the characteristic history, SAH is frequently misdiagnosed. Nearly half of the patients present with milder symptoms caused by a warning leak before full rupture of the aneurysm.

Although the pathogenesis and etiology of cerebral aneurysms has been studied extensively, both are still poorly understood. Endogenous factors like elevated blood pressure, the special anatomy of the circle of Willis or the effect of hemodynamic factors, particularly originating at vessel bifurcations, are all known to be involved in the growth and rupture of an aneurysm. Arteriosclerosis and inflammatory reactions, however, might also have an impact. Exogenous factors like cigarette smoking, heavy alcohol consumption or certain medications are thought to be risk factors in the pathogenesis of an aneurysm or at least to increase the risk of rupture.

Furthermore, a genetic component is discussed. First degree relatives of patients with an aneurysmal SAH have a significant higher risk to harbour a cerebral aneurysm compared with the normal population.

The incidence of SAH in the western world is around 6-10 per 100 000 person per year, peaking in the sixth decade with risk for SAH increasing linearly with age. The incidence in some other countries like Finland or Japan is known to be higher – about 15 / 100000 / year. SAH accounts for a quarter of cerebrovascular deaths. Aneurysms increase in frequency with age beyond the third decade, are approximately

1.6 times more common in women and are associated with a number of genetic conditions.

Hydrocephalus, rebleeding from aneurysmal rerupture and cerebral vasospasm with ischemia are the three major complications following SAH. Intracerebral hematoma occurs in up to 30% of patients with aneurysmal rupture. The outcome is clearly worse than with SAH alone. If a space-occupying hematoma compressing neural structures is present, immediate evacuation of the hematoma is mandatory, eventually in combination with clipping of the aneurysm, if it can be identified. In this setting, CT angiography might serve as a valuable and fast imaging modality to disclose the aneurysm prior to surgical intervention. Immediate surgical evacuation is also indicated in acute subdural hematoma, which is usually associated with recurrent aneurysmal rupture. However, this can also occur with the initial SAH or can be the only extra vascular space involved after aneurysmal rupture.

Vasospasm is a major cause of morbidity and mortality in patients after SAH and is often associated with delayed cerebral ischemia. However, many patients are asymptomatic despite various degrees of angiographically visible vasospasm. Although vasospasm is noted angiographically in 70% after SAH, it becomes symptomatic only in about half of those patients.

If SAH is suspected clinically, CT of the brain is the initial diagnostic imaging modality of choice and clearly the gold standard to identify, localize and quantify subarachnoid hemorrhage. Typically, the subarachnoid blood appears hyperdense on an unenhanced CT. The pattern of SAH can suggest the location of the underlying aneurysm. Intraparenchymal hemorrhage occurs with aneurysms of the posterior communicating artery and middle cerebral artery more frequently than with other locations. Inter-hemispheric or intraventricular hemorrhage, occurring in autopsy studies in about 50% of patients, is characteristic of anterior communicating artery or distal anterior cerebral artery aneurysms. Ruptured PICA aneurysms almost always coexist with hydrocephalus and intraventricular hemorrhage in the fourth ventricle, which can be also seen on CT. Intracerebral hemorrhage is also more common in patients who rebleed, since the first bleeding may lead

**Table 1.** Fisher's grading scale for SAH

Group	Subarachnoid blood	Risk of vasospasm
1	No blood	Low
2	Diffuse or vertical layers < 1mm	Only moderate
3	Localized clot and / or vertical layer > 1mm	High
4	Intracerebral or intraventricular clot with only diffuse or no SAH	

to fibrosis of the surrounding subarachnoid space and adhesion of the aneurysm to the brain. Subdural hematoma occurs in about 5% of patients, but is rarely the only location of bleeding.

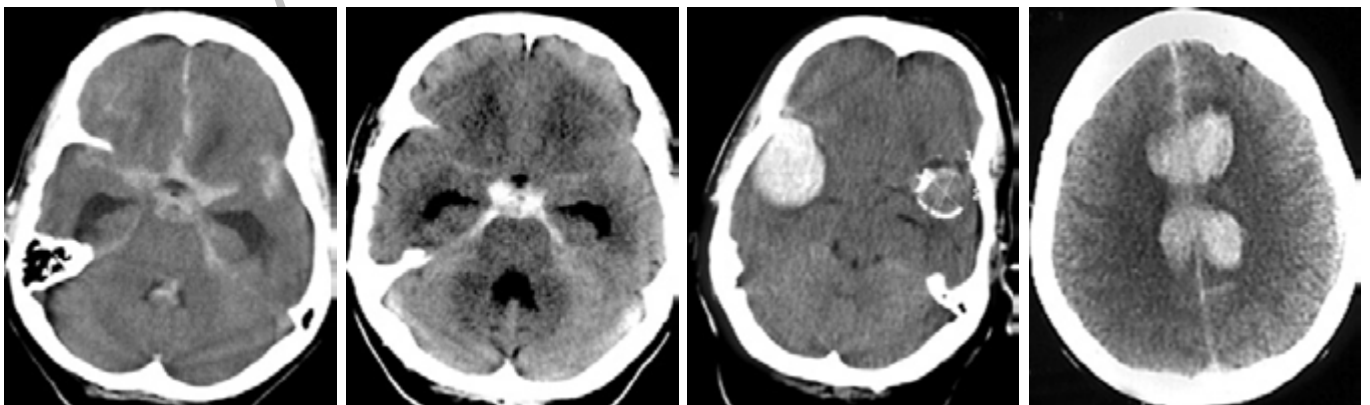
Small amounts of SAH may be overlooked, CT thus should be carefully read. However, even if the CT scan is really normal (no reading fault!), aneurysmal SAH cannot be ruled out. The sensitivity of CT for detecting SAH depends on the volume of the extravasated blood, the hematocrit, and the time elapsed after the acute event. Using modern CT scanners and performed within 24 hours after the ictus CT detects SAH in up to 95%. However, due to dilution by CSF the density of the hematoma decreases rapidly over time, thus after only a few days it may be impossible to demonstrate subarachnoid blood on CT. Sensitivity of CT thus decreases to 80% at day 3, 70% at day 5, 50% at one week, and 30% at 2 weeks (Figures 2a-d).

Identification of factors predictive of outcome or specific complications is important in the management of SAH. The risk of a given patients to suffer from vasospasm can be estimated by the location, thickness, and density of subarachnoid blood on CT. In 1980 Fisher and colleagues have provided a description of 47 patients in whom the amount and dis-

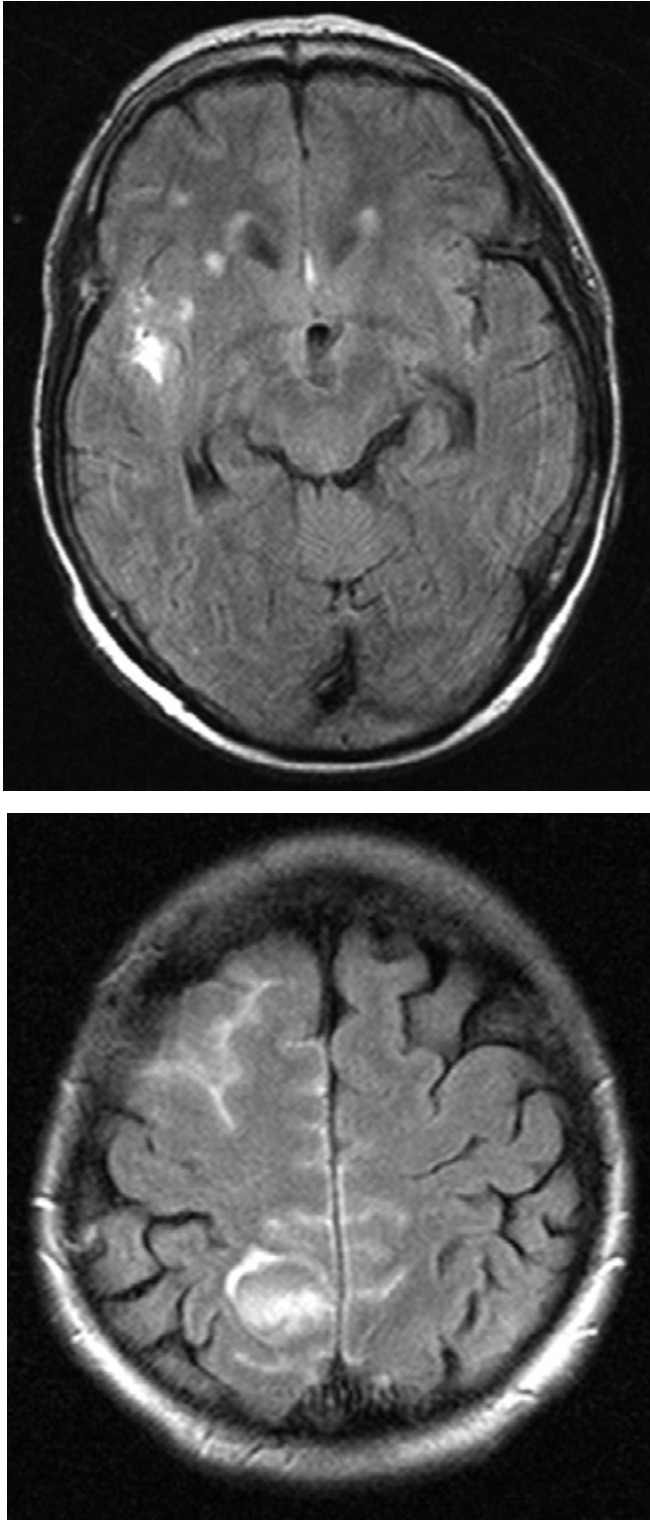
tribution of subarachnoid blood after aneurysmal rupture on the initial CT was correlated with the subsequent occurrence of vasospasm demonstrated by angiography.<sup>2</sup> Two of 18 patients (11%) developed vasospasm when no or diffuse thin SAH was present on CT, whereas none did with only intraventricular or intracerebral hemorrhage. Of 24 patients with diffuse, thick SAH, 23 (96%) developed severe symptomatic vasospasm. Since then, the CT-based Fisher classification of quantifying local amounts of subarachnoid blood as a powerful predictor for the occurrence of vasospasms and delayed cerebral ischemia has been confirmed by several clinical and experimental studies.

Sensitivity of single-slice CT angiography (CTA) in the investigation of intracranial aneurysms has been reported to range from 67 to 100%, with an accuracy of approximately 90% and an interobserver agreement ranging from 75 to 84%. Nevertheless, this technique has demonstrated a limited sensitivity for aneurysms smaller than 3 mm (25-64% compared with 92-100% for aneurysms > 3mm).<sup>3</sup> Moreover, CTA still has pitfalls if the aneurysm is located at a site where adjacent bone or considerable vessel overlap exist, such as the paraclinoid and terminal ICA segments or at the MCA bifurcation.

The implantation of multidetector row technology led to a major step forward in the field of CT angiography, notably for small vessels and for intracranial aneurysms. This technique offers a reduction in acquisition time despite the use of pitch values inferior to unity. The improvement of image quality and spatial resolution ends up in better diagnostic results for intracranial aneurysms. Multi-row CT technology will clearly make life easier at emergency depart-



**Fig 2. a-c;** Three different variants of SAH on CT; In each patient the blood is clearly visible. In c additionally reveals a large, partially calcified aneurysm in the left sylvian fissure. **d;** Typical callosal hemorrhage due to a ruptured aneurysm of the pericallosal artery.



**Fig 3.** a; reveals a subtle subarachnoid hemorrhage in the right sylvian fissure on a PD-weighted image. b; reveals a more parietal SAH, not typical for an aneurysmal rupture.

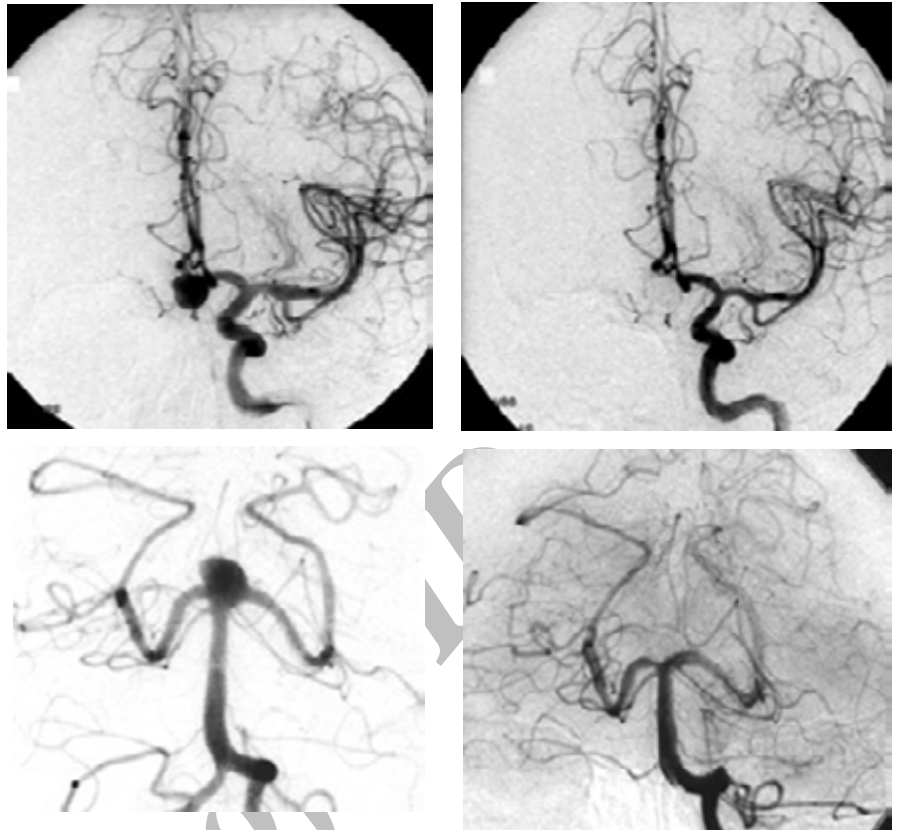
ments. Patients with a never-before-experienced headache and a negative unenhanced CT scan will get a quick and reliable CTA. To optimise treatment planning and work-flow CTA may also be used to

stratify patients into endovascular and surgical treatment groups. CTA clearly plays a role in the pretherapeutic phase in large or giant aneurysms. In these patients it is often difficult to visualize the exact anatomy of the neck and the relationship to adjacent bony structures, such as in the paraophthalmic region than with conventional DSA alone. Moreover, CTA is very helpful in the pretherapeutic planning of partially calcified and thrombosed aneurysms and might help to determine the best treatment modality. In patients with large, space-occupying hematomas CTA is clearly enough to rule out an underlying aneurysm. In this specific situation DSA is probably not indicated any more.

Magnetic resonance imaging and MR angiography are increasingly used in the diagnostic work-up of patients with cerebral aneurysms. However, MRI is less suitable than CT in patients with acute SAH because they are often restless and need extensive monitoring. It is used in patients with a negative angiogram to detect other causes of SAH, such as a thrombosed aneurysm or spinal vascular malformation and it will increasingly be used in screening programs and as a follow-up tool after endovascular therapy.

Conventional MRI sequences are less sensitive to SAH than CT scanning. Since SAH is mostly arterial in origin, the predominant form of hemoglobin is Oxy-Hb. Immediately after the extravasation of blood into the subarachnoid space, there is a shortening in T1 due to the increase in hydration layer water owing to the higher protein content of CSF. This results in an increased signal on T1-weighted and proton-density images. Fluid-attenuation inversion recovery (FLAIR) sequences are highly sensitive. The signal from CSF is almost completely reduced while producing a heavy T2-weighting. On FLAIR images SAH appears hyperintense compared to CSF and the surrounding brain. Currently, it is widely accepted that even subtle amounts of subarachnoid blood can be detected by MR when using FLAIR or proton-density weighted MR sequences. False-positive FLAIR results may be caused by flow-related enhancement within the CSF is not considered. Even hyperacute SAH can be detected with MR. Compared with CSF the hyperacute blood has a slightly lower signal intensity on T2\*-weighted gradient-echo images and increased signal intensity on T2-weighted spin-echo images

**Fig 4. a,b;** Typical Acom A aneurysm before (a) and after (b) endovascular therapy. **c,d;** Basilar tip aneurysm before (c) and after (d) endovascular therapy with stent and coils.



(Figures 3a+b). Aneurysm size is a crucial factor for the sensitivity. MRA studies consistently indicate sensitivity rates of more than 95% for aneurysms larger than 6 mm, but much less for smaller aneurysms. For aneurysms smaller than 5 mm, which constitute as many as a third of aneurysms in asymptomatic patients detection rates of 56% and less have been reported. However, these aneurysms should not be ignored even if their rupture risk seems to be low. In our experience, in most patients MRA can detect aneurysms as small as 3 mm, the problem to detect lesions below this size is well known. This should be taken into account for all screening programs, but also for those follow-up examinations (after coiling), when the initial size of the aneurysm was around 3 mm.

Present indications for MR angiography in the evaluation of cerebral aneurysms include:

- Incidental findings on CT or MRI suspicious for an aneurysm
- Evaluation of specific clinical symptoms (i.e., third cranial nerve palsy) or non-specific symptoms in whom an aneurysm might explain the clinical presentation (thunderclap- headache).
- Non-invasive follow-up of patients with known

aneurysms or endovascular treated aneurysms

- Screening in “high risk” patients (first degree relatives of patients with SAH or multiple aneurysms, patients with polycystic kidney disease or with connective tissue disease)

Owing to its excellent spatial resolution conventional cerebral angiography is still the gold standard for the detection of a cerebral aneurysm. Currently, this is performed during the first available moment after presentation of the patient at the hospital. Considering that the risk of hemorrhage is highest in the first 24 hours (4%), an early angiogram is crucial for any therapeutic decision and for the patient’s outcome.

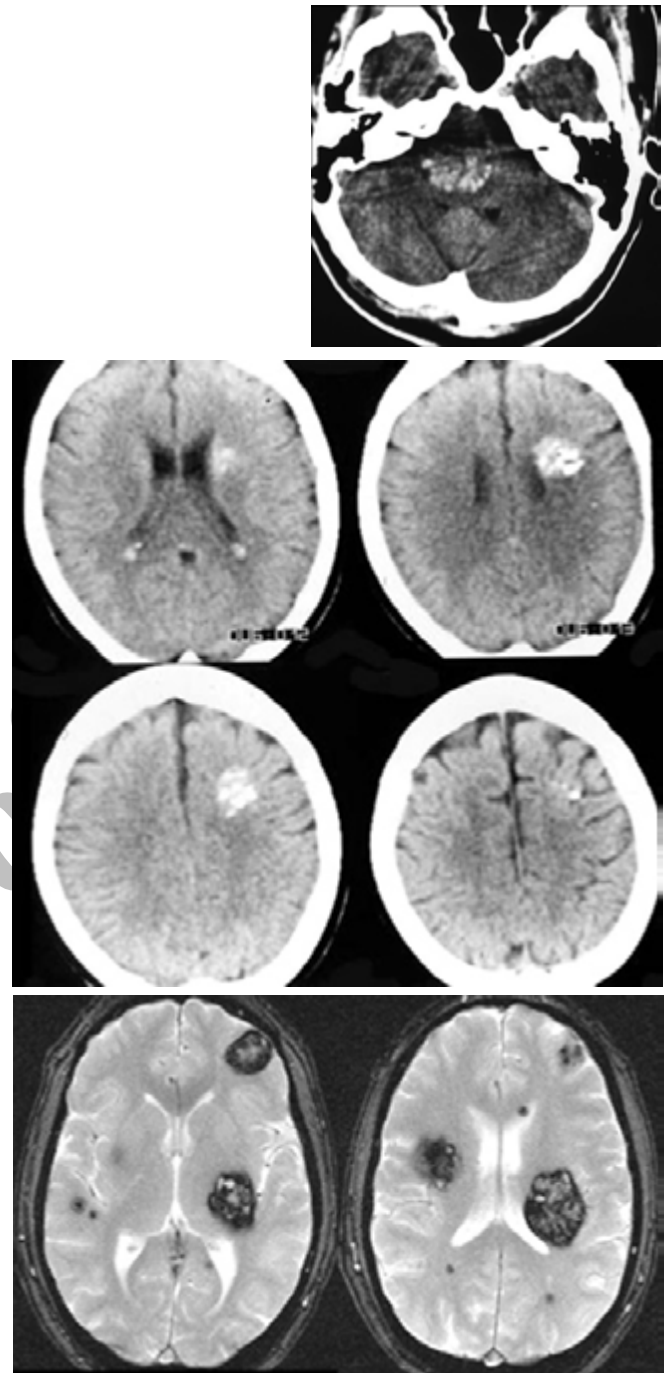
Cerebral angiography can localize the lesion, reveal the aneurysm shape and geometry, determine the presence of multiple aneurysms, define the vascular anatomy and collateral situation, and assess the presence and degree of vasospasm. Due to the frequency of multiple aneurysms a complete four-vessel angiography is essential. However, in case of a space occupying hematoma angiography of the most likely affected vessel is sufficient. Anteroposterior, lateral, and oblique views are systematically performed with cross-compression to demonstrate the anterior com-

municating artery, if necessary. Additional views may be necessary to optimize demonstration of the aneurysm neck. If no aneurysm is found, selective catheterisation of both external carotid arteries is performed to exclude a dural arteriovenous fistula. The potential for collateral circulation from the vertebrobasilar system may be evaluated when the vertebral artery is injected during carotid artery compression (Allcock test) demonstrating the patency, size and collateral potential of the P1 segment of the PCA and the posterior communicating artery ipsilateral to the carotid artery compressed.

The primary treatment goal of cerebral aneurysms is prevention of rupture. Surgical clipping has been the treatment modality of choice for both ruptured and unruptured cerebral aneurysms since decades. Twenty years ago endovascular treatment was mainly restricted to those patients with aneurysms unsuitable for clipping due to the size or location, or in whom surgical clipping was contraindicated because of the general medical condition. Since the introduction of controlled detachable coils for packing of aneurysms, endovascular embolization is increasingly used. Numerous observational studies have published complications rates, occlusion rates and short-term follow-up results. These have been summarized up to March 1997 in a systematic review of 48 eligible studies of 1383 patients with ruptured and unruptured aneurysms. Permanent procedural complications occurred in 3.7% of 1256 patients. In 2002 the results of the ISAT study were published; the clear benefit of the endovascular treated patients led to an premature stop of the study will definitely change treatment strategies for patients with intracranial aneurysms.<sup>4</sup> The endovascular approach will become the first line treatment option, whenever this option is available. New devices like self-expandable stents for the intracranial use now allow to treat even broad-based aneurysms. As a rule of thumb, around 70-80% of intracranial aneurysms can nowadays be treated via the endovascular approach. That is true even for the broad based aneurysms (Figures 4a-d).

### Cavernomas

Cavernomas, also called cerebral cavernous malformations or cavernous angiomas (CA) are characterised by endothelium lined, sinusoidal blood cavities

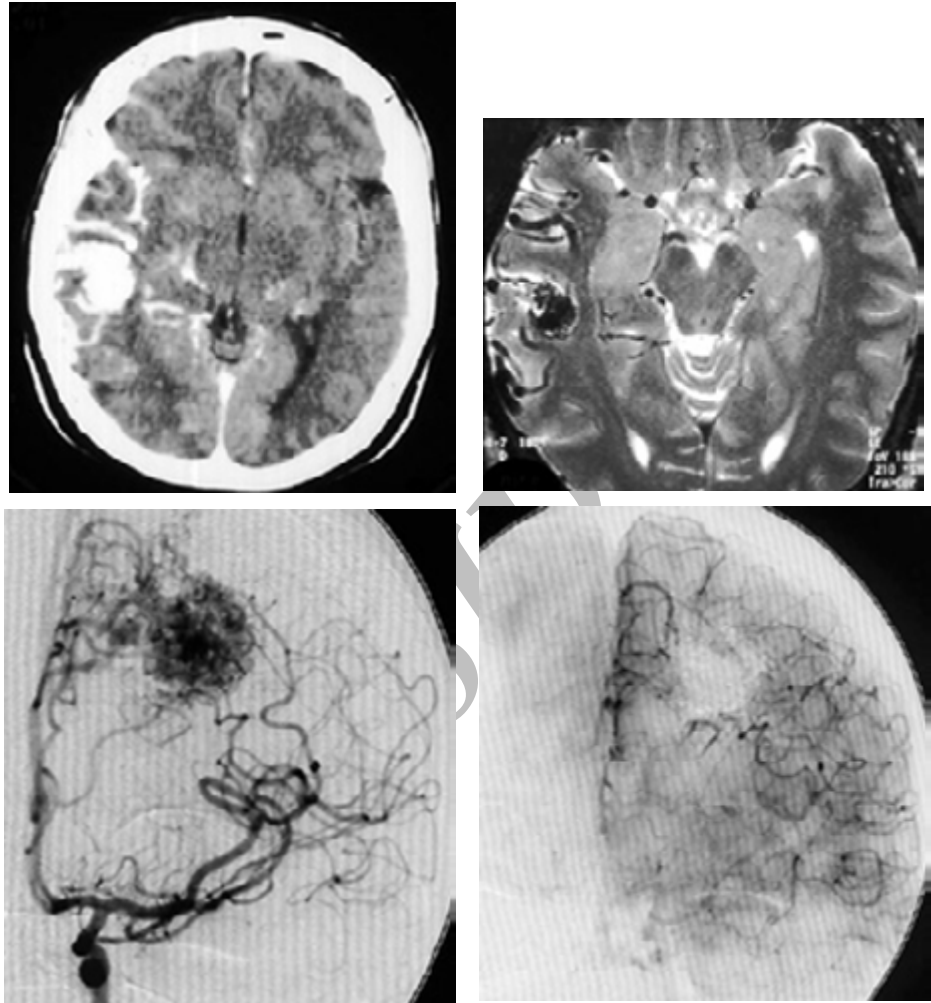


**Fig 5. a,b;** CT appearance of cavernomas within the brainstem (a) and multiple cavernomas supratentorial. **c;** T2\*-image of multiple cavernomas.

without other features of normal blood vessels like muscular or adventitial layers. No brain tissue is present between the blood cavities, which are embedded into connective tissue. This is from a pathological point of view the major difference between cavernomas and capillary teleangiectasias. In the latter ones there is intervening brain parenchyma between the vascular channels. During follow-up



**Fig 6. a,b;** CT (a) and MR (b) of a large, right temporal AVM. **c,d;** DSA of an AVM before (c) and after (d) endovascular therapy.



growth of cavernomas can occur, but this is exclusively related to osmotic changes or differences (like in chronic subdural hematoma) and never related to infiltration or any active growth. Cavernomas may occur sporadic, after radiation therapy and hereditary following an autosomal dominant trait.

The prevalence has been estimated on the basis of autopsy or MR imaging to be 0.5%-0.7%. The incidence of cavernomas has been estimated to be in the range between 0.4 and 0.9%; cavernomas; cavernomas account for 8% - 15% of all intracranial vascular malformations. During the last two decades incidence data have been confirmed by MRI-based retrospective studies. There is no male or female preponderance, up to 25% of all CA are found in the pediatric population.

Multiple cavernomas due occur in up to 90% of familial cases and in around 25% of sporadic cases. Therefore: whenever you see a single cavernoma on the MR scan of a patient, make sure that this is the

only one !!

Patients with cavernomas present with a variety of symptoms. Seizures are reported as the most common symptom, accounting for 38% - 55% of patient complaints. Other symptoms include focal neurologic deficits in 12%-45% of patients, recurrent hemorrhage in 4%-32%, and chronic headaches in 5%-52%. Brainstem cavernomas nearly never cause seizures! Most of these patients do have typical brainstem symptoms like diplopia, face or body sensory disturbances or ataxia. Without imaging this subgroup of patients with intratentorial located cavernomas can nicely mimic the clinical picture of Multiple Sclerosis.

The majority of patients become symptomatic between the 3rd and 5th decades, and there is no definite association between symptoms and gender. The frequency of asymptomatic cavernomas is not precisely known, but due to the literature it seems to be around 40%!



The central clinical problem in patients with cavernomas is the question of hemorrhage! On a first view, this should be a simple question with a simple answer. However, both is wrong. The problem starts with the definition of a hemorrhage and ends with individual answers to a single patient.

On one side, hemorrhage can be defined clinically: First or sudden onset of new neurologic symptoms in a patient with a cavernoma are usually related to a new or first hemorrhagic event. But looking into the literature you'll find a amazing amount of different descriptions and terms to describe cavernoma related hemorrhages: overt hemorrhage, symptomatic hemorrhage, gross hemorrhage, microhemorrhage, intralesional or perilesional ooze or diapedesis, clinically significant hemorrhage, subclinical hemorrhage and others. The reason for this variety of descriptions is that sometimes just clinical events were used to define hemorrhage and in other studies different imaging modalities (mainly MR) had a major impact on the definition of hemorrhage. The problem in defining a hemorrhage is a major reason for the still ongoing debate about the risk of hemorrhage and bleeding rates in patients with cavernomas.

Most estimations assume, that cavernomas are present since birth and risk of hemorrhage and bleeding rates are mainly based on that assumption. In 1991 Del Curling et al. and Robinson et al. were the first calculating the annual hemorrhage rate and figured out that it is between 0.25% and 0.7% per patient and per year.<sup>5,6</sup> Aiba et al. (1995) analysed their group based on the initial finding: If bleeding was the initial symptom the annualised hemorrhage rate was 22.9%, if seizures were the first symptom the bleeding rate was calculated with 0.39% per patient and year.<sup>7</sup> Kondziolka (1995) also stratified his patient group into those who had previously experienced a hemorrhage and those who had not.<sup>8,9</sup> Patients with one previous hemorrhage had a yearly 4.5% risk of hemorrhage, whereas those without a previous hemorrhage had a 0.6% yearly risk. An analysis of the symptomatic bleeding risk in untreated patients who had experienced two or more hemorrhages found the rate to be approximately 30% per year. Other authors, usually not differentiating between initial symptoms published hemorrhage rates between 1.1% and 3.1%. Porter et al. reported in 1999 that brains-

tem cavernomas might have a significant increased risk of hemorrhage and calculated it with 5% per person and year.<sup>10</sup> Contrary, Kupersmith and coworkers found a bleeding rate of 2.46% in brainstem cavernomas.<sup>11</sup> However, the rebleeding rate – and this is quite good supported by other data – seems to be beyond 5% in brainstem cavernomas. All studies suggest that the occurrence of a rebleeding is an indication of a higher bleeding probability of a given cavernoma. The risk of a symptomatic rebleed at least doubles in comparison to asymptomatic cavernomas. These findings clearly should have an impact on therapeutic decisions. The bleeding incidence is higher in patients with the inherited form of cavernomatosis, however, not for a single given cavernoma, but in terms of patient years.

Patients younger than 35 years of age experienced more bleeding episodes and the same was true for those with cavernomas of at least 10mm. A number of studies addressed the increased bleeding risk of women, the majority of studies, however, did not find any gender difference in bleeding risks.

The main problem in all these studies is a substantial selection bias and the definition of hemorrhage. Another, but probably more important aspect for patients when discussing bleeding risks is the clinical significance of hemorrhage and the probability of a good recovery. The probability of a fatal hemorrhage is low and many patients do show a complete or nearly complete recovery after the initial bleeding.

Finally, discussing the risk of a cavernoma with the patient, the majority of data in the literature calculate an annual risk of 0.5% - 1% (which is much lower than in true AVMs) and a low risk of fatal hemorrhage. In the majority of patients, specifically those older than 35 years of age, harbouring from a single cavernoma below 10 mm of size and with seizures as the initial symptom a wait-and-see strategy seems to be reasonable. In patients presenting with an initial hemorrhage the repeat hemorrhage risk seems to be much higher, specifically if already more than one bleeding event has happened.

As mentioned above the majority of patients with cavernomas present with seizures as the initial symptom. It is important to know that in the vast majority of patients these seizures are not related to acute bleeding events, but to hemosiderin deposition

adjacent to neurons. Hemosiderin or ferritin is a well-known epileptogenic agent (at least in animal experiments). The knowledge about the relation between seizures and hemosiderin deposition is specifically important, if surgical removal of the cavernoma is considered because of conservative not treatable seizures. It is of utmost importance not only to remove those parts of the cavernoma with blood flow, but also to remove the hemosiderin ring around the cavernoma within the adjacent brain tissue. This part of the malformation is responsible for the seizure.

Due to the slow blood flow cavernomas are angiographic occult vascular malformations. If the lesion has hemorrhaged, an avascular area with moderate mass effect can sometimes be identified. Occasionally – in less than 10% - a faint blush on the late capillary or early venous phase of high resolution angiograms can be seen. Angiography is rarely necessary in typical cavernomas.

The CT appearance of a cavernoma depends on the amount of internal thrombosis, haemorrhage and calcification. The lesions appear hyperdense compared to the adjacent brain parenchyma, but can have variable attenuation values. Because the density of blood on CT depends on clot formation, the attenuation of a thrombosed cavernoma changes with time. Calcifications do not change that much, however, cavernomas tend to calcify only partially. In patients with a recent haemorrhage, the cavernoma may be suspected by CT mainly by taking into account the site of hemorrhage, the patient's history and thus exclude other typical causes for intracerebral bleeding. Differential diagnosis must cover calcified brain tumour, mainly oligodendroglioma, which have a high tendency of intratumoral bleeding. Contrast enhancement can be observed on CT, but usually requires a substantial delay between contrast agent injection and scanning. But even with standardized 10 to 15 minutes delay between contrast agent injection and scanning, the enhancement of a cavernoma varies from non or minimal to striking (Figures 5a, b)!

The imaging modality of choice is MRI. Typically, cavernomas have a popcorn-like appearance with a well-delineated complex reticulated core of mixed signal intensities representing hemorrhage in different stages of evolution and / or different velocities of blood flow. Typical is a low signal hemosiderin rim,

which completely surrounds the lesion. The dark signal "blooms" on T2-weighted images, and is best visible on gradient-echo T2\*-weighted studies. Brunereau and colleagues studied the sensitivity of T2-weighted MR versus gradient-echo (GRE) sequences in patients with the familial form of cavernomas.<sup>12</sup> The mean number of lesions detected on SE images versus the mean number detected on GRE images was significantly different (7.2 versus 20.2 in symptomatic subjects). Owing to the blood stagnation phenomenon or to, true chronic microhemorrhages, cavernous angiomas contain deoxyhemoglobin or hemosiderin, which generate susceptibility effects and cause a decrease in signal intensity. This loss of signal intensity is much better demonstrated with T2\*-weighted GRE-sequences. This sequence should be part of the imaging protocol in all patients with a positive family history of cavernoma, all patients with a suspicion of focal or generalized seizures and in all patients with venous angiomas (there is a significant coincidence between occurrence of venous angiomas and cavernoma).

However, turbospin-echo sequences using a long echo train, i.e. all FLAIR sequences, are very insensitive to this susceptibility effect. Furthermore, even large lesions may not have a visible hemosiderin ring, if there were no relevant associated bleeding episodes (Figures 5c).

### Arteriovenous Malformations

Arteriovenous malformations of the brain (brain AVMs) correspond to congenital cerebrovascular anomalies, also known as intracerebral or pial AVMs. First of all, it is important to stress on the fact that this is not a neoplastic lesion and therefore not an "angioma", which is obviously an inappropriate term although it is a commonly used term.

Because of the rarity of the disease and the existence of asymptomatic patients, establishing a true prevalence rate is difficult, and probably not feasible. If considering unselected populations, Al-Shahi and al. found a prevalence of AVMs in a retrospective study in a region of Scotland of 15 per 100 000 living adults over 16 years of age.<sup>13</sup> In this series, prevalence is obviously underestimated, since it does not consider asymptomatic AVMs. Only large post-mortem studies in general population could give a more accurate

estimation of the prevalence of both symptomatic and clinically silent AVM. However, such series does not exist. Even though brain AVMs are considered to be congenital disorder, non systematized familial AVMs are extremely rare and only very few familial cases have been reported in the literature. No genetic predisposition was found and occurrence of brain AVMs in two members of the same family could be only a fortuitous event. Autopsy data showed that only 12% of AVMs become symptomatic during life and intracranial hemorrhage is the most common clinical presentation. In macroscopic pathology, brain AVMs are composed of (1) clustered and abnormally muscularized feeding arteries, which may also show changes such as duplication or destruction of the elastica, fibrosis of the media and focal thinning of the wall (2) arterialized veins of varying size and wall thickness, (3) structurally ambiguous vessels formed solely of fibrous tissue or displaying both arterial and venous characteristics and (4) intervening gliotic neural parenchyma. They anastomose with normal cerebral vessels. Intracranial hemorrhage is the most frequent clinical presentation of brain AVM with a frequency comprised between 30 to 82 % (Mast, 1995).<sup>14</sup> Overall, the percentage are relatively closed between the different series with annual rates of bleeding between 2 and 4%.<sup>15,16</sup>

The occurrence of a first hemorrhage seems to be associated with an increased risk of subsequent hemorrhage. In the series of Graf et al., patients with ruptured AVMs had a risk of rebleeding of 6% in the first year after hemorrhage and 2% thereafter.<sup>17</sup> On the basis of retrospective analysis, the rupture of brain AVMs is estimated to be less severe than that of intracranial aneurysms with a rate of deaths between 10 to 15% and an overall morbidity rate less than 50% (The arteriovenous malformation study group 1999). Hemorrhage of brain AVMs are subarachnoidal (30%), parenchymal (23%), intraventricular (16%) and in combined locations in 31% of cases. Parenchymal hemorrhages were most likely to result in a neurological deficit (52%). Overall, in the series of Hartmann (1998), 47% of patients have a good outcome after the bleeding and additional 37% of patients were independent in their daily life.<sup>18</sup> In patients with a sudden-onset of a neurological deficit, CT scan is usually the first imaging modality used,

mainly to rule out hemorrhage. CT is able to show very early parenchymal, subarachnoid and intraventricular bleeding. The diagnosis of brain AVM should be discussed when the patient is young, if the parenchymal hematoma has a lobar topography, and if calcifications or spontaneously hyperdense serpiginous structures are visible.

In case of unruptured AVM, non-contrast-enhanced CT scans can be normal. However, in some patients slightly hyperdense serpiginous can be seen. Parenchymatous calcifications are observed in 20% of cases related to intravascular thrombosis or evolution of an old hematoma. Contrast agent injection is absolutely mandatory to depict the brain AVM on CT. Abnormalities of the parenchymal density are visible in approximately 25% of cases related to the presence of a gliosis or an old hematoma. Abnormalities of the ventricular system can be observed: focal dilatation in case of associated parenchymal atrophy; compression of the ventricular system in case of mass effect caused by the AVM. Hydrocephalus can be observed in case of previous hemorrhage or if the ventricular system is compressed by enlarged draining veins of the AVM. MRI is currently used in case of unruptured AVM or to find the underlying lesion in case of lobar hematoma, generally days or weeks after the bleeding (Figures 6a+b).

Despite recent developments, CTA and MRA are currently not sufficient to obtain a precise description of the AVM from an anatomical and hemodynamical point of view. Selective angiography is still always necessary to make a decision regarding the treatment. In summary: the diagnosis of an AVM nowadays is usually based on CT or MR, the exact and therapeutic relevant anatomical and functional information has still to be obtained by angiography.

Technically, selective angiography has to be performed with a rigorous protocol. To assess as precisely as possible, the anatomical components of the AVM, it is important to performed selective injection of internal, external carotid arteries and vertebral arteries. Analysis of the arterial feeders, nidus, and venous drainage is obtained by performing multiple projections (anteroposterior, lateral and obliques). Three dimensional angiography may be helpful.

However, even excellent angiograms are often inadequate for correct therapeutic decisions. The exact

anatomy of large feeding arteries may be obscure with selective injections. Small feeding arteries are sometimes not visible on selective angiograms. If the size of the nidus is generally well evaluated by selective angiography, intranidal aneurysms and direct intranidal AV fistulas are often misdiagnosed. The venous drainage of the AVM is generally well studied by selective angiography, but the compartments of the AVM and their venous drainage is often not depicted, because the AVM is injected as a whole.

For all these reasons, superselective angiography often gives a more detailed analysis of the AVM and may become more important in the diagnosis decision. Superselective angiography is performed by manual injection of each separate arterial feeder. It is usually the first step of the Embolization (Figures 6c-d).

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