5 Intracranial Aneurysms

I. Wanke, A. Dörfler, M. Forsting

CONTENTS

5.1 Pathology *144*
5.1.1 Classification *144*
5.1.2 Saccular Aneurysms *144*
5.1.3 Dissecting Aneurysms *145*
5.1.4 Fusiform Aneurysms *147*
5.1.5 Infectious Aneurysms *147*
5.1.6 Traumatic Aneurysms *149*
5.1.7 Inflammatory Aneurysms *149*
5.1.8 Neoplastic and Radiation-Induced Aneurysms *149*
5.1.9 Aneurysms Associated with Arteriovenous Malformations *149*
5.1.10 Distribution *150*
5.1.11 Familial Occurrence *151*

5.2 Clinical Presentation *152*
5.2.1 Epidemiology *152*
5.2.2 Incidence and Risk of Rupture *153*
5.2.3 Natural History of Ruptured Aneurysms and Patient Outcome *154*
5.2.4 Pathophysiology of Aneurysm Rupture *154*
5.2.5 Other Causes of SAH *154*
5.2.5.1 Perimesencephalic Non-aneurysmal Hemorrhage *154*
5.2.5.2 Dural Arteriovenous Fistulae *155*
5.2.5.3 Cervical AVMs *156*
5.2.5.4 Saccular Aneurysms of Spinal Arteries *156*
5.2.5.5 Cardiac Myxoma *156*
5.2.5.6 Sickle Cell Disease *156*
5.2.5.7 Cocaine Abuse *156*
5.2.5.8 Anticoagulants *157*
5.2.5.9 Sinus-Venous Thrombosis *157*
5.2.6 Complications of SAH *157*
5.2.6.1 Hydrocephalus *157*
5.2.6.2 Rebleeding *157*
5.2.6.3 Hematoma *158*
5.2.6.4 Vasospasm *159*
5.2.6.5 Cerebral Ischemia and Infarction *159*
5.2.7 Unruptured Aneurysms *160*

5.3 Imaging *162*
5.3.1 Computed Tomography *162*
5.3.1.1 CT Angiography *164*
5.3.2 Magnetic Resonance Imaging *165*
5.3.2.1 Magnetic Resonance Angiography *169*
5.3.4 Cerebral Angiography *171*
5.3.4.1 3D Rotational Angiography *171*
5.3.5 Patients with SAH of Unidentifiable Cause *173*
5.3.5.1 Screening *174*
5.3.6 Transcranial Ultrasound *174*

5.4 Therapy *175*
5.4.1 General Considerations *175*
5.4.2 The ISAT Study *175*
5.4.3 Treatment of Unruptured Aneurysms *176*
5.4.4 Treatment of Ruptured Aneurysms *179*
5.4.5 Endovascular Therapy *180*
5.4.5.1 History *180*
5.4.5.2 Basic Assumptions for Endovascular Aneurysm Therapy *181*
5.4.6 Devices for Endovascular Aneurysm Therapy *184*
5.4.6.1 Catheters and Delivery Systems *184*
5.4.7 Embolic Materials for Endovascular Aneurysm Therapy *185*
5.4.7.1 Detachable Balloons *185*
5.4.7.2 Nondetachable Balloons *185*
5.4.7.3 Coils *185*
5.4.7.4 Electrolytically Detachable Coils *185*
5.4.7.5 Hydrogel-Coils *187*
5.4.7.6 Three-Dimensional Coils: TriSpan *187*
5.4.7.7 Other Devices *187*
5.4.7.8 Stents *188*
5.4.7.9 Neurovascular Stent *189*
5.4.7.10 Liquid Embolic Agents *189*
5.4.8 Techniques of Endovascular Therapy *189*
5.4.9 Anatomic Considerations for Endovascular Aneurysm Therapy *192*
5.4.9.1 Internal Carotid Artery *192*
5.4.9.2 Anterior Cerebral Artery *198*
5.4.9.3 Middle Cerebral Artery *204*
5.4.9.4 Vertebrobasilar Arteries *204*
5.4.9.5 Rare Locations *213*
5.4.10 Special Considerations *218*
5.4.10.1 Giant Aneurysms *218*
5.4.10.2 Pediatric Aneurysms *220*
5.4.10.3 Aneurysms in the Elderly *220*
5.4.10.4 Multiple Aneurysms *221*
5.4.10.5 Incompletely Treated Aneurysms/Aneurysm Remnants *225*
5.4.10.6 Combined Therapies *226*
5.4.10.7 Complications of Endovascular Therapy *228*
5.4.10.8 Monitoring and Therapy of Vasospasm *230*
5.4.10.9 Follow-Up and Outcome *234*
5.4.10.10 Final Remarks *236*
References *237*

I. Wanke, MD; A. Dörfler, MD; M. Forsting, MD, PhD
Institute of Diagnostic and Interventional Radiology, Department of Neuroradiology, University of Essen, Hufelandstrasse 55, 45122 Essen, Germany

Intracranial aneurysms do not fall precisely into the category of true vascular malformations; they are usually acquired. However, we included them because any neuroradiologist with an interest in vascular malformations and/or endovascular therapy clearly expects this entity to be covered extensively in a book such as this. Instead of using the modern way of communicating data (coloured boxes and tables), we have used the traditional form of writing with reiteration, mixing facts with opinions and illustrating as much as possible with radiological images. It is our hope that many people will read the chapter from beginning to end, and that redundancy and images will help to memorize new information.

5.1 Pathology

5.1.1 Classification

Classification of intracranial aneuryms may be based on morphology, size, location and etiology. The majority of intracranial aneurysms are true aneurysms containing all layers or components of the normal vessel wall. In contrast, in false aneurysms or pseudoaneurysms the vascular lumen does not enlarge, although the external diameter of the abnormal segment may be increased. These aneurysms are rare within the skull.

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. While traumatic, infectious or tumor-associated aneurysms are rare, most of them develop spontaneously. However, the pathogenetic criteria for the development of spontaneous aneurysms are only partially understood. Endogenous factors like elevated arterial blood pressure, special anatomical relationships given by the Circle of Willis, altered flow conditions, and exogenous factors like cigarette smoking, heavy alcohol consumption and anticoagulant or contraceptive medications have all been found to be associated with the occurrence of cerebral aneurysms (Juvela et al. 2001; Longstreth et al. 1985; Stehbens 1989; Teunissen et al. 1996; Weir et al. 1998). The most common causes for the development of an aneurysm are hemodynamically induced vascular injuries, atherosclerosis, underlying vasculopathy and high flow states. More uncommon etiologies are trauma, infection, drug abuse and neoplasms.

5.1.2 Saccular Aneurysms

Saccular aneurysms are berry-like vessel outpouchings mostly arising from arterial bifurcations and account for 66%–98% of intracranial aneurysms (Yong-Zhong and van Alphen 1990). The vast majority of aneurysms (85%) are located in the anterior and only 15% are located in the posterior circulation (Kassell and Torner 1983).

The majority of saccular aneurysms are not considered to be congenital, but develop during life. Cerebral aneurysms are rare in children and almost never occur in neonates (Heiskanen 1989). If a neonate or young baby suffers from an aneurysmal hemorrhage, usually a connective tissue disease is the underlying cause.

In adults the role of acquired changes in the arterial wall is likely because there are general risk factors for subarachnoid hemorrhage (SAH) and presumably for the development of aneurysms like hypertension, smoking and alcohol abuse (Teunissen et al. 1996). These factors might contribute to general thickening of the intimal layer in the arterial wall, distal and proximal to branching sites. These "intimal pads" are probably the earliest stages of aneurysm formation. Within these pads, the intimal layer is inelastic and therefore causes increased strain of the more elastic portions of the vessel wall (Crompton 1966). Abnormalities in structural proteins of the extracellular matrix additionally contribute to aneurysm formation (Chyatte et al. 1990). However, it is not known why only some adults develop aneurysms at arterial bifurcations and most do not. The popular theory of a congenital defect in the tunica media of the muscle layer as a weak spot through which the inner layer of the arterial wall would bulge has had doubt cast upon it by a number of contradicting observations. Gaps in the muscle layer are equally present in patients with and without aneurysms (Stehbens 1989). If the aneurysm has formed, any defect in the muscle layer is not located at the neck, but somewhere in the aneurysmal wall of the sac (Stehbens 1989).

The most plausible pathogenetic theory is that they are acquired due to hemodynamic stress on the relatively unsupported bifurcations of cerebral arteries (Timperman et al. 1995). This is supported by the

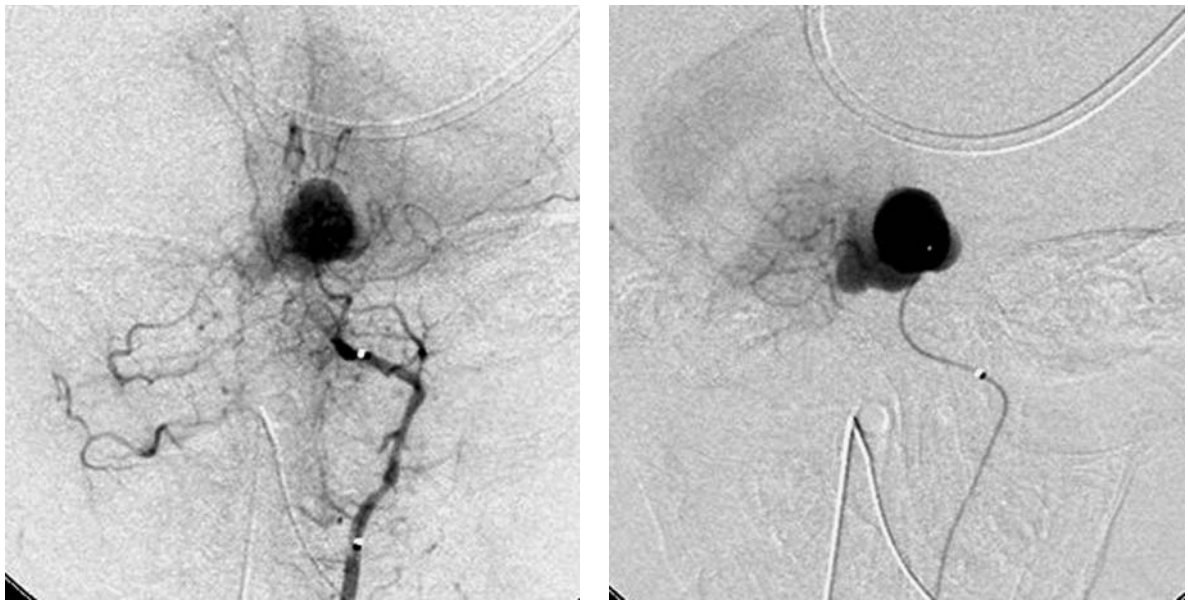


Fig. 5.1.1. a Aneurysm of the basilar artery in a newborn (ap view). **b** Aneurysmography revealed a large bilobulated aneurysm (ap view)

clinical observation that many patients with an anterior communicating artery (Acom) aneurysm do have one hypoplastic or absent A1 segment and thus an increased hemodynamic stress on the AcomA. Other factors than hemodynamics and structural alterations of the vessel wall contributing to the development of saccular aneurysms may be genetic, infection, trauma, neoplasms, radiation or idiopathic.

5.1.3 Dissecting Aneurysms

Spontaneous arterial dissection has been well recognized at the cervical portion of the carotid artery and extracranial vertebral artery as an important cause of ischemic stroke in young adults. In contrast, intracranial or intradural dissections more often cause subarachnoid hemorrhage instead of stroke. The true prevalence of intracranial dissections is unknown. Sasaki et al. (1991) described dissecting aneurysms accounting for 4.5% of the autopsy cases of SAH. In contrast to saccular aneurysms dissecting aneurysms occur much more often in the vertebrobasilar system and more often in man than in woman (Yamaura et al. 2000).

Dissecting aneurysms of the extracranial carotid and vertebral arteries are often traumatic in origin. However, they may also be caused by fibromuscular dysplasia, atherosclerosis, infection, arthritis, heritable connective tissue disorders and chiropractic manoeuvres, or may occur spontaneously. Dissecting aneurysms are usually false aneurysms consisting of a false lumen within an injured arterial wall. An intimal tear is followed by an intramural hemorrhage between the media and adventitia (Schievink 2001). The majority of dissecting aneurysms in supraaortal vessels are found at extracranial segments. However, if dissections occur intracranially, e.g. at the intradural portion of the vertebral or carotid artery, these can clearly cause subarachnoid hemorrhage. In our experience these dissecting aneurysms may be the most often overlooked cause of the so-called non-perimesencephalic form of non-aneurysmal SAH.

Magnetic resonance imaging is the diagnostic modality of choice, since the intramural hematoma can be directly visualized. Angiography may reveal luminal dilatation followed by tapering of the vessel (string sign). The major clinical concern of extracranial dissections are distal embolization or subsequent arterial occlusion. Rupture of an extracranial dissecting aneurysm is rare (Schievink 2001). The therapeutic gold standard is anticoagulation and this usually leads to a good outcome. Surgical or endovascular therapy is generally reserved for those patients who do not respond to medical therapy or those with enlarging lesions.

The major clinical feature of intracranial arterial dissection is SAH due to rupture (58%). Ischemic infarction due to stenosis or occlusion by the intra-

mural hematoma or by remote embolism occurs in around 42% of patients (Yamaura et al. 2000). Intracranially, there is some difficulty in differentiating dissection from stenotic lesions. Isolated unusual locations of arterial stenosis as well as the presence of smooth rather than irregular narrowing should help to differentiate dissection from vasospasm due to SAH. The optimal treatment of intracranial dissection has not been determined. Dissections that result in a complete stroke are beyond treatment; however, those within a certain time window might be candidates for recanalization therapy.

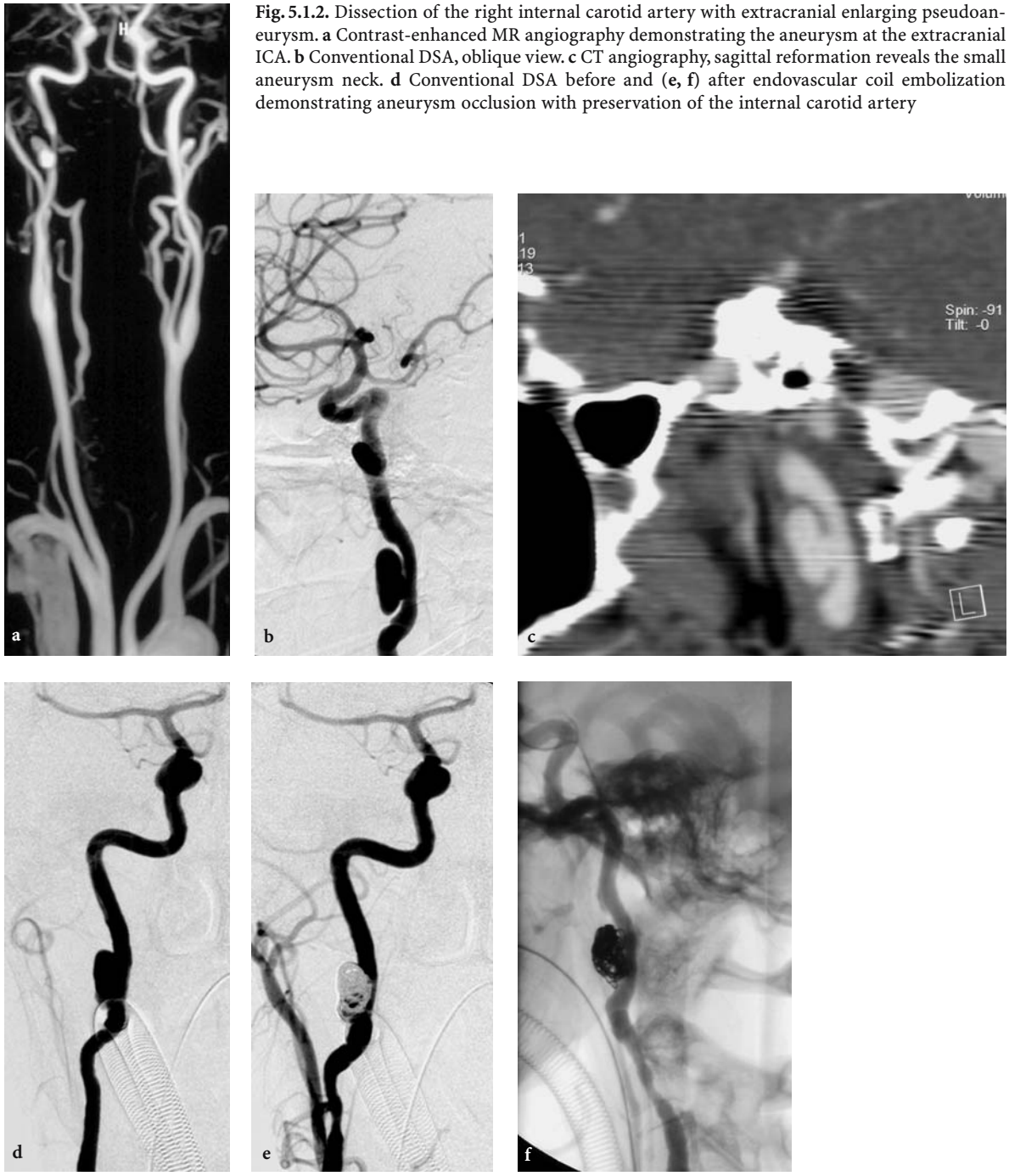


Fig. 5.1.2. Dissection of the right internal carotid artery with extracranial enlarging pseudoaneurysm. **a** Contrast-enhanced MR angiography demonstrating the aneurysm at the extracranial ICA. **b** Conventional DSA, oblique view. **c** CT angiography, sagittal reformation reveals the small aneurysm neck. **d** Conventional DSA before and (**e, f**) after endovascular coil embolization demonstrating aneurysm occlusion with preservation of the internal carotid artery

In patients with SAH due to dissecting aneurysms endovascular therapy with stents to remodel the lumen will probably be the future type of therapy.

In contrast to extracranial dissections, the intramural hematoma in most intracranial dissections forms between the internal elastic lamina and the media (Endo et al. 1993). Intracranial dissections may not be explained solely by a defect in the media. Rather, they originate at intimal alterations due to defects of the elastic tissue. The absence of external elastica may allow rupture into the subarachnoid space. Aneurysmal dilatation might occur if the underlying media is also abnormal (Endo et al. 1993).

5.1.4 Fusiform Aneurysms

Fusiform aneurysms are dilated, tortuous and elongated arterial segments. The term dolichoectasia describes a giant ectatic vessel of this type of aneurysms. Fusiform aneurysms are characterized by the absence of a defined neck, circumferential involvement of the parent artery and a longish course. The aneurysm can be partially thrombosed.

The spectrum of fusiform aneurysms may arise from congenital, acquired, or iatrogenic defects in the vessel wall, with or without atherosclerosis, and hypertension, or may develop after intimal tear from dissection (Anson et al. 1996; Gobin et al. 1996). Fusiform aneurysms can occur in any location; however, they most frequently occur in the distal vertebral artery, basilar artery, P1 segment of the posterior cerebral artery and the supraclinoid internal carotid artery. Hemorrhage from these aneurysms is unusual. Presenting symptoms such as cranial neuropathy, brain stem compression and cerebral ischemia are mainly due to mass effect and distal embolization.

A distinct subgroup of fusiform aneurysms are serpentine aneurysms: large and partially thrombosed tortuous aneurysms with a central parent channel, eccentrically located within the intraluminal clot. This channel is not endothelialized and does not contain elastic lamina or media. The clot may become organized or calcified over time. The etiology of serpentine aneurysms is still totally unclear. They may develop from a degenerative form of atherosclerosis, infection, or may be congenital (Mawad and Klucznik 1995). They occur most commonly in the internal carotid artery, the middle cerebral artery and posterior cerebral artery. Typically, they present with symptoms of mass effect. Subarachnoid or intracerebral hemorrhage is rare. MRI may reveal different stages of hemoglobin degradation within the thrombosed part of the aneurysm.

Fusiform aneurysms are usually not suitable for endovascular obliteration because they do not have a circumscribed neck. In selected cases, endovascular parent vessel occlusion may be a therapeutic option, particularly if mass effect is the leading symptom. The aneurysm may subsequently shrink in size or completely resolve (Mawad and Klucznik 1995).

5.1.5 Infectious Aneurysms

The first infectious intracranial aneurysm was probably described by Church in 1869 when he established a relationship between an intracranial aneurysm and infectious endocarditis. The term "infectious aneurysm" should be preferred, "bacterial" or "mycotic" should be used only if bacteria or fungi are demonstrated as the causative organisms. The frequently used term "mycotic" is misleading in the vast majority of patients because bacterial infection represents the most common cause for infectious cerebral aneurysms.

The pathogenesis of infectious aneurysm formation has been well characterized in animal models. After septic emboli arise, polymorphonuclear leucocytes infiltrate the vessel wall from toward the internal elastic membrane. Most of them concentrate within Virchow-Robin spaces.

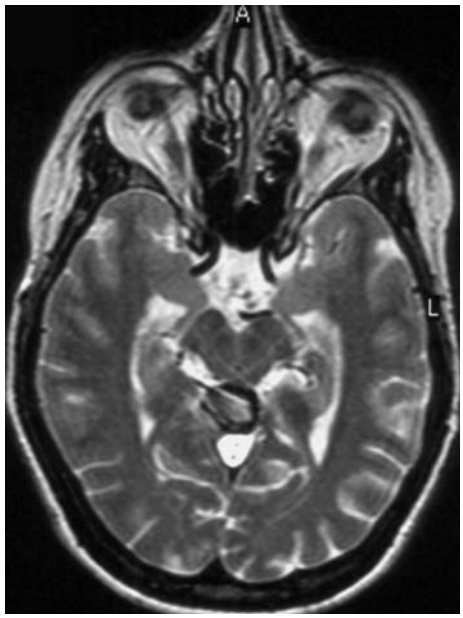
Infectious intracranial aneurysms account for 2%–3% of all intracranial aneurysms. They commonly result from embolization of cardiac vegetations in endocarditis, with *Streptococcus* as the most frequent organism, followed by *Staphylococcus* and *Enterococcus.* Infected tissue debris entering the blood stream may embolize in cerebral artery walls leading to aneurysmal dilatation. The risk of aneurysm formation due to endocarditis is 5%. While there is decreasing overall incidence of infectious cerebral aneurysms, the incidence of infectious aneurysms increased in drug abusers and immunocompromised patients.

Pathologically, a loss of intima is characteristic in bacterial cerebral aneurysms. Subendothelial inflammation and necrosis of the media and internal elastic lamina results in weakening of the vessel wall, leading to aneurysm formation. Aneurysms associated with infective endocarditis are often irregularly shaped, fusiform, frequently multiple and peripheral and in the majority of patients located at distal branches of the middle cerebral artery. The time interval from septic embolism to aneurysmal dilatation can be as short as 24 h.

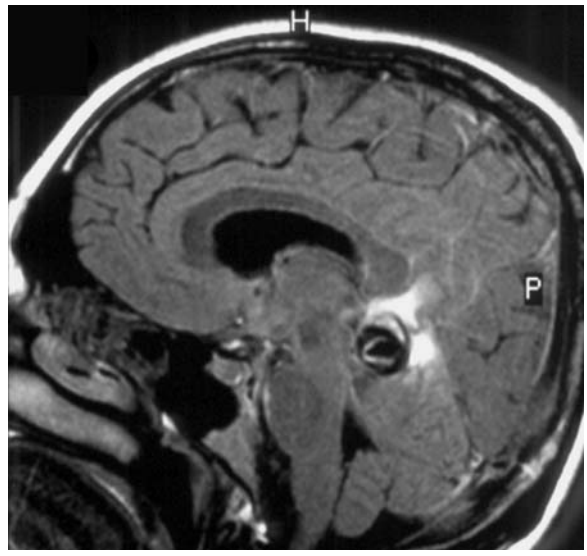
True mycotic aneurysms are rare. The underlying condition is often a craniofacial infection with aspergillus, phycomycetes or candida endocarditis. In contrast to bacterial etiology the time course of mycotic aneurysms is longer, sometimes taking months to develop. Mycotic aneurysms are typically proximal in location (carotid or basilar artery) and fusiform (Lau et al. 1991). Rupture of such aneurysms may lead to massive SAH in the basal cisterns, indistinguishable from SAH of saccular aneurysms. Aspergillosis is difficult to diagnose, but should be considered particularly in patients undergoing long-term treatment with steroids, immunosuppressive agents and antibiotics, or in HIV-infected patients.

The course of infectious aneurysms is unpredictable. Under antibiotic or antimycotic therapy they may shrink, or completely disappear. However, enlargement during treatment has also been reported (Brust et al. 1990). Septic aneurysms can be obliterated surgically or by endovascular treatment (Chapot et al. 2002; Phuong et al. 2002; Steinberg et al. 1992). The theoretical assumption that implantation of foreign material – like platinum coils – into an infectious lesion might worsen the problem is not true for infectious intracranial aneurysms.

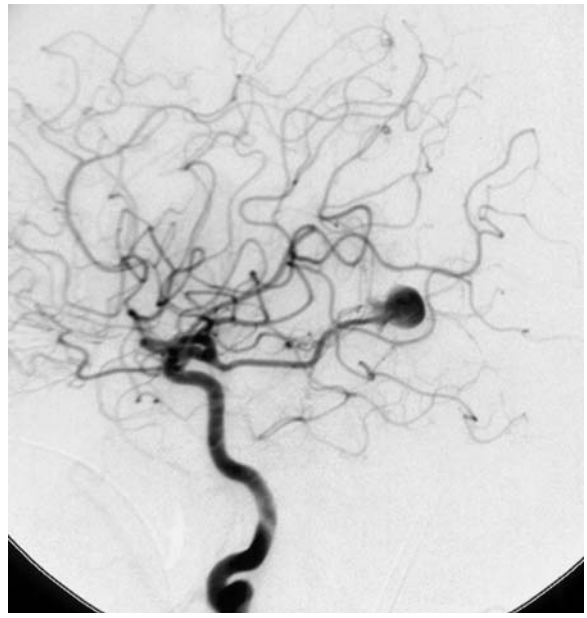
Mortality due to rupture of bacterial cerebral aneurysms is reported to be up to 60% (Barrow and Prats 1990; Bohmfalk et al. 1978; Clare and Barrow 1992).



a



b



c

Fig. 5.1.3. Infectious aneurysm of the right posterior cerebral artery. T2-weighted image (**a**), FLAIR image (**b**) with subarachnoid blood around the aneurysm and DSA (**c**)

There is no scientific opinion about screening high risk patients for infectious aneurysms, e.g. those with a bacterial endocarditis. However, this may be a field of collaboration between cardiologists and neuroradiologists.

5.1.6 Traumatic Aneurysms

Traumatic aneurysms result from a direct injury to the arterial wall or to acceleration-induced shear. Cervical, cerebral or meningeal arteries can be affected. Traumatic aneurysms may develop within hours after trauma and the majority are false aneurysms. More than 50% of traumatic aneurysms are associated with a skull fracture (Holmes and Harbaugh 1993). Traumatic aneurysms tend to develop on the longitudinal aspect of the injured vessel.

The majority of intracranial traumatic aneurysms are located at the distal middle cerebral artery (MCA) or at anterior cerebral artery (ACA) branches. Angiography typically demonstrates irregular aneurysms, absence of a true neck, and a peripheral location (Amirjamshidi et al. 1996). They may regress, thrombose, enlarge or rupture. Late, often fatal subarachnoid or intraparenchymal hemorrhage may occur in up to 60% with an associated mortality of 50% (Holmes and Harbaugh 1993).

5.1.7 Inflammatory Aneurysms

Inflammatory transmural angiitis in systemic lupus erythematosus, polyarteritis nodosa, or giant cell arteritis cause focal fibrinoid necrosis and elastic tissue disruption. Subacute or chronic changes usually produce ectasia and may facilitate aneurysm formation. Aneurysms in acute arteritis tend to be multiple, peripheral and non side-wall in configuration.

5.1.8 Neoplastic and Radiation-Induced Aneurysms

Oncotic aneurysms may arise from cerebral embolization of neoplastic cells with infiltration of the vessel wall and subsequent aneurysm formation. Thus, the underlying pathomechanism is quite similar to infectious aneurysms. Subarachnoid or intraparenchymal hemorrhage may result. Neoplastic aneurysms have been reported with cardiac myxoma, choriocarcinoma, bronchogenic and undifferentiated carcinomas. Treatment consists of resection of the involved segment, if possible, and evacuation of the symptomatic lesion (Weir et al. 1978).

Formation of fusiform aneurysms following radiation and radioactive intrathecal gold therapy has been reported after treatment of germinoma and medulloblastoma. These aneurysms are located in the midline or parasellar region, and tend to enlarge and rupture (Benson and Sung 1989).

5.1.9 Aneurysms Associated with Arteriovenous Malformations

There is an increased incidence, or better, an increased amount of visible aneurysms associated with arteriovenous malformations. The incidence of these aneurysms in AVMs is up to 25% (Brown et al. 1990; Stapf et al. 2002). Approximately 50% of these aneurysms are located on a feeding artery, 25% within the nidus. Stapf and colleagues analysed their extensive AVM database and figured out that feeding artery aneurysms are an important independent determinant for an increased risk of hemorrhage in AVM.

Flow-related aneurysms probably develop due to hemodynamic stress caused by increased flow and pressure, with subsequent dilatation and pathologic changes in feeding arteries.

AVM-associated aneurysms contribute to an increased risk of hemorrhage. A 7% risk of hemor-

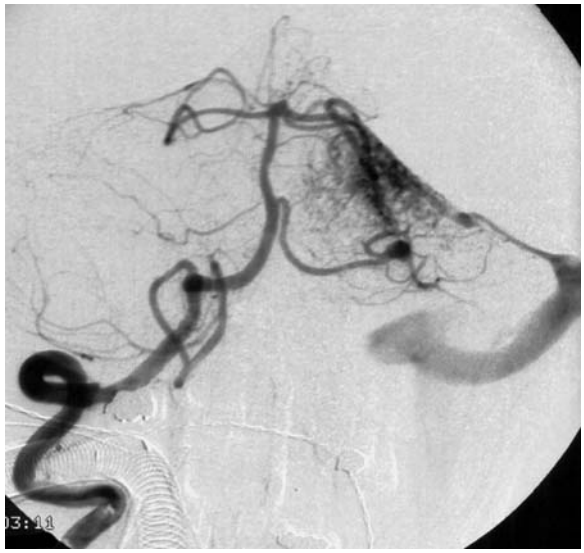


Fig. 5.1.4. Distal small aneurysm of the anterior inferior cerebellar artery (AICA) associated with a high-flow arteriousvenous malformation

rhage for these combined lesions is estimated compared to a 1.7%–3% risk for AVMs without associated aneurysms (Turjman et al. 1994). In case of rupture the hemorrhage is more often located intraparenchymally than subarachnoidally (Brown et al. 1990). Management of these combined lesions is still discussed controversially. However, in our opinion these aneurysms should be treated – preferentially by the endovascular route-in order to reduce the bleeding risk of the combined lesion. In fact, elimination of the AVM with subsequent change in hemodynamics might place the aneurysm at risk. In accordance to our opinion, other authors also advocate to treat the aneurysm before eliminating the AVM (Nakahara et al. 1999; Thompson et al. 1998). On the other hand, proximal asymptomatic aneurysms may regress after removal of the AVM. If this is not the case, an interval of 3 months after AVM treatment might be justified before considering a further therapy for a proximal aneurysm. However, aneurysms located in the posterior circulation associated with an AVM are at higher risk of rupture and therefore should be treated as soon as possible even if they have not ruptured before.

5.1.10 Distribution

Most arterial aneurysms arise at the bifurcation of major arteries, and this is also true for the intracranial location. Around 85% of all intracranial aneurysms originate from the anterior circulation. The most common location (30%–35%) is the anterior communicating artery (Acom). However, many of these so-called Acom 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 artery aneurysms account for 30% and middle cerebral artery (MCA) bifurcation aneurysms for 20%. Around 15% of intracranial aneurysms arise at the vertebrobasilar circulation. Half of them develop at the basilar tip (with various degrees of involvement of the P1 segments) and the other 50% from other posterior fossa vessels. Aneurysms of the anterior inferior cerebellar artery (AICA) and vertebral artery (VA) aneurysms without involvement of the VA-PICA junction or the vertebrobasilar union are extremely rare.

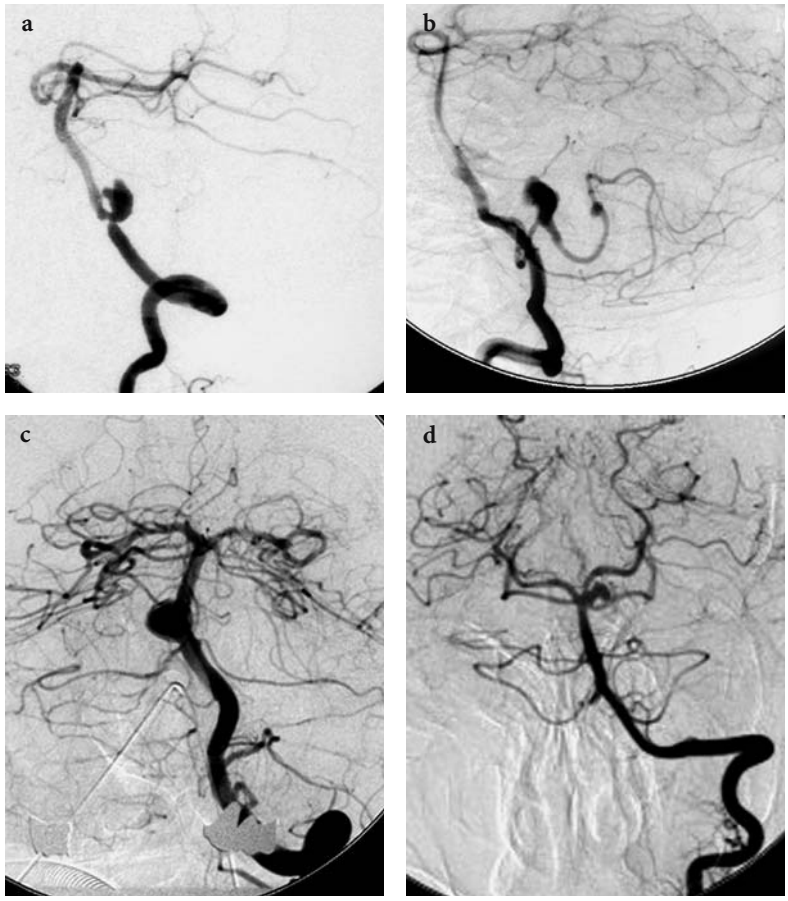


Fig. 5.1.5a–d. Various locations of aneurysms. **a** Vertebral basilar junction aneurysm. **b** True PICA aneurysms. **c** Basilar trunk aneurysm. **d** Basilar trunk aneurysm between origin of superior cerebellar artery and posterior cerebral artery, so-called superior cerebellar artery aneurysm. ▷

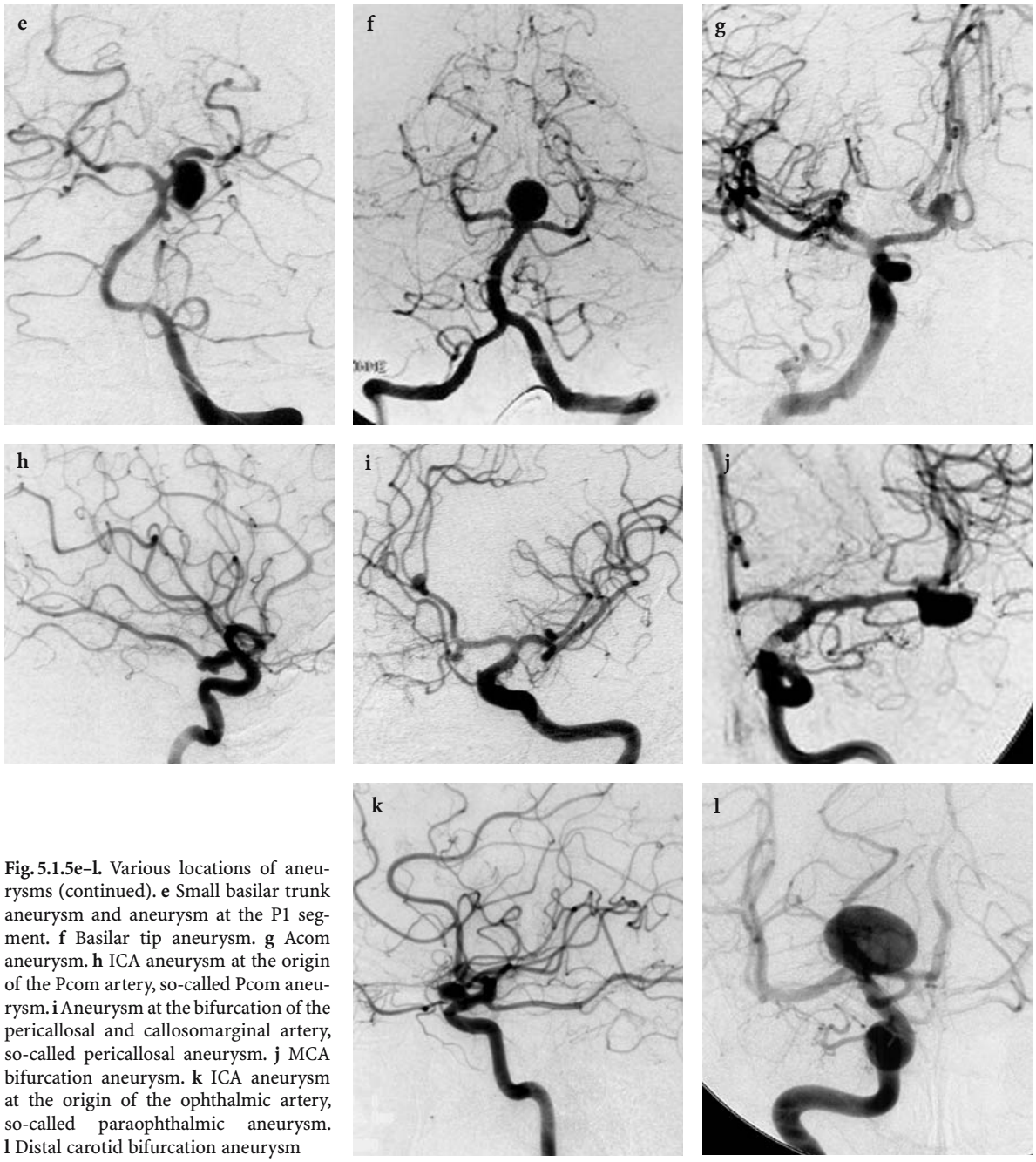


Fig. 5.1.5e–l. Various locations of aneurysms (continued). **e** Small basilar trunk aneurysm and aneurysm at the P1 segment. **f** Basilar tip aneurysm. **g** Acom aneurysm. **h** ICA aneurysm at the origin of the Pcom artery, so-called Pcom aneurysm. **i** Aneurysm at the bifurcation of the pericallosal and callosomarginal artery, so-called pericallosal aneurysm. **j** MCA bifurcation aneurysm. **k** ICA aneurysm at the origin of the ophthalmic artery, so-called paraophthalmic aneurysm. **l** Distal carotid bifurcation aneurysm

5.1.11 Familial Occurrence

The prevalence of intracranial aneurysms among first-degree relatives of patients with cerebral aneurysms is higher than in the general population. The risk for a first-degree relative harbouring an aneurysm is about three to four times higher than for someone from the general population (Raaymakers 1999, 2000; Ronkainen et al. 1997). In other words: The incidence of intracranial aneurysms is between 8% and 9% in persons with two or more relatives who have had a SAH or an aneurysm (Raaymakers et al. 1998b; Ronkainen et al. 1997).

Recently, this was confirmed by Okamoto and colleagues (2003). They found that the SAH risk was elevated when: (1) any first degree relative had a positive episode of SAH, (2) a mother or father had a

relative with a positive episode of SAH (an effect much greater in magnitude in a positive maternal rather than paternal history), (3) any first-degree relative <50 had had a SAH. Kojima et al. (1998) confirmed that asymptomatic aneurysms were more likely to rupture among family members with aneurysmal SAH than among those without. According to the group around Leblanc (Leblanc 1996; Lozano and Leblanc 1987) cerebral aneurysms in patients with a positive family history might result from a mesenchymal defect affecting the cerebral vessel wall produced by a lesion of chromosome 16. Okamoto et al. (2003) found an urgent need for early prevention of SAH by screening individuals with any positive family members (first-degree relatives with an episode of SAH).

Various hereditary connective tissue disorders have been associated with formation of aneurysms, most likely as a result of the weakening of the vessel wall. Intracranial aneurysms may develop in 10%–15% of patients with polycystic kidney disease, an autosomal dominant disorder. Although Marfan syndrome was previously identified as a risk factor for aneurysms, a recent study did not find any significant relationship (Conway et al. 1999). Coarctation of the aorta, fibromuscular dysplasia and pheochromocytoma have been associated with intracranial aneurysms, most likely because of the elevated blood pressure that occurs in these conditions.

There are some presumptions on neurofibromatosis type 1 (NF1) and intracranial aneurysms. In a recent study, Conway and colleagues (2001) concluded from their own data and an extensive analysis of the literature that an association between NF1 and intracranial aneurysms has never been identified in large clinical studies of NF1 patients and that there is no evidence for any association between NF1 and intracranial aneurysms.

5.2 Clinical Presentation

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 (Ostergaard 1991). Another problem – from a clinical point of view – is the so-called thunderclap headache which is caused by a SAH in only 10%–20%. Other findings in these patients are: cerebral infarction, meningitis, intracerebral hemorrhage, cerebral edema or even nothing. From a pure clinical standpoint it sometimes can be difficult to decide whether a thunderclap headache was related to the SAH/warning leak complex or not. There is no clear evidence what to do in a situation like this; our recommendation is to perform a CSF examination and a MRI plus MRA. Landtblom and colleagues (2002) figured out that it is clearly not justified to do an invasive angiogram in these patients (Landtblom et al. 2002).

5.2.1 Epidemiology

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

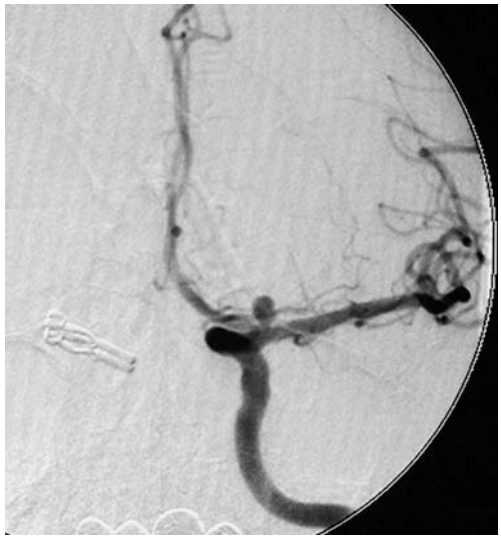
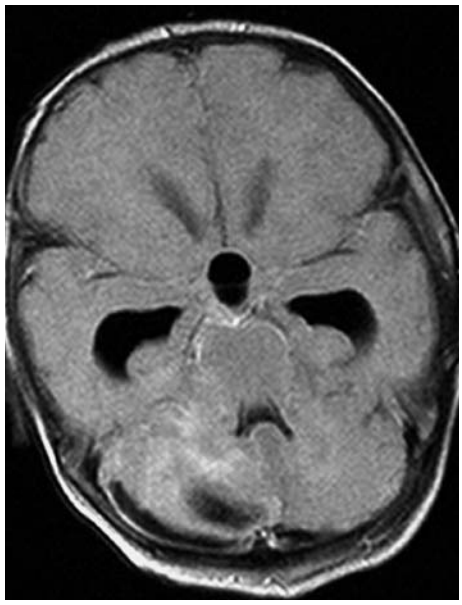
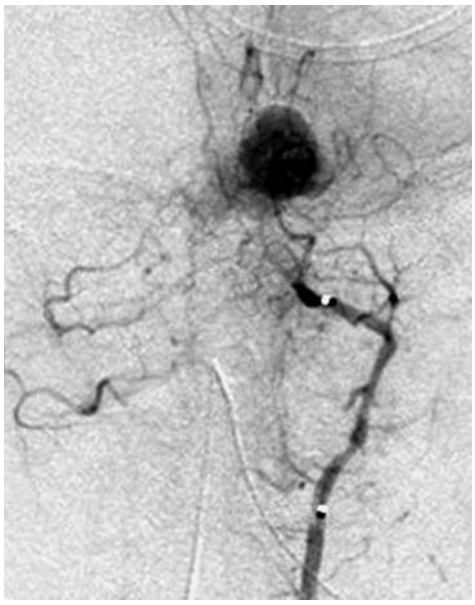


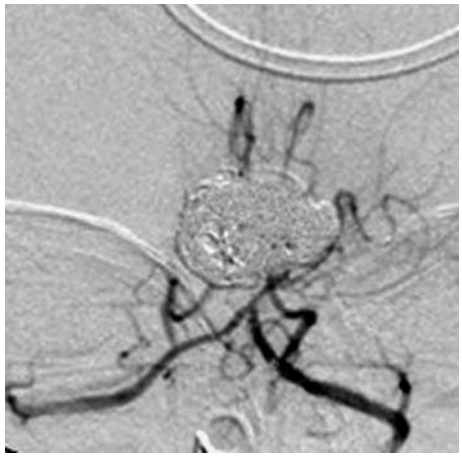
Fig. 5.2.1. Seven years after clipping an Pcom aneurysm on the right side a de novo aneurysm at the distal carotid bifurcation was found on the left side, primarily seen on MRI performed because of headache



a



b



c

Fig. 5.2.2. Basilar trunk aneurysm in a newborn after bleeding (**a**, FLAIR) resulting in acute hydrocephalus, before (**b**) and after (**c**) endovascular treatment with selective occlusion of the aneurysm. The baby's outcome was excellent with no neurologic deficits

be risk factors in the pathogenesis of an aneurysm or at least 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.

5.2.2 Incidence and Risk of Rupture

Intracranial aneurysms are common. Autopsy studies have shown that the overall frequency in the general population ranges from 0.4% to 10% (Chason and Hindman 1958; Housepian and Pool 1958; Inagawa and Hirano 1990; McCormick and Acosta-Rua 1970). Rinkel et al. (1998) analysed 23 studies with 56304 patients published between 1955 and 1996 and found a prevalence of 2.3 % in adults without a risk factor for SAH and an overall annual risk of rupture of 1.9 %. They included retrospective and prospective autopsy and angiographic studies and found a higher incidence in the prospective arm of their analysis. It might be reasonable to assume that the average prevalence is around 2%. Based on this number, in the German population approximately 1.5 to 2 million people are assumed to harbour an intracranial aneurysm.

The incidence of SAH in the Western hemisphere is around 6–10 per 100,000 people 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 15/100,000 per year. SAH accounts for a quarter of cere-

brovascular 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 (Wardlaw and White 2000). The incidence not only of aneurysms but also of SAH is higher in Japan than in Western countries, and it has increased around three times during the past 20 years in Japan (Okamoto et al. 2003).

There are some risk factors associated with aneurysm rupture or aneurysm development beyond genetic determinants:

Elevated arterial blood pressure (hypertension) and endovascular flow conditions seem to be important for the development, growth and rupture of cerebral aneurysms. There is also a strong correlation between the presence of multiple aneurysms and hypertension: Patients with multiple aneurysms present significantly more often with hypertension than patients with solitary aneurysms or the normal population.

Other risk factors for the development of aneuryms are smoking, heavy alcohol consumption, arteriosclerosis and hyperlipidemia (for more details see Sect. 5.1.11).

5.2.3 Natural History of Ruptured Aneurysms and Patient Outcome

The peak incidence of rebleeding after the initial rupture is during the first day. Early rebleeding within hours after the onset of initial hemorrhage occurs in about 15% of patients (Fujii et al. 1996). As many as 20% of patients may rebleed within the first 2 weeks, one third in the first month, and 50% will rebleed within 6 months, if the aneurysm is not treated.

Mortality of recurrent SAH is up to 50% (Weaver and Fisher 1994). In patients surviving the first day, the risk of rebleeding is evenly distributed over the next 4 weeks with a second peak early in the third week (Hijdra et al. 1987). Between 4 weeks and 6 months after SAH, the risk of rebleeding gradually decreases from initially 1%–2% per day to a constant level of approximately 3% a year (Winn et al. 1977).

Of patients who survive the hemorrhage, approximately one third remain dependent. However, even recovery to an independent state does not necessarily mean that outcome is good. Only a small minority of patients with SAH has a truely good outcome, around 20% of them do not have a reduction of quality of life.

5.2.4 Pathophysiology of Aneurysm Rupture

There may be a small number of SAH presenting as "warning leak" or sentinel hemorrhage, usually only associated with a sudden severe headache (Hughes 1992). In general, there is a correlation between the extent of SAH and the clinical grade, incidence of vasospasm, and other complications such as cerebral ischemia, increased intracranial pressure, and hydrocephalus.

With increased severity of SAH there are increasing changes in physiologic parameters such as reduced cerebral blood flow (due to reduced cerebral autoregulation), hypovolemia, hyponatremia, hypermetabolism and cardiac arrhythmia. If intracerebral pressure is increased up to diastolic blood pressure cerebral blood flow persists during systole (Nornes 1973).

Stopping of an SAH is caused by a combination of tamponade due to reduced transmural pressure gradient across the arterial wall and coagulation.

5.2.5 Other Causes of SAH

5.2.5.1 Perimesencephalic Non-aneurysmal Hemorrhage

Perimesencephalic hemorrhage constitutes approximately 10% of all SAH. Mean age at onset is 50 years with a preponderance in male. The subarachnoid blood is confined to the perimesencephalic cisterns. The centre of the bleeding is anterior to the midbrain (Schwartz and Solomon 1996). Usually, there is no subarachnoid blood in the sylvian fissure or the anterior interhemispheric fissure. There might be some sedimented blood in the occipital horns of the lateral ventricles, but massive intraventricular hemorrhage or intracerebral hemorrhage is not a feature of this benign perimesencephalic hemorrhage.

Conventional angiography is the next step to rule out an aneurysm, although this is hardly found. In the presence of the typical CT pattern the yield of repeated angiography is low, and some investigators have abandoned it. Some of them even consider CT angiography sufficient to rule out an aneurysm. From a clinical perception, perimesencephalic non-aneurysmal hemorrhage is barely distinguishable from aneurysmal hemorrhage. The onset of headache is often more gradual than in true aneurysmal hemorrhage (Linn et al. 1998),

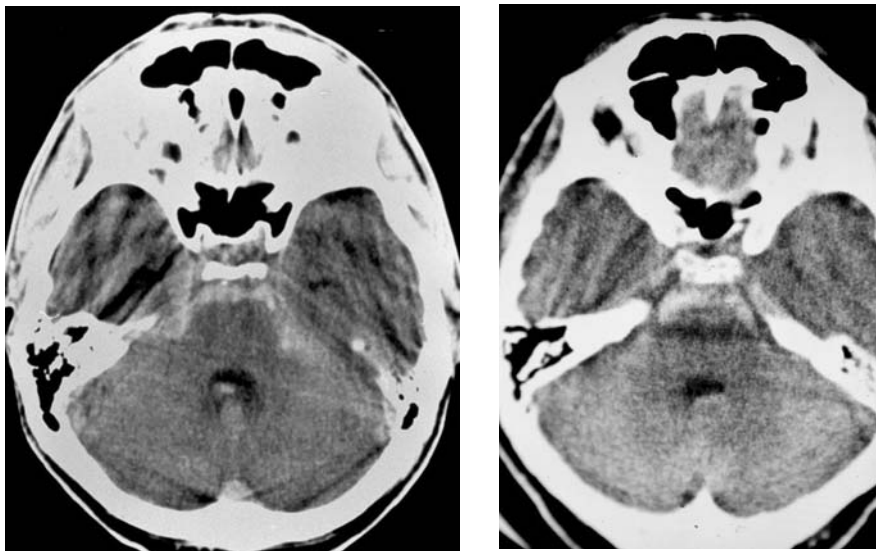


Fig. 5.2.3a,b. Typical perimesencephalic hemorrhage on CT scan

but this is a poor diagnostic hint. Focal symptoms or loss of consciousness are exceptional and do occur only transient. Usually, these patients are clinically Hunt and Hess grade I. Seizures were never reported in perimesencephalic hemorrhage. Apart from their headache the patients are in a very good clinical condition. The clinical course is typically uneventful. Rebleeding, acute hydrocephalus, or secondary cerebral ischemia due to vasospasm do not typically occur in this entity. Rebleeds after the hospital period have not been reported and the quality of life in the long-term is excellent. The time of convalescence is usually short and the outcome is good or excellent with almost all patients (94%) able to return to their previous work and activities (Brilstra et al. 1997). In summary, this is really a benign variant of SAH, but clearly requires a diagnostic work-up like a typical SAH in order not to overlook the rare aneurysmal-caused perimesencephalic SAH and other causes.

5.2.5.2 Dural Arteriovenous Fistulae

Hemorrhage from a basal dural arteriovenous fistulae might be not distinguishable from aneurysmal SAH. The risk of hemorrhage in dural arteriovenous fistulae depends on the pattern of venous drainage (Cognard et al. 1995). A cortical venous drainage is associated with a relatively high risk of hemorrhage, drainage into the main sinus is associated with a very low risk of bleeding. After a first rupture has occurred, the risk of rebleeding is very high.

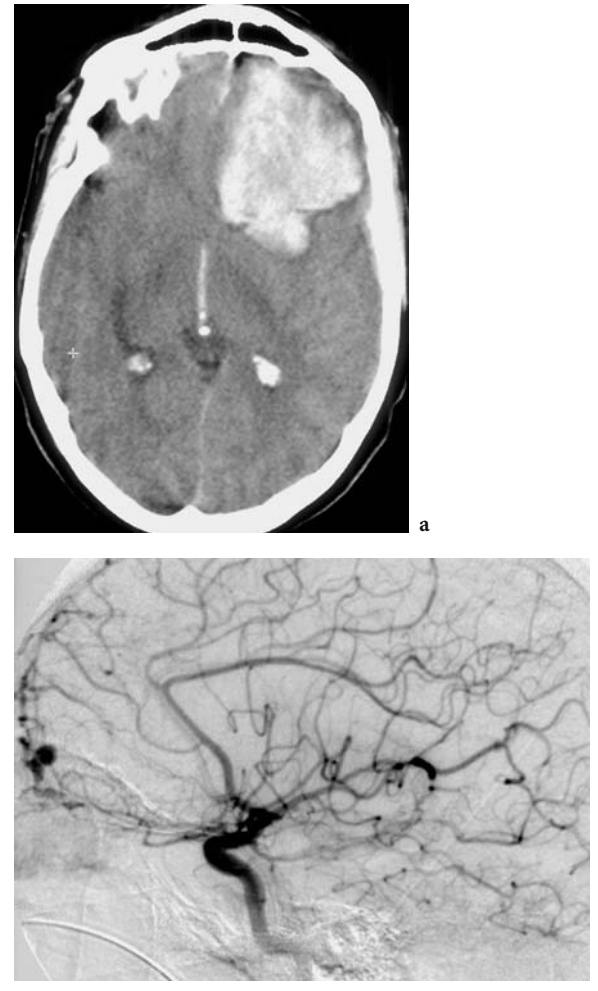
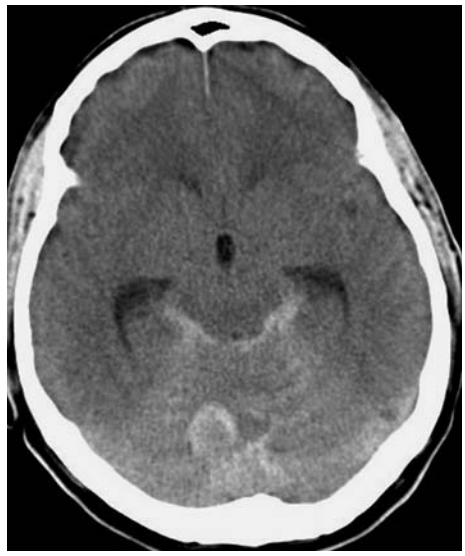
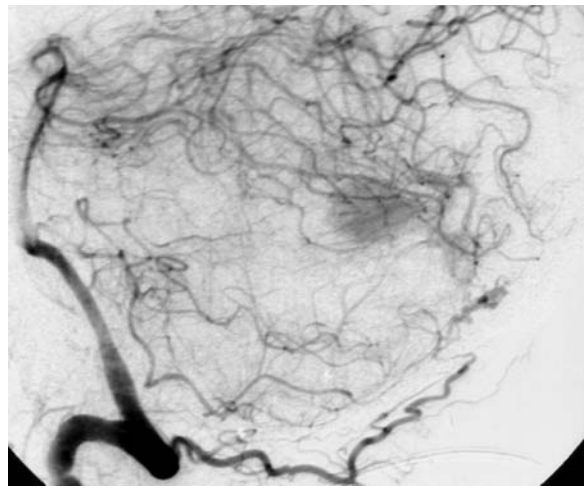


Fig.5.2.4a,b. Frontal dural AV-fistula with cortical drainage and left frontal intraparenchymal hemorrhage



a



b

Fig. 5.2.5a,b. Infratentorial dural AV-fistula and subarachnoid hemorrhage

5.2.5.3 Cervical AVMs

Intracranial SAH is the presenting symptom of a spinal AVM in about 10% of patients. In more than 50% of these patients, the first hemorrhage occurs before the age of 20 (Kandel 1980). Clinically, a severe pain in the lower part of the neck radiating to the shoulders and arms may indicate the cervical source of bleeding. MRI should be the first imaging modality to localize the source of bleeding, followed by selective spinal angiography. However, it is difficult to establish the spinal source of hemorrhage. In many patients CT reveals an intracranial SAH and the four-vessel angiogram is negative. In an ideal setting cervical vessels are additionally injected, but it is clearly not routine to do a spinal angiogram in this subgroup of patients. However, in all SAH patients with a negative angiogram a cranial and spinal MR should be performed to rule out a vascular malformation.

5.2.5.4 Saccular Aneurysms of Spinal Arteries

Saccular aneurysms of spinal arteries are rare. The clinical features of spinal SAH are usually associated with those of a transverse spinal cord lesion (Mohsenipour et al. 1994).

5.2.5.5 Cardiac Myxoma

Cardiac myxoma may be a very rare cause of SAH. In exceptional cases it may metastasize into an intracranial artery, infiltrate the vessel wall and initiate aneurysm formation, even more than 1 year later after excision of the primary tumour (Furuya et al. 1995).

5.2.5.6 Sickle Cell Disease

SAH in sickle cell anemia is characterized by multiple hemorrhages, often distally and in unusual locations. CT scan demonstrates blood in the superficial cortical sulci. Angiography reveals multiple distal branch occlusions and a collateral circulation via leptomeningeal vessels. SAH is attributed to rupture of these leptomeningeal collaterals, the outcome is usually poor (Carey et al. 1990). Approximately 30% of patients with sickle cell disease and SAH are children.

5.2.5.7 Cocaine Abuse

SAH related to the abuse of cocaine is associated with an underlying aneurysm in 70% of patients using hydrochloride ("crack") versus 30%–40% of patients using the alkaloid form (Levine et al. 1990, 1991). The pattern of SAH on CT may be the same as that of a ruptured saccular aneurysm. Rebleeding frequently occurs and the outcome is often poor. The association between cocaine use and the formation and rupture of aneurysms is thought to be due to increased turbulence of blood flow and repeated, transient bouts of hypertension. Among cocaine users, aneurysms have been found in significantly younger patients and in vessels with a smaller diameter (Nanda et al. 2000).

5.2.5.8 Anticoagulants

Anticoagulant drugs are rarely the sole cause of SAH (Mattle et al. 1989). If SAH occurs in a patient under anticoagulation therapy the outcome is poor.

5.2.5.9 Sinus-Venous Thrombosis

It is well known that sinus-venous thrombosis can cause atypical intracerebral hemorrhage. Under rare circumstances, however, thrombosis of the superior sagittal sinus can cause pure subarachnoid hemorrhage without intraaxial bleeding. Mostly, SAH is then located at the Sylvian fissure, probably due to dilated Sylvian veins, and in the parietal sulci.

5.2.6 Complications of SAH

Hydrocephalus, rebleeding from aneurysmal rerupture and cerebral vasospasm with ischemia are the three major complications following SAH.

5.2.6.1 Hydrocephalus

Acute hydrocephalus within the first 24 h of hemorrhage may develop due to blood within the basal cisterns or in the ventricular system causing CSF obstruction. Clinically, slow pupillary responses to light and deviation of the eyes is characteristic for acute hydrocephalus. If confirmed by CT, early ventricular drainage is indicated and can dramatically improve the clinical status of the patient. Nowak and colleagues (1994) reported the use of a ventricular drainage as an early test to evaluate neurologic viability. They chose surgical candidates in whom neurologic improvement occurred after CSF drainage. Thereby, ventriculostomy might not only serve as a therapeutic device but also as an indicator which severe-grade patients should be treated more aggressively (Arnold et al. 1994; Nowak et al. 1994). However, caution during placement of a ventricular drain is important, since sudden drainage may precede aneurysm rerupture, mainly because the transmural pressure along the aneurysm wall may exceed the intraventricular pressure. Large amounts of intraventricular blood are often associated with a poor clinical condition.

Hydrocephalus may also develop over days or weeks following SAH, clinically often presenting with gait disturbance, impaired intellectual function, and progressive lethargy. In these cases, ventriculo-peritoneal or ventriculo-atrial shunting is commonly indicated.

The possibility to eliminate major parts of the subarachnoid blood by intraoperative lavage and thereby decreasing the incidence of vasospasm and hydrocephalus is widely considered as an advantage of the neurosurgical approach compared to the endovascular route. However, in a retrospective study comparing 100 matched patients who had suffered SAH, the therapeutic procedure, either clipping or coil embolization, did not significantly affect the development of chronic hydrocephalus (Sethi et al. 2000).

If the initial CT already reveals early signs of hydrocephalus, the ventricular drainage should be placed before endovascular treatment starts. This schedule avoids a neurosurgical approach after having the patient on heparin and aspirin (which in many institutions is the case after coiling). In addition, a ventricular drainage is extremely helpful in the rare event of aneurysm rupture during the endovascular procedure.

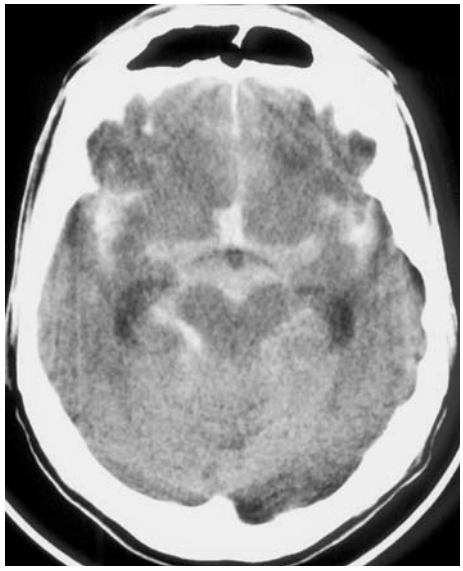


Fig. 5.2.6. CT reveals massive basal subarachnoid hemorrhage and dilated temporal horns of the lateral ventricles

5.2.6.2 Rebleeding

Rebleeding is a frequent and sometimes devastating neurologic complication of SAH and is postulated to be due to breakdown of perianeurysmal clot. Early rebleeding in the first hours after admission for the initial hemorrhage with clinical deterioration occurs

in up to 18% of patients (Fujii et al. 1996). Since these early rebleedings commonly occur before the first CT scan is obtained, the true frequency of early rebleeding is definitely underestimated. As many as 20% of patients may rebleed within the first 2 weeks, one third in the first month, and 50% will rebleed within 6 months, if the aneurysm is not treated. The peak incidence of rebleeding is during the first day. There is a secondary peak 1 week after SAH. Mortality of recurrent SAH is 50% (Weaver and Fisher 1994). Between 4 weeks and 6 months after SAH, the risk of rebleeding gradually decreases from initially 1%–2% a day to a constant level of approximately 3% a year (Winn et al. 1977).

The Cooperative Aneurysm Study reported that women have a 2.2 times higher recurrence rate of hemorrhage than men. Recurrent hemorrhage was also more frequently associated with a poorer neurologic grade at presentation and increased systolic blood pressure (Torner et al. 1981). Clinically, recurrent hemorrhage may present with new neurologic deficits, increasing headache, vomiting and a depressed level of consciousness. Seizures might occur as a result, but not as the cause of bleeding.

Clot formation and tissue damage stimulate fibrinolytic activity in the CSF, increasing the potential risk of rebleeding. This observation justified the rationale for the use of antifibrinolytic drugs such as aminocaproic acid and tranexamic acid to prevent rebleeding. A randomized placebo-controlled trial, a non-randomized trial and other reports assessing the efficacy of antifibrinolytic therapy showed a significantly decreased incidence of rebleeding. However, mortality was not altered, but this therapeutic approach was associated with an increased risk of delayed cerebral ischemia, embolism, and deep venous thrombosis (Vermeulen et al. 1984; Roos et al. 2000).

The ISAT study revealed aneurysmal rebleeding before treatment in 23 neurosurgical patients – 16 of them died – and in only 14 patients randomized for coiling. The reason for this significant difference was probably that the delay between initial bleeding and surgery is longer than the interval between the bleeding and coiling (Molyneux et al. 2002). Again, this indicates strongly that early rebleeding is a significant prognostic factor and any therapeutic delay might turn into a problem for the patient. However, we are not voting for immediate angiography and subsequent endovascular therapy for all SAH patients. Usually, we provide this service during the day until 10.00 p.m.. Patients admitted later get their diagnostic angiogram and endovascular therapy early in the next morning.

5.2.6.3 Hematoma

Intracerebral hematoma (ICH) occurs in up to 30% of patients with aneurysmal rupture (van Gijn and van Dongen 1982). The outcome is clearly worse than with SAH alone. If a space-occupying hematoma compressing nerval 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 valuable and fast imaging modality to disclose the aneurysm prior to surgical intervention. Immediate surgical evacuation is also indicated in acute subdural hematoma (SDH), which is usually associated with recurrent aneurysmal rupture. However, SDH can also occur with the initial SAH or can be the only extravascular space involved after aneurysmal rupture.

There is an ongoing debate about endovascular therapy in patients with ICH due to aneurysm rupture. If the hematoma is acute life threatening, it is no question that surgical evacuation needs to be done as soon as possible. However, it is a well known clinical experience that during hematoma evacuation – due to the decrease of tissue pressure – the risk of aneurysm rerupture increases. Having this in mind it might be advantageous to coil the aneurysm first – in order to prevent rebleeding – before surgical evacuation of the hematoma in those patients with a stable clinical condition.

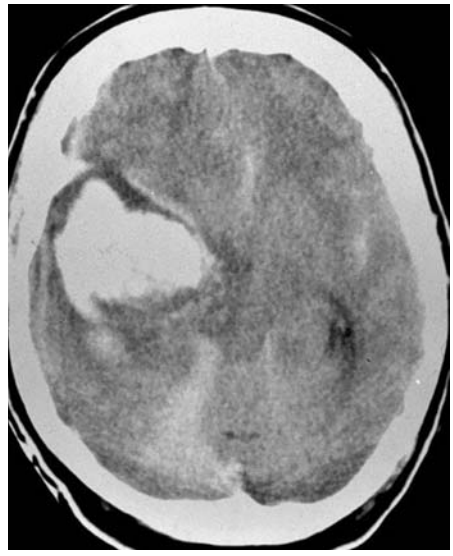


Fig. 5.2.7. Right temporal lobe intracerebral hemorrhage due to a ruptured MCA aneurysm. Beside basal subarachnoid hemorrhage CT reveals brain edema, compression of the basal cisterns and the cerebral peduncle

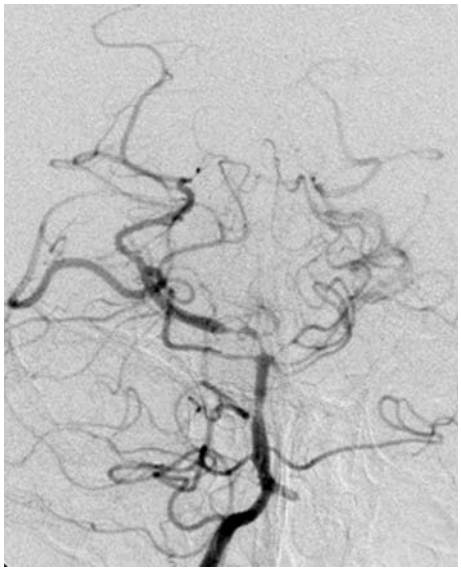
5.2.6.4 Vasospasm

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 (Biller et al. 1988). This difference probably reflects the different collateral circulation and different degrees of vasospasm. Unlike rebleeding, the clinical presentation of vasospasm develops slowly over hours to days. Delayed cerebral ischemia occurs usually first on the third day after hemorrhage, peaks between day 4 and 12, and may persist as long as 3 weeks after SAH (Biller et al. 1988).

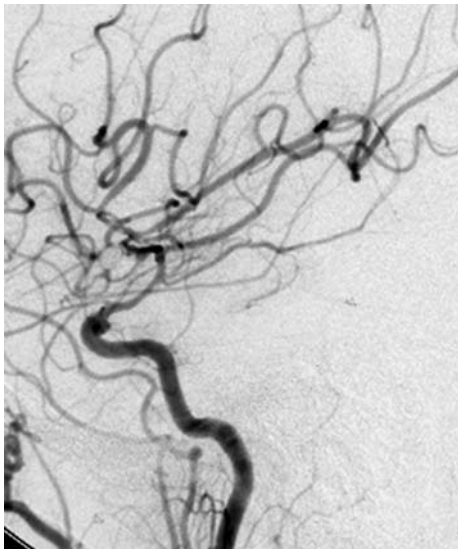
Vasospasm is best detected on angiograms. However, transcranial Doppler ultrasound is the method of choice to monitor blood flow velocities in patients after SAH. The role of CTA and MRA has not been determined in this subgroup of patients.

5.2.6.5 Cerebral Ischemia and Infarction

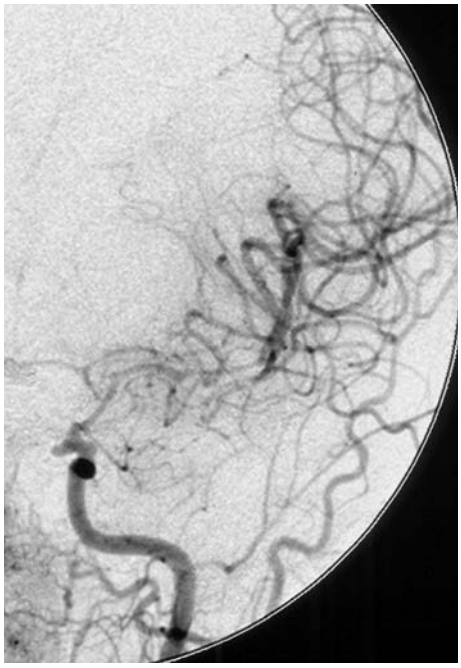
In some patients, aneurysmal rupture leads to a prolonged period of global cerebral ischemia at the time of hemorrhage, probably as a result of increased intracranial pressure to a level above that in arterial vessels (Grote and Hassler 1988). Clinically, these



a



b



c

Fig. 5.2.8a–c. Different grades of vasospasm after SAH. **a** Moderate vasospasm of the basilar artery and severe vasospasm of both P1 segments of the posterior cerebral artery. **b,c** Severe vasospasm of the intradural ICA (sagittal view) and proximal MCA and ACA (ap view)

patients present with progressive dysfunction of the brainstem. Outcome is generally fatal. CT might reveal no other abnormality than subarachnoid blood. This entity is quite distinct from delayed cerebral ischemia, which is focal or multifocal. A major factor for this condition of global cerebral ischemia is vasospasm that in some patients occur immediately after aneurysmal rupture. From our experience aneurysm rupture during endovascular therapy has more or less no consequence in those patients without immediate severe vasospasm. Morbidity and mortality of acute aneurysm rupture is probably most strongly associated with the amount and the length of acute vasospasms.

Delayed cerebral ischemia usually occurs in the first or second week after SAH in up to one-third of patients. Despite intensive research, the pathogenesis has not been entirely elucidated. Release of yet unidentified factors into the subarachnoid space are considered to induce vasospasm and subsequent cerebral ischemia.

There is widespread postulation of a close relationship between the amount of subarachnoid blood clots and the degree of vasospasm and delayed cerebral ischemia (Fisher et al. 1980). However, there are several arguments against these assumptions. Subarachnoid blood is not a predictor of vasospasm per se, since vasospasm and delayed cerebral ischemia rarely occur in patients with SAH after rupture of an AVM or perimesencephlic SAH. Furthermore, the site of delayed cerebral ischemia does not always correspond with the distribution of subarachnoid blood (Hop et al. 1999). The fact that many patients with angiographically visible vasospasms never develop cerebral ischemia suggests additional factors determining whether and where secondary cerebral ischemia occurs. There is additional evidence that it is not simply the amount of blood that determines the severity of vasospasm. Since there is no way to remove subarachnoidal clot during coiling one would expect a lower incidence of vasospasm after clipping. But this effect has not been observed. So far, there are slight tendencies towards a lower frequency of vasospasm after coiling (Yalamanchili et al. 1998).

5.2.7 Unruptured Aneurysms

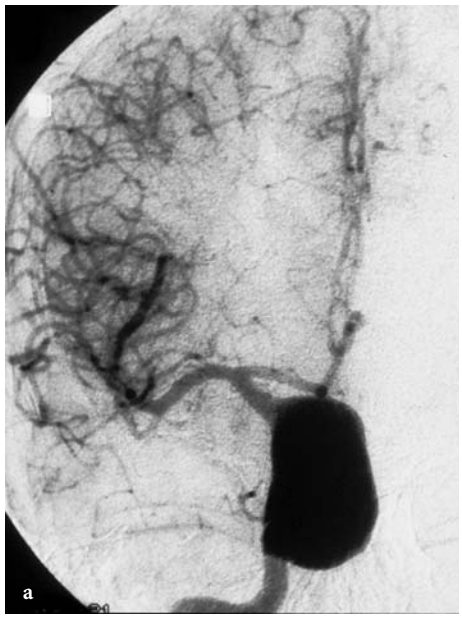
Asymptomatic aneurysms may be defined as additional aneurysms found in patients with another symptomatic aneurysm, which are not responsible for the clinical symptoms or those aneurysms found in patients investigated because they are at risk of harbouring an aneurysm. *Incidental* aneurysms may be defined as those found unexpectedly in patients undergoing investigation for any other suspected pathology. Depending on the location of an unruptured aneurysm it can be completely asymptomatic.

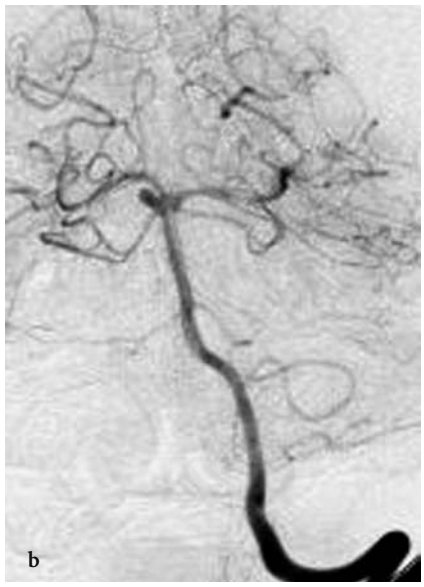
On the other hand, unruptured aneurysms can cause neurologic symptoms while touching cranial nerves or other cerebral structures. Symptoms can be pain, cranial nerve palsies, visual disturbances, dysesthesia, vertigo and seizures. In case of thrombembolism, mainly out of large or giant aneurysms, but also occurring in small aneurysms in any location, symptoms due to transient ischemia or permanent infarction do appear.

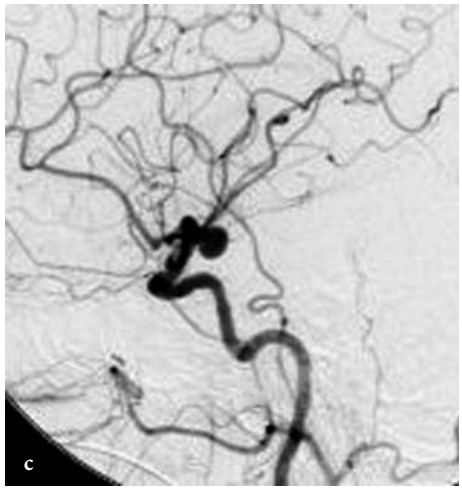
Ischemic events can occur distal to both small and large unruptured intracranial aneurysms (predominantly in the anterior circulation). In a series of 269 patients harbouring unruptured aneurysms ischemic strokes or transient ischemic attacks (TIAs) attributable to embolization from the aneurysmal sac were observed in 3.3% (Qureshi et al. 2000a). *Symptomatic* unruptured aneurysms are usually larger than incidental aneurysms and are often discovered near to the skull base where they are more likely to affect cranial nerves. The most frequent affected cranial nerves are the oculomotor nerve and the optic nerve.

Given the high mortality and morbidity associated with aneurysm rupture, it is crucial to determine the likelihood of rupture to decide whether to treat an aneurysm or not.

The findings of the International Study of Unruptured Intracranial Aneurysms (Wiebers 1998) were published in 1998 and in 2003. Up to now, the ISUIA is the largest evaluation of the risk of aneurysmal rupture. Examination of 2621 patient records at 53 medical centres over 7.5 years yielded an average annual rupture rates below those of previous estimates. Aneurysms less than 10 mm in diameter had an average annual rupture rate of 0.05% in patients with no history of SAH; however, the rupture rate was ten times higher for aneurysms of a similar size in patients with a history of SAH. The annual rupture rate for larger aneurysms approached 1%. However, there was a lot of criticism to that study. The authors included a large number of patients with aneurysms of the cavernous portion of the ICA. These aneurysms are usually large or giant, but due to their anatomical location they almost never cause a subarachnoid hemorrhage. Including a fairly high number of large aneurysms with almost no risk of SAH in a study cohort clearly leads to an overestimation of the critical aneurysm size. And it is a well accepted







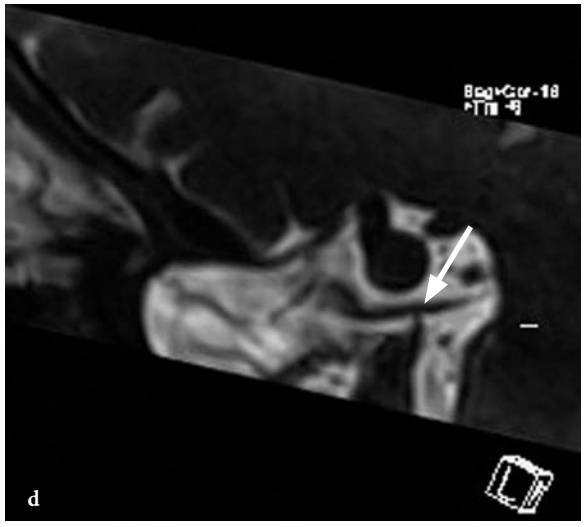


Fig. 5.2.9a–d. a Giant ICA aneurysm inducing optic nerve compression in a 10-year-old boy with visual deficit on the right eye. **b** Brain stem aneurysm between origin of the superior cerebellar artery and posterior cerebral artery resulting in right sided oculomotor palsy. **c, d** Pcom aneurysm (**c** DSA, lateral view) in a 46-year-old-patient with oculomotor palsy, note the close relationship of the aneurysm and the oculomotor nerve (*arrow*) but without visible contact (**d**, sagittal reconstruction of CISS sequence)

clinical experience that the majority of ruptured aneurysms are far below the ISUIA value of 10 mm; in our patient population the average aneurysms size in patients with SAH was between 4 mm and 7 mm. Very recently, the ISUIA group did redefine the critical aneurysm size from 10 mm down to 7 mm, indicating that the clinical impression and the evidence-based data are coming closer together (Wiebers et al. 2003). Nevertheless, all these results still do not explain why the majority of ruptured aneurysms are below the size of 7 mm! In our opinion there are at least two major drawbacks in the ISUIA study:

1 The criteria for or against treatment of an aneurysm remain unclear. Assuming that the majority of patients were seen and advised by experts, factors like multi-lobularity or hypoplastic vessel segments might have had a major impact on treatment decisions and thus heavily biased the results.
2 Another problem is the under-representation of Acom aneurysms and again the over-representation of those aneurysms located at the cavernous part of the ICA. Usually Acom aneurysms account for around 30% of all intracranial aneurysms, in the ISUIA study only 10% were located at that site. It may be that these aneurysms just develop, grow up to 4 mm and rupture. The cavernosal aneurysms are usually large and never – or at least rarely – do cause a SAH. This way the bias of these aneurysms is that they increase the average size of non-ruptured aneurysms.

5.3 Imaging

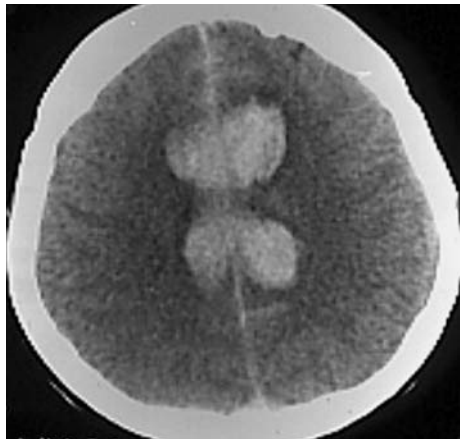
5.3.1 Computed Tomography

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 (van Gijn and van Dongen 1982). Intraparenchymal hemorrhage occurs with aneurysms of the posterior communicating artery and middle cerebral artery more frequently than with other locations. Interhemispheric or intraventricular hemorrhage, occurring in autopsy studies in about 50% of patients, is characteristic of Acom or distal anterior cerebral artery aneurysms. Ruptured PICA aneurysms almost always coexist with hydrocephalus and intraventricular hemorrhage in the fourth ventricle, which be can also seen on CT. Intracerebral hemorrhage is also more common in patients who rebled, since the first bleeding may lead 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.

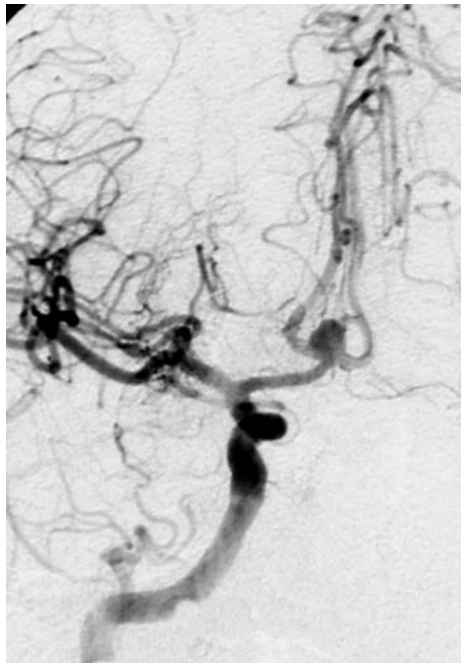
Small amounts of SAH may be overlooked, CT thus should be carefully read. However, even if the CT scan is really normal (no mis-reading!), aneurysmal SAH cannot be ruled out. The sensitivity of CT for detecting SAH depends on the volume of the extravasated blood, the hematocrit, and the time elapsed after the acute event. Using modern CT scanners and performed within 24 h after the ictus CT detects SAH in up to 95%. However, due to dilution by CSF the density of the hemorrhagel decreases rapidly over time, thus after only a few days it may be impossible to demonstrate subarachnoid blood on CT (van der Wee et al. 1995). Sensitivity of CT decreases to 80% at day 3, 70% at day 5, 50% at 1 week, and 30% at 2 weeks (Adams et al. 1983).

CT may also help to distinguish aneurysmal from traumatic SAH. In traumatic SAH the subarachnoid blood is usually located on the brain convexity. In patients with basal contusions there might be a pattern of hemorrhage resembling aneurysmal SAH due to a rupture of an aneurysm at the anterior part of the Circle of Willis. The same might be the case for hemorrhage into the Sylvian fissure. In these patients, in whom it is impossible to exclude aneurysmal hemorrhage or in whom the trauma might be a consequence of the initial aneurysm rupture, conventional angiography should be performed. In patients with Sylvian fissure hemorrhages (and without angiographically visible aneurysm) any imaging modality should be used to rule out sinovenous thrombosis.

Very rarely, massive brain edema and meningitis may mimic SAH on brain CT and may lead to a false positive diagnosis of SAH.

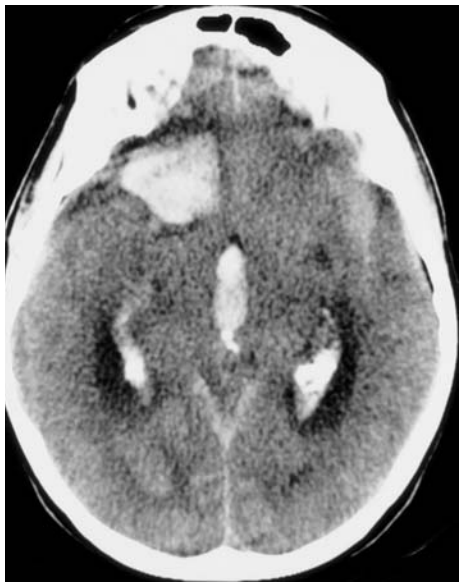


a

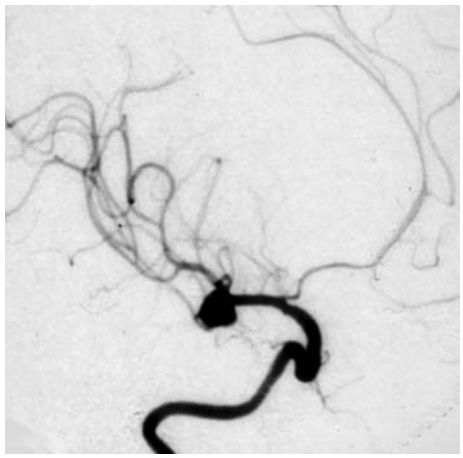


b

Fig. 5.3.1. a Massive subarachnoid and intraventricular hemorrhage. Even without any vessel visualization the pattern of hemorrhage on CT already suggests that the underlying cause will be an aneurysm of the anterior cerebral artery complex. **b** DSA reveals a typical Acom aneurysm filling from the right. The left A1 segment was hypoplastic

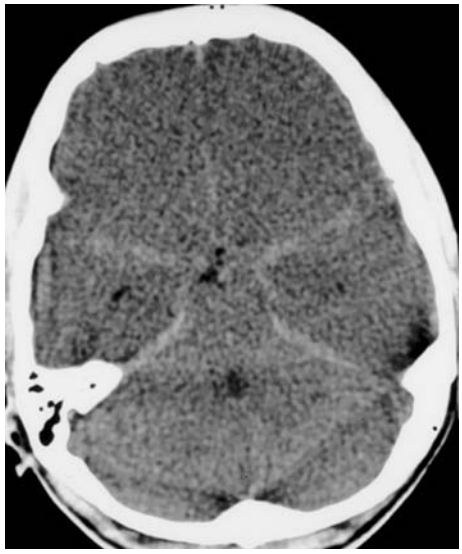


a

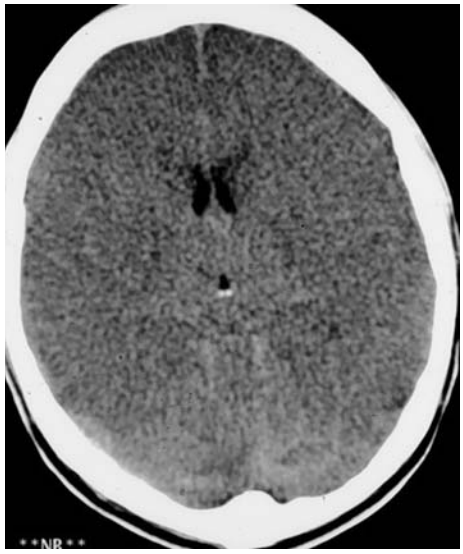


b

Fig. 5.3.2a,b. Sometimes it is more difficult to localize an aneurysm based on the bleeding pattern. **a** CT reveals frontal intracerebral hemorrhage, subarachnoid, and intraventricular hemorrhage. **b** DSA: The bleeding source in this patient was an MCA aneurysm



a



b

Fig. 5.3.3a,b. Severe hypoxia and brain edema mimicking basal SAH on CT

However, if CT is negative despite a convincing history of sudden headache, lumbar puncture is still the next diagnostic step to rule out SAH, if there is no contraindication such as bleeding disorder or space-occupying intracranial lesion (MacDonald and Mendelow 1988). Lumbar puncture should not be performed before 6 h after onset of headaches, preferably 12 h between onset of headache and spinal tap have elapsed. After this interval sufficient lysis of erythrocytes occurred to form bilirubin and oxyhemoglobin. These pigments give the CSF the "typical" xanthochrome yellowish tinge after centrifugation, an essential feature in the differentiation from traumatic SAH. This xanthochromia is invariably detectable until at least 2 weeks, usually 3 (in 70% of patients) to 7 weeks after SAH (Vermeulen et al. 1989).

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

rupture on the initial CT was correlated with the subsequent occurrence of vasospasm demonstrated by angiography. 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 (Fisher et al. 1980). 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 (Grosset et al. 1992; Findlay 1995; Jarus-Dziedzic et al. 2000; Suzuki et al. 1980). However, the predictive value of the Fisher grading system is not perfect. Never assume that a patient will not develop vasospasm just because he has a low Fisher score! All patients with SAH have to be carefully monitored during the first 2 weeks after the ictus, regardless of their initial CT score.

Table 5.3.1. Fisher's grading scale for SAH

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

Hijdra et al. (1990) suggested a new grading system for the amount of subarachnoid blood estimating separately ten subarachnoid cisterns and fissures and scoring on a scale of 0 to 3, as follows: 0 = no blood, 1 = small amount of blood, 2 = moderately filled with blood, and 3 = completely filled with blood. The total SAH score is then calculated by adding the scores of the ten subarachnoid compartments (total score 0–30) (Hijdra et al. 1990). Despite the excellent idea to use a more detailed scoring system to estimate the risk of vasospasm, it was not well accepted by the clinical community and does not play a relevant role in daily practise.

Aneurysmal rupture is followed by intraventricular spread of blood in up to 50% (Le Roux and Winn 1998). Solely primary intraventricular hemorrhage is usually associated with good outcome. The outcome is particularly better than in patients with a comparable volume of subarachnoid blood, indicating that the subarachnoid blood component is by far the most important determinant for clinical outcome (Roos et al. 1995).

In a study analyzing 219 patients with ruptured aneurysms Mayfrank et al. (2001) reported increased mortality and unfavourable outcome in patients with additional moderate and severe intraventricular hemorrhage, indicating that severity of intraventricular hemorrhage is an independent predictor of mortality and functional outcome.

5.3.1.1 CT Angiography

Selective catheter angiography is still the standard method for diagnostic work-up of intracranial aneurysms (see below). Although the risk of permanent neurologic complications in patients undergoing DSA for suspected cerebral aneurysms is low, this method remains time consuming and invasive. To identify patients with unruptured aneurysms among those with thunderclap headache, an accurate noninvasive vascular imaging technique would be of considerable interest.

Sensitivity of single-slice CT angiography in the investigation of intracranial aneurysms has been reported to range from 67% to 100% (Liang et al. 1995; Vieco et al. 1995) with an accuracy of approximately 90% and an interobserver agreement ranging from 75% to 84% (White et al. 2000). Nevertheless, this technique has demonstrated a limited sensitivity for aneurysms smaller than 3 mm (25%–64% compared with 92%–100% for aneurysms > 3 mm) (Korogi et al. 1999; White et al. 2000). 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 implementation 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. Wintermark et al. (2003) found sensitivity, specificity and accuracy values of multi-row CTA of 99%, 95.2% and 98.3%, respectively. The positive and negative predictive values on a per-patient basis were 99% and 95.2%, respectively. In aneurysms smaller than 2 mm sensitivity was 50%; in aneurysms larger than 2 mm sensitivity was 95.8%. The interobserver agreement was 98%. Multi-row CT technology will clearly make life easier at emergency departments. Patients with a first-time 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. However, whether CTA really will allow us to figure out which therapeutic modality is best suited still has to be determined. In our opinion there are drawbacks when describing the anatomy of the neck and the true relationship of tiny vessels originating near to the entrance of the aneurysm or adjacent to the aneurysm dome. However, CTA clearly plays a role in the pre-therapeutic 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.

Comparing CTA with the non-invasive competitor MRA there are pros and cons for both methods.

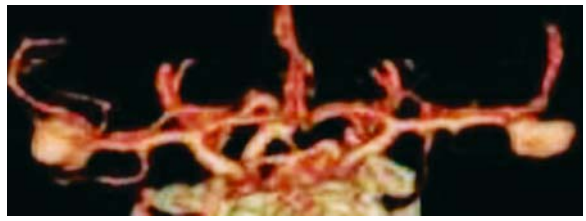
Patients with typical contraindications for MRA, such as ferromagnetic clips (Klucznik et al. 1993) or pacemakers, or patients on life-support devices and claustrophobia are usually candidates for CTA. CTA is more or less independent of flow rate, the images will be diagnostic even in patients with a low cardiac output, whereas in MRA this may lead to saturation effects. Flow-related artefacts seen in larger aneurysms on MRA are not seen with CTA. Additionally, CTA may depict aneurysm wall calcifications, for example at the neck, which might cause difficulties during clipping (Schwartz et al. 1994). CTA is more likely to be useful in patients after aneurysm clipping: there are reconstruction algorithms available allowing to reduce clip-related artefacts to a minimum and thus enabling us to decide whether the aneurysm is completely clipped or not (Brown et al. 1999; Vieco et al. 1996). On MRA, however, even the standard non-magnetic clips do cause severe field disturbances. Therefore, MRA is not a diagnostic tool for these patients. However, technical developments are on-going. Gonner and colleagues (2002) recently described a MRA technique with ultrashort echo times reducing clip artefacts significantly. The images are still not diagnostic, but progress is still going on.

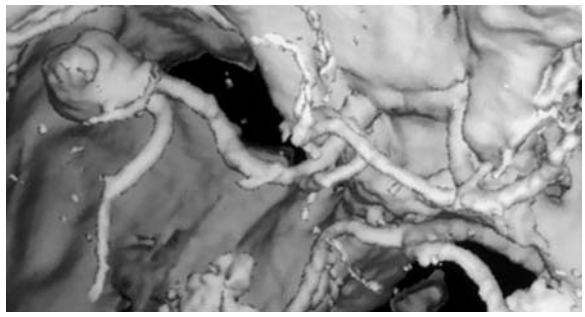
Patients treated with endovascular methods need angiographic follow-up. But coil artefacts preclude the use of CTA in these patients. MRA is clearly an excellent tool for patients with previously coiled aneurysms. In this patient group we think time-of-flight MRA (TOF-MRA) is the method of choice (Brunereau et al. 1999; Kahara et al. 1999; Weber et al. 2001). And there are limitations of CT due to artefacts at the skull base. Furthermore, CTA requires iodine contrast agent and is associated with radiation exposure, which is a significant drawback in using CTA for community screening, particularly if this needs to be performed several times during a patient's lifetime.

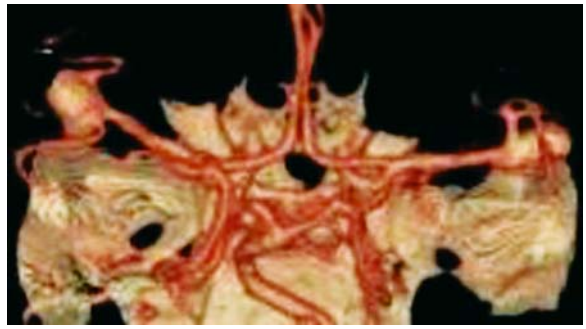
5.3.2 Magnetic Resonance Imaging

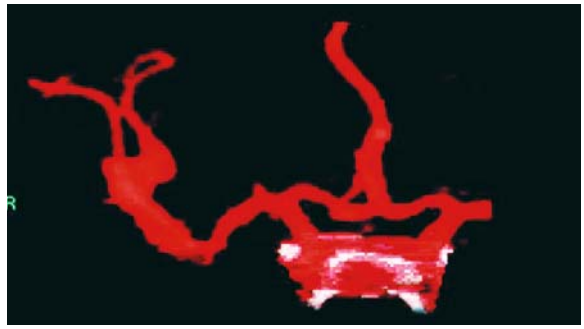
Magnetic resonance imaging and MR angiography are increasingly used in the diagnostic work-up of patients with cerebral aneurysms. However, MRI is less suitable than CT in patients with acute SAH because they are often restless and need extensive monitoring. It is used in patients with a negative angiogram 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.

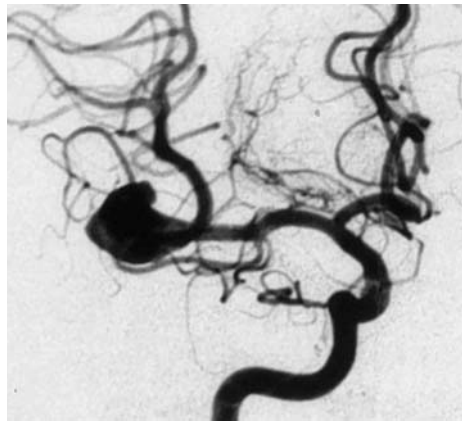
Conventional MRI sequences are less sensitive to SAH than CT scanning. Since SAH is mostly arterial in origin, the predominant form of hemoglobin is oxy-Hb. Immediately after the extravasation of blood into the subarachnoid space, there is a shortening in T1 due to the increase in hydration layer water 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 (Noguchi et al. 1995). 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 (Wiesmann et al. 2002). False-positive FLAIR results which may be caused by flow-related enhancement within the CSF may occur. However, this problem could be overcome with the interpretation of protondensity weighted sequences. 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 (Rumboldt et al. 2003).

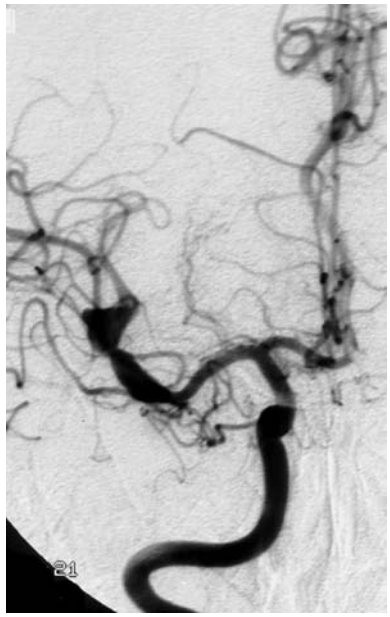

a


e


b


f


c


g

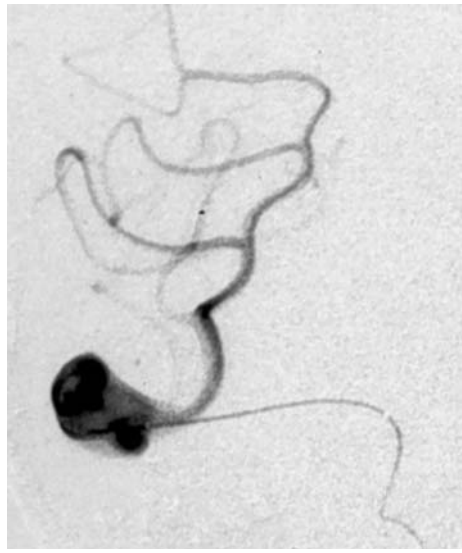
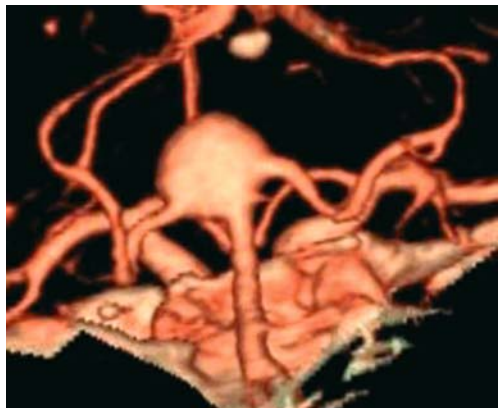
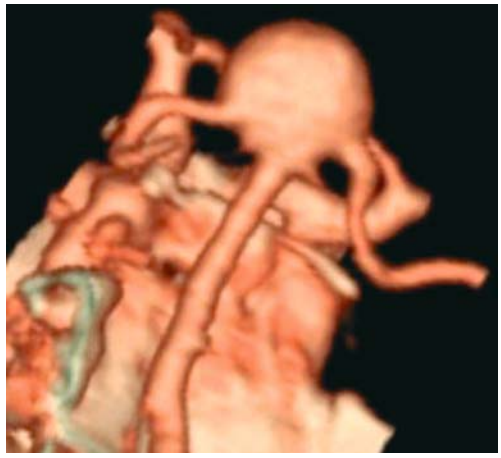

d

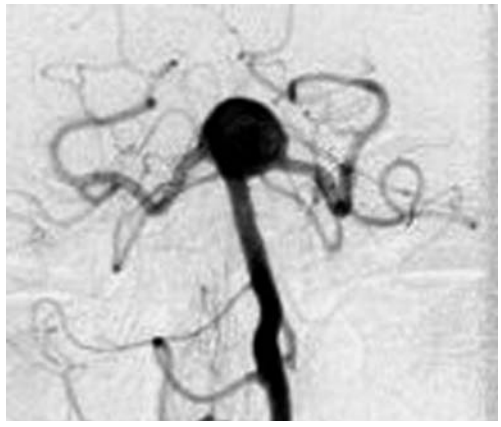
Fig. 5.3.4. a, b 3D CTA of bilateral MCA aneurysm and a small vertebral aneurysm. **c–e** DSA (ap view), aneurysmography and 3D CTA of a large MCA aneurysm demonstrating that one major MCA branch is originating very close to the neck of the aneurysm. **f, g** Fusiform MCA aneurysm: 3D CTA and DSA match perfectly. **h–j** Broad-based basilar artery aneurysm encroaching both P1 segments demonstrated on 3D CTA as well as on DSA. **k–m** Ruptured Pcom aneurysm (*arrow*)



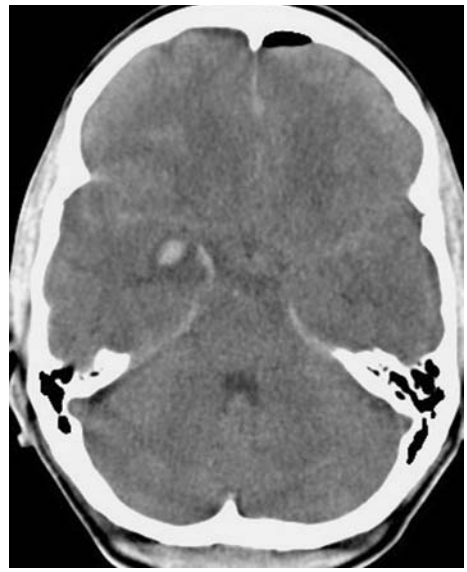
h



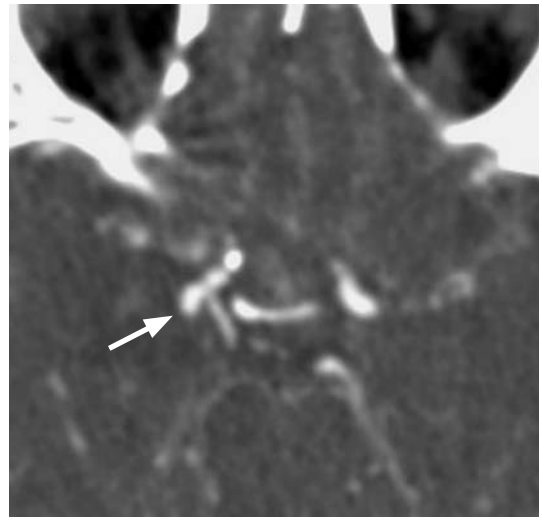
i



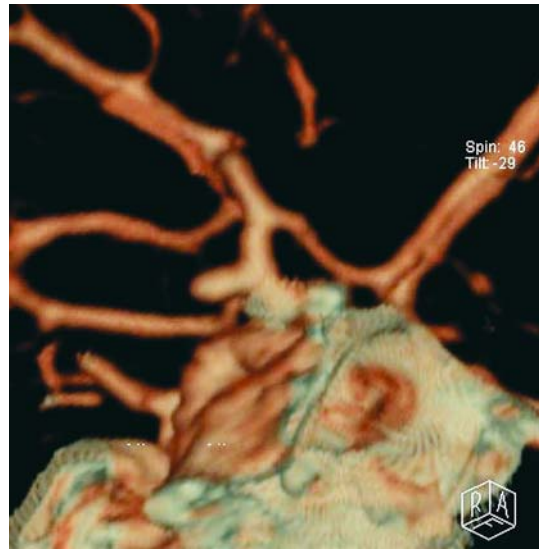
j



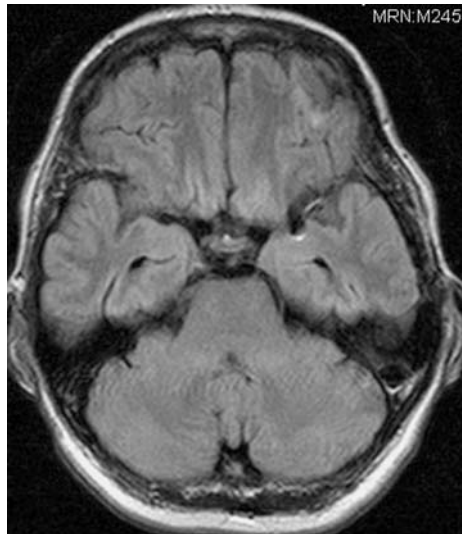
k



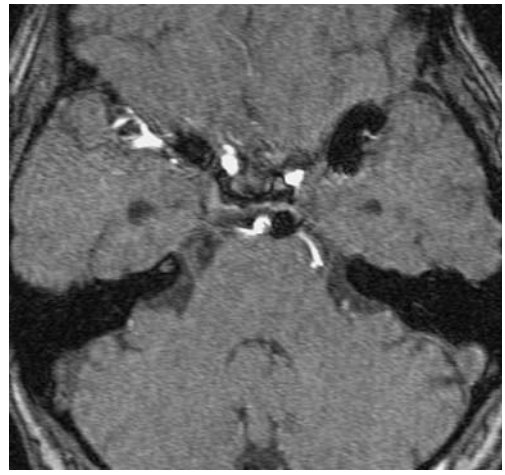
l



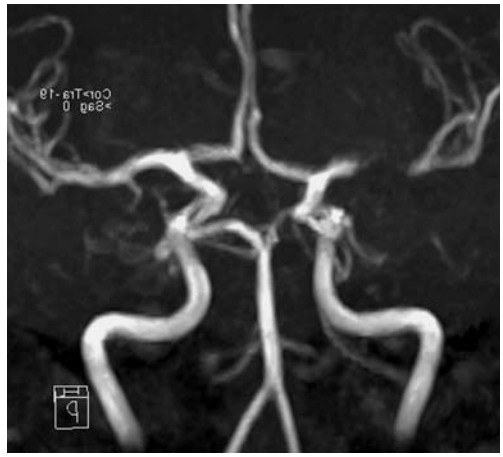
m



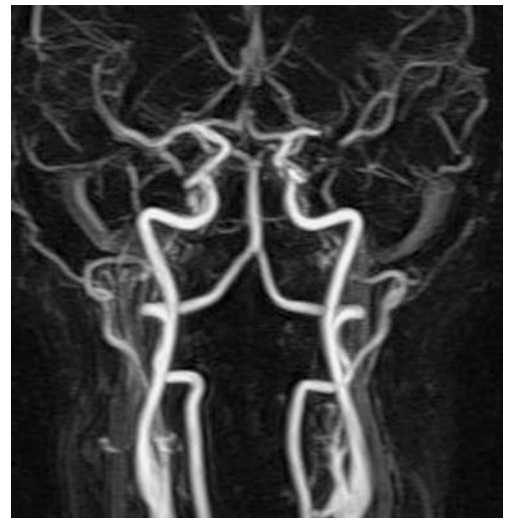
a



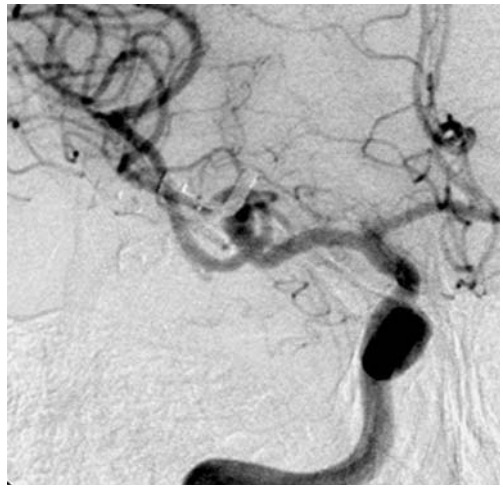
b



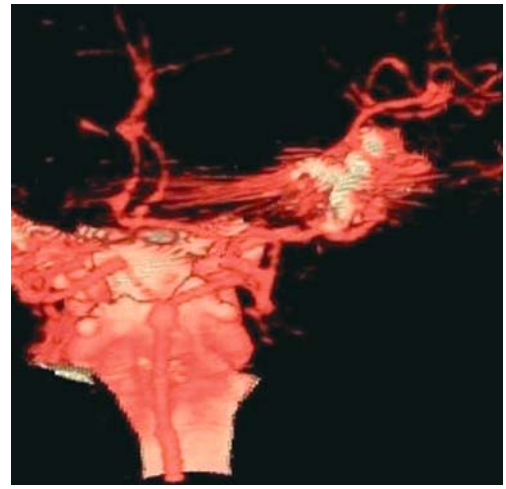
c



d

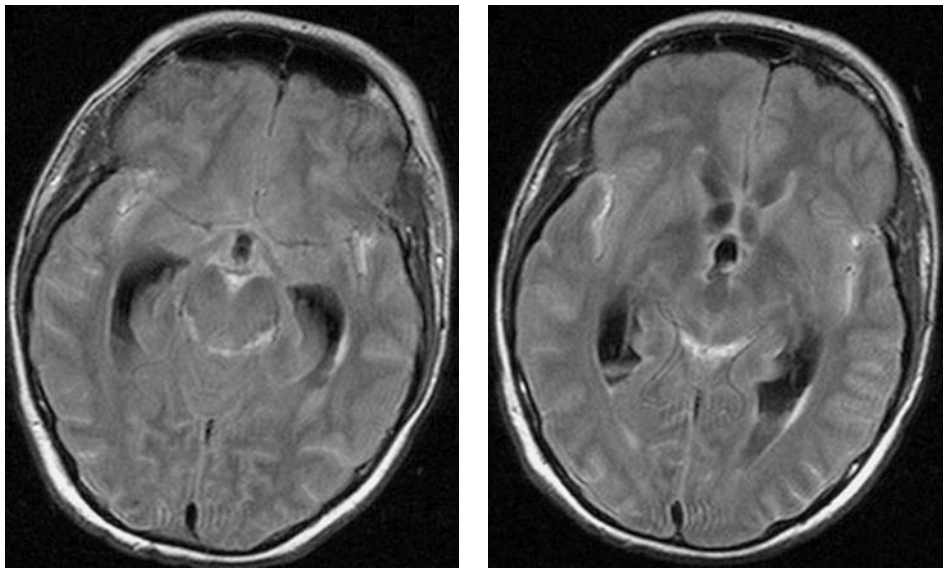


e



f

Fig. 5.3.5. a Flair sequence with some artefact after clipping of a MCA aneurysm on the left side. **b** Axial source image of the TOF-MRA reveals signal loss at the course of the MCA and next to the basilar artery after coiling of a left superior cerebellar artery aneurysm. **c** There is no flow signal on the 3D reconstruction images of the TOF-MRA as well as of the contrast-enhanced MRA. **d** DSA of an incompletely clipped MCA aneurysm. **e** Due to the artefacts caused by the clip 3D CTA is not useful in evaluating residual aneurysm after clipping



a b

Fig. 5.3.6. Flair Sequence demonstrating blood in the subarachnoid space around the brain stem and predominantly on the occipital surface and in the ventricles as well as acute hydrocephalus after rupture of a left vertebral aneurysm

5.3.2.1 Magnetic Resonance Angiography

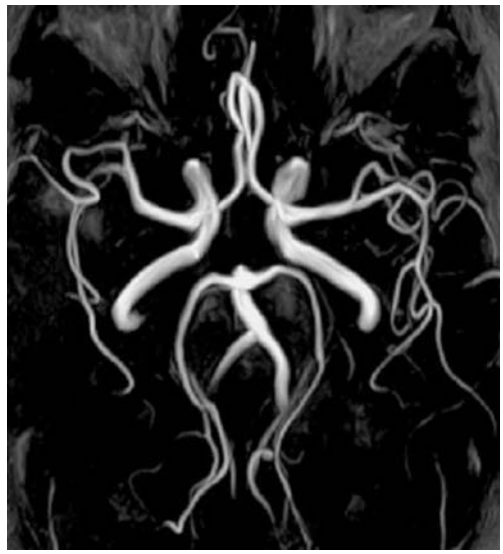
MR angiography provides a fast, accurate and non-invasive evaluation of intracranial aneurysms without the risk of conventional angiography. The TOF-MRA technique has an excellent spatial resolution and sufficient field of view, covering all relevant intradural arteries and can be performed within a reasonable acquisition time.

However, MRA has not replaced catheter angiography yet. The accuracy of MRA depends on how the images are processed and reviewed. Using maximum intensity projection alone sensitivity for identification of at least one aneurysm per patient was 75%, increasing to 95% when axial source and spin-echo images were reviewed as well (Ross et al. 1990).

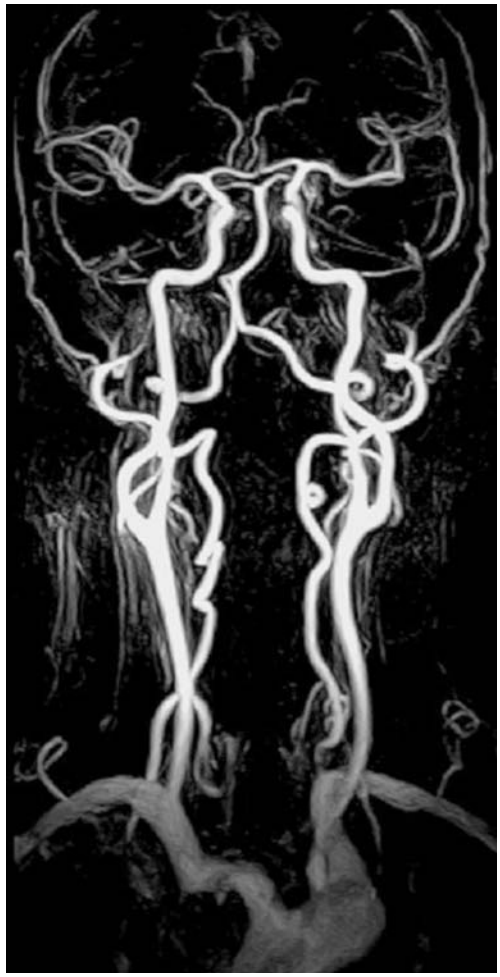
Aneurysm size is a crucial factor for sensitivity. MRA studies consistently indicate sensitivity rates of more than 95% for aneurysms larger than 6 mm, but much less for smaller aneurysms (Atlas et al. 1997). For aneurysms smaller than 5 mm, which constitute as many as a third of aneurysms in asymptomatic patients (Kojima et al. 1998) detection rates of 56% and less have been reported (Korogi et al. 1996). However, these aneurysms should not be ignored even if their rupture risk seems to be low (Wiebers et al. 2003). 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. The results of Atlas et al. (1997) and Korogi et al. (1996) reported problems in the identification of untreated aneurysms smaller than 3 mm in size. Therefore, TOF-MRA might not be reliable in patients with an aneurysm initially smaller than or equal to 3 mm. 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.

In a study comparing 3D TOF-MRA with intra-arterial DSA, Adams et al. examined 29 patients harbouring 42 intracerebral aneurysms. MR data were examined in different forms, i.e. axial source data, maximum intensity projection images, multiplanar reconstructions, and 3D isosurface images. Three aneurysms were not detected by MRA. These aneurysms were either smaller than 3 mm or in anatomically difficult locations (MCA bifurcation) or obscured by an adjacent hematoma. Time-of-flight techniques may obscure some anatomical details due to flow disturbances. The authors conclude that MRA is inferior to intraarterial DSA for pre-treatment assessment of intracranial aneurysms; however, MRA can provide complementary information to DSA such as intramural thrombus. If MRA is used analysis of both axial source data and reconstructed images is mandatory (Adams et al. 2000).

The study by Ronkainen et al. (1997) illustrates the current problems of non-invasive aneurysm imaging. Screening 85 families of patients with SAH using MRA, Ronkainen (1997) and colleagues found 58 aneurysms in 45 of 438 screened patients. Conventional angiogra-



a



b

Fig. 5.3.7. a Time-of-flight MR angiography of normal intracranial vessels and (**b**) contrast-enhanced MRA technique with a large field-of-view covering all vessels from the aortic arch to the circle of Willis

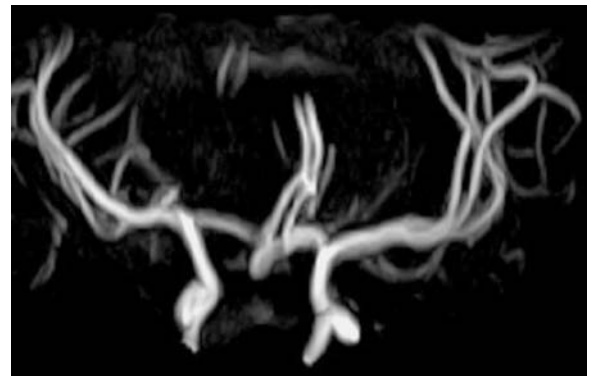


Fig. 5.3.8. TOF-MRA of a small Acom aneurysm

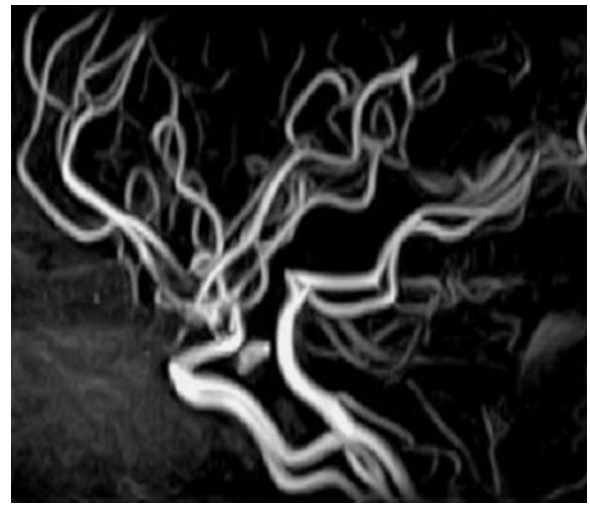


Fig. 5.3.9. TOF-MRA of an ICA/Pcom aneurysm. MRA even reveals that the aneurysm has a small neck and is suitable for endovascular therapy

phy was performed in 43 of these 45 patients, revealing that seven of these 43 did not have an aneurysm (MRA false positive), and the remaining 36 actually had 60 aneurysms (13 of which had been missed on MRA false negative). The true positive rate for MRA was 78%, the false positive rate was 15% and the false negative rate was 22%. Positive predictive value was 87%, but since 395 subjects did not undergo conventional angiography, the true negative rate and negative predictive value cannot be calculated for the whole study. Okahara et al. (2002) compared MRA with DSA in 133 patients with aneurysms. This study is of particular interest because the authors mainly focussed on evaluation of the images by a neuroradiologists, a neurosurgeon, a general radiologist and a resident in neuroradiology.

This study clearly has more clinical impact than many others done before. The diagnosis is not made by the technique – not surprising, but never mentioned with such evidence – but is dependent on the skills of the reader. The results were as follows: 79% of aneurysms were detected by the neuroradiologist, 73% by the neurosurgeon, 63% by the general radiologist and 60% by the resident in neuroradiology. Again, 3 mm was a crucial size of aneurysms: below that size, it seems to be very difficult to get reliable results.

Despite all these mentioned limitations – and we have given details about these studies, because the scientific community is still discussing this problem without an evidence based solution – MRA is increasingly used for screening of aneurysms (Kojima et al. 1998), especially in families of SAH patients.

However, another excellent indication for MRA is clearly follow-up in patients who had endovascular aneurysm treatment before. It is increasingly accepted that MRA techniques in this patient subgroup are sufficient enough to detect those aneurysm recanalizations that require retreatment. In addition to TOF techniques contrast-enhanced MR angiography is a complementary tool to visualize supraaortal and intracranial arteries. The spatial resolution is still lower than with TOF, acquisition time is much shorter (down to 12 s for a 3D data set) and the FOV covers the whole area from the aortic arch to the circle of Willis. However, up to now we do not have exact data about sensitivity and specificity of this technique in aneurysm patients.

Present indications for MRA 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)
- Contraindications for conventional angiography
- 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)

5.3.4 Cerebral Angiography

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 after SAH. Considering that the risk of rehemorrhage is highest in the first 24 h (4%), an early angiogram is crucial for any therapeutic decision and for the patient's outcome.

Cerebral angiography can localize the lesion, reveal aneurysm shape and geometry, determine the presence of multiple aneurysms, define 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 the 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 Acom, if necessary. Additional views may be necessary to optimize demonstration of the aneurysm neck. If no aneurysm is found, selective catheterization 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 patency, size and collateral potential of the P1 segment of the PCA and the posterior communicating artery ipsilateral to the carotid artery compressed.

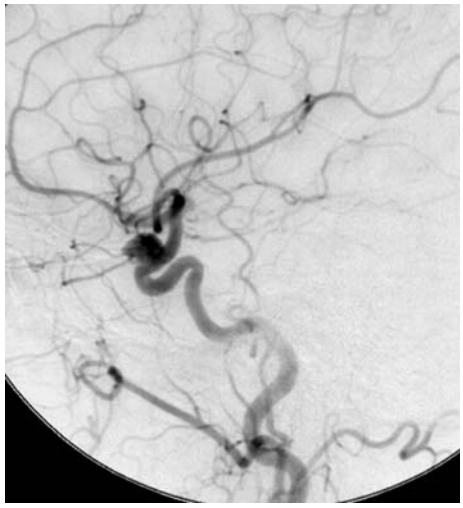
As a prerequisite to angiography, survey of renal function and coagulation factors is required in all patients. Digital subtraction angiography technique is necessary, biplane angiography facilitates the diagnostic workup and is useful for safe and fast therapeutic interventions. It shortens examination time and increases the safety during aneurysm obliteration. High-quality fluoroscopy and roadmapping are essential to perform intracranial interventions.

5.3.4.1 3D Rotational Angiography

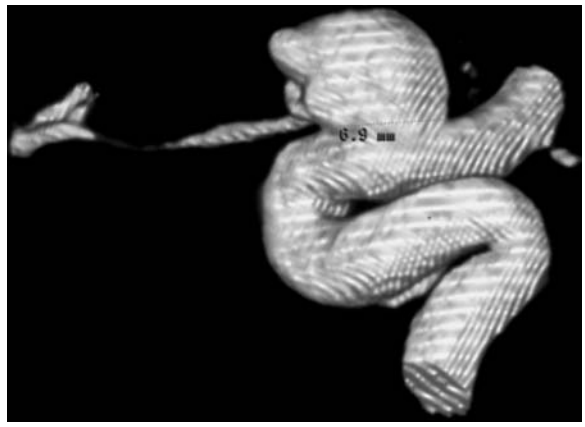
The precise visualization of the aneurysm neck, the shape and the size of the aneurysm, and its relationship to parent vessels are important factors for endovascular therapy. Rotational angiography in a 2D or 3D mode is available on most new generation neurointerventional angio suites and represents a valuable supplement to standard biplane DSA. Using rotational angiography multiple oblique views are obtained as source for 3D reconstruction. Data acquisition consists of a rotational mask followed by a second run during contrast injection. During data acquisition the C-arm rotates in a continuous 200°

arc around the patients's head placed in the isocenter (Fahrig et al. 1997). Rotational angiography helps to define the aneurysm neck, find the appropriate working position and perform accurate measurements. 3D angiography thereby improves planning of surgical and interventional procedures, especially in complex aneurysms (Anxionnat et al. 2001). However, even the highest standard 3D DSA techniques cannot always precisely describe the exact anatomy of the neck and the exact relationship of tiny adjacent vessels to the aneurysm dome and neck. As an interventionalist you still have to rely on your experience and – sometimes – on superselective catheterization of the aneurysm itself. And sometimes you have to combine it with temporary coil placement without subsequent detachment.

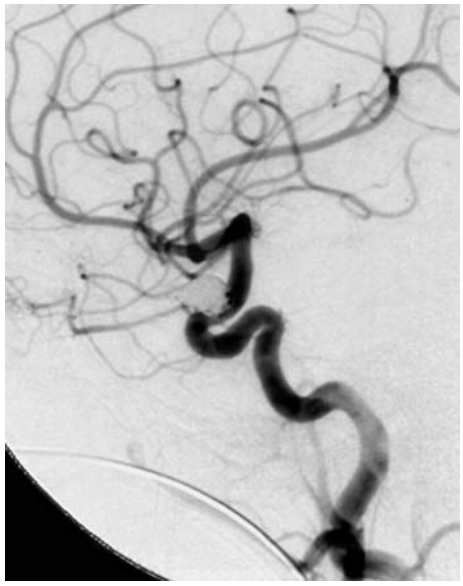
Stroke complication rate for diagnostic angiography at our institution is less than 0.5%, comparable to other major interventional centres across Europe and the US (Heiserman et al. 1994). Thus the risk: benefit ratio still justifies conventional angiography in the diagnostic management of aneurysms. Other complications may include allergic reaction to contrast agent, renal failure, bleeding at the puncture site. In fact, incidence of allergic reaction seems to be very low (we did not see a single instance during the last 6 years) and bleeding complications will probably further decrease with the availability of specific devices allowing a "surgical" closure of the puncture site. Aneurysm rupture during angiography is reported in less than 3% of patients investigated with SAH. "Less than 3%" is correct, but for us it



a

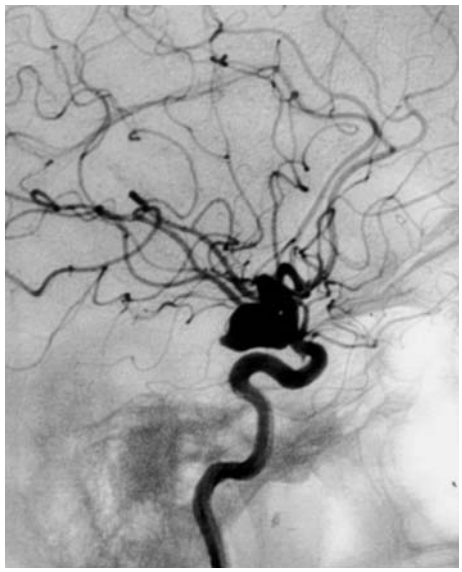


b



c

Fig. 5.3.10. a Paraophthalmic aneurysm. **b** On 3D rotational DSA the ophthalmic artery is assumed to originate from the aneurysm, but after complete occlusion of the aneurysm this vessel remained patent (**c**)



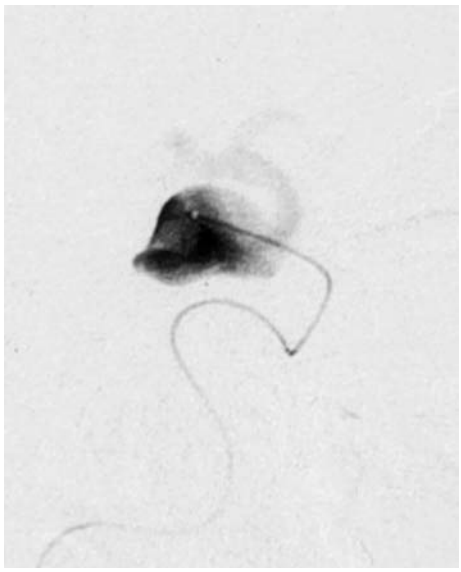


Fig.5.3.11. a ICA aneurysm. **b** Aneurysmography: selective angiography with the tip of the microcatheter placed within the aneurysm

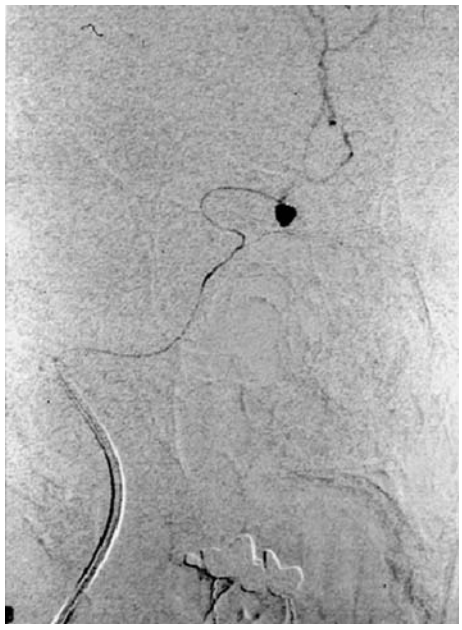


Fig. 5.3.12. Aneurysmography of a small Acom aneurysm

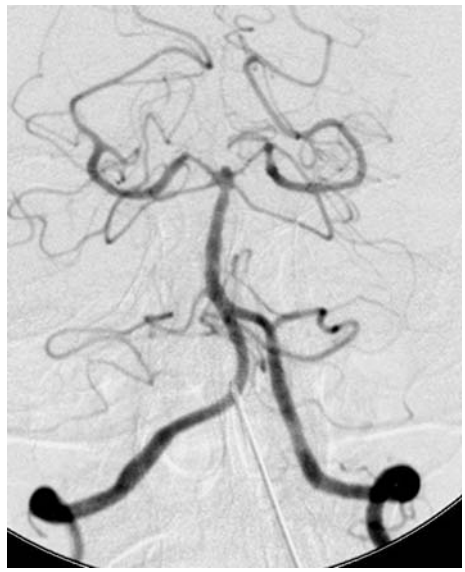
sounds higher than reality shows. In our institution, and now studying about 200 patients per year with intracranial aneurysms, we have not seen an aneurysm rupture during diagnostic angiography in the last 6 years.

The risk of aneurysm rupture, however, may be increased during superselective aneurysmography. Superselective angiography with the tip of the microcatheter placed within the aneurysm and gentle injection of contrast may be helpful in demonstrating morphological details of the entire aneurysm, especially concerning the identification of vessels arising from the aneurysm. Gailloud et al. (1997) reported a posterior perforating artery originating from the dome of a basilar tip aneurysm identified only by selective aneurysmography.

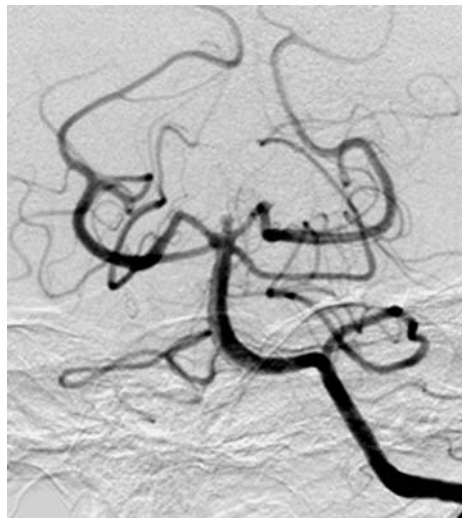
5.3.5 Patients with SAH of Unidentifiable Cause

If the initial angiography is negative despite aneurysmal pattern of hemorrhage, repeated angiography within 2–3 weeks is clearly indicated. Cranial or spinal MRI may be indicated to exclude other sources of hemorrhage. The risk of rebleeding is up to 10% (Canhao et al. 1995). There might be several explanations for the missing radiological detection of an aneurysm: apart from technical limitations such as insufficient projections, vasospasm, aneurysm thrombosis or obliteration of the aneurysm by pressure of adjacent hematoma might contribute to the failing radiological demonstration. If a second angiogram also fails to reveal the suspected aneurysm a third angiography might be indicated after an interval of several months and may then demonstrate the aneurysm (Rinkel et al. 1991).

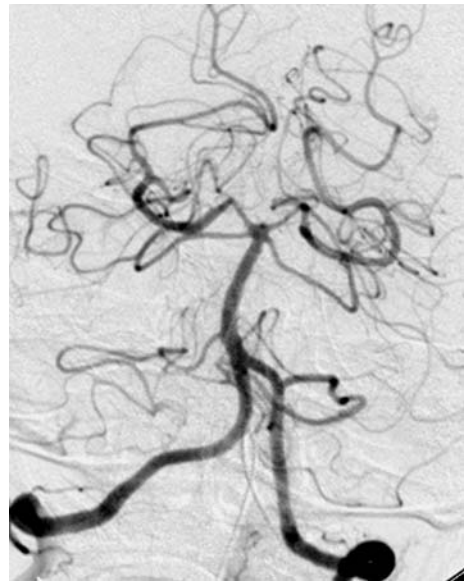
If cerebral angiography is negative in a pattern of perimesencephalic hemorrhage the diagnosis of non-aneurysmal hemorrhage should be established and no repeat studies are needed.



a



b



c

Fig. 5.3.13. Patient after SAH with a basilar tip aneurysm seen on CTA in an outside hospital. **a** Initial DSA did show vasospasm of the P1 segment and the superior cerebellar artery on both sides. In addition, some irregularity at the tip of the basilar artery was noted but no real aneurysm. **b** Repeated DSA 2 months later showed a small basilar tip aneurysm suitable for endovascular treatment. **c** The patient was scheduled for embolization 10 days later but the aneurysm again was not visible. The patient was referred to surgery

5.3.5.1 Screening

Screening for a cerebral aneurysm is indicated in patients in whom the risk of investigations to detect and treat the aneurysm is less than the risk of the natural history of the aneurysm. The natural history, however, is not clearly defined. Screening has been recommended for first-degree relatives of a family member with two or more aneurysms and for patients with autosomal dominant polycystic kidney disease (Schievink 1997; Schievink et al. 1997). In identical twins with one suffering SAH, the risk of harbouring an aneurysm is increased in the other and screening is also indicated.

5.3.6 Transcranial Ultrasound

Transcranial Doppler sonography (TCD) has proved to be a suitable non-invasive technique for measuring cerebral blood flow velocity in large cerebral arteries. The technique of TCD can be combined with duplex imaging and with colour coding. Colour TCD ultrasound became available in the early 1990s, with some success at identification of aneurysms (Becker et al. 1992). A recently developed technology of colour coded Doppler, i.e. colour Doppler energy or power Doppler, showed a significant greater sensitivity to flowing blood than standard colour flow imaging (Wardlaw and Cannon 1996).

However, in the detection of cerebral aneurysms power TCD is less sensitive than other non-invasive techniques such as CTA and MRA. Especially in small aneurysms of less than 6 mm sensitivity is very poor (0.35), the internal carotid artery is the most difficult segment to interpret on ultrasound (Griewing et al. 1998; White et al. 2001). Additionally, insonation of the MCA is inadequate or even not possible in 5%–20% of all patients because of insufficient ultrasound transmission through the skull (White et al. 2001). Although the technique is quick, safe, inexpensive and non invasive, it is highly dependent on the skills of the operator. At the moment, TCD for the detection of cerebral aneurysms is only of scientific interest and cannot be recommended for routine use. In fact, it does not play any role in the diagnostic work-up of SAH patients nor in screening.

5.4 Therapy

5.4.1 General Considerations

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. Just over 20 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 (Guglielmi et al. 1991ab), 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 (Brilstra et al. 1999). Permanent procedural complications occurred in 3.7% of 1256 patients. More than 90% occlusion of the aneurysm was achieved in around 90% of patients. The most frequent procedural complication was cerebral ischemia, the second most frequent complication was aneurysm perforation, which occurred in about 2% of patients. Rerupture of angiographically successful coiled aneurysms may occur, long-term rates of rebleeding after endovascular coiling still need to be established. In 2002 the results of the ISAT study were published; the clear benefit of the endovascular treated patients will definitely change treatment strategies for patients with intracranial aneurysms (Molyneux et al. 2002). The endovascular approach will become the first line treatment option, whenever this option is available. ISAT represents a landmark in the evolution of aneurysm treatment and, therefore, a more detailed discussion of these results seems justified.

5.4.2 The ISAT Study

ISAT was a randomised, prospective, international, controlled trial of endovascular coiling versus surgical clipping for a selected group of patients with ruptured intracranial aneurysms deemed suitable for both types of therapy. Most patients were treated at high-volume centres in the United Kingdom, with the remainders from other European countries, Australia, Canada, and the United States. The primary endpoint was patient outcome, defined as a modified Rankin scale of 3–6 (dependent or deceased) at 1 year. The primary hypothesis was that endovascular treatment would reduce the proportion of patients dependent or deceased by 25% at 1 year. A total of 9559 patients with SAH were screened and around one quarter (n = 2143) were randomly assigned to both treatment groups. Those patients who were screened but not randomized were treated surgically in 39%, endovascularly in 29% or by an unrecorded therapy (11%). Most randomized patients had aneurysms located at the AcomA or intracranial ICA. A total of 94% of randomised patients were in good condition (WFNS grades I–III). The study was prematurely stopped after the results of a planned interim analysis were available: at 1 year, 23.7% of the patients allocated to endovascular treatment were dependent or dead, as compared with 30.6% of patients in the surgical group. Later on, the study group reported the revised outcome results with an even greater absolute risk reduction of 8.7% and a relative risk reduction of 26.8% for coiling over clipping (Kerr and Molyneux 2003). The results of the ISAT study were not readily accepted, particularly not in the neurosurgical community. We strongly recommend reading the statement written by the Executive Committee of the American Society of Interventional and Therapeutic Neuroradiology and the American Society of Neuroradiology (Derdeyn et al. 2003). The authors answer a lot of frequently asked questions about ISAT.

A major issue is the durability of aneurysm occlusion after coiling. It is true that long-term durability of endovascular therapy remains to be determined.

The present data, however, suggest that it is very unlikely that late aneurysm rebleeding will occur at a rate that would significantly affect the difference in outcome between surgery and coiling. The ISAT data indicate a risk of rebleeding after 1 year of 0.16% patient-years of follow-up. Thus it would take more than 40 years to overcome the benefit seen at 1 year with endovascular treatment.

Another major issue was the doubt about the competence of British neurosurgeons. However, they were very experienced – just looking at the numbers of patients they treated – and their results pretty much matched the results of the tirilazad study, a prospective multicenter study, mainly involving US neurosurgeons (Haley et al. 1997; Lanzino and Kassell 1999). In this study, in the 3-month follow-up, 9.2% of the grades I–III patients had died. In ISAT 8.3% of the surgically randomised patients were dead at 2 months, increasing to 10.1% at 1 year. Incidentally, similar data were reported from the European and Australasian arm of the tirilazad study (Lanzino et al. 1999a).

The low randomization rate is another point of criticism: randomization rates were less than 40% in NASCET and less than 4% in ACAS. ISAT is within the range of randomization rates given by other large studies. There is absolutely no indication that the randomisation rate could affect the final result.

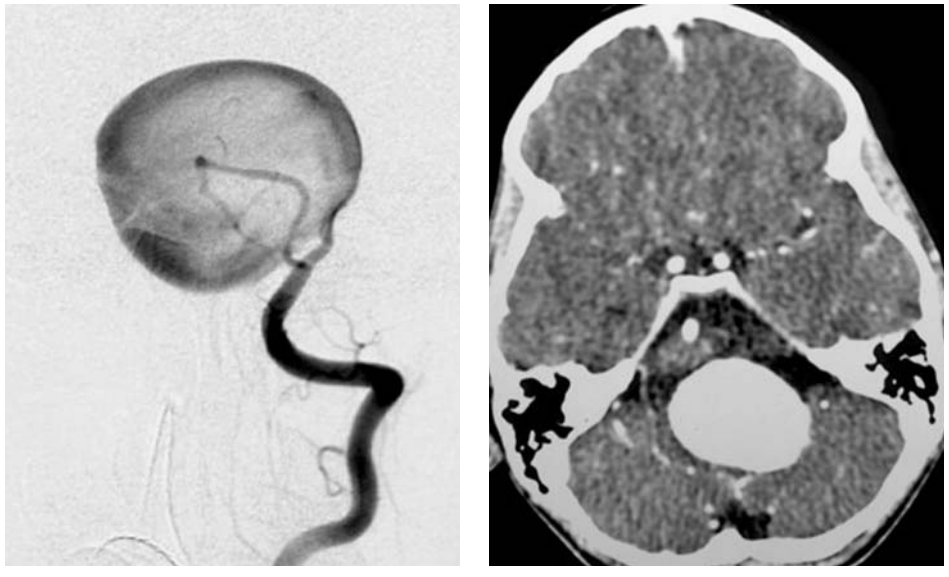
Beside these frequently asked questions there are a number of important implications of ISAT: ISAT will significantly change our policy for patients with unruptured aneurysm. We look ahead for those meta-analyses based on the treatment results of ISAT.

Since ISAT it is mandatory that all patients should be seen by a neurointerventionalist to decide whether the aneurysm is suitable for coiling or not. If one treatment is recommended over another, the reasons for this decision should be documented as in accordance with the usual standards for informed consent. Furthermore, the ISAT data add support for the treatment of patients with aneurysmal SAH in high-volume centres that offer both surgery and endovascular therapy.

5.4.3 Treatment of Unruptured Aneurysms

This is still a controversial topic and up to now there is still no total agreement about indications. First of all, the easiest parts: There are two groups of unruptured aneurysms, asymptomatic aneurysms detected incidentally and those causing clinical symptoms due to compression of nerval structures or emboli arising from the non-ruptured sac. The former group also includes those aneurysms detected during angiography in patients with SAH with an aneurysm in another location.

The management of unruptured aneurysms remains controversial and depends on a full understanding of their natural history balanced against the risks of treatment and long-term protection afforded.



a **b**

Fig. 5.4.1. Giant vertebral aneurysm in a 9-year-old boy with nausea and vomiting due to brain stem compression (**a**, DSA ap view; **b**, axial contrast-enhanced CCT)

Aneurysm prevalence in the general population shows wide variation. However, in those with a family history of SAH, the prevalence of unruptured aneurysms has been reported from 10% to 13% (Kojima et al. 1998). And, detection of aneurysms during life is increasing due to increased use of accurate imaging methods and due to screening programs introduced, e.g. in Japan. In summary, unruptured aneurysms will be identified with regularity in most units involved in neuroimaging and the management of these patients is a universal problem.

Unfortunately, unruptured aneurysms are a heterogeneous entity, both in terms of morphology and behaviour, e.g. tendency to rupture. This is in part reflected in the extreme variation in reported rupture risk in the literature between 0.05% and 5% a year (Wiebers 1998; Wiebers et al. 1981).

Aneurysm size seems to be an important factor to predict the risk of rupture: ISUIA part one tried to teach us that 10 mm is a critical size. Smaller aneurysms (without a history of SAH from another aneurysm) had a rupture risk of 0.05% per year. There was a lot of criticism about this study, mainly because the daily experience of nearly all physicians treating aneurysmal SAH patients is, that the vast majority of ruptured aneurysms are less than 7 mm in size. The second part of the ISUIA study – published in July 2003 – came out with a slightly different result: the critical size of the aneurysm was downsized to 7 mm and there were certain locations with an increased risk of rupture per se: Posterior circulation aneurysms and those aneurysms arising from the posterior communicating artery (Wiebers et al. 2003).

Table 5.4.1. 5-Year cumulative rupture rates of intracranial aneurysms (Wiebers et al. 2003)

Size/location	<7 mm	7–12 mm	13–24 mm	>25
ICA/AcomA/ ACA/MCA	0%	2.6%	14.5%	40%
PcomA/Posterior circulation	2.5%	14.5%	18.4%	50%

Other studies found the incidence of rupture of all coincidental aneurysms to be between 1% and 3.2% per year, with hypertension and aneurysm multiplicity being specific risk factors (Winn et al. 1983; Yasui et al. 1997). Other factors for a higher probability of rupture include: multilobular aneurysm morphology (Hademenos et al. 1998), posterior location (Hademenos et al. 1998; Rinkel et al. 1998; Wiebers et al. 2003), symptoms related to mass effect, and female sex, smoking and hypertension.

A striking observation in many studies on unruptured aneurysms is that Acom aneurysms are generally underrepresented. One possible explanation is that these aneurysms have a different natural history; they may form and subsequently rupture rapidly so that the opportunity to detect these as unruptured lesions is limited. If this explanation is true, the ISUIA findings (see Table 5.4.1) have to be interpreted with much more care than previously.

The early and late outcome after surgery of unruptured aneurysms is well documented in the literature. A meta-analysis by Raaymakers et al. (1998) of 61 studies on 2460 patients with 2568 clipped aneurysms showed a permanent morbidity of 10.9% and mortality of 2.6% with the best results in small and anterior circulation aneurysms. A study by Johnston et al. (1999a) compared the clinical outcomes of patients who had unruptured aneurysms treated by surgery and endovascular therapy. Morbidity was significantly higher in the surgical group (18.5%) than in the endovascular group (10.6%). Mortality was 2.3% after surgery and 0.4% after coiling. A further study by the same authors showed improved clinical outcomes, shorter hospital stay, shorter recovery period, reduced costs and reduced long term symptoms in those patients treated with coil embolization (Johnston et al. 2000). Technical feasibility in over 90% in our patient group and in those of other authors with a high occlusion rate justify comparison with neurosurgical data on unruptured aneurysms (Murayama et al. 1999; Wanke et al. 2002). We had a morbidity of 4.8%, mortality was zero (Wanke et al. 2002). Murayama et al. (1999) reported a morbidity of 4.3% in a total of 109 patients after endovascular treatment of unruptured aneurysms, with no morbidity in the last 65 patients. Comparisons between surgical and endovascular treatment of unruptured aneurysms demonstrated that the costs treating an unruptured aneurysm are significantly lower than treating patients with SAH regarding length of hospital stay and sequelae of morbidity (Johnston et al. 1999a,b, 2000; Murayama et al. 1999; Wardlaw and White 2000; Wiebers et al. 1992). By comparing the results of surgical clipping and coil embolization of 60 university hospitals, Johnston et al. (1999) reported significant higher costs ($43.000 vs. $30.000) and significant longer hospital stay (9.6 days vs. 4.6 days) for the surgical cases. All these facts encourage us to use the endovascular route instead of clipping in the vast majority of patients with unruptured aneurysms.

In cases of a ruptured aneurysm in another location the relative risk of rupture of an additional nonruptured aneurysm is higher than without a history

of SAH (Wiebers 1998) and, therefore treatment is indicated. However, in this specific subgroup there are different opinions about the best strategy (Inagawa et al. 1992; Mizoi et al. 1995; Raaymakers et al. 1998; Wiebers 1998; Wiebers et al. 2003). The MARS group analyzed risk and benefit of screening for intracranial aneurysms in first-degree relatives of patients with SAH (626 first-degree relatives). 18 out of 25 patients with aneurysms had neurosurgical clipping of their unruptured aneurysm, none of them had endovascular therapy. They conclude that screening is not warranted at this time since the slight increase in life expectancy does not offset the risk of postoperative sequelae (Raaymakers 2000). Wardlaw and White (2000) concluded that the indication and cost-effectiveness of screening for aneurysms is totally unclear because prevalence varies, rupture rate is still unclear and non-invasive imaging modalities are not yet accurate enough to exclude aneurysms smaller than 5 mm. The major drawback of all these studies is that the results of endovascular treatment in unruptured aneurysms were not taken into account. More recently, Hoh et al. (2003) established that endovascular treatment of unruptured aneurysms has an average mortality of 1.7% and morbidity of 7.6%. However, mortality rate was lower at high-volume hospitals (1% versus 3.7%), morbidity at hospitals with high referral rates was 5.2% versus 17.6% for hospitals treating less than four unruptured aneurysms per year. In addition,

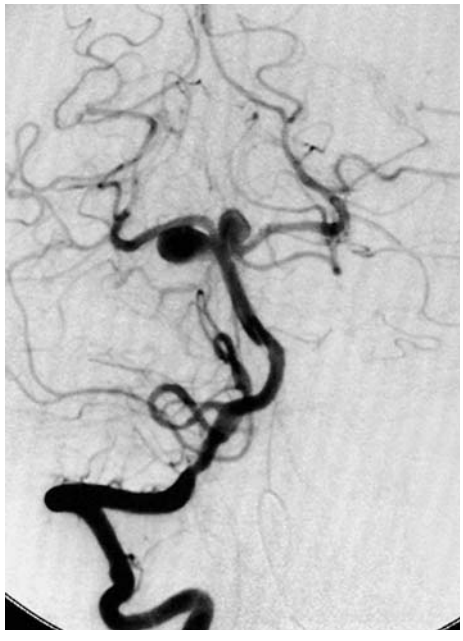


Fig. 5.4.2. Distal basilar artery aneurysms in a patient with right-sided oculomotor palsy

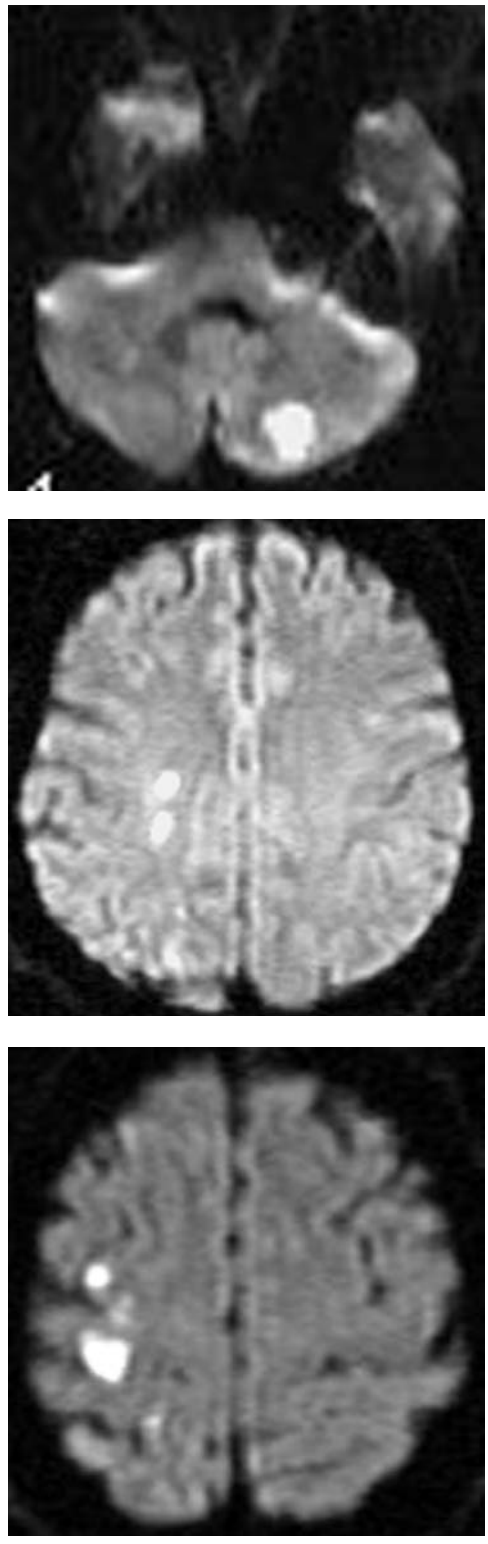


Fig. 5.4.3a–c. a DWI with silent small infarct of the PICA after embolization of a left vertebral aneurysm. **b, c** DWI showing small acute cerebral infarctions in the territory of the MCA after embolization of an unruptured right paraophthalmic aneurysm; the patient had no neurological symptoms

at high volume hospitals length of stay was shorter and total hospital charges were significantly lower. In conclusion, their recommendation to patients with unruptured aneurysms is to look for high-volume hospitals and physicians treating a high number of patients (Hoh et al. 2003).

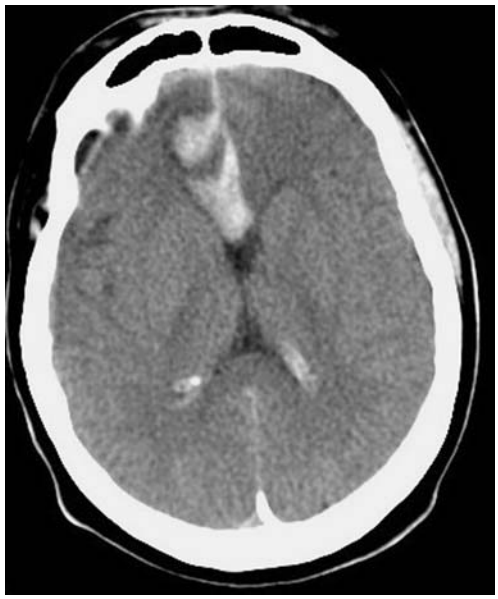
Currently, healthcare is undergoing a major reorganization to meet growing economic pressure and the aspect of preventive therapy becomes more and more important. Therefore, aneurysm treatment has to be considered in several respects: what is the risk of aneurysm rupture and what are the costs to treat a subarachnoid hemorrhage? What are the costs of treating an unruptured aneurysm either neurosurgically or via an endovascular approach to avoid SAH with possibly fatal complications? Costs arising treating an aneurysmal hemorrhage have to be weighted against the risk of rupture of an incidentally detected aneurysm.

It is necessary to provide the patient all treatment options. Regarding the cost-effectiveness and the fact that endovascular treatment has a lower morbidity and mortality than neurosurgically treated patients, in our opinion, unruptured cerebral aneurysms in any location should be considered first for endovascular treatment.

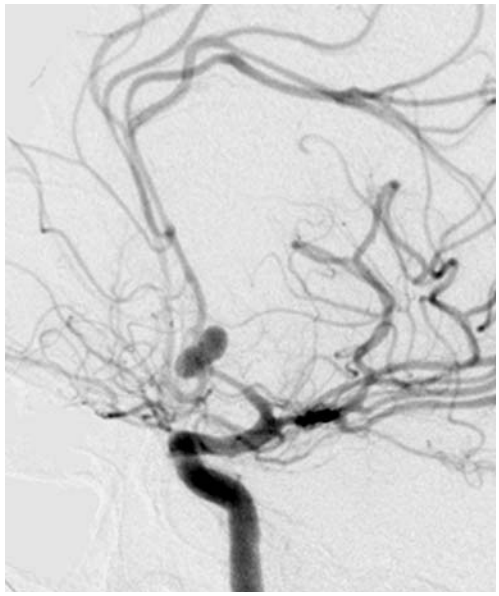
5.4.4 Treatment of Ruptured Aneurysms

SAH is the most common sequelae in patients with a ruptured intracranial aneurysm. The first clinical symptom is usually an acute onset of headache. In most patients, such headache was not experienced ever before in life ("the worst headache of my life"). In patients with known migraine or other types of headache SAH can be overlooked, but usually patients themselves can clearly distinguish between these different types of headache. Aspirin should be avoided at all cost in these patients. A warning leak, defined as a sudden episode of headache, vomiting, nuchal pain, dizziness or drowsiness, might precede this event in a considerable number (Hauerberg et al. 1991). The first symptom could also be due to an intraparenchymal bleeding preceded by a minor SAH. These patients typically suffer from a frontobasal bleeding and might be referred to a psychiatric department because of a sudden onset of a psychotic episode. Therefore, cross sectional imaging is indicated in patients with sudden change of behaviour.

Very few patients do not experience the onset of SAH as an acute onset of headache, but realize the symptoms of infarction due to subsequent vasospasm.



a



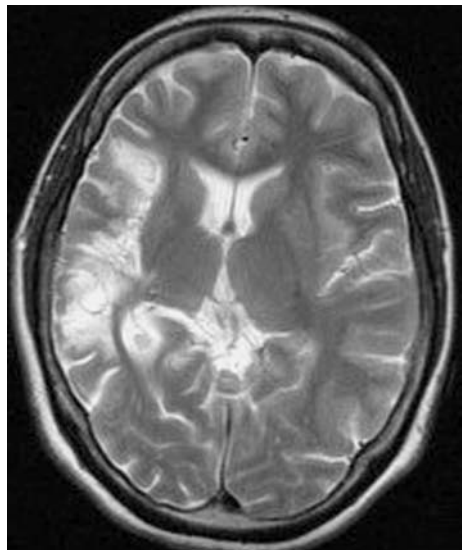
b

Fig. 5.4.4. Frontal intraparenchymal hemorrhage without SAH due to a ruptured Acom aneurysm in a patient with sudden onset of a psychotic episode

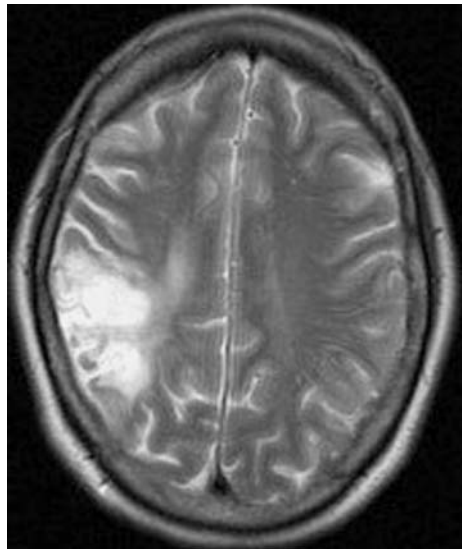
In these patients, Doppler sonography and lumbar puncture should reveal the cause of the disease.

Since the rebleeding rate of a ruptured aneurysm depending on the location is as high as 50% the urge to treat a ruptured aneurysm is obvious.

The clinical categorization of patient's symptoms was summarized by Hunt and Hess. This classification is internationally accepted and widely used to describe the patient's condition at admission after SAH.



a



b

Fig. 5.4.5a,b. Right MCA infarct in a patient who was administered with mild left sided hemiparesis. Doppler sonography revealed slightly increased velocity of the ICA and MCA and lumbar puncture showed hemosiderin. The patient did not report a typical sudden onset of headache. DSA revealed a small Pcom aneurysm but no visible vasospasms

Table 5.4.2. Hunt and Hess classification of SAH

I	Asymptomatic, or minimal headache and slight nuchal rigidity
II	Moderate or severe headache, nuchal rigidity, no neurological deficit (except cranial nerve palsy)
III	Drowsiness, confusion, or mild focal deficit
IV	Stupor, moderate or severe hemiparesis, possible early decerebrate rigidity and vegetative disturbance
V	Deep coma, decerebrate rigidity, moribund

5.4.5 Endovascular Therapy

5.4.5.1 History

Attempts to induce thrombosis of systemic aneurysms either by introducing foreign bodies or application of electrical or thermic injury date back to the first half of the 19th century. Velpeu (1831) and Phillips (1832) independently described a method of introducing arterial thrombosis by inserting a needle into the aneurysmal lumen and withdrawing it after thrombus have formed. In 1941 Werner et al. reported successful electrothermic thrombosis of an acute ruptured intracranial aneurysm. Through a transorbital approach, a silver wire was introduced and heated, causing arrest of the aneurysmal bleeding. In 1963 Gallagher proposed a technique of inducing thrombosis of intracranial aneurysms by high-speed delivery of dog or horse hairs into the aneurysm using a pneumatic gun ("pilojection") (Gallagher 1963, 1964; Gallagher and Baiz 1964). However, despite encouraging early results this method did not gain acceptance.

Further improvements in endovascular devices, balloon techniques, and arterial catheterization, rapidly led to the idea of endovascular navigation and occlusion of the aneurysmal sac. The first successful balloon embolization was performed by Serbinenko in 1973 (Serbinenko 1974a,b), establishing the way for modern endovascular treatment of cerebral aneurysms. However, several drawbacks of latex balloons, i.e. deflation, aneurysm rupture, protrusion into the parent vessel, distal embolization, and frequent rebleedings, prompted the search for better materials for aneurysm occlusion. Although balloon occlusion of parent vessels is still a therapeutic option for large, giant, or fusiform aneurysms, this technique has been mainly abandoned in favour of coil embolization. In 1991, the Italian neurosurgeon Guido Guglielmi published his preliminary experience with electrolytically detachable platinum coils (Guglielmi Detachable Coils, GDC), opening a new era in aneurysm treatment (Guglielmi et al. 1991a,b, 1992). The GDC technique represents the current "gold standard" in endovascular aneurysm therapy with more than 80,000 patients having been treated world-wide to date. And there is still ongoing progress in the field of endovascular therapy for intracranial aneurysms with development of new coil designs or other endovascular devices. The next step is supposed to replace the simply filling techniques with materials that promote real endothelialization of the aneurysm neck.

5.4.5.2 Basic Assumptions for Endovascular Aneurysm Therapy

5.4.5.2.1 Contraindications to Endovascular Aneurysm Therapy

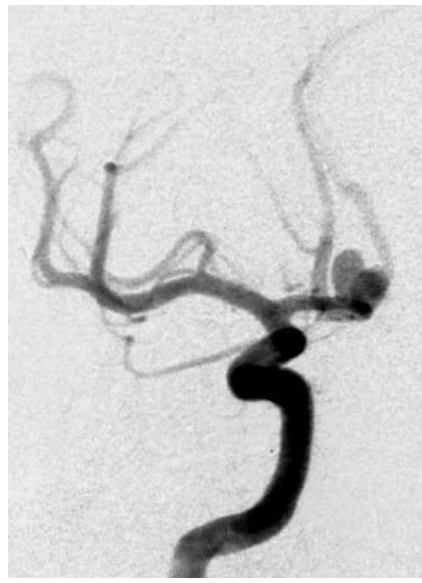
True contraindications to endovascular aneurysm therapy (EVT) are very rare including not manageable coagulopathies and known adverse reactions to heparin or contrast agents. Renal failure restricting the use of contrast material might be a relative contraindication.

5.4.5.2.2 General Considerations About Surgery or Endovascular Aneurysm Therapy

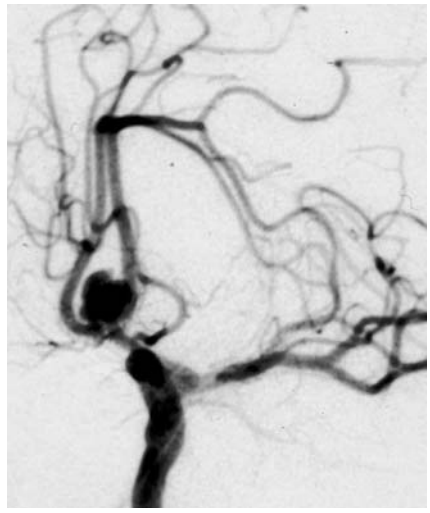
Initially, endovascular therapy was restricted to surgical "difficult" or inaccessible lesions, predominantly in the posterior circulation. Nowadays, the increasing experience and development of appropriate devices has widened the indications, and EVT has become a true alternative to surgical treatment (Molyneux et al. 2002).

However, the current state of the art in endovascular therapy has still some limitations such as the anatomic situation of the aneurysm, aneurysm size or unfavourable or invisible geometry (neck/fundus ratio). For aneurysms with a wide neck or difficult geometry surgery is still the preferred treatment. Relative limitations correspond to the expertise and experience of a given team. With increasing experience even wide neck or multilobulated aneurysms can be successfully treated via the endovascular approach.

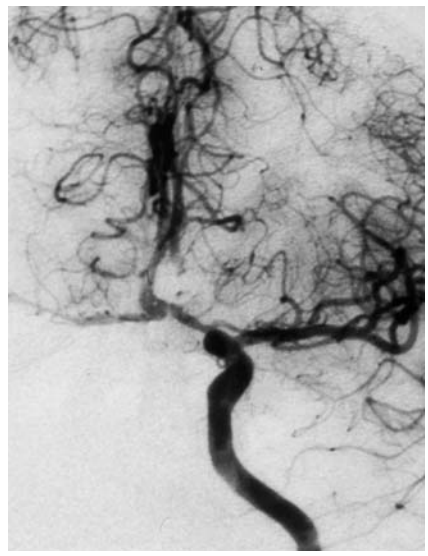
The decision to treat an aneurysm endovascularly rather than surgically is not easy and requires a multidisciplinary input. It is important to jointly discuss the cases, preferentially in daily conferences and rounds. This collaboration requires both the neurosurgeon and the interventionalist to be extremely honest about what they think they can achieve with each approach. Neurosurgery and interventional neuroradiology are not competitive facilities, but the complementary nature of techniques offers the best chance for reducing treatment morbidity and improving long-term outcome in difficult aneurysms. However, currently more and more aneu-



a



b



c

Fig. 5.4.6a–c. Multilobulated Acom aneurysm before (**a, b**) and after embolization (**c**)

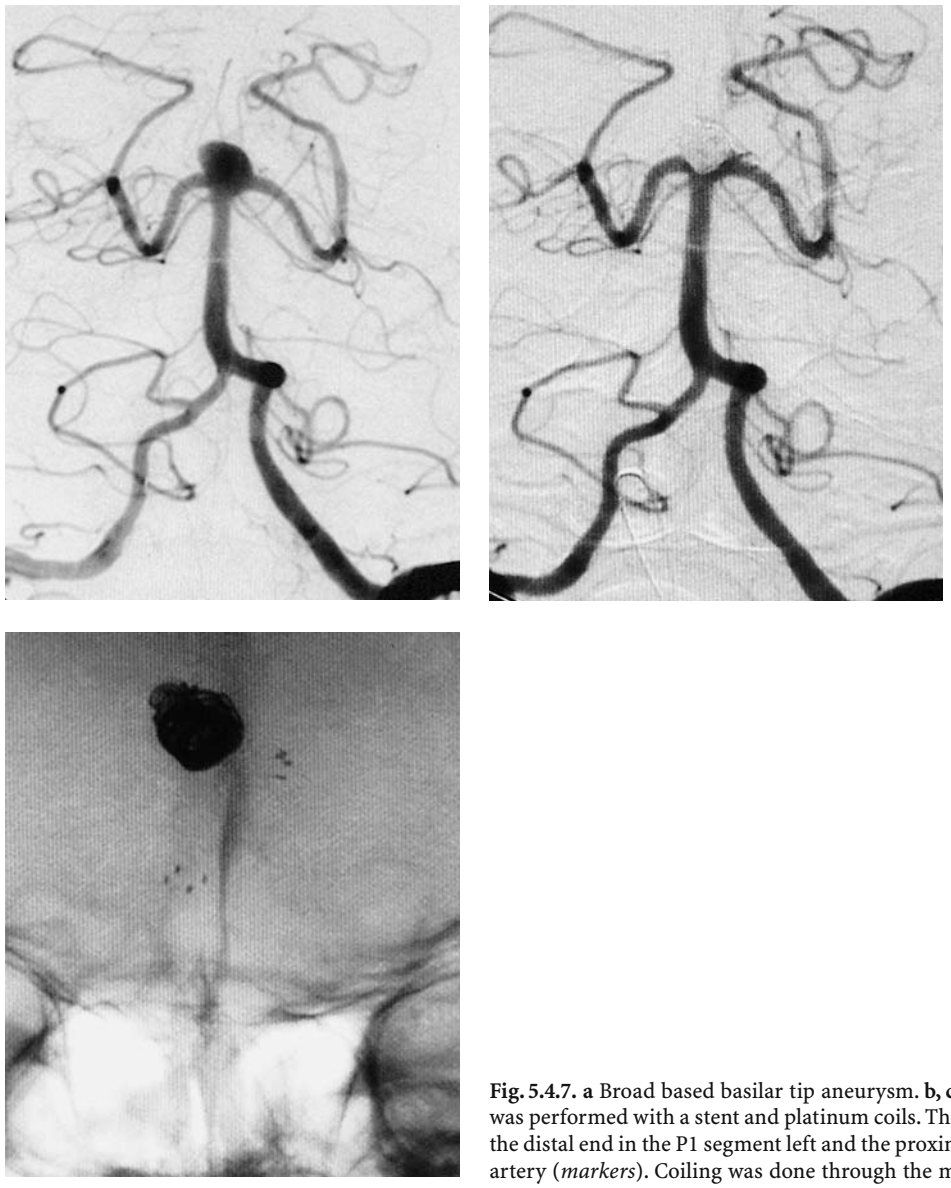


Fig. 5.4.7. a Broad based basilar tip aneurysm. **b, c** Endovascular treatment was performed with a stent and platinum coils. The stent was deployed with the distal end in the P1 segment left and the proximal end in the mid basilar artery (*markers*). Coiling was done through the mesh of the stent

rysms are treated via the endovascular approach and – in complete contrast to the situation of two decades ago – surgery is increasingly indicated in difficult endovascularly inaccessible aneurysms.

In our institution, the way to decide who treats the patient has changed somewhat over time. During the first 2 years each individual aneurysm was discussed between neurointerventionalists and the vascular neurosurgeons. Over time it turned out – promoted by scientific data and by the institutional experience – that the endovascular route should be preferred, if technically possible, e.g. if the geometry and anatomy of the aneurysm makes it suitable for embolization. We have reached a point where most of the aneurysms are treated by an endovascular technique (up to 75%).

Due to this circumstance the question of how to maintain the neurosurgeon's expertise is becoming increasingly important.

Timing: In recent years, the strategy of overall management has changed, focussing now on early referral and immediate therapeutic intervention to minimize the risk of rebleeding and enhance the possibilities of aggressive neurointensive care to prevent vasospasm and secondary ischemic complications. One benefit for the endovascular arm in ISAT was the earlier time of treatment compared to the surgical group.

5.4.5.2.3 Standards for Endovascular Aneurysm Therapy

The neurointerventionalist performing the procedure should have appropriate training and experience in neuroangiography and cerebral interventions, a full understanding of the disease process and alternative methods of treatment, and should fully appreciate the risks and benefits of the procedure. A thorough understanding of vascular neuroanatomy, angiographic equipment, radiation safety considerations, and physiologic monitoring equipment is taken for granted, as well as access to an adequate supply of catheters, guidewires, embolic devices, equipment for intraarterial thrombolysis or treatment of vasospasm. The neurointerventionalist should be familiar with anticoagulation regimens and the management of neuroangiographic complications, such as intraarterial thrombolysis and the treatment of vasospasm.

Endovascular treatment should be performed within an environment in which appropriate neurosurgical care can be instituted promptly. A readily available neurosurgeon should be aware of the endovascular procedure prior its start and available to back up if necessary. A CT scanner should be readily available in the facility.

5.4.5.2.4 Radiographic Equipment Standards for Endovascular Aneurysm Therapy

The availability of a biplane angiography with digital subtraction technique, a high resolution image intensifier and road-mapping fluoroscopy capability is desirable for endovascular aneurysm therapy. Specifically in difficult anatomic locations the capability of 3D angiographic techniques (either CTA or DSA) can be extremely helpful.

5.4.5.2.5 Peri- and Postprocedural Care

The role of anaesthesia in interventional neuroradiology consists in providing patient comfort by analgesia and sedation, adequate monitoring, maintenance of vital functions and (if required) the management of systemic heparinization. The patient's underlying condition, the duration and the kind of intervention have to be considered to decide on the anaesthetic management (Luginbuhl and Remonda 1999).

Embolization of intracranial aneurysms is performed with the patient in general anaesthesia at most centres. Although such an approach does not allow intraprocedural evaluation of the patient's neurological status and carries additional risks associated with general anaesthesia and mechanical ventilation (Phuong et al. 2002) we clearly prefer it during all endovascular procedures occluding intracranial aneurysms.

A British group recently published that GDC occlusion of an intracranial aneurysm can be performed in a safe manner with the patient awake (Qureshi et al. 2001). However, if aneurysm rupture occurs during treatment it is quite difficult to continue embolization if the patient is under local anaesthesia alone.

In order to minimize thromboembolic complications we recommend the administration of heparin, which we routinely start in ruptured aneurysms after insertion of the first coil. In unruptured aneurysms heparinization is started after insertion of the femoral sheath. The value of the activated clotting time (ACT) should be between 250 and 300 s and this level should be maintained for about 24–48 h postprocedure. Every patient receives aspirin (100 mg/d) for at least 3 months. If the patient was in good condition before the treatment or had an unruptured aneurysm he should be extubated in the angiosuite. This is specifically important after treatment of MCA and basilar tip aneurysms: these are usually more difficult to treat and carry a higher risk of thrombotic complications.

After the procedure the patient should be supervised on an intensive care unit and must be monitored by an experienced neurovascular team in order to detect symptomatic vasospasms before occurrence of infarction. Monitoring (clinical status including transcranial Doppler sonography, heart rate, blood pressure, pO2, puncture site) should be done at least for 24 h in all patients with an unruptured aneurysms, in case of a recent bleeding monitoring is depending upon the clinical status and on the interval of the bleeding, but should at least continue for 7 days. The patient then could be transferred to a neurosurgical step-down unit, where continuous surveillance of vital parameters and a periodically examination by experienced nurses is performed.

No endovascular procedure should be performed without an appropriate follow-up imaging protocol. In our institution, every patient gets a MR scan (MRI and MRA: TOF and contrast enhanced technique) within 3 days after the procedure. In cases of satisfied occlusion rate (total or subtotal occlusion) the patient should be scheduled for a control DSA and MRA 6 months after the procedure. If there is a good correlation between DSA and MRA at this time point

follow-up could be done solely with MRA. We try to get follow-up imaging for at least 3 years.

5.4.6 Devices for Endovascular Aneurysm Therapy

5.4.6.1 Catheters and Delivery Systems

Since 1960, when Luessenhopp et al. reported the first intravascular cerebral embolization of an AVM by injecting silastic beads into the arteries of the neck, endovascular treatment of brain diseases has been considerably refined. There has been improvement in fluoroscopic equipment, angiographic techniques and progressive miniaturization of endovascular devices to permit increasingly more distal, so to say "superselective", catheterization. The following section tries to give an overview of the different materials to be used in endovascular therapy of intracranial aneurysms. However, it is a subjective choice. We did not want to give a complete overview, this can be done by the companies. In addition, products change so fast that a book like this cannot be up-to-date. We simply picked a few examples and give some general comments. We were not paid by any company to either mention or not mention any particular products. In general, it depends on individual experiences what type of catheter, wire or coil you use. Having the latter in mind we decided to mention our first and second choice materials. A book is written by individuals and we do have individual opinions. Every reader, however, is welcome to comment on our recommendations.

5.4.6.1.1 Guiding catheters

Distal placement of the guiding catheter in the internal carotid or vertebral artery facilitates stable navigation of the microcatheter and subsequent coil placement. A soft tip with hydrophilic coating allows atraumatic distal catheterisation. A large inner lumen enables continuous flushing and road mapping or angiograms during the procedure without a second guiding catheter in place. Continuous flushing with heparinized saline through a hemostatic valve is essential to prevent retrograde flow and clotting.

In general, this is possible with 5- or 6-F guiding catheters, such as Envoy (Cordis), or FasGuide (Boston Scientific). In our institution, we prefer the Guider XF Soft Tip (Boston Scientific) because of its soft tip and the lower risk to damage the vessel wall.

5.4.6.1.2 Microcatheters

In general, there are two types of microcatheters available: wire-directed microcatheters of 0.010- to 0.016-in. calibre, and flow-guided microcatheters usually close to 0.010-in. Flow-guided microcatheters are mainly used for the treatment of AVMs to deliver liquid embolic agents or small particles. For endovascular aneurysm therapy wire-directed microcatheters are mandatory. Their hydrophilic coating facilitates distal catheterizations. Microcatheters for aneurysm therapy usually have two markers at the distal end to allow alignment of the detachment zone of coils regardless of the type of detachment.

We prefer to use a Tracker-Excel 14 (Boston Scientific) but a Tracker-18 and Tracker-10 are also suitable to treat aneurysms.

Steam shaping of the distal tip, individually formed according the neck, direction and size of the aneurysm to be catheterized might be helpful. Microcatheters already preshaped (Prowler; Cordis Corp.) are also available, but do not have a major advantage per se. Shaping of a microcatheter should be part of the training of all neurointerventionalists.

5.4.6.1.3 Microwires

The ideal microwire is flexible, soft, shapeable, with an atraumatic tip, easy to navigate, and has no or minimal friction. These qualities are difficult to combine in one device. Neurointerventional microwires are of 0.014–0.016 in. caliber. Most of the available microwires have a hydrophilic coating. In our institution, we prefer the Transend 0.014 (Boston Scientific) combining most of these qualities. The Terumo wire 0.016 and 0.010 are of excellent torqueability, but have a very stiff preformed tip, that can easily injure the vessel wall or rupture the aneurysm sac. Therefore, we do not use them for aneurysm therapy any more.

And – surprisingly enough – it is still possible to improve the quality of these simple wires. In those situations where we are really struggling with anatomy and do not get access to the aneurysm, we switch to a wire called Synchro; this wire has a marvellous one-to-one torque and usually we can overcome the problem.

For intracranial stenting long exchange microwires (>300 cm) may be helpful. They vary considerably in stiffness. Most of the wires from cardiology are too stiff and therefore can not be recommended for intracranial use. Softer wires, like the ACS High Torque Traverse (Guidant), or the ChoICE (Boston Scientific) are better, but they still have the potential to perforate distal vessels. Recently, the Transend became available with a length of 300 cm and is now the standard wire at our institution for intracranial stent procedures. However, we are convinced that even the delay between writing the manuscript and availability of the book will give the companies enough time to further improve their products.

5.4.7 Embolic Materials for Endovascular Aneurysm Therapy

In general, there are four different types of embolic materials available: balloons, particles, coils and liquids.

5.4.7.1 Detachable Balloons

Detachable balloons, initially developed by Serbinenko for the selective treatment of aneurysms, now are mainly used for major vessel occlusion, such as the internal carotid or vertebral artery. The balloon is mounted at the distal end of a microcatheter, then navigated in the targeted position and after filling with contrast material or a solidifying agent it is detached from the microcatheter. Balloons are available with self-sealing valves ensuring that the balloon remains inflated when the microcatheter is withdrawn. There are two types of balloons available: latex balloons and silicone balloons.

Latex balloons: While latex is an essentially impermeable membrane, silicone is semipermeable. They have a tendency to undergo spontaneous deflation within days or weeks.

Silicone balloons: These have to be inflated with isomolar solutions. Silicone balloons have a higher expansion coefficient and are softer and less rigid than latex balloons. Under normal circumstances they do not deflate, unlike latex balloons, and do not induce a surrounding inflammatory reaction in adjacent tissue. Silicone balloons have a propensity for forward movement. Unfortunately, the so-called detachable silicone balloons (DSB) are not available any more. At this time it seems to be unlikely that they will be back on the market soon.

5.4.7.2 Nondetachable Balloons

Various nondetachable balloons are available for temporary vessel occlusion, angioplasty for vasospasm therapy or remodelling techniques for broad based aneurysms. Larger vessels like the carotid or vertebral artery can be occluded with a double lumen balloon catheter, i.e. Meditech (Cook). For intracranial angioplasty smaller, more flexible balloons, like the wire-directed Equinox (MTI) and Hyperglide (MTI), Commodore (Cordis), or Sentry (Boston Scientific), or the non-wire-directed Endaevor (Boston Scientific) are required. Additionally to these balloons the Hyperform (MTI) can be used for the remodelling technique.

5.4.7.3 Coils

There is a great variety of different coils currently available. Stainless steel coils have been used for a long time for peripheral embolizations. Due to an attached Dacron fibre they are extremely thrombogenic, facilitating even parent vessel occlusion. They might be increasingly used for this indication, if detachable balloons are really not available any more. However, for cerebral embolizations they are too stiff. Platinum coils are much softer than stainless steel coils. Meanwhile, there exist different types of CE marked detachable platinum coils provided from different companies. All of those are retrievable and are similar in the compound of the alloy, but they mainly differ in their technique to detach. The newest generation of coils have a coated surface in order to facilitate endothelial growth and real healing of the aneurysm entrance.

Over the last several years, the number of coil sizes has been increased, multidimensional coils have become available, and, more recently, softer coils allowing safer initial coil placement have been introduced.

They are available in different shapes, lengths and diameter for neurointerventional procedures.

5.4.7.4 Electrolytically Detachable Coils

Guglielmi et al. (1991a,b) developed electrolytically detachable platinum coils (GDC) for endovascular

occlusion of aneurysms. The coil is attached to a stainless steel delivery wire. This allows repositioning and selective placement of the coil within the aneurysm. The coil can be delivered through a microcatheter and is detached electrolytically by applying a 9V positive electric current to the patient. The current dissolves the non-insulated stainless steel junction located between the GDC and the insulated delivery wire. Using the new generation GDC detachment takes about 20–30 s. GDC has to be delivered through special microcatheters, which have a radiopaque marker located 3 cm from the distal tip of the microcatheter. For detachment of the GDC the radiopaque marker of the delivery wire of the coil has to be aligned to the proximal marker of the microcatheter. The GDC design combines the advantage of very soft, compliant platinum and retrievability resulting in markedly improved safety and efficacy. An improperly fitting coil can be removed, repositioned or replaced with another coil of different size, length or shape. There are several sizes of GDCs, ranging from 2–20 mm in coil diameter and 2–30 cm in length to fit the needs

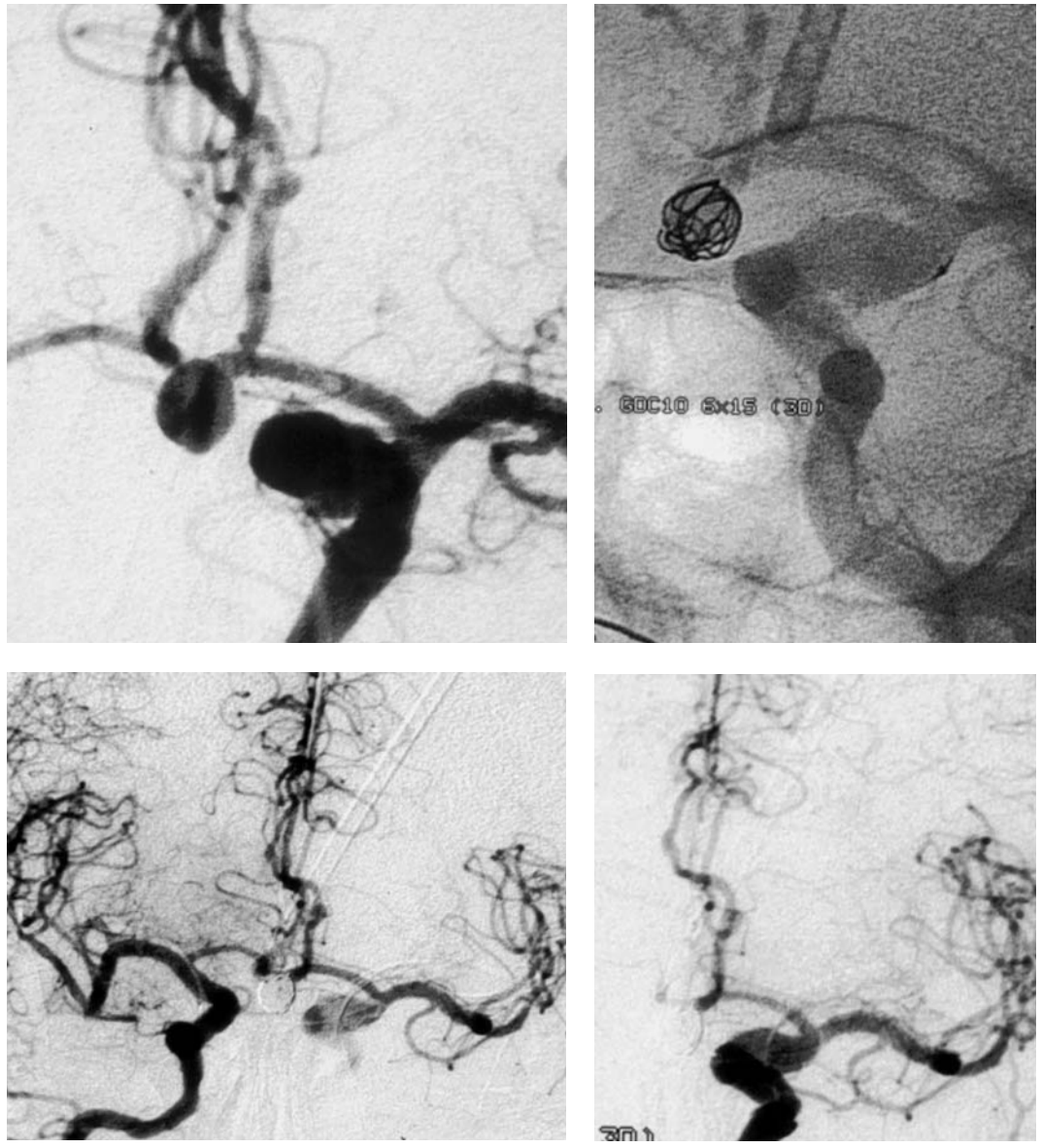


Fig. 5.4.8a–d. Acom aneurysm: angiogram before endovascular therapy, after placement of the first GDC (GDC 10: 6×15 3D) and after complete coil occlusion

of embolizing different aneurysms. GDCs exist in two thicknesses, 0.010 rather for small and acutely ruptured aneurysms and 0.015 for large and giant aneurysms.

Recently, many new designs in coil configuration, shape, and material have become available by numerous vendors and have significantly increased the versatility of this device for aneurysm therapy. Bi-dimensional GDC (2D GDC), in which the first 1.5 coil loop is of 75% smaller helical diameter, helps the following loops to stay within the aneurysm and avoids protruding into the parent artery. A three dimensional (3D)-shape GDC configuration has been developed in which the secondary structure consists of a series of omega-like loops. Due to its spherical shaped memory this 3D coil spontaneously forms a complex cage after deployment thereby serving as basket for subsequent coils. To be honest, we very rarely use this 3D type of coil. In the vast majority of patients, conventional 2D coils allow a complete and dense packing of an aneurysms. But again, this is our personal view and experience.

5.4.7.5 Hydrogel-Coils

Hydrogel-coils (MicroVention, Inc., Aliso Viejo, CA) consist of a carrier platinum coil coupled to an expandable hydrogel material, which undergoes a tremendous increase in volume when placed into a physiological environment with a certain pH value, e.g. blood. Compared to a non coated platinum coil 10, a fully expanded hydrogel coil 14 of the same length will have seven times the volume. The hydrogel coils were designed to offer an enhanced ability to fill aneurysm cavities. Distinct from previous devices aimed at speeding the organization of thrombus, the new device has been designed to entirely fill the aneurysm cavity, with complete or near-complete exclusion of thrombus. Unlike thrombus, the hydrogel material is stable and unaffected by natural thrombolytic processes and thus may reduce observed rates of aneurysm recanalization (Kallmes and Fujiwara 2002). In our own small series aneurysm treatment with hydrogel coils was extremely promising. Complication rate was not higher than usual, but so far no published data exist in patients treated with hydrogel coils. Long-term observations need to reveal if there is a real benefit over bare platinum coils. Additionally, the detachment mechanism is different; it is not based on electrolysis, but mainly on hydraulic forces.

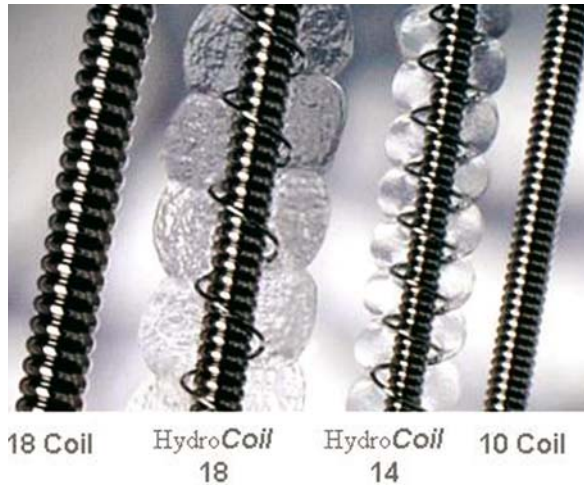


Fig. 5.4.9. Different size of Hydrogel-coated coils in comparison with bare coils

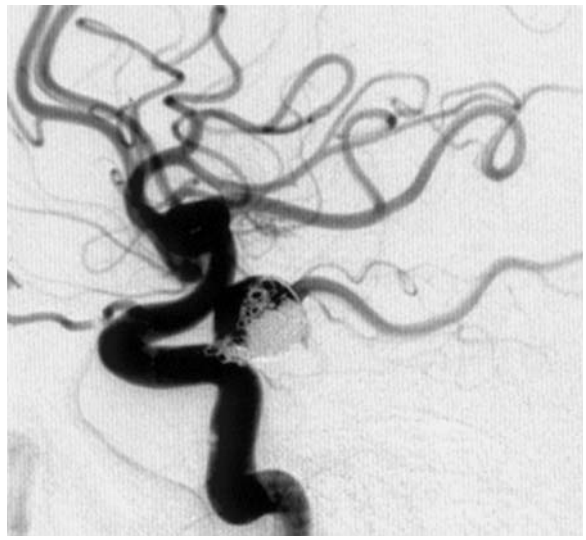
5.4.7.6 Three-Dimensional Coils: TriSpan

To support coil deposition of wide-necked aneurysms a new detachable device, the TriSpan (Boston Scientific, Fremont, USA) was designed and recently approved for clinical use in Europe. The TriSpan can be placed at the base of the aneurysm prior to coil embolization which is delivered through a second microcatheter. The TriSpan acts as a supporting structure and bridges the neck for subsequent coils. However, experience with this new device is limited mainly to broad-based basilar tip aneurysms. Further evaluation and especially long-term results are necessary to assess this new method.

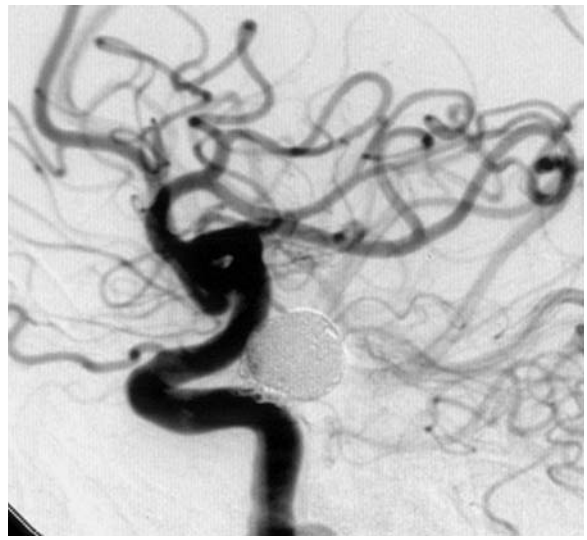
5.4.7.7 Other Devices

Stretch-resistant (SR) coils have a polypropylene thread through the primary helix, associated with greater strength of the coil. It provides more safety against damage if it needs to be withdrawn from the aneurysm. We strongly recommend using the stretch-resistant-type coils whenever possible or available. This technology really helps to protect patients and reduces the stress factor for the interventionalist.

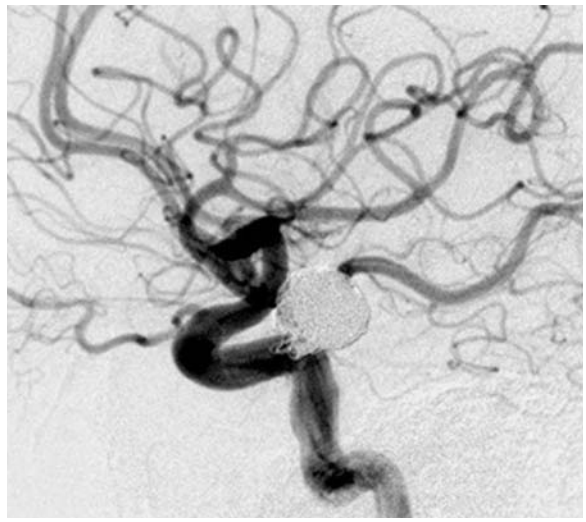
Recently there has been growing interest in modifying platinum coils by coating the surface with extracellular matrix proteins, non-biodegradable polymers, fibroblasts, and vascular endothelial growth factors. Experimental studies indicate that these modifications might promote endothelializa-



a



b



c

Fig. 5.4.10a–c. A 39-year-old male, SAH 2 years previously, second recurrent aneurysm after embolization with bare coils (**a**) after hydrogel-coil-embolization (**b**), and 6-month FU with a stable result (**c**)

tion, clot organization, and tissue integration of the coils and thereby may lead to improved aneurysm occlusion and outcome (Abrahams et al. 2000, 2001a,b; Dawson et al. 1995; Kallmes et al. 1998; Murayama et al. 1997, 2001).

5.4.7.8 Stents

The idea of using an intravascular stent followed by trans-stent placement of coils may provide another treatment option in patients with a wide-necked aneurysm in which direct surgical clipping or conventional endovascular therapy would be difficult or impossible, and in whom parent artery occlusion is not a viable option (Byrne et al. 2000; Lanzino 1999b; Horowitz et al. 2001; Lownie et al. 2000; Lylyk et al. 2001).

Stents are deployed either by balloon expansion or release of a self-expanding nitinol or steel stent from a constraining sheath. Up to now stents used for intracranial treatment, usually coronary stents (covering size ranges up to 4 mm), are balloon expandable stents bearing the risk of damaging a dysplastic aneurysm bearing segment of the artery with eventual rupture of the vessel. In addition, the large profile and relative stiffness of these stent delivery systems limit the locations that are able to be accessed and increase the risk of vessel dissection.

In summary, the balloon expandable stents were not a real treatment option. Complication rates were too high and in the majority of patients it was impossible to obtain access to the intracranial target vessel.

5.4.7.9 Neurovascular Stent

The Neuroform Stent (Boston Scientific, USA) is a new self-expanding microstent system designed specifically for intracranial vessels. It consists of three parts: the self expanding microstent, which is supplied in a 3-F delivery microcatheter, and a 2-F stabilizer. The stent comes preloaded in a 3-F delivery catheter and is currently available in diameters from 3.0 to 4.5 mm, in 0.5-mm increments, and in lengths of 15 mm and 20 mm. In our experience in a still limited number of cases the stent revealed an excellent tractability and could be easily navigated even through very tortuous vessels. We did not observe permanent parent artery occlusion nor occlusion of perforating arteries which were covered by the stent (Wanke et al. 2003). In our experience with nearly 30 implanted stents of this type the self-expandable Neuroform is an enormous improvement in treating formerly endovascularly untreatable aneurysms. Many broad-based aneurysms – most of them surgical candidates up to now – can be treated with this device.

Future developments, such as covered or coated stents lining the neck of the aneurysm would effectively exclude the aneurysm from the circulation and might theoretically present a perfect cure for selected aneurysms.

5.4.7.10 Liquid Embolic Agents

Liquid materials are commonly used for endovascular treatment of AVMs. Cyanoacrylate, the most common currently used liquid embolic material in brain AVMs, polymerises after contact with blood and becomes solid (Eskridge 1989). The use of liquid embolics for endovascular occlusion of cerebral aneurysms is still limited to a small group of patients and there is only limited experience with that technique (Macdonald et al. 1998; Tokunaga et al. 1998). An important issue of this technique is the difficulty to prevent migration of the liquid adhesive into the parent artery.

New liquid embolic agents, such as Onyx (MTI, Irvine, CA), are used in combination with protective devices, such as balloons, and/or stents. But so far we are convinced that liquids are only justified in those aneurysms than cannot be treated with any other methods because of the higher complication rate.

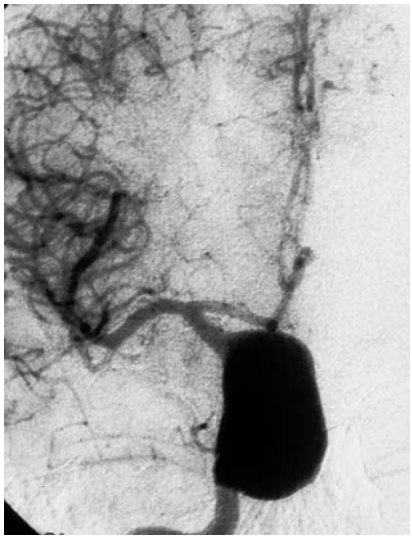
Onyx (MTI, Irvine, CA) is a biocompatible polymer (ethylene-vinyl alcohol copolymer, EVOH) dissolved in its organic solvent dimethyl sulfoxide (DMSO). To obtain an appropriate radiopacity micronized tantalum powder is added. When this mixture contacts a liquid agent such as blood, DMSO rapidly diffuses away from the mixture, causing in situ precipitation and solidification of the polymer. The use of Onyx and DMSO requires dedicated microcatheters to prevent material incompatibility between the solvent and the hub plastics. In their experimental study, Murayama et al. (2000) demonstrated the technical feasibility of endovascular therapy using this liquid agent and different protective devices in porcine side-wall aneurysms. Currently, mainly large or giant ICA aneurysms are treated with this technique because this approach usually allows selective occlusion of the aneurysm with preservation of the parent artery. However, clinical studies are necessary before this technique becomes clinical routine.

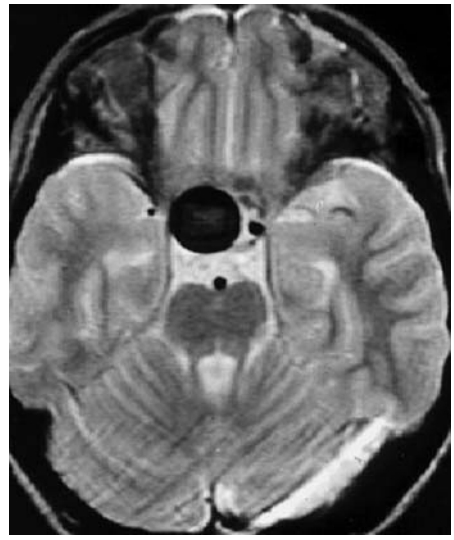
5.4.8 Techniques of Endovascular Therapy

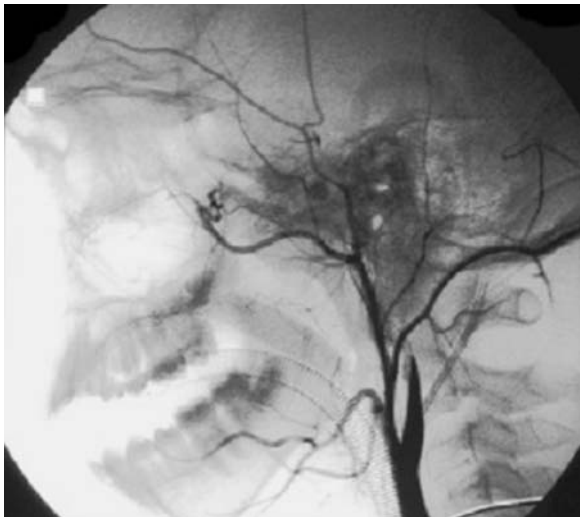
Neurointerventional methods concerning aneurysm treatment are broadly classified as deconstructive or reconstructive procedures. We therefore distinguish two strategies to treat cerebral aneurysms via the endovascular approach: first, occlusion of the aneurysmal sac with embolic material preserving the parent artery, and second in otherwise untreatable aneurysms occlusion of the parent artery in order to exclude the aneurysm from the blood circulation.

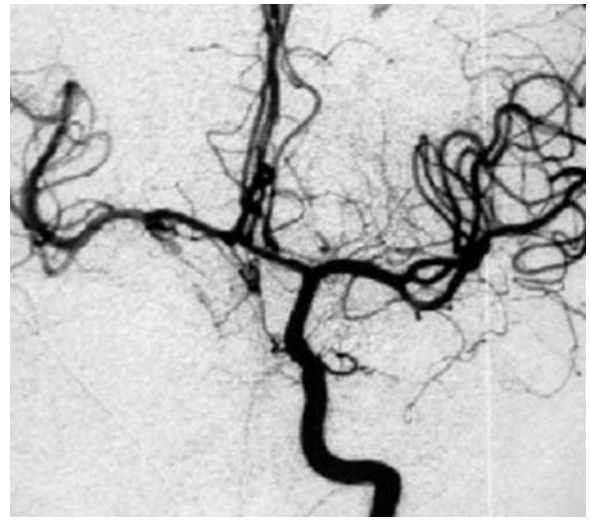
Endovascular therapy for intracranial aneurysms has evolved since Serbinenko pioneered embolization of the parent artery with latex balloons in the 1970s (Serbinenko 1974a,b). Occlusion of the parent artery has become a therapeutic alternative especially in patients with giant broad-based aneurysms of the internal carotid artery which are surgically inaccessible. The basic assumption for this treatment modality is that the patient will tolerate parent vessel occlusion without ischemic complications. Although there is no general consensus about the protocol to predict patient's tolerance to permanent vessel occlusion, some authors recommend blood flow studies to decide which patient will tolerate acute balloon occlusion and who will need an extracranial-intracranial (EC-IC) bypass to avoid ischemic complications (Brunberg et al. 1994; Eckard et al. 1992; Fox et al. 1986; Linskey et al. 1994; Standard et al. 1995; Yonas et al. 1992). Complex scenarios include balloon test occlusion with SEP monitoring, SPECT imaging before, during and after test occlusion, and different degrees of hypotension during test occlu-

sion. In our experience, a pretty simple test has a high predictive value: the compression test with injection into the contralateral ICA while the symptomatic ICA gets compressed. If the veins of the compressed side opacify not more than 1 s later than those of the injected site, anatomical preconditions for ICA occlusion are excellent. More important than the "development" of numerous test or pre-test procedures is


a


b


c


d

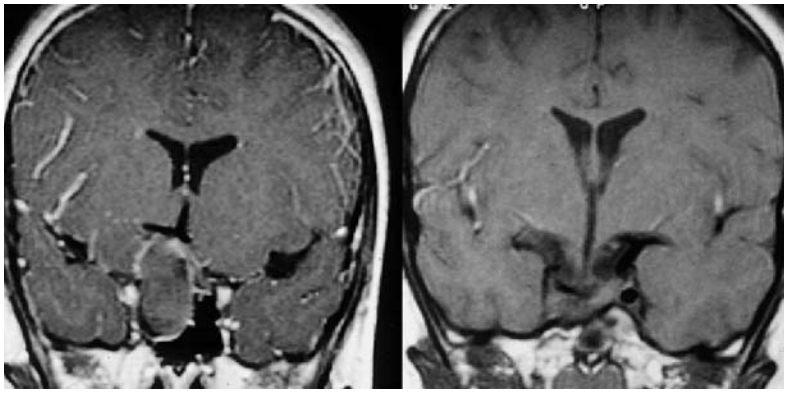

e

Fig. 5.4.11a–e. Giant internal carotid artery aneurysm in a 10-year-old boy presenting with visual disturbance of the right eye. **a** Conventional angiography. **b** T2-weighted MRI. **c** Endovascular occlusion of the right internal carotid artery with balloons was performed. **d** Injection in the left ICA demonstrates sufficient collateralization of the right hemisphere via the Acom. **e** T1-weighted MRI, coronal plane: before therapy and at 6-month follow-up demonstrating complete retraction of the aneurysm

probably how to take care for the patient after the procedure. Our strategy is to keep the patient recumbent and elevate his head by 30°/day. Blood pressure should be a little bit above the normal level. After the third day the patient is allowed to sit on the bed, on day 4 he can walk with assistance. In case of any problems during the first walk around, the period of laying down should be prolonged.

In experienced hands occlusion of the parent artery has proved to be safe, convenient and effective. Vessel occlusion could be done either with a detachable balloon or detachable coils positioned proximal to the aneurysm. Some authors recommend lesion trapping in order to prevent retrograde filling of the aneurysm (Berenstein et al. 1984; Debrun et al. 1981; Fox et al. 1987; Hieshima et al. 1981; Higashida et al. 1989, 1991; Kupersmith et al. 1984; Larson et al. 1995; Nelson 1998; Pasqualin et al. 1988; Serbinenko 1974a,b; Tan et al. 1986; van Rooij et al. 2000).

In order to reconstruct an aneurysm bearing vessel there exist different techniques nowadays. In the past aneurysmal sac occlusion with a detachable balloon was performed but this is now clearly obsolete. Although it is technically feasible there is no detachable balloon with different configurations which could be navigated over a microwire in order to access the aneurysm lumen in an arbitrarily manner. In addition, the relative high risk of complications – mainly due to thromboembolic events as well as aneurysm rupture during or after the procedure - with a high procedure-related mortality (reported up to 18%) as well as the fact that the balloon would not keep its configuration over time necessitated a more sophisticated endovascular technique for aneurysm embolization (Debrun et al. 1981; Higashida et al. 1989, 1990, 1991).

In the last 10 years, improvement in the development of flexible microcatheters which can navigate through cerebral vessels to lesions deep within the brain has allowed the treatment of an increasing range of intracranial aneurysms. The focus of modern endovascular therapy has shifted to the use of detachable platinum coils. In 1991, the first detachable platinum coil was introduced for treatment of cerebral aneurysms – the so-called Guglielmi detachable coil (GDC) developed by Target Therapeutics, CA, USA. Through a guiding catheter (e.g. 5 F, 6 F) a microcathether (2.3 F) is coaxially advanced into the cerebral vasculature and over a soft microwire it can be navigated into the aneurysm lumen, optimal placed in the aneurysm centre in a stable position. To ease the access into the aneurysm the microcatheter can be preshaped over steam but is also available in a preshaped configuration with different angles. Therefore, it is very important that neither the catheter nor the wire will contact the aneurysm wall too strongly in order to avoid aneurysm rupture. The interventionalist should be always aware of possible movements of the catheter while manipulating with the wire or with the coil. After gently and slowly removing the microwire the first platinum coil is delivered through the microcatheter. Pioneering in the development was that these coils are retrievable until the operator is satisfied with placement and then could be detached. The diameter of the first coil should be chosen according to the aneurysm diameter. The size of the following coils is usually the same of the first coil or smaller to densely pack the centre of the aneurysm. Introduction of coils should be continued until no more coils can be deployed into the aneurysm. The idea of this treatment is to fill the aneurysmal sack with coils and thrombus in order to exclude it from the blood circulation and thereby prevent bleeding. This technology is based on electrothrombosis and electrolytic detachment of platinum coils. Despite the extensive use of this treatment technique, the role of electrothrombosis has not been fully investigated and clarified. It is believed that the passage of electric current through the GDC induces attraction of blood constituents. This attraction may trigger a thrombotic reaction on the surface of the coil. The greater the time of current application, the more pronounced the cellular reaction and deposition of fibrin and blood cells on the surface of the GDC (Padolecchia et al. 2001).

Endosaccular embolization with platinum coils is performed in unruptured aneurysms and in patients acutely ill after subarachnoid haemorrhage. Usually and specifically in patients in the acute stage of bleeding endovascular embolization is done under general anaesthesia (GA). We recommend intubating all patients because in the case of a complication, e.g. aneurysm perforation, the patient‘s status could deteriorate suddenly and dramatically.

A standard transfemoral approach is used like in diagnostic angiography. Endovascular embolization of cerebral aneurysms could be done without GA (Qureshi et al. 2001). But in order to better manage procedure-related complications such as aneurysm perforation we recommended local anaesthesia only for those patients who clearly have an increased risk with GA.

Although there are several advantages of coil embolization over surgery, there is a disadvantage of endovascular treatment. Due to coil compaction and residual inflow in initially incompletely obliterated

aneurysms there is a potential risk of recanalization with aneurysmal regrowth. In particular, the geometry of wide-necked aneurysms is less favourable for obtaining maximal coil packing (Tong et al. 2000). In cases of an unfavourable dome to neck ratio endovascular treatment can be feasible and sometimes more effective by simultaneous temporary balloon protection. Hereby, a microcatheter-mounted nondetachable balloon provides a temporary barrier across the aneurysmal neck while introducing the coils into the aneurysmal sac. Reports in the literature have offered discussions of the feasibility, efficacy, and safety of balloon-assisted coil placement in wide-necked intracranial aneurysms which was first described by J. Moret in 1997 as the "remodelling technique". The use of simultaneous temporary balloon protection may allow more dense intra-aneurysmal coil packing, especially at the neck, without parent artery compromise than did the use of Guglielmi detachable coils alone (Aletich et al. 2000; Malek et al. 2000; Mericle et al. 1997; Moret et al. 1997; Nelson and Levy 2001). Despite enormous advances in the development of flexible microcatheters, coil configurations, and embolic materials and use of remodelling technique, wide-necked aneurysms still remain a therapeutic challenge. The geometry of wide neck aneurysms sometimes makes it impossible to treat the aneurysm via the endovascular route or at least reduces the possibility of obtaining satisfactory coil packing. However, incomplete occlusion carries the risk of aneurysm recanalization, regrowth and rerupture (Byrne et al. 1999; Cognard et al. 1999). With the recent development and refinement of endovascular stents, the significant potential for these devices in the treatment of wide-necked and fusiform aneurysms has become apparent.

The technique of using an intravascular stent to create a bridging scaffold followed by endovascular placement of coils through the interstices of the stent into a wide-necked or fusiform aneurysm has been described in experimental studies (Byrne et al. 2000; Massoud et al. 1995; Szikora et al. 1994) and in humans (Higashida et al. 1997; Horowitz et al. 2001; Lanzino et al. 1999; Lownie et al. 2000; Lylyk et al. 1998, 2001; Mericle et al. 1998; Sekhon et al. 1998; Weber et al. 2000). It may provide another treatment option for patients who present with a wide-necked aneurysm in which direct surgical clipping or conventional endovascular therapy would be difficult or impossible, and in whom parent artery occlusion is not a viable option. As described before, new flexible and self expanding stents are available now and create the next shift from surgery towards endovascular therapy.

5.4.9 Anatomic Considerations for Endovascular Aneurysm Therapy

Usually, there is not only one way to treat an aneurysm. The right treatment depends on the skill and experience of the team and may differ from our recommendations. We mainly report *our* way of treating different aneurysms, but do not think that it can not be done in another way.

5.4.9.1 Internal Carotid Artery

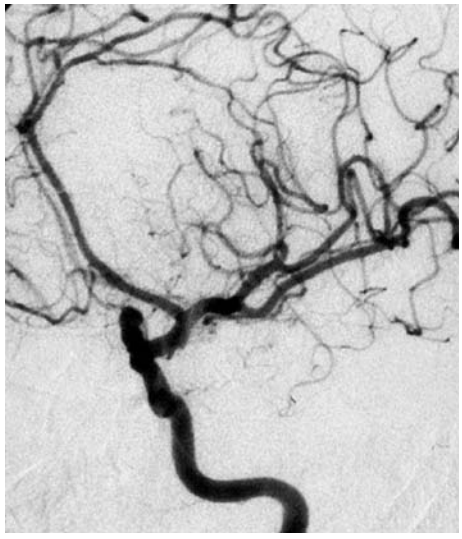
Aneurysms of the internal carotid artery account for about 30%–40% of all intracranial aneurysms. Therefore, the ICA is the most frequent aneurysm bearing artery. In descending frequency ICA aneurysms do occur at the following sites: posterior communicating artery (52%), termination of ICA (20%), paraophthalmic segment (13%), cavernous ICA (10%), anterior choroidal artery (5%).

Due to the surgical inaccessibility the endovascular approach is the therapeutic modality of choice in proximal symptomatic aneurysms. Carotid artery occlusion is usually the therapeutic modality of choice in giant symptomatic wide-necked ICA aneurysms. This leads to subsequent thrombosis and regression of the aneurysmal sac. Ideally, ICA occlusion is performed distal and proximal to the aneurysm origin in order to prevent retrograde filling of the ICA with subsequent filling of the aneurysm (see section parent artery occlusion). However, the proximal *and* distal occlusion is more important in patients with CCF. If the passage of the aneurysm is not possible – due to elongation of the ICA itself or the giant nature of the aneurysm – proximal occlusion is usually enough and should be performed.

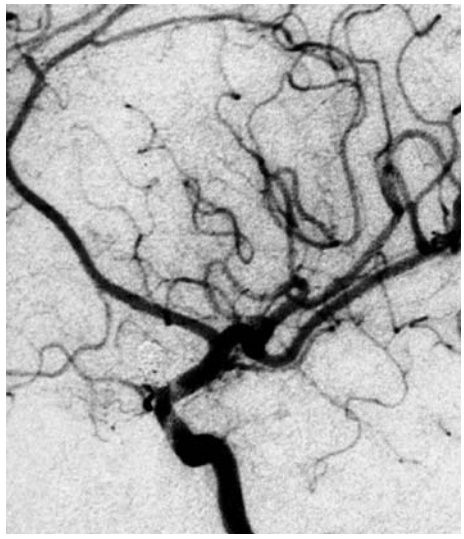
5.4.9.1.1 Cavernous ICA/Paraclinoid/Paraophthalmic

Aneurysms related to the carotid artery in the region of the anterior clinoid process, the so-called "paraclinoid" aneurysms are often in association with the ophthalmic artery. They may originate in the cavernous sinus and extend into the subarachnoid space, carrying the risk of subarachnoid hemorrhage, even if the origin of the aneurysm is clearly extradural.

Frequently presenting symptoms of aneurysms located within or around the cavernous sinus and the paraophthalmic region are visual deficits or cranial nerve palsies since the cavernous sinus harbours cranial

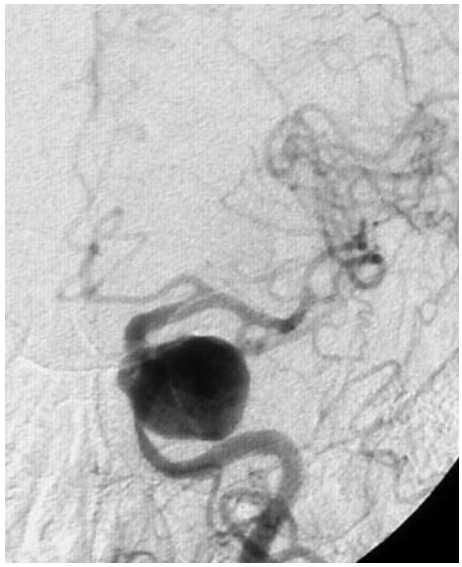


a

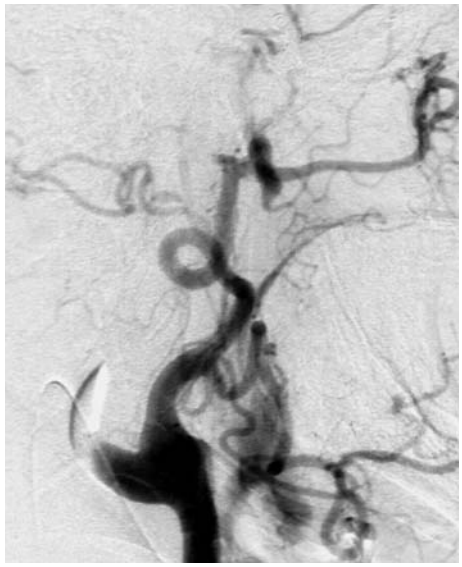


b

Fig. 5.4.12a,b. Before and after GDC treatment of a paraophthalmic ICA aneurysm

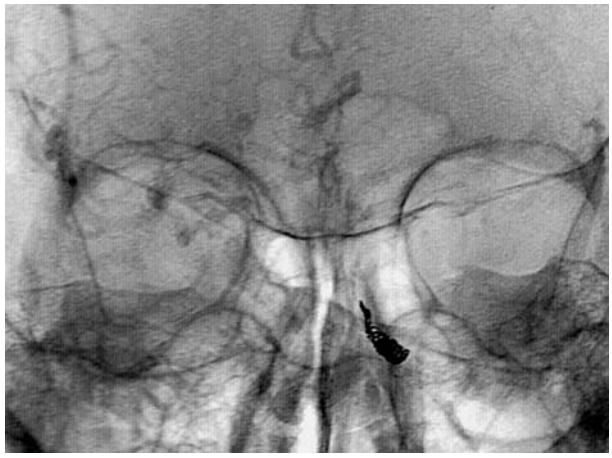


a

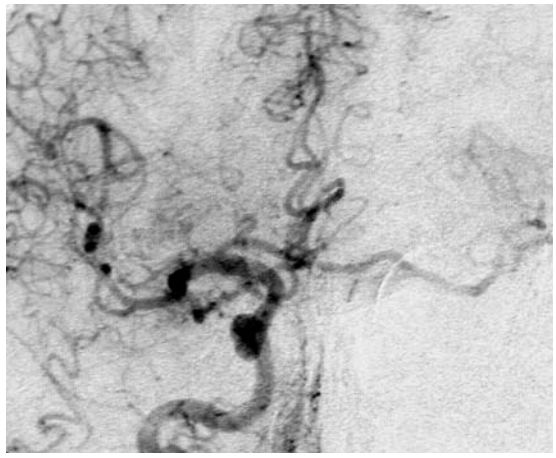


b

Fig. 5.4.13. a Cavernous ICA aneurysm. **b, c** After balloon test occlusion the parent artery was occluded with platinum coils. **d** Although cross filling via the Acom is flimsy the patient had no neurologic deficit after the intervention



c



d

nerves III, IV, V, and VI. Retroorbital pain due to venous congestion and visual field limitations due to compression of the optic nerve or chiasm may also occur. If aneurysms of the intracavernous portion of the carotid artery rupture they cause a carotid-cavernous fistula rather than bleeding into the subarachnoid space.

Sufficient radiologic evaluation with delineation of the extent and location of the aneurysm in relation to the subarachnoid space is extremely important to decide whether or not to treat an aneurysm in this location. For surgical planning it is important to visualize the relationship of the aneurysm to the anterior clinoid process which can be best achieved by CT angiography.

In general, treatment of this entity is controversial. Since the mortality rate from untreated cavernous aneurysms is low, treatment in asymptomatic patients should be reserved for those aneurysms extending into the subarachnoid space, because this is associated with a risk of subarachnoid hemorrhage, and those who demonstrate aneurysm enlargement (Linskey et al. 1990). Treatment in symptomatic patients should be reserved for those with progressive ophthalmoplegia or visual loss, ipsilateral facial or orbital pain, epistaxis or SAH. Treatment of these symptomatic aneurysms is aimed to eliminate mass effect and to cure symptoms. Eliminating the aneurysm also protects the patient from risk of subarachnoid hemorrhage. Treatment of choice is the endovascular approach since surgery is accompanied by significant morbidity and mortality, and those aneurysms involving the cavernous sinus are usually regarded as not surgically accessible.

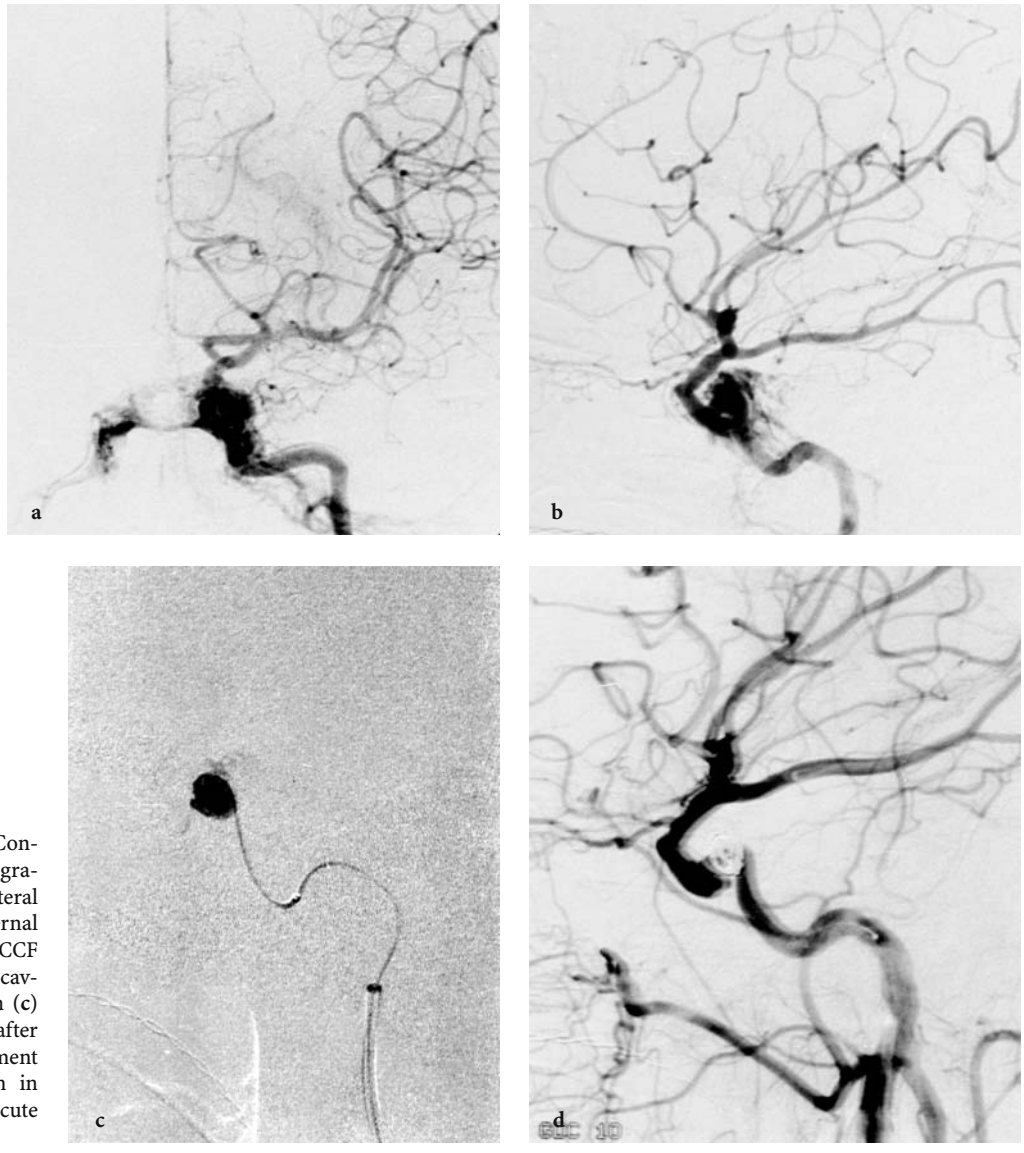
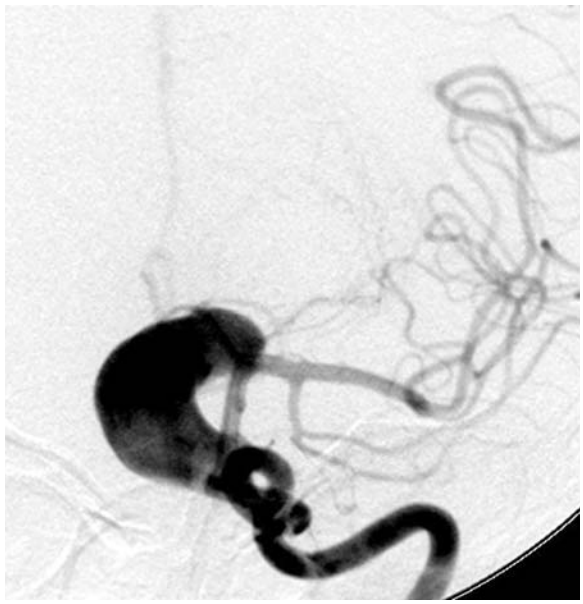
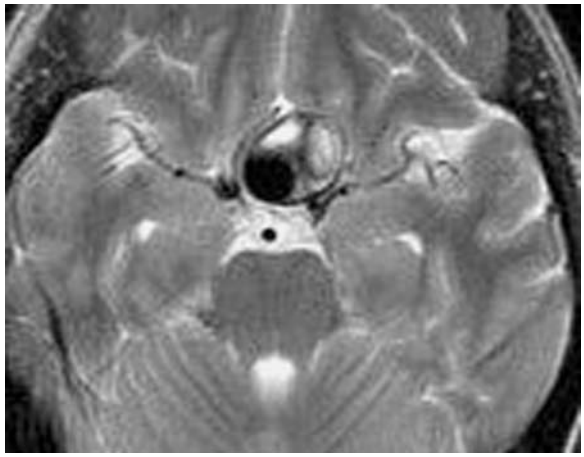


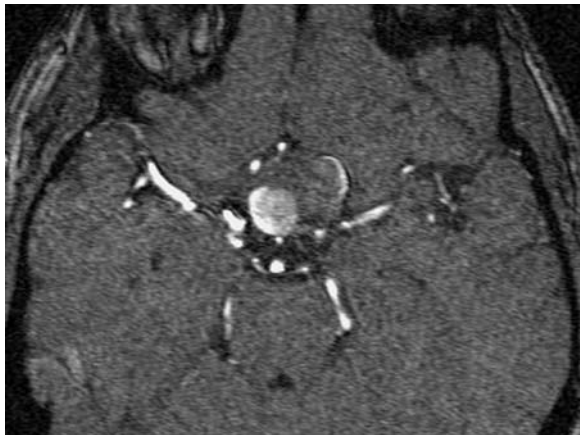
Fig. 5.4.14. a, b Conventional angiography, ap and lateral view, of the internal carotid artery: CCF due to a ruptured cavernous aneurysm (**c**) before and (**d**) after selective treatment of the aneurysm in a patient with acute ophthalmoplegia



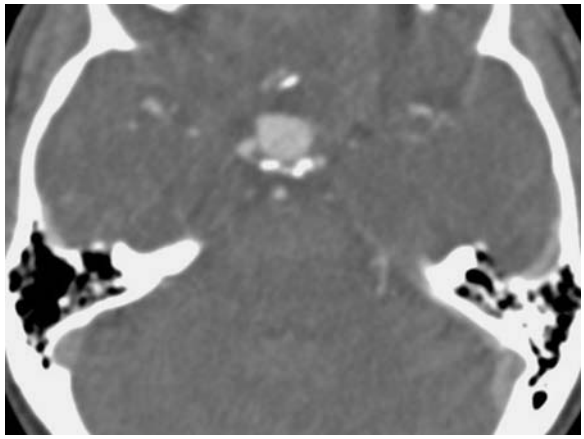
a



b



c



d

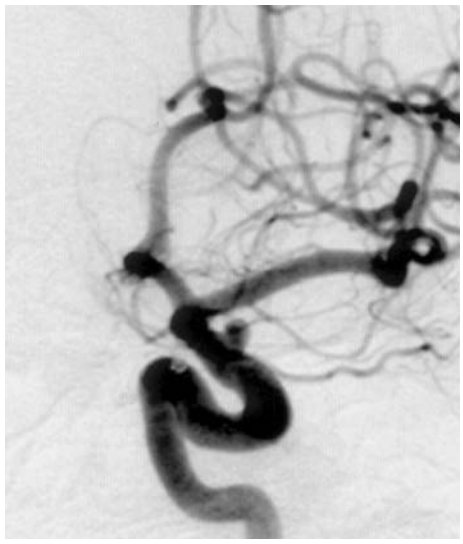
Fig. 5.4.15a–d. Giant partially thrombosed paraophthalmic ICA aneurysm with some calcification at the ventral rim

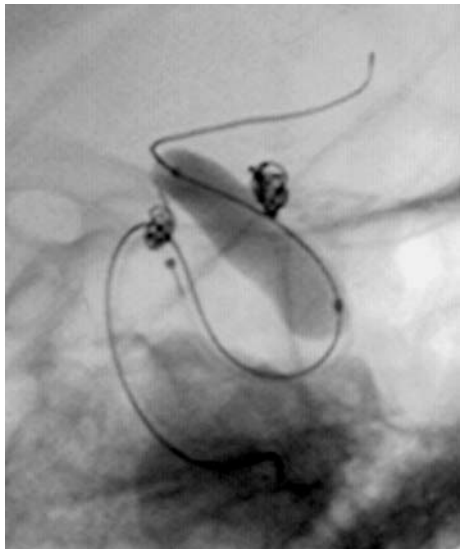
With endovascular treatment rapidly undergoing major developments, the treatment of carotid artery aneurysms have improved significantly in recent years. The primary aim is selective occlusion of the aneurysm with preservation of the parent artery. However, many aneurysms located at the paraophthalmic region have an unfavourable aneurysm geometry with a wide neck. Additionally, they may be large, partially thrombosed or calcified.

Thornton et al. reviewed 66 patients with 71 ruptured and unruptured paraclinoid aneurysms (distal to the cavernous segment of the internal carotid artery and proximal to the posterior communicating artery) treated by an endovascular approach. GDC coiling was performed in 78 aneurysms (including 45 with the remodelling technique), permanent balloon occlusion in 9, and 3 had both GDC coiling and permanent balloon occlusion. In ten aneurysms it was not possible to place coils in the lumen of the aneurysm, five of these were treated surgically and 5 remain untreated. All patients had immediate post procedure angiography. In 90 procedures performed, 2 (2.2%) patients had major permanent deficits (1 monocular blindness, 1 hemiparesis), 1 (1.1%) had a minor visual field deficit, and 2 (2.2%) patients died from major embolic events. Follow up 6 months after treatment showed more than 95% occlusion in 52/61 (85.2%) and less than 95% occlusion in 9/61 (14.8%). The authors concluded that properly selected paraclinoid aneurysms can be successfully treated by endovascular technology with a morbidity and mortality rate equal to or better than the published surgical series of similar aneurysms (Thornton et al. 2000a).

Despite these advances, occlusion of the parent artery is sometimes necessary because of the wide aneurysm neck. Balloon occlusion of the ICA is a reliable treatment for intracavernous giant aneurysms. In a series of 58 patients, Larson et al. (1995) reported a morbidity rate of 10% caused by transient cerebral ischemia, a permanent ischemic morbidity rate of 5%, and mortality rate of 5%. The authors reported a good resolution of cranial nerve deficits and visual impairment. For preocclusion work-up prior definite occlusion of the carotid artery balloon test occlusion should be performed to assess if occlusion is tolerated. In a series of 500 temporary balloon occlusions of the ICA, Mathis et al. (1995) described a complication rate of 1.6% asymptomatic, and 1.2% transient and 0.4% permanent ischemic complications. During temporary balloon occlusion, it is of crucial importance to evaluate cross-filling from the other side and simultaneous venous drainage. There is an increased risk for delayed ipsilateral ischemic deficits after ICA occlusion for treatment of aneurysms (Larson et al. 1995; Linskey et al. 1994). Ischemia associated with ICA occlusion may be secondary to thromboembolic events rather than decreased blood flow in the ICA distribution. In our opinion, prolonged heparinization for 72 h starting during treatment should therefore be performed.

Proximal ICA occlusion alone will cure the aneurysm in most cases, except those that have collateral inflow from cavernous or petrous branches of the ICA keeping the aneurysm open. The incidence of de novo aneurysm formation was reported from 1.4%–4% after carotid ligation. A direct relation between hemodynamic stress and the development of aneurysms at the anterior communicating artery has been suggested by several authors (Timperman et al. 1995). Therefore, a close long term follow-up, preferentially using non-invasive MRA to detect a possible development of an aneurysm at the Acom region should be done in these patients. In patients with bilateral aneurysms of the internal carotid artery, carotid occlusion on one side should be performed with caution since this might stress the contralateral aneurysm leading to potentially catastrophic results.


a


b

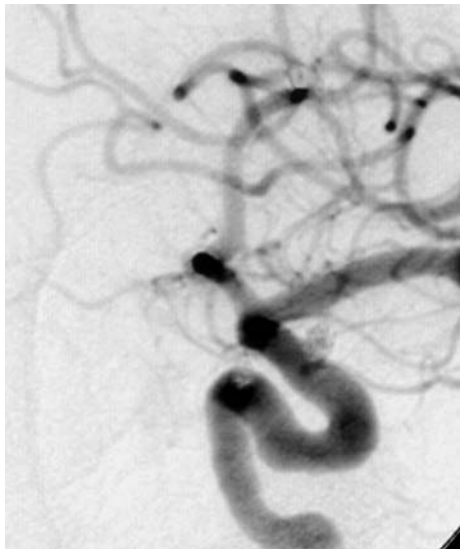

c

Fig. 5.4.16. a–c Small broad-based paraophthalmic aneurysm treated with remodelling technique, previously coiled Acom aneurysm

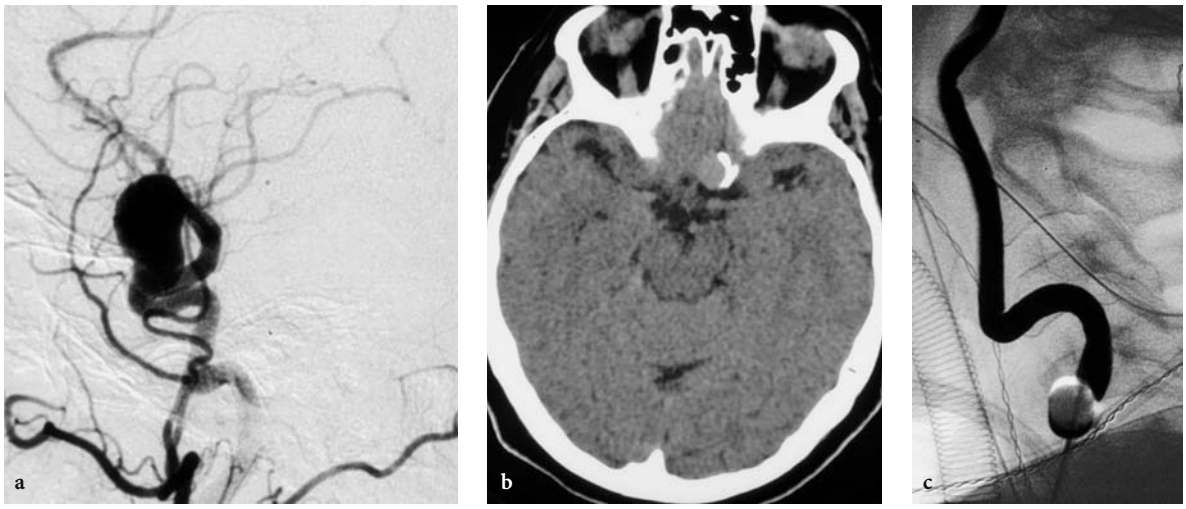


Fig. 5.4.17. a, b Large paraophthalmic broad-based ICA aneurysm extending cranially superior to the clinoid process with partial calcification. **c** "Evacuation trapping technique" during clipping was performed after transient balloon occlusion of the left internal carotid artery

5.4.9.1.2 Supraclinoid/Intracranial Carotid Bifurcation

The majority of posterior communicating artery (Pcom) aneurysms arise from the ICA at the origin of the Pcom. True Pcom aneurysms are rare and might be more difficult to catheterize. In about 30%–40% of Pcom aneurysms are associated with third nerve cranial palsy with or without subarachnoid hemorrhage (Birchall et al. 1999; Perneczky and Czech 1984). From a surgical point of view the approach to these aneurysms is not too difficult. However, many of them have a small neck and are good candidates for endovascular therapy. In our experience, those aneurysms arising from the posterior wall of the ICA might be slightly different compared to other intracranial aneurysms. They might have a higher tendency of recanalization than generally expected from a side wall aneurysm and some of them are more fragile and have a tendency not only to rupture at the dome, but also to pop out of the ICA wall. The latter situation is extremely difficult to handle and usually ends up with a parent vessel occlusion of the ICA.

Aneurysms of the intracranial carotid bifurcation usually arise at the apex of the T-shaped bifurcation and the majority of them points upward and towards the anterior perforated substance. Due to the perforating branches at this site clipping of these aneurysms is associated with a substantial risk of ischemic infarctions. The endovascular approach is usually easy from a technical point of view (like in basilar tip aneurysms). Even if these aneurysms look broad based coiling is usually possible without the aid of remodelling or stenting.

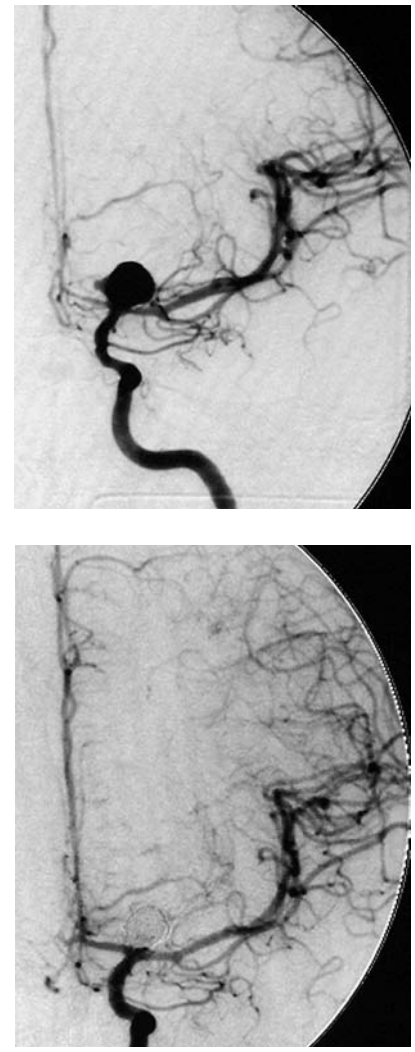
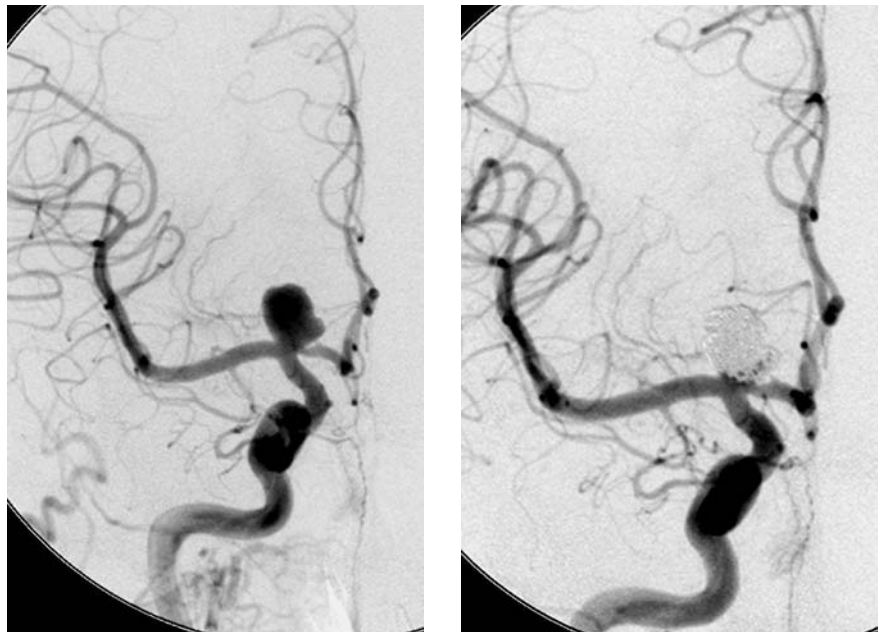
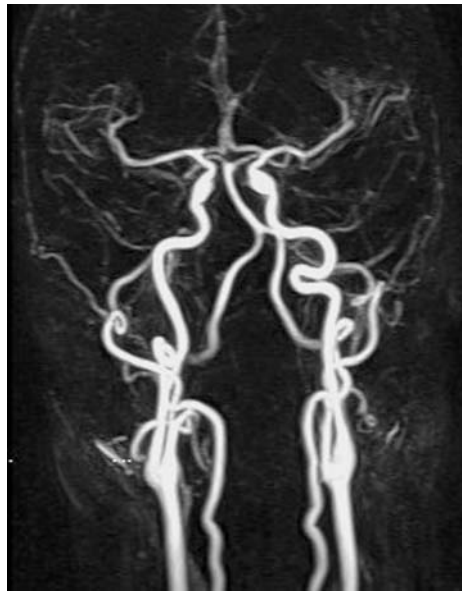


Fig. 5.4.18a,b. Conventional angiography, before and after coil treatment of a distal ICA aneurysm



a b



c

Fig. 5.4.19a–c. Typical intracranial carotid bifurcation aneurysm. MRA 6 month after embolization revealed stable occlusion

5.4.9.2 Anterior Cerebral Artery

5.4.9.2.1 Anterior Communicating Artery

The rupture of an aneurysm at the anterior communicating artery (Acom) is responsible for approximately 40% of subarachnoid hemorrhages (Kassell et al. 1990a,b). Treatment of these aneurysms is thus a frequent situation and of great importance. In the past, Acom aneurysms were treated nearly exclusively by surgical clipping, using either a pterional or interhemispheric approach. With the increasing use of endovascular techniques Acom aneurysms are frequently treated by coil embolization and in some institutions it is already the first-line treatment. Moret et al. (1996) reported their results on 251 berry aneurysms treated by detachable coils, of which 36 were located at the Acom and treated with GDC. There were 23 aneurysms which were completely and six were partially occluded. In three cases, no endovascular treatment was attempted because the aneurysmal neck was not clearly distinct from the adjacent, or parent vessels. In

four cases, treatment failed because of atheroma of the cervical and intracranial vessels. The authors reported one permanent neurologic complication, two patients died as a result of complications of subarachnoid haemorrhage. In summary, the authors concluded that endovascular treatment using GDC is an efficient technique for treating anterior communicating artery aneurysms even in the acute phase of SAH (Moret et al. 1996). This is in accordance with our own results, demonstrating that GDC treatment of ruptured Acom aneurysms is effective and can be performed with acceptable mortality and morbidity, also during the vulnerable period of vasospasms.

Remodelling seems to be feasible for wide-necked aneurysms of the Acom (Levy 1997), but is not routine at this location. In our experience recanalization of these aneurysms is usually not a problem in downward looking aneurysms. Those aneurysms looking upward indeed have a higher tendency of recanalization even after initial complete occlusion. Follow-up is therefore of utmost importance in the latter group.

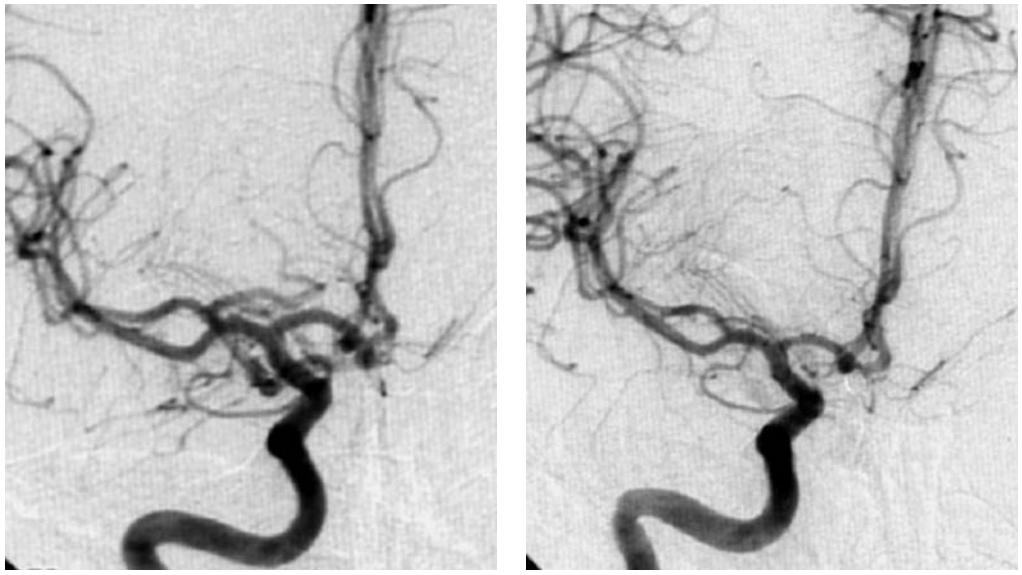


Fig. 5.4.20a,b. Small Acom aneurysm: (**a**) before and (**b**) after endovascular embolization

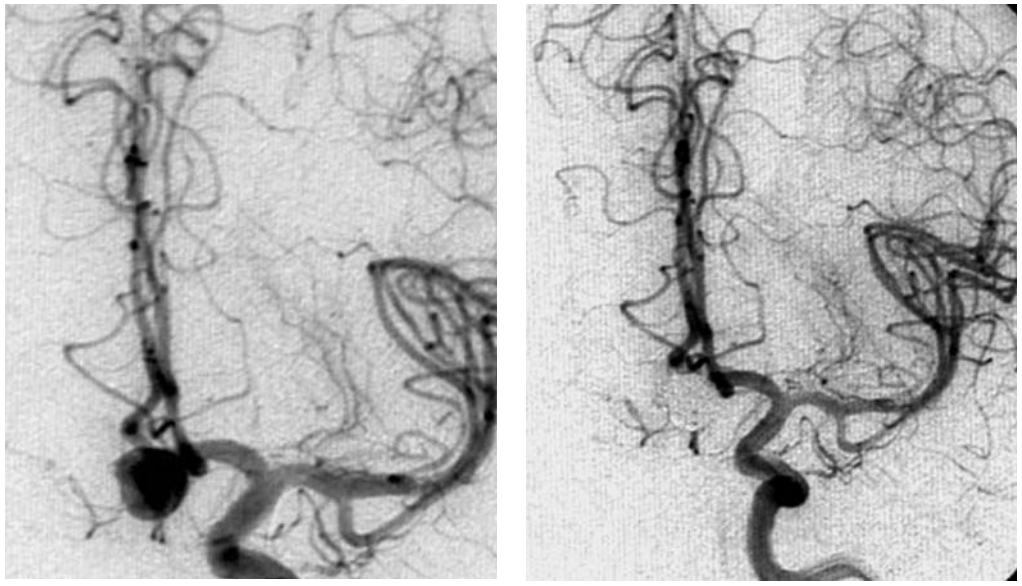
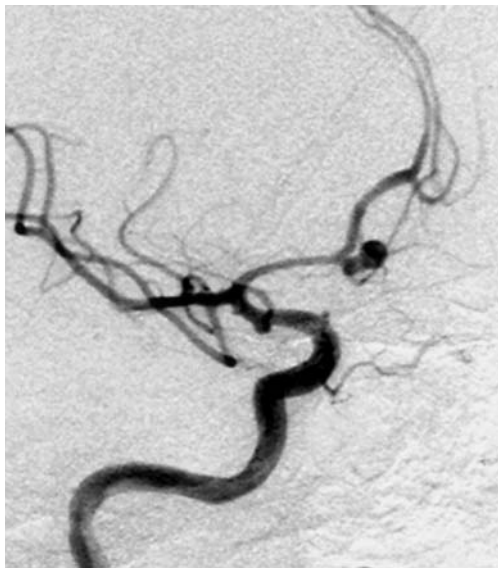
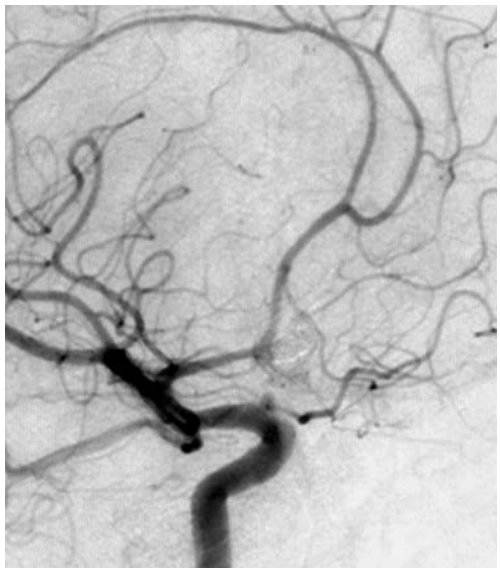


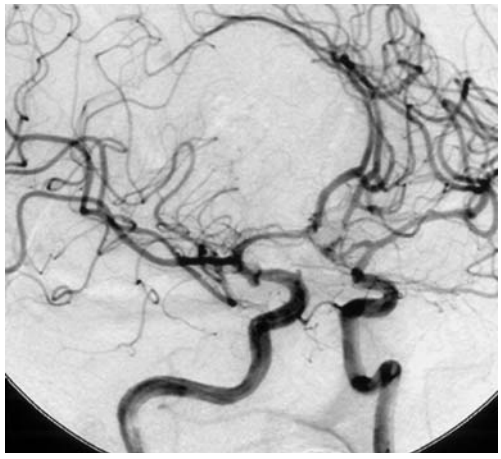
Fig. 5.4.21a,b. Medium sized Acom aneurysm: (**a**) before and (**b**) after endovascular treatment; the parent artery is still open



a

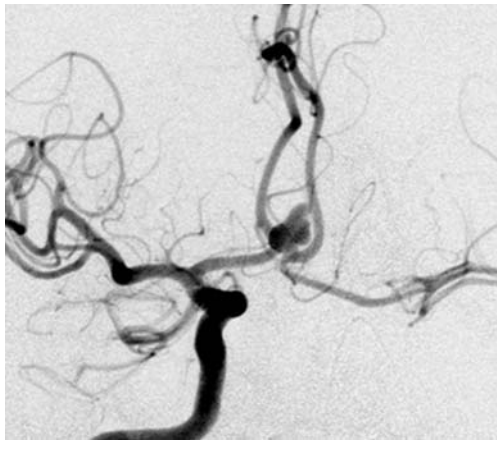


b

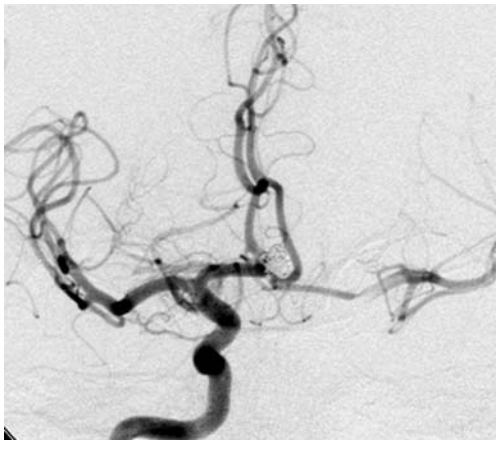


c

Fig. 5.4.22a–c. Before and after complete coil embolization of an Acom aneurysm. Note, the simultaneous bilateral carotid injection demonstrating patency of the Acom

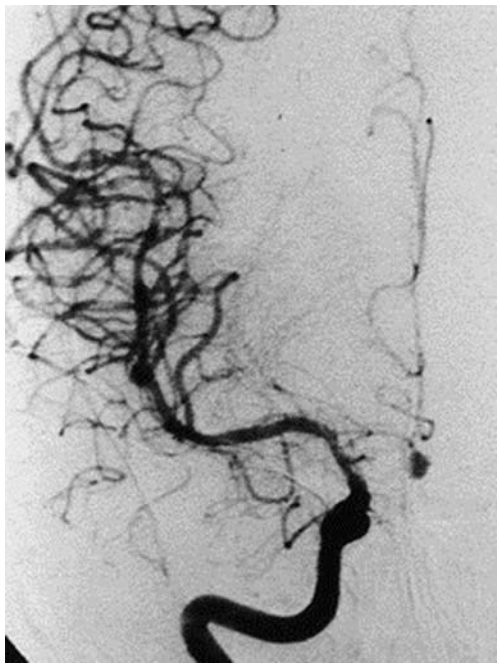


a

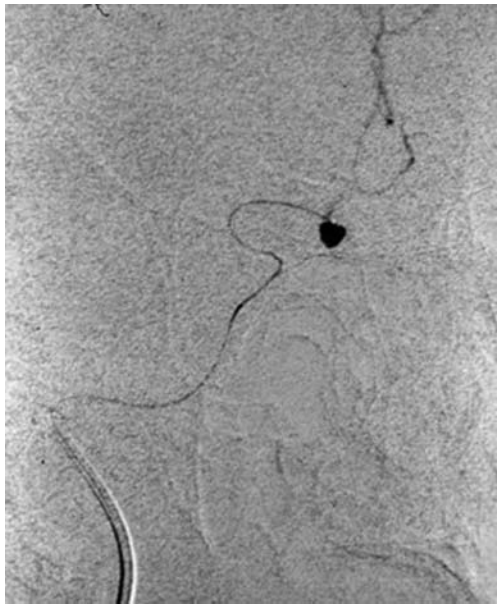


b

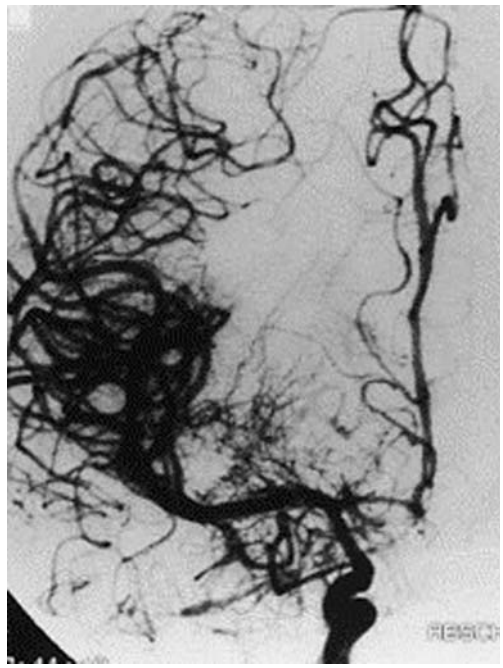
Fig. 5.4.23a,b. Before and after complete coil embolization of a multilobulated Acom aneurysm



a



b



c

Fig. 5.4.24a–c. Conventional angiography before treatment revealed severe vasospasm of the ACA, despite the spasm endosaccular treatment with complete obliteration of the Acom aneurysm was performed and vasospasmolysis after treatment resulting in almost complete regression of spasm

5.4.9.2.2
Distal Anterior Cerebral Artery/Pericallosal Artery

Distal anterior cerebral artery aneurysms are rare, accounting for about 4.5% of all intracranial aneurysms (Inci et al. 1998), and usually arise at the bifurcation of the pericallosal and callosomarginal arteries. SAH due to rupture of a distal anterior cerebral artery aneurysms is frequently associated with ICH in and/or along the corpus callosum and anterior interhemispheric fissure and subsequent intraventricular hemorrhage.

Pericallosal aneurysms frequently have a broad base or absent neck associated with a small diameter of the parent vessel. In some cases the pericallosal artery arises out of the aneurysm sac. This anatomic feature is difficult for both surgery and endovascular therapy. Due to the particular anatomy of pericallosal aneurysms surgical approach is different from those of other anterior circulation aneurysms and precise neck clipping might be difficult even for an experienced surgeon. Using the frontal interhemispheric route, which is the usual approach for most surgeons, the pericallosal aneurysm neck is exposed after the fundus, which might become a delicate procedure and is frequently associated with intraoperative aneurysm rupture (Proust et al. 1997). Additionally, there might be difficulties in clip application due to the small space of the pericallosal cistern, dense adhesions between the cingulate gyri, difficulty in controlling the parent artery, and the association of vascular anomalies (Inci et al. 1998).

Proust et al. (1997) reported the results of a retrospective multicenter study in 43 patients with 50 distal anterior cerebral artery aneurysms, with only two aneurysms treated endovascularly. In their series an 11.4% incidence of thrombosis was observed on postoperative control angiography, mainly in the distal pericallosal segment or callosomarginal artery, associated with a poor outcome. The authors reported a higher tendency of rebleeding in this location. This is in accordance with the results of Sindou et al. (1988) reporting a 16% rebleeding rate in their series. But, times are changing. Recently, Menovsky et al. (2002) reported on 12 patients with pericallosal aneurysms, all treated with the endovascular method. In all 12 patients, the pericallosal aneurysm could be reached with a microcatheter and platinum coils could be deployed. There were no procedure-related complications. Initial occlusion was complete in 11 aneurysms and near complete in 1 patient. The conclusion of the authors is that coiling of ruptured pericallosal aneurysms can be considered as an alternative to surgical clipping. Increasingly improved results of endovascular therapy at different locations of the Circle of Willi are mainly based on increased skills of the interventionalist, but are also related to the continuous improvement of all parts of the material, allowing easier access to the aneurysm and denser packing with softer coils.

In our opinion, the endovascular approach in pericallosal artery aneurysms is often feasible.

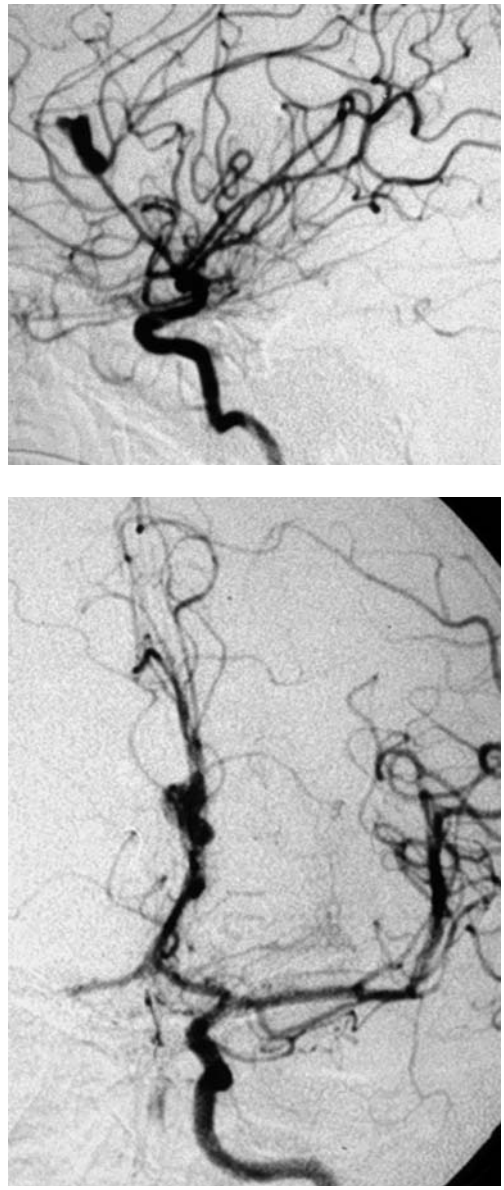
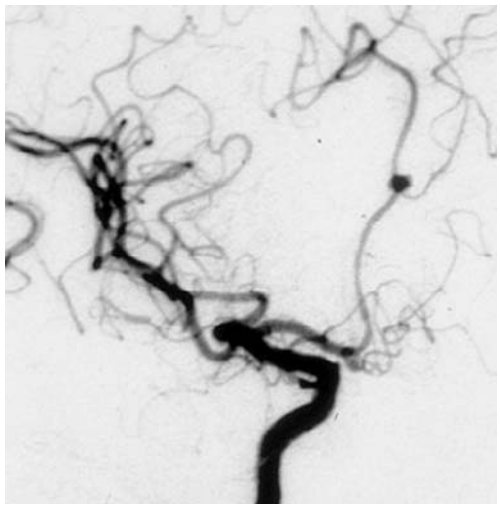
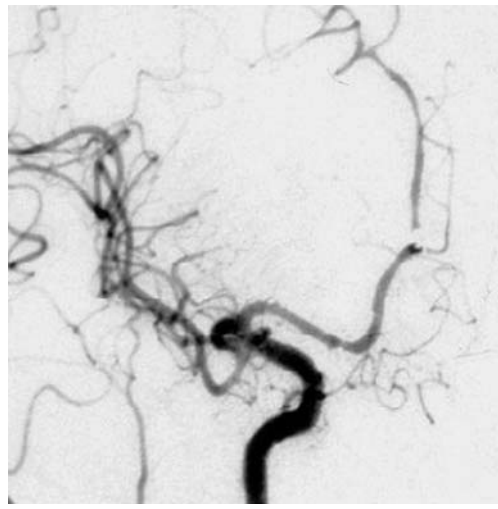


Fig. 5.4.25a,b. Multilobulated aneurysm of the pericallosal artery; because of an associated intraparenchymal hematoma surgery was performed

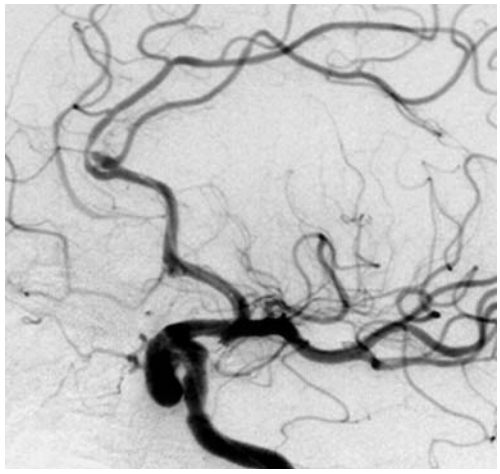


a

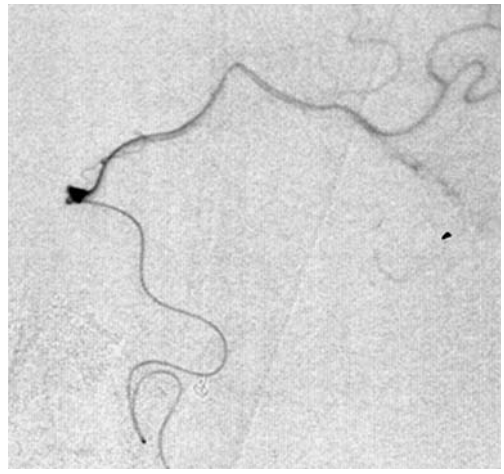


b

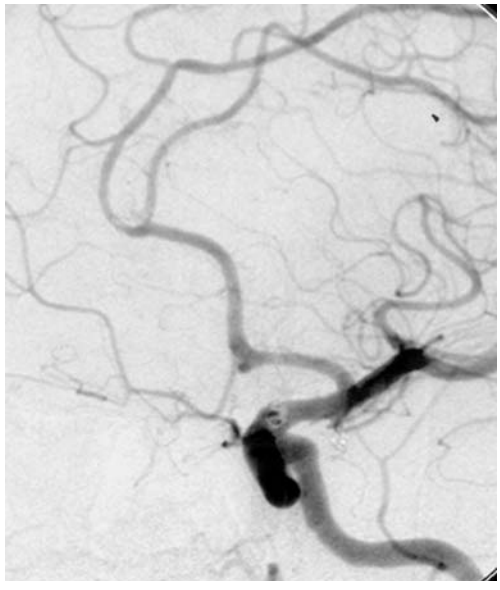
Fig. 5.4.26a,b. Before and after endovascular treatment of a small aneurysm of the pericallosal artery



a



b



c

Fig. 5.4.27a–c. Before and after endovascular treatment of a small aneurysm of the pericallosal artery; aneurysmography revealed a very close relationship of the aneurysm and the callosomarginal artery

5.4.9.3 Middle Cerebral Artery

MCA aneurysms are often small and wide necked, and often incorporate neighbouring arterial branches in the aneurysm base. Additionally, they are frequently associated with multiple intracranial aneurysms ("mirror aneurysms"). Due to the local anatomy and neck configuration MCA aneurysms need particular consideration. For aneurysms with a very wide neck or difficult geometry surgery is still the therapy of choice. If a space-occupying hematoma is present, immediate evacuation of the hematoma is mandatory, in combination with clipping of the aneurysm (van Gijn and van Dongen 1982). Regli et al. (1999) recommend not to attempt coil embolization in MCA aneurysms since in their study of 35 consecutive patients harbouring 40 unruptured MCA aneurysms, only 6% could be successfully embolized with coils whereas 94% (32/34) of patients had to be clipped. The two major angioanatomic features responsible for the failure of endovascular treatment were an unfavourable dome-to-neck ratio of less than 1.5, and/or arterial branching from the aneurysm base.

Compared to other aneurysm locations, the risk of thromboembolic complications or local compression of surrounding neighbouring vessels seems to be increased. We also made the experience that endovascular treatment in this location is more often associated with complications such as thrombus formation at or near the base of the aneurysm. However, we could not confirm the results of the above mentioned study. Regarding feasibility we were able to treat almost 90% of MCA aneurysms and the clinical outcome of our consecutive series of 39 patients with 41 ruptured and unruptured aneurysms at the middle cerebral artery encountered only 2.6% with a permanent neurologic deficit due to the procedure. Although the total rate of complications including vessel occlusion, coil protrusion and groin hematoma was higher, this number of 2.6% reflects a very low procedural permanent morbidity. Therefore, we think after appropriate patient selection endovascular therapy in these aneurysms might become more applicable as it is by now. Careful evaluation of the angioarchitecture using rotational 3D angiography, superselective angiography with the microcatheter (aneurysmography), or 3D helical CT angiography might be extremely helpful in the precise visualization of the aneurysm neck, shape and the size of the aneurysm, supporting further treatment decisions and planning. MRA can provide complementary information to DSA, such as intraaneurysmal thrombus. Sometimes the endovascular attempt only with introducing the microcatheter and delivering a coil could reveal if coiling seems to be possible without an unusual high risk. In selected cases the remodelling technique in broad based MCA bifurcation aneurysms can be very helpful; in many cases it is even not necessary to inflate the balloon; it may be enough to have just a second microcatheter at the aneurysm entrance to provide coils from migration into a parent branch.

To prevent thromboembolic complications and compression of neighbouring arterial branches by coils, our "philosophy" for selected MCA aneurysms treated endovascularly is to wait longer (5–10 min) before detachment of the coils. In these aneurysms we prefer to rather underestimate the coil diameter than to choose a coil which is slightly greater than the maximum diameter of the aneurysm. In an unruptured aneurysm we administer aspirin intravenously before application of the first coil and after introducing the microcatheter into the aneurysm. If there is at least subtotal occlusion, further aneurysm thrombosis is possible and was observed in some of our patients at follow up on DSA and MRA 6 months after coil embolization.

However, Pierot et al. (1997) reported rebleeding in an only partially treated MCA aneurysm. General recommendation should imply dense packing for MCA aneurysms. In patients with loose coil packing follow up is essential like in any other locations, to see if there is growth of neck remnants or subsequent thrombosis during follow up.

When unclippable or endovascularly untreatable aneurysms involve the M1, M2, and M3 branches of the middle cerebral artery (MCA), bypass surgery can obviously be a therapeutic option in combination with parent artery occlusion (Drake and Peerless 1997; Peerless et al. 1982). However, and this again is our experience, this is the exception.

5.4.9.4 Vertebrobasilar Arteries

Aneurysms of the posterior circulation account for about 15% of all intracranial aneurysms saccular aneurysms and those of the basilar tip are the most frequent accounting for 5%–8% of all intracranial aneurysms. Ruptured aneurysms in the posterior circulation have a worse prognosis than patients with a ruptured aneurysm in another location (Schievink et al. 1995) and early rerupture occurs more often in this location.

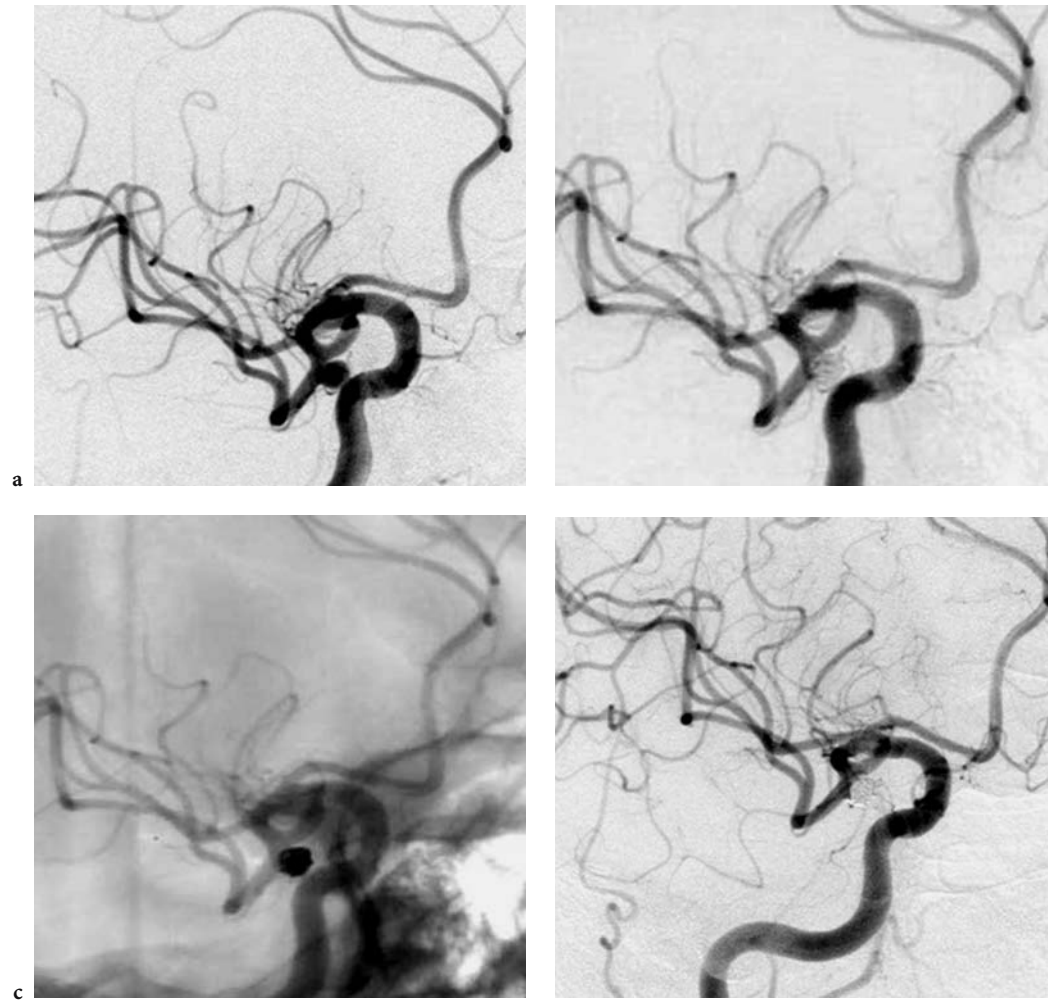
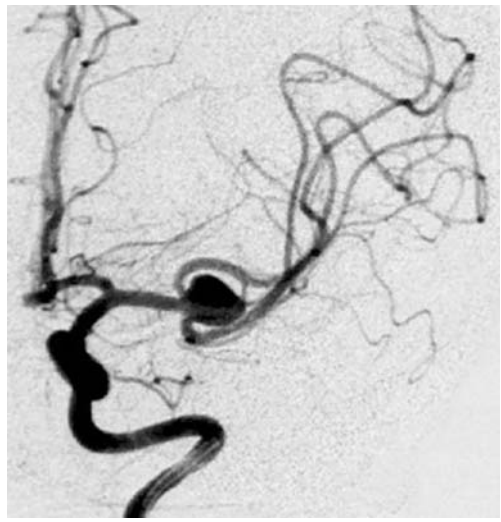


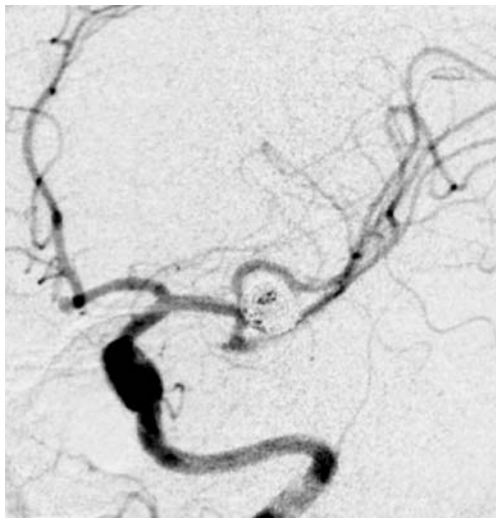
Fig. 5.4.28a–d. Small broad-based ruptured MCA bifurcation aneurysm before and after endovascular embolization with a stable occlusion after 6 months

Despite improvement in microsurgical therapy, clipping for posterior circulation aneurysms remains challenging. The main problems are the deep location, the presence of many eloquent structures around the sac and the neck as well as the restricted access to the aneurysm neck. Furthermore, SAH and cerebral edema increase the difficulties of the surgical approach much more than in any other location. Surgical complications specific for non-giant basilar bifurcation aneurysms are midbrain and/or thalamic infarctions from perforator injury or occlusion, intraoperative rupture, and frequent but nearly always transient cranial nerve paresis (Drake 1965; Horikoshi et al. 1999; Peerless et al. 1987, 1994; Rice et al. 1990). Another complication of surgery in this region is a major operative tear of the aneurysm or incomplete clipping of the aneurysm with the potential for rebleeding during closure or early in the postoperative period.

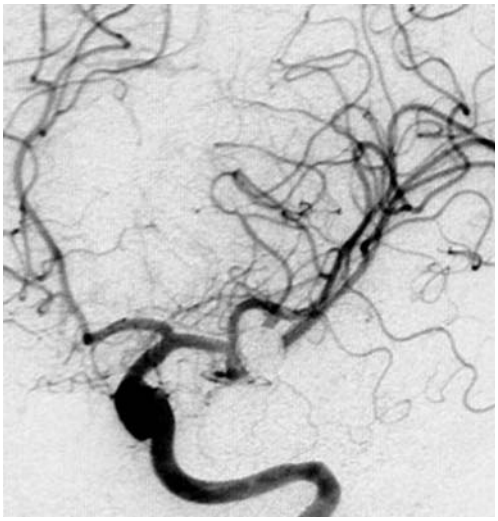
With introduction of detachable platinum coils for endovascular obliteration of cerebral aneurysms a major shift towards this method is established now specifically for aneurysms located in the posterior circulation (Bavinzski et al. 1999; Lusseveld et al. 2002; Richling et al. 1995; Tateshima et al. 2000; Vallee et al. 2003). The early recognition and acceptance that coiling is clearly better than clipping in hind brain circulation aneurysms is the reason that these aneurysms are underrepresented in the ISAT study (Molyneux et al. 2002). Almost exclusively aneurysms of the anterior circulation were involved, posterior circulation aneurysms, for which the endovascular approach is generally accepted as first-line treatment, made up only 2.7%. In most of the cases inclusion was thought to be unethical.



a



b



c

Fig. 5.4.29a–c. Before and after GDC treatment of a left MCA aneurysm, note the slight persistent inflow in the centre of the aneurysm **b** immediately after embolization; **c** 6-month follow-up demonstrated complete occlusion without any residual inflow

5.4.9.4.1
Tip of the Basilar Artery

Aneurysms of the basilar tip remain an extreme surgical challenge, both in terms of technical difficulties associated with the access and the significant postoperative morbidity and mortality rates reported by experienced centres following direct clipping. Clear results about morbidity and mortality rates in patients surgically clipped for an unruptured aneurysm gives the meta-analysis of Raaymakers et al. (1998). This analysis included 61 studies with a total of 2460 patients with at least 2568 unruptured aneurysms. Only 158 patients had a postoperative angiogram which revealed a residual aneurysm in 7%. Although the proportion of aneurysms in the posterior circulation of about 30% was somewhat high the study revealed a mortality and morbidity rate for non-giant aneurysms of 3% and 12.9%, respectively. The results for giant aneurysms in the same location were much worse with a morbidity and mortality of 37.9% and 9.6%, respectively.

In contrast to the surgical approach, the endovascular approach is relatively easy (unless the patient has severe arteriosclerotic disease with increased vessel elongation and stenosis). However, the access to the basilar tip plays a minor role in most cases. The main technical challenge of the endovascular procedure depends on the shape of the aneurysm and not on its location. But since the introduction of a very flexible neurostent and the development of different coil designs most of the basilar tip aneurysms are now treatable with the endovascular approach. This

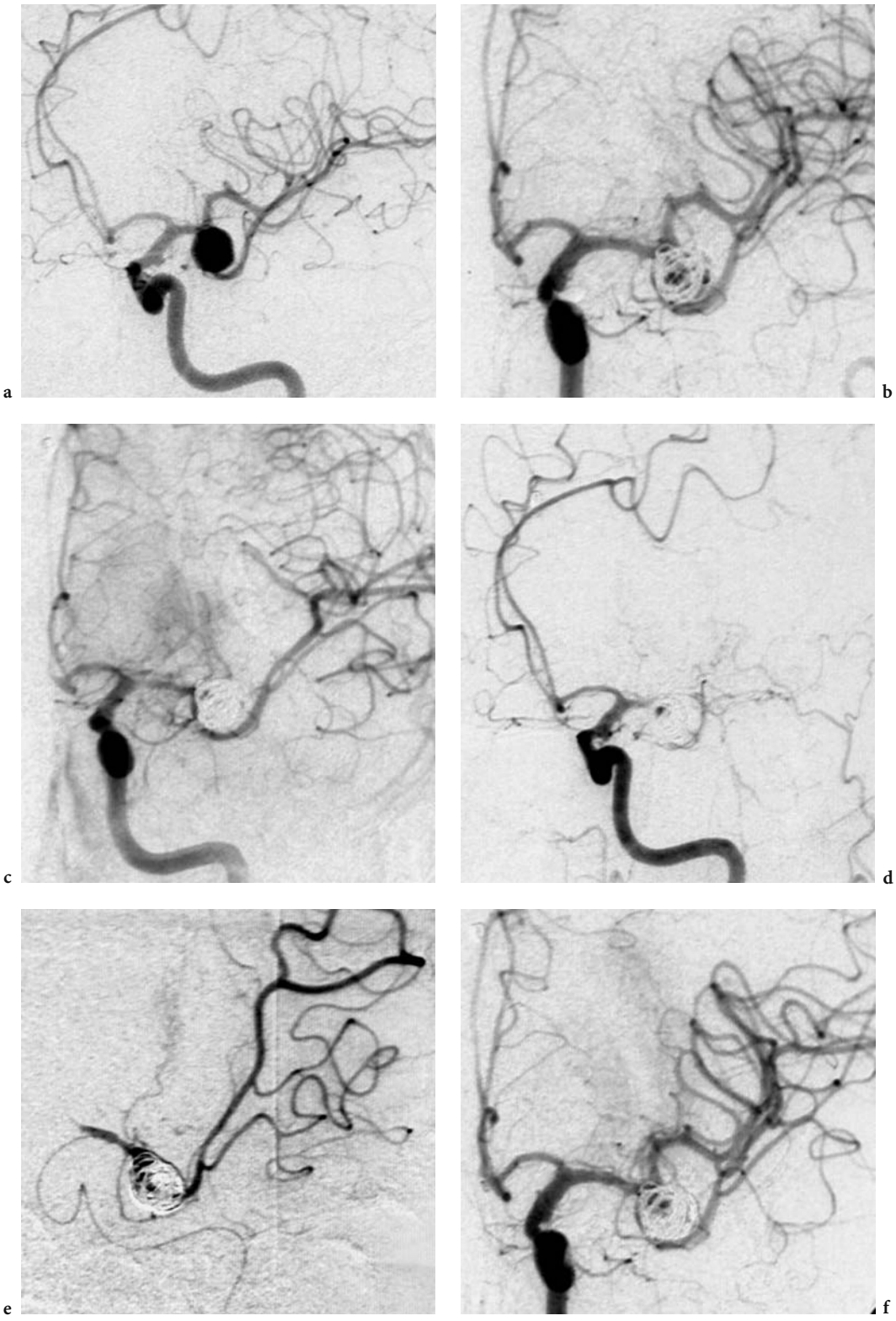
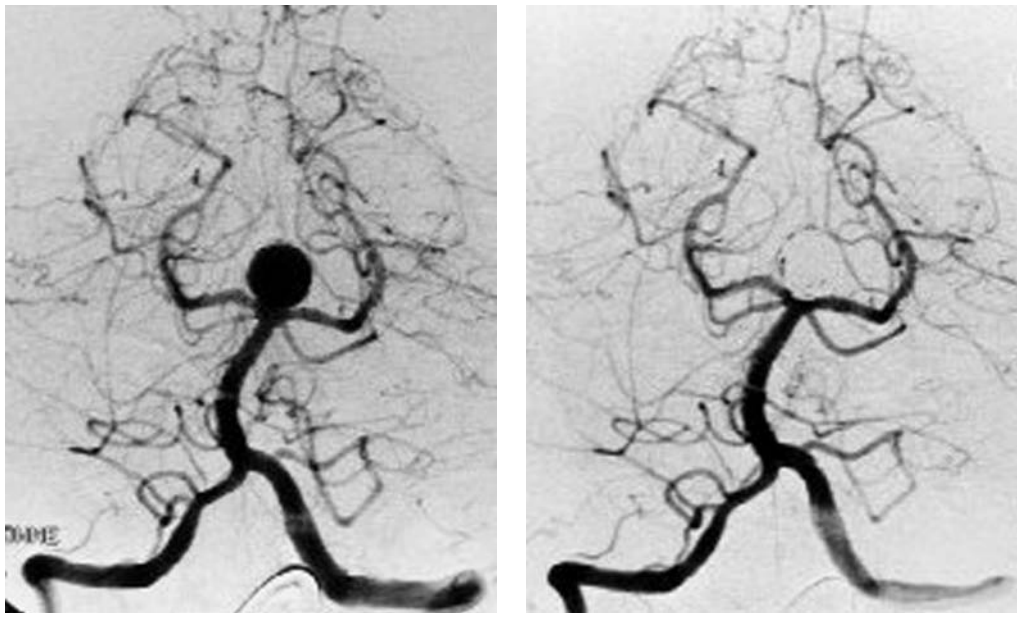
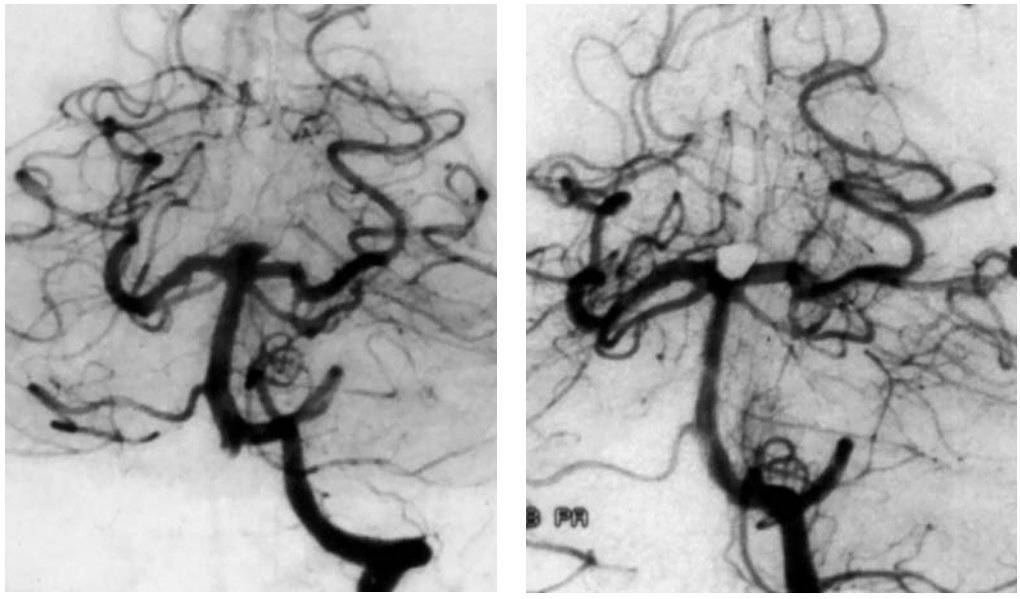


Fig. 5.4.30a–f. Angiography: before and after incomplete coil embolization of an unruptured left MCA aneurysm. Due to progressive thrombosis out of the aneurysm gradual MCA occlusion developed 4.5 h after the intervention. The vessel could be reopened by selective intraarterial thrombolysis using urokinase (1,000,000 IU). Although a small basal ganglia infarction was induced the patient had a good recovery with only mild deficits



a b

Fig. 5.4.31a,b. Before and after endovascular treatment of a non-ruptured basilar tip aneurysm



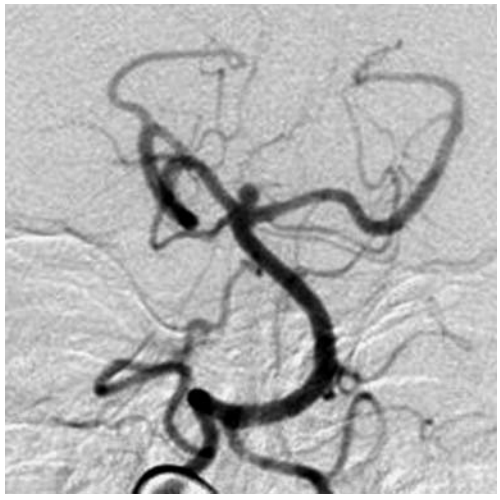
a b

Fig. 5.4.32a,b. Before and after endovascular treatment of a broad-based ruptured basilar tip aneurysm

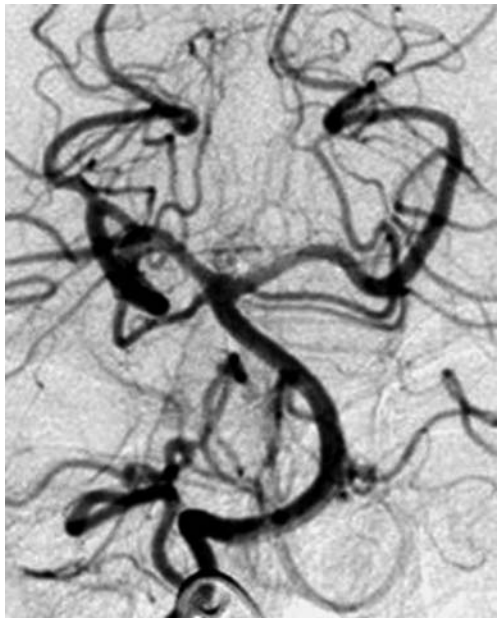
is also true for broad-based aneurysms which may encroach one or both P1 segments.

Bavinzski et al. (1999) treated a series of ruptured (n=34) and unruptured (n=11) basilar tip aneurysms and had a morbidity of 4.4% and a mortality of 2.2%. Even better results were obtained by the group with Tateshima (2000) who treated 73 patients with 75 basilar tip aneurysms of which 42 patients had a SAH, eight presented with symptoms due to mass effect and 23 had an incidental finding. The procedure-related morbidity was 4.1% and mortality was 1.4%.

Because most single center reports on endovascular treatment of basilar tip aneurysms revealed an

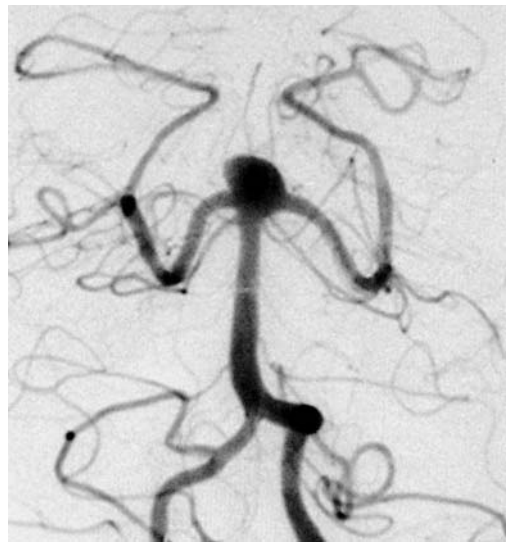


a

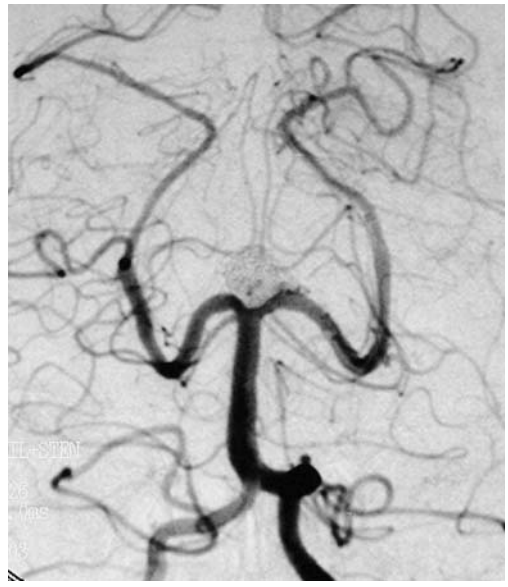


b

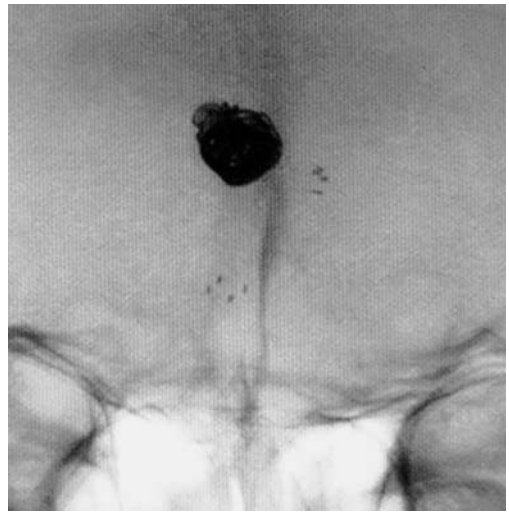
Fig. 5.4.33a,b. Before and after endovascular treatment of a small ruptured basilar tip aneurysm



a



b



c

Fig. 5.4.34a–c. Before and after endovascular treatment of a broad-based non-ruptured basilar tip aneurysm encroaching the P1 segment on the left. A neurovascular stent (Neuroform) was placed from the left P1 to the basilar artery before embolizing the aneurysm through the stent interstices

extremely low morbidity and mortality rate which matches our own experience we do recommend endovascular treatment as the treatment of choice in ruptured or unruptured aneurysms in this location (Bavinzski et al. 1999; Birchall et al. 2001; Pierot et al. 1996; Richling et al. 1995; Tateshima et al. 2000; Vallee et al. 2003).

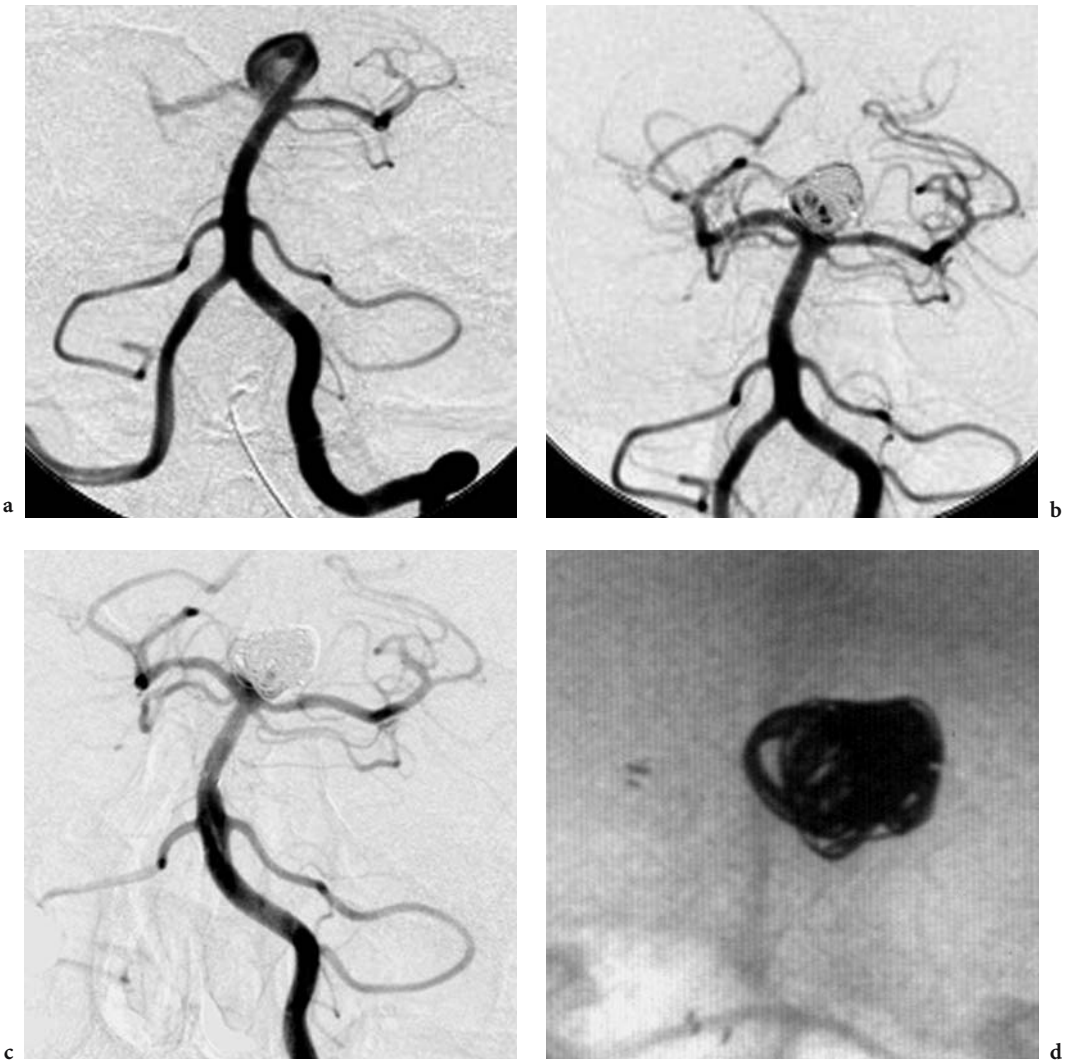


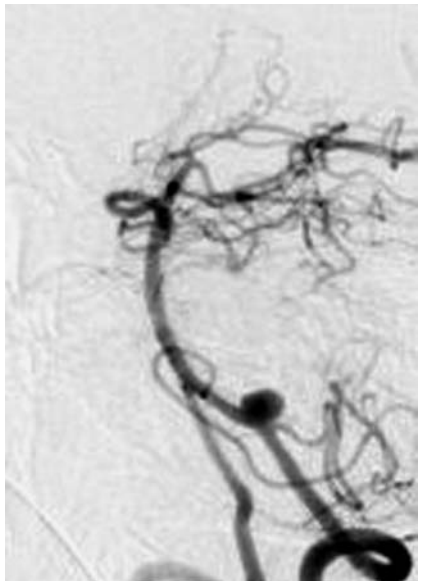
Fig. 5.4.35. a, b Before and after stent application in combination with coil treatment in a broad-based basilar tip aneurysm encroaching the P1 segment on the right side. **c** The stent was placed from the right P1 segment to the basilar artery. **d** 7-Month FU showed further obliteration of the initially subtotal occluded aneurysm

5.4.9.4.2
Vertebral Aneurysms

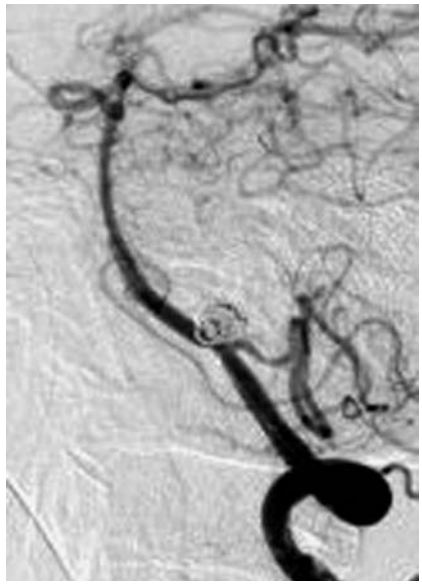
Aneurysms of the vertebral artery leading to SAH are located at the V4 segment. Dissecting aneurysms are more frequent in this location than non-dissecting berry aneurysms. Aneurysms are located proximal to the origin of the PICA, at the origin of the PICA (so-called PICA aneurysms) or slightly distal to the origin of the PICA.

In patients with a dissecting aneurysm of the vertebral artery resulting in subarachnoid hemorrhage, either proximal occlusion or trapping of the lesion is commonly advocated to prevent subsequent rupture. If proximal occlusion alone is performed, retrograde flow from the contralateral vertebral artery into the distal vertebral artery might be maintained. This may retard thrombosis and organization of the dissected lumen, leading to the possibility of postoperative rebleeding.

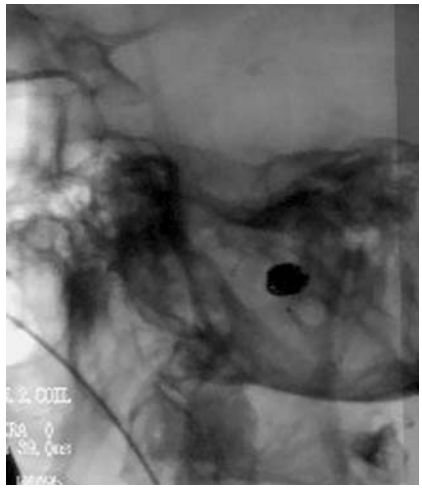
Fusiform aneurysms are usually considered due to atherosclerosis in adults. But, more common in the vertebrobasilar system, there is a subset of cerebral aneurysms with fusiform morphology, apparently unrelated to cerebral atherosclerosis or systemic connective tissue disease, thin-walled in part or whole, possibly containing thrombus (Findlay et al. 2002). These aneurysms can rupture or cause cranial nerve or brain stem compression.



a



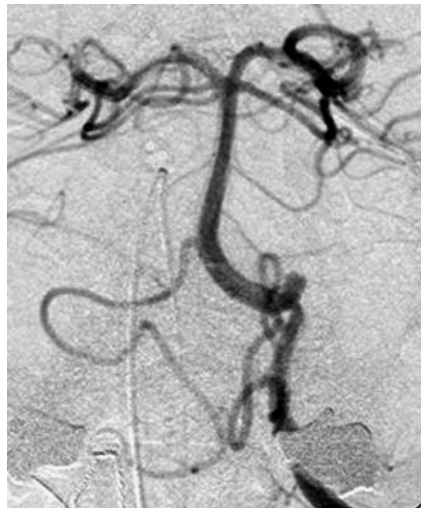
b

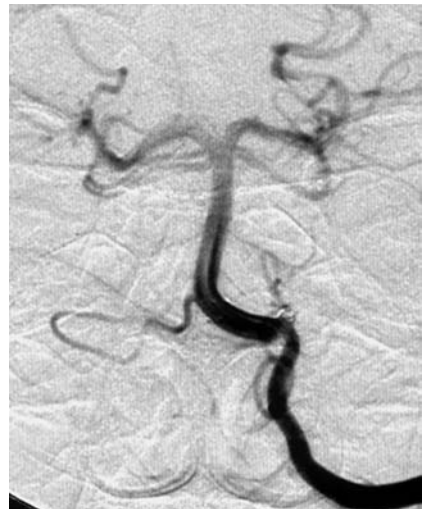


c

Fig. 5.4.36a–c. Broad based vertebral aneurysm at the origin of the PICA before and after stent placement and implantation of platinum coils

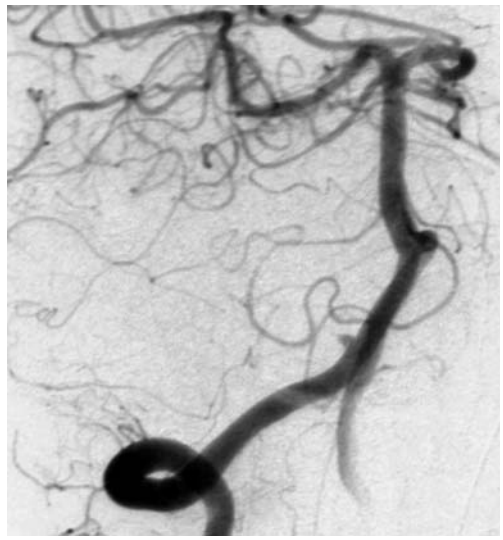
a



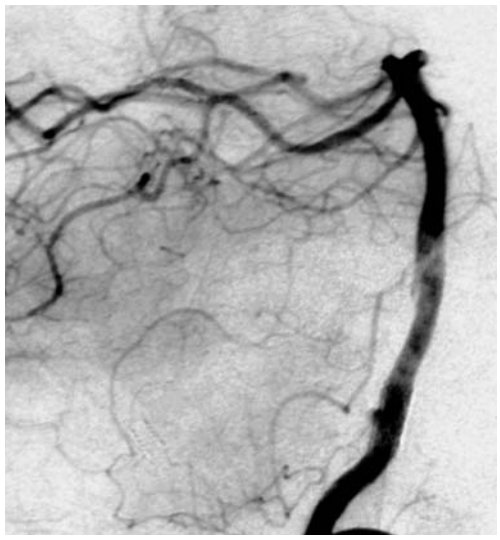


b

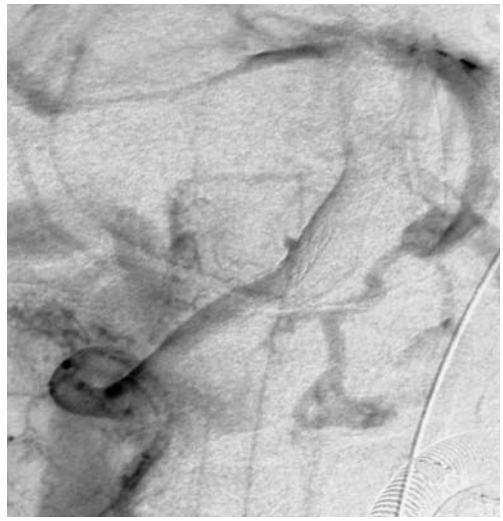
Fig. 5.4.37a,b. Small vertebral aneurysm before and after endovascular treatment



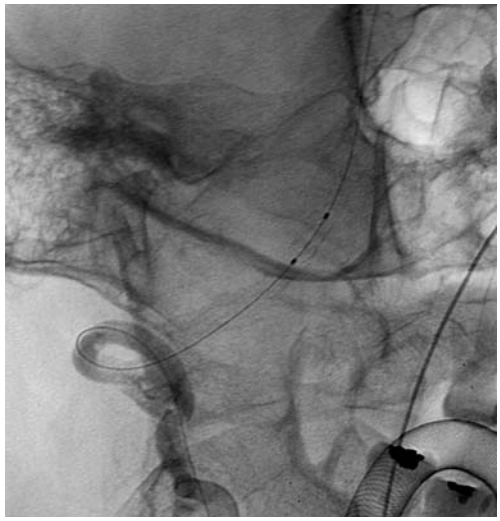
a



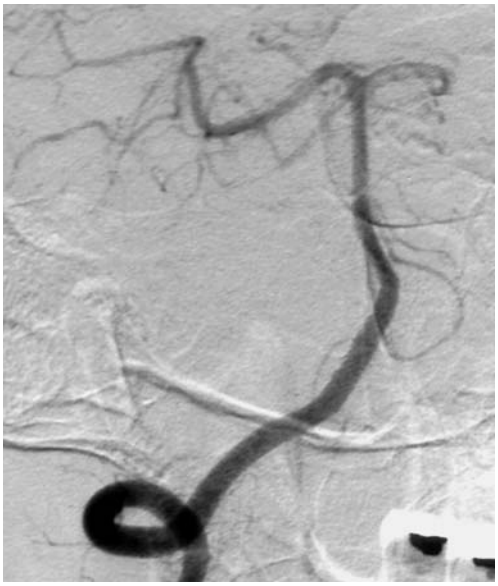
b



c



d



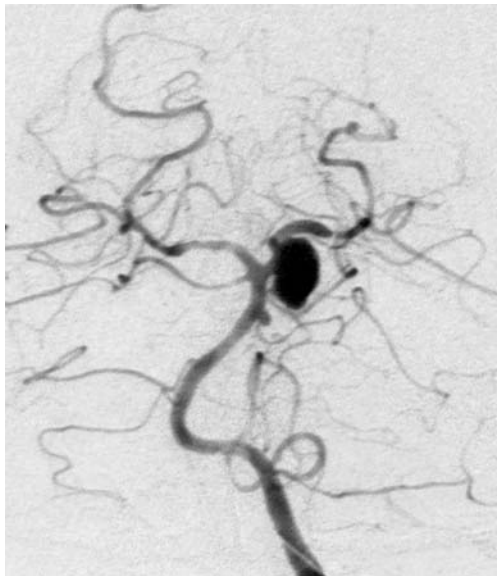
e

Fig. 5.4.38. a Very small ruptured vertebral aneurysm. **b, d** Two microstents (INX, Medtronic) were placed in front of the aneurysm. **c** Immediately, contrast stasis in the aneurysm was noted. Repeated DSA 10 days and (**e**) 7 months after intervention revealed complete aneurysm obliteration

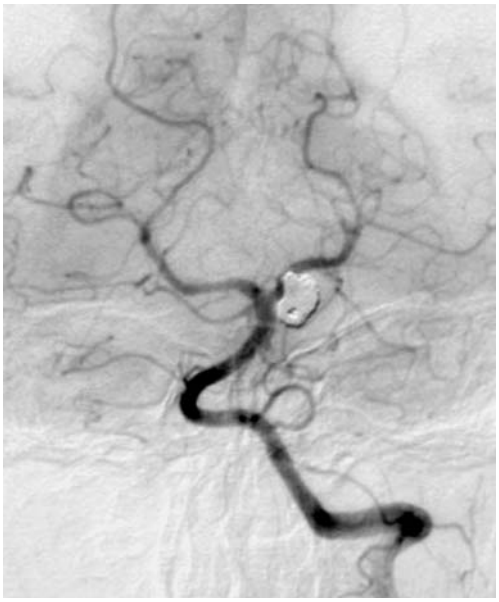
5.4.9.5 Rare Locations

5.4.9.5.1 Posterior Cerebral Artery

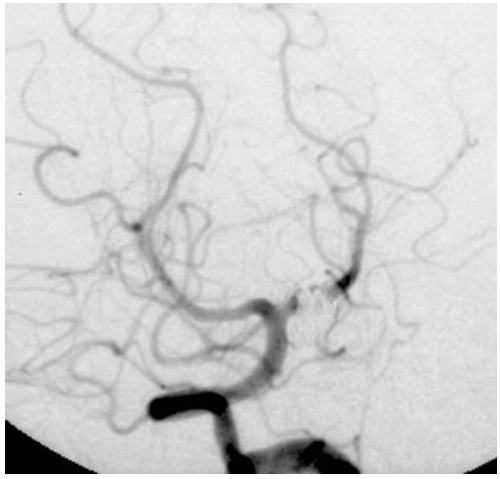
Aneurysms of the posterior cerebral artery (PCA) are relatively rare compared with those in other locations. Extremely rare are singular berry aneurysms of the PCA. Often, this type of aneurysm is either associated with the incidence of multiple aneurysms or with other vascular disorders like arterious-venous-malformations, moyamoya disease or ipsilateral internal carotid occlusion for various reasons. Other rare causes are infectious and posttraumatic conditions. Some authors figured out that the incidence of PCA aneurysms is approximately 1% of all intracranial aneurysms (Ciceri et al. 2001; Drake 1977; Sakata et al. 1993). Surgical treatment of these aneurysms is complex and often associated with high morbidity rates due to the close relationship to cranial nerves and the upper brain stem. A precise knowledge of the segmental anatomy of the PCA and its branches is essential when the surgical or endovascular approach to an aneurysm is planned, particularly if parent vessel occlusion is intended. In our opinion, the treatment of choice is selective endovascular obliteration of the aneurysm with preservation of the parent artery. In cases of fusiform aneurysms or wide-necked aneurysms occlusion of the parent artery might be necessary. Although no evaluation of potentially existing collaterals prior to endovascular treatment can be performed parent artery occlusion can be performed with a low incidence of visual field deficits. Nevertheless, one should be aware of the perforating arteries arising from the P1 and P2 segment supplying the brain stem and thalamus.



a

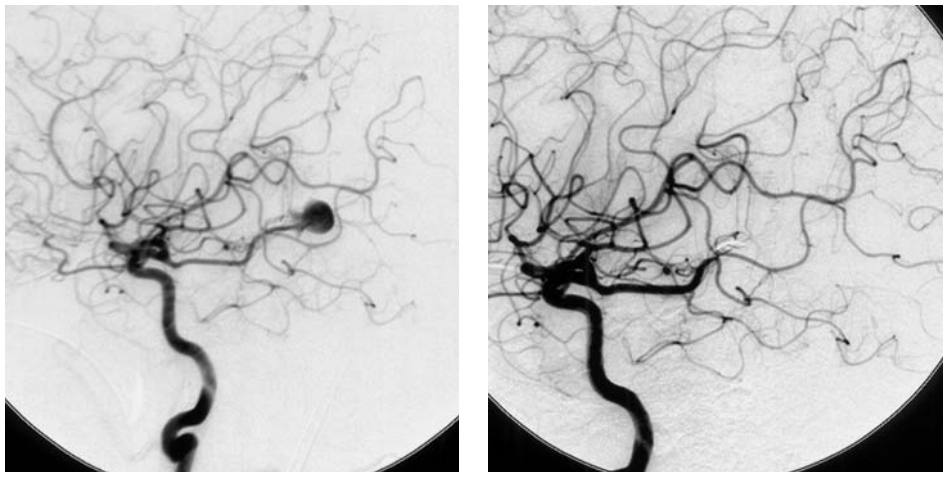


b

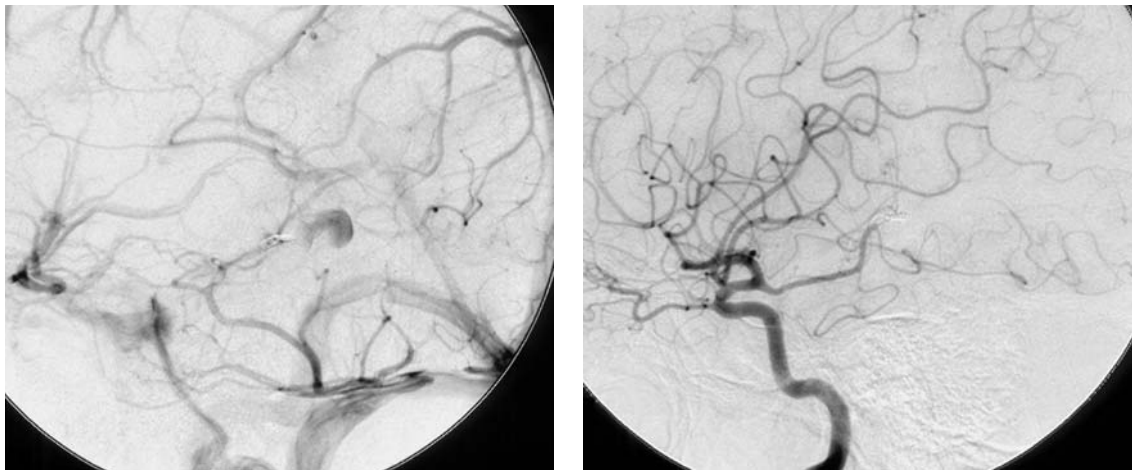


c

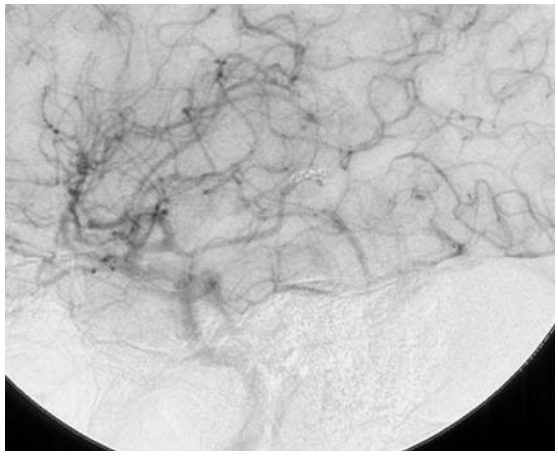
Fig. 5.4.39a–c. Before, 6 months after and 1 year after endosaccular treatment of a proximal PCA aneurysm (P1 segment), an additional small basilar stem aneurysm was not treated



a b



c d



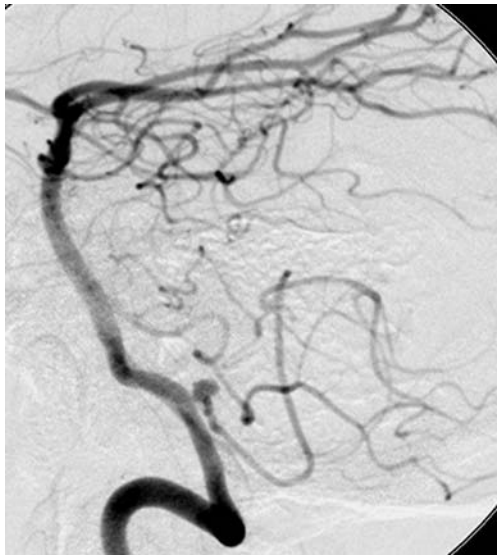
e

Fig. 5.4.40. a, b DSA before and after endovascular treatment of a right distal PCA aneurysm. **c** At 15 min after selective parent artery occlusion there is still some residual aneurysm filling immediately after parent vessel occlusion. Control angiography (**d, e**) 3 days after vessel occlusion demonstrated complete aneurysm occlusion

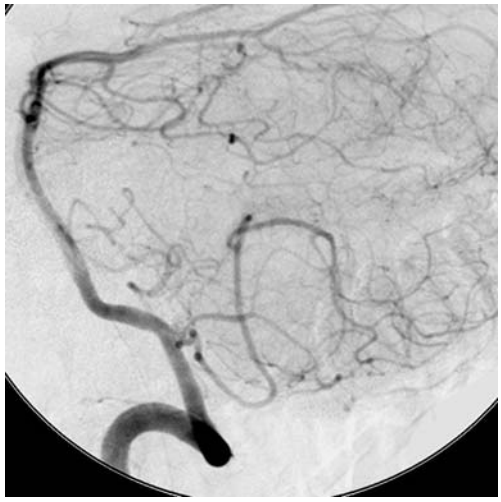
5.4.9.5.2
Posterior Inferior Cerebellar Artery

In contrast to vertebral aneurysms located at the origin of the PICA, real PICA aneurysms are located either proximally or distally at the PICA itself.

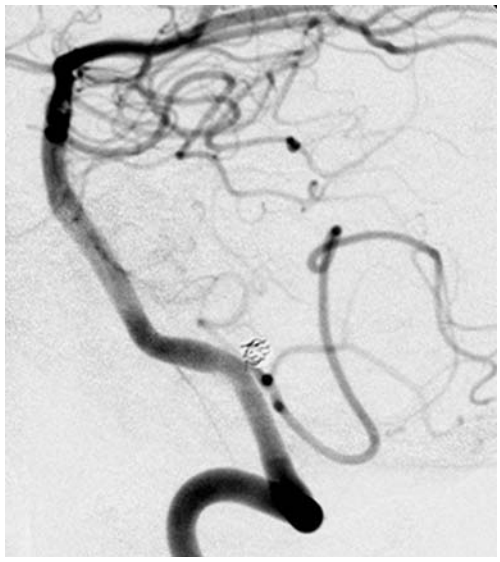
Endovascular therapy with preservation of the parent artery was thought to be very difficult in this location. Like in basilar tip aneurysms and brain stem aneurysms the access to aneurysms at the PICA is easy to perform and this is in contrast to the surgical approach. Although PICA aneurysms tend to be fusiform or at least broad based most of these aneurysms can be occluded sufficiently and often with preservation of the PICA via the endovascular route.



a



b



c

Fig. 5.4.41a–c. Before and after selective endosaccular treatment of a PICA aneurysm with preservation of the parent artery, 7-month FU showed a stable obliteration

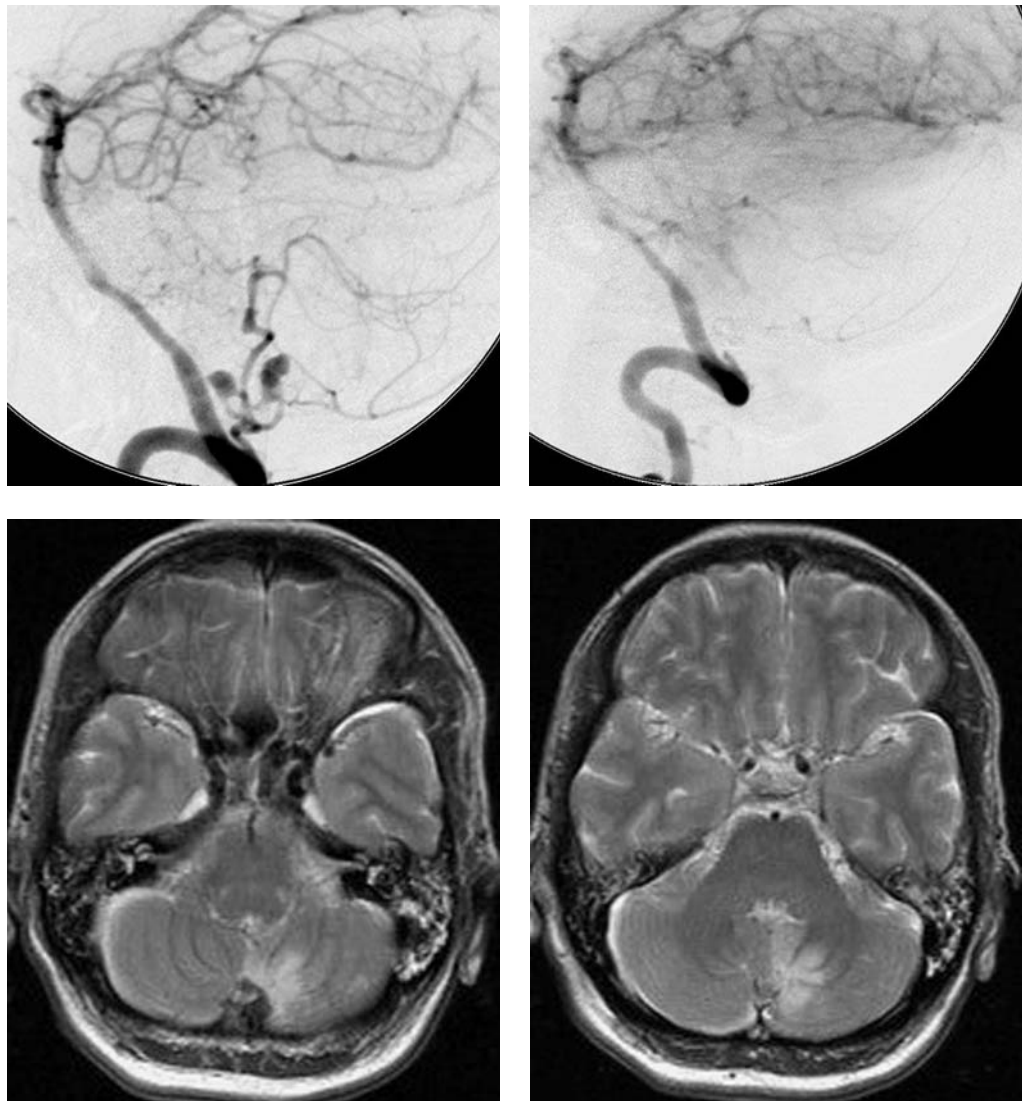
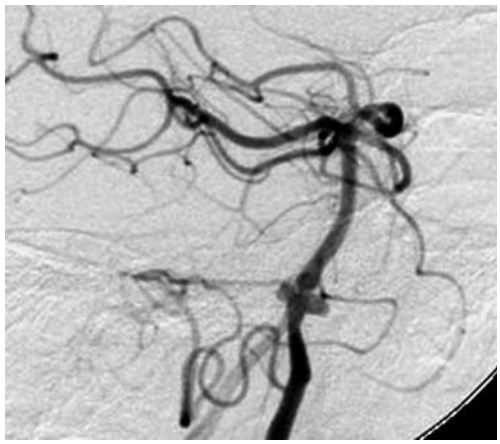


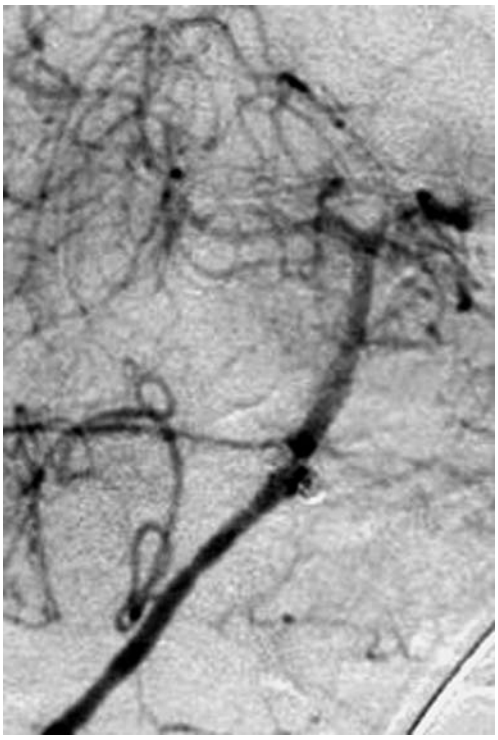
Fig. 5.4.42a–d. Before and after intended endovascular occlusion of a dysplastic PICA revealing at least four aneurysms. MRI: T2 images showed only a very small infarction in the PICA territory without causing clinical symptoms

5.4.9.5.3
Basilar Trunk Aneurysms

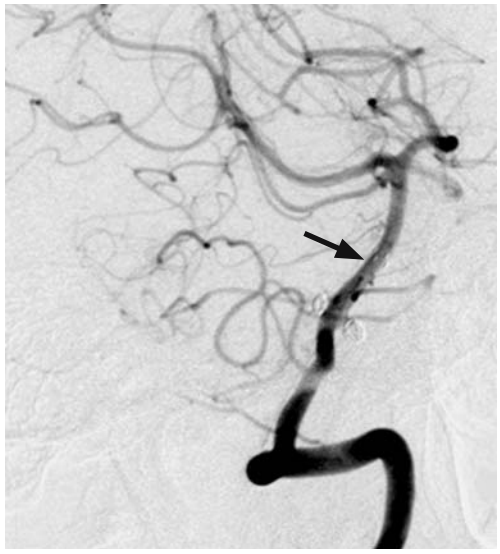
Saccular aneurysms of the basilar trunk are rare lesions with an incidence of less than 1% of all intracranial aneurysms. Damage to the perforating arteries is one of the major complications during surgery. Given the high risk of surgery on basilar trunk aneurysms and the simple endovascular access endovascular therapy should be first line treatment option. Van Rooij and colleagues (2003) treated a consecutive series of eight patients with this type of aneurysm, only one was non-ruptured. All patients had a good outcome except one patient who died as a consequence of the SAH. Procedure-related complications were not noted. As a consequence the authors do recommend treatment of aneurysms in this location via the endovascular route as first option. Uda et al. (2001) had the same conclusion. They treated 41 basilar trunk aneurysms and had a morbidity and mortality rate of 2.6% each. The endovascular catheterization of these lesions is relatively simple, in contrast to the complex neurosurgical approaches. Obviously, obliteration of these aneurysms decreases the possibility of unwanted occlusion of perforating arteries to the brainstem and therefore prevents brain stem infarction. In case of a broad base or a very small size a stent to bridge the neck might be necessary.



a



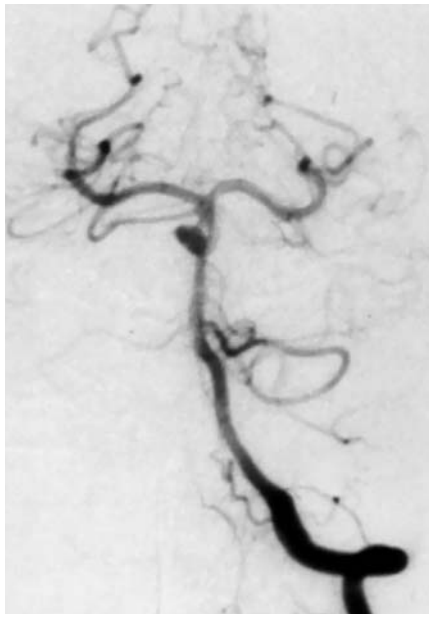
b

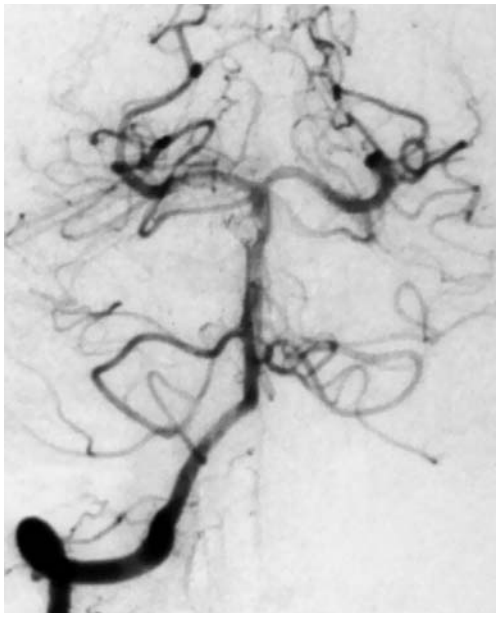


c

Fig. 5.4.43a–c. Conventional angiography: (**a, b**) before and after stent placement in combination with platinum coils to treat two small proximal located basilar stem aneurysms, (**c**) 6-month control angiography demonstrated complete obliteration of the two aneurysms, the distal markers of the stent are slightly seen (*arrow*)

a





b

Fig. 5.4.44a,b. Conventional angiography: before and after selective obliteration of a basilar stem aneurysm located in the distal third of the vessel proximal to the origin of the superior cerebellar artery

5.4.10 Special Considerations

5.4.10.1 Giant Aneurysms

Giant aneurysms, defined as larger than 25 mm, are rare intracranial lesions with a prevalence of about 5%–8% of aneurysms. Only one fourth to one third of giant aneurysms present with subarachnoid hemorrhage. Presenting symptoms are usually due to mass effect (75%), intracerebral hemorrhage or thromboembolism. Thrombosis and stroke due to blood clot formation within the aneurysm and subsequent distant emboli, occur in 2%–5% of patients with giant aneurysms. Symptoms are related to the anatomic location, headache is also a frequent symptom. Typically, giant aneurysms in the anterior circulation are in vicinity of the optic pathway, associated with symptoms related to vision. Sixty percent of giant aneurysms occur at the internal carotid artery. The most common site is the cavernous part of the internal carotid artery. Approximately 40% have calcifications in their walls that usually make clipping difficult. These calcifications can easily be identified on CT, which should be part of the diagnostic work-up in all these giant aneurysms. An additional 10% occur at the anterior communicating artery region, 10% are located at the middle cerebral artery. Some 15% of giant aneurysms occur at the top of the basilar artery, and approximately 5% arise from the vertebral artery.

Giant aneurysms are frequently (at least 60%) associated with either partial, or less common complete thrombosis. Recanalization of a completely thrombosed giant aneurysm has been also reported (Lee et al. 1999).

Symptomatic giant aneurysms usually have a grim natural history and poor prognosis.

There are several different strategies available to manage giant aneurysms. This is mainly due to the fact that no single technique is perfect in dealing with all giant aneurysms. Treatment options for giant lesions include surgical clipping, endovascular embolization, and combined approaches. Indirect surgical techniques include proximal occlusion and trapping of the aneurysm. Trapping and proximal ligation are usually definitive treatments provided that the patient's collateral circulation can tolerate major vessel occlusion. Depending on the location of the aneurysm, patients should have pre-operative evaluation with temporary balloon occlusion to test tolerance of trapping or proximal ligation. Major arterial branches leaving from the aneurysm dome can make proximal ligation the only therapeutic option. In some patients inadequate collateral circulation mandates the inclusion of an arterial bypass procedure in the therapeutic approach. This is specifically true for patients with giant aneurysms at the MCA bifurcation or the intracranial ICA.

There seems to be a correlation between size and incidence of complications during surgery for unruptured intracranial aneurysms. Aneurysms larger than 2.5 cm (giant aneurysm) in diameter have a 20-fold risk of significant surgical morbidity or poor outcome during surgical treatment. However, giant aneurysms are also not real good candidates for endovascular therapy, since they carry a high risk of recanalization and regrowth, due to the size of aneurysm, nature of coils and continuous flow-related stress on the aneurysm. Pre-existing thrombus within the aneurysm and coil migration into the thrombus may additionally facilitate coil compaction. Up to now it is totally unclear, whether combined techniques with stents and coils might overcome this problem of recanalization.

Endovascular techniques also include parent vessel occlusion using balloons or coils. Proximal balloon occlusion is a useful and often used technique for giant internal carotid artery aneurysms. There are several advantages of intravascular balloon treatment over other treatment modalities. If an extradural aneurysm is excluded from circulation by placing the balloon across or proximal to the aneurysm neck, there is a very low probability of aneurysm filling by collateral circulation. The anatomical dead space is decreased, reducing the incidence of emboli potentially associated with ICA thrombosis. Additionally, there is thrombosis and shrinkage of the aneurysm and decrease of pulsatility. The mass effect is also gradually decreasing.

Unfortunately, transient worsening of mass effect can happen shortly after endovascular therapy (Hecht et al. 1991). There may be also a late increase in mass effect as reported by Blanc et al. (2001) after parent vessel occlusion of the internal carotid artery for a giant supraclinoid aneurysm in a 47-year-old woman, who became hemiparetic and dysphasic 8 days after treatment. It has been shown experimentally that a thrombosed aneurysm may swell up to 15%, specifically if located at the basilar tip. In experimental aneurysms extensive neovascularity was observed within the first week after coil embolization. Increased capillary permeability of these neovessels within the evolving thrombus likely promotes transient enlargement of the aneurysm cavity. Steroid medication (100 mg methylprednisolone three times a day) prior and up to 5 days after therapy might be indicated, and may prevent these delayed complications in an individual patient. However, this is not an evidence-based therapeutic regimen.

5.4.10.1.1
Results of Endovascular Therapy in Giant Aneurysms

Different endovascular techniques may serve as an adjunct to surgery and may further improve therapy of giant aneurysms. In general, therapy of giant aneurysms should be tailored to each patient and always arise from the combined therapeutic plan of neurosurgeons and neurointerventionalists using a multimodality approach to minimize morbidity and mortality. However, as mentioned above: parent vessel occlusion – if tolerated by the patient – is by far the most effective type of treatment. Surgery alone has an extensive risk, endovascular therapy alone has a lower procedural risk but recanalization is a frequent observation during follow-up.

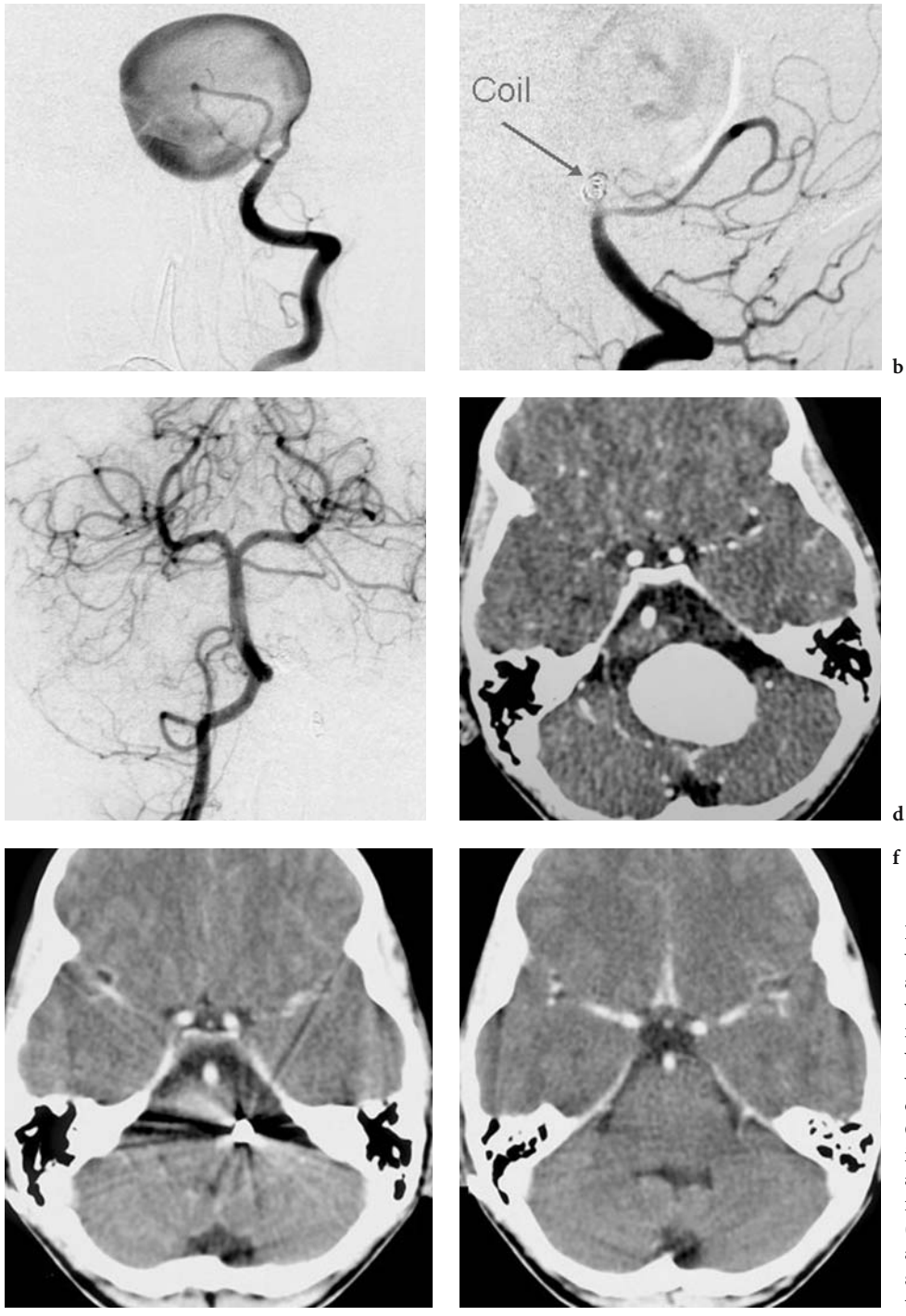


Fig. 5.4.45. **a** PA view. Giant vertebral artery aneurysm in a 9-year-old boy presenting with dizziness, vomiting and nausea. **b** Lateral view. Endovascular occlusion of the left vertebral artery was performed distal to the PICA using one GDC-Vortx-Coil. **c** Injection into the contralateral vertebral artery revealed no retrograde filling of the aneurysm. CT: (**d**) before and (**e, f**) 6 months after vessel occlusion demonstrated complete retraction of the aneurysm

5.4.10.2 Pediatric Aneurysms

The incidence of cerebral aneurysms in children is low. In patients under 15 years of age, it constitutes 1%–2% of all intracranial aneurysms (Patel and Richardson 1971), in children under 5 years, 0.1%–0.05% (Locksley et al. 1966). In a large cooperative study of intracranial aneurysms and subarachnoid hemorrhage including 2627 aneurysms, in only 1.5% of patients the aneurysm ruptured before the age of 19 (Locksley et al. 1966). Analysis of previous reports indicated several distinct characteristics of this entity. There is a predominant male:female ratio approaching 2:1 to 3:1. Compared with adults a high number of these aneurysms arise in the posterior circulation (Allison et al. 1998). Aneurysms in children tend to be large, approximately 30%–45% are giant aneurysms (Patel and Richardson 1971). Ferrante et al. (1988) reported the prevalence of giant aneurysms in children to be 26.8% compared to 2% in adults, and the prevalence for large aneurysms to be 50% compared to 27% in adults. In contrast, multiple aneurysms are less common in children (3%–5%) compared to adults (20%). Presenting symptoms are rather due to the mass effect of the aneurysm than due to aneurysm rupture. Compared to adults there is an increased incidence of infectious or mycotic aneurysms in the pediatric population, frequently secondary to bacterial endocarditis (Allison et al. 1998; Lee et al. 1998). Since general anaesthesia is mostly necessary for balloon occlusion of the internal carotid artery in children and clinical monitoring during occlusion is impossible, monitoring of somatosensory evoked potentials as a simple and reliable neurophysiological technique is very helpful. Median nerve sensory evoked potentials (SEP) may be an ideal monitoring during occlusion of aneurysms of the carotid artery territory because the ICA supplies the hand area of the somatosensory cortex. Likewise, basilar aneurysms may not be effectively monitored with SEP or brain stem auditory evoked potentials because basilar perforator occlusion may not affect either the somatosensory or auditory pathways (Friedman et al. 1987, 1991; Friedman and Grundy 1987). Again: as mentioned above, we do not perform balloon test occlusions any more, but rely more – and in the majority of patients exclusively – on the analysis of the circle of Willis.

Patients who do not tolerate the balloon test occlusion or do not have a simultaneous filling of the veins via the circle of Willis while compressing the target vessel, should undergo extracranial-intracranial bypass before parent vessel occlusion.

5.4.10.3 Aneurysms in the Elderly

Definition of the term "elderly" varies widely. Perhaps the most widely accepted definition for elderly is more than 65 years old, primarily since this is associated commonly with retirement. Incidence of SAH increases with age, from 1.5 to 2.5 per 100,000 per year in the third decade of life to 40 to 78 per 100,000 in the eighth decade of life (Phillips et al. 1980; Sacco et al. 1984). Advanced age is commonly associated with a poorer outcome after SAH (Elliott and Le Roux 1998). This might be for several reasons: older patients are more likely than younger patients to present with a poor clinical status at admission, larger amounts of SAH, and due to a diminished cerebrovascular reserve capacity a higher incidence of symptomatic vasospasm. Additionally, older patients more frequently have preexisting comorbidities, such as hypertension or atherosclerosis, which might independently have an adverse effect on outcome. Anticoagulation therapy for the treatment of atherosclerotic heart or cerebrovascular disease is also more frequent in older patients, which also increases the risk of poor outcome following aneurysmal SAH (Rinkel et al. 1997).

However, when stratifying older patients according to clinical grade, an association of advanced age and outcome is not observed (Elliott and Le Roux 1998). This is in accordance with the results of our institution. As a consequence, we think to decline treatment solely on the basis of advanced age is not justified. The decision to treat elderly patients should be made according to the patient`s overall situation, including clinical grade, overall physiologic condition and associated risk factors.

Conservative treatment of ruptured aneurysms in older patients seems to be associated with a poor outcome (Ellenbogen 1970). There is some evidence that surgically treated elderly patients do better than conservatively treated patients after aneurysm rupture. Fridikson et al. (1995) reported that two thirds of patients between 70 and 74 treated surgically returned to independent living and good mental state, whereas among 93 age-matched controls, refusion of surgery because of age, 75% suffered significant morbidity and mortality with more than 50% died within 3 months (Fridriksson et al. 1995).

In a small series of patients over 80 years old with ruptured anterior circulation aneurysms and a poor

Hunt and Hess grade of III, Hamada et al. (2001) reported a bad outcome for the conservatively treated patients, and still disappointing results for the surgically treated patients. The best results were obtained for MCA aneurysms.

Although little data is available on the results of endovascular aneurysm therapy in elderly patients, the reported results suggest this modality is promising in this age group (Rowe et al. 1996). In our opinion, endovascular therapy should be more strongly considered as first line therapy for elderly patients with SAH whenever possible. This way the aneurysms can be embolized in the acute phase with coils and preventing rebleeding (Fridriksson et al. 1995; Hamada et al. 2001).

Atherosclerotic vascular disease is more frequently in elderly patients and may be associated with more tortuous vessel anatomy. Superselective catheterizations of distal cerebral vessels might thus become technically more difficult. Atherosclerotic carotid bifurcation disease is frequently associated in patients with advanced age and might increase the risk of thromboembolic complications. In selected cases, a combined approach, first stenting of the carotid artery stenosis and subsequently coil embolization of the ruptured aneurysm might be a therapeutic option. Aneurysms at the anterior communicating artery are reported to be associated with a higher incidence of poor neuropsychologic outcome than aneurysms in other locations (Bornstein et al. 1987). In elderly patients even subtle changes in neuropsychology can have a strong influence.

5.4.10.3.1 Unruptured Aneurysms in the Elderly

Treatment decisions for unruptured aneurysms in older patients require estimation of the patient`s individual life expectancy and the risk of aneurysm rupture. Since the last results of the ISUIA study the critical size seems to be 7 mm and – beside size – location at the posterior wall of the ICA and the posterior circulation per se seem to have a higher risk of rupture.

Taylor et al. (1995) reported that only 2% of unruptured aneurysms in elderly patients rupture within 2.5 years of diagnosis. Considering these data, aggressive treatment, either surgical or endovascular do not appear to be beneficial. In any case, careful consideration should be given to the patient`s general health, coexisting morbidities, and personal and familial background before considering aneurysm therapy (Taylor et al. 1995). However, for many patients an explanation of the statistics is not the solution of the problem. If the first physician compares the – let‘s say – incidental aneurysm with a bomb in the head, quality of life usually drops dramatically and sometimes occlusion of the aneurysm is the only way to overcome the psychologic problem of the patient.

5.4.10.4 Multiple Aneurysms

The frequency of multiple aneurysms ranges from 5%–33% (Andrews and Spiegel 1979; Bigelow 1955; Inagawa 1991; McKissock et al. 1964; Mizoi et al. 1989) and seems to be higher in females than in males (Andrews and Spiegel 1979; McKissock et al. 1964). Multiple aneuryms are found in up to 34% of patients presenting with aneurysmal SAH (Rinne et al. 1994). In our patient population every third patient had two or more aneurysms.

The optimal treatment of associated – and asymptomatic aneurysms is still controversial. Treatment of multiple aneurysms should always consider location, patient‘s age, and neurological status, as well as anatomic relation to the symptomatic aneurysm. Some experts think that surgical treatment of unruptured aneurysms is not indicated. However, because of the presumed natural history of unruptured aneurysms and the progress in therapy the majority of neurosurgeons agree that associated aneurysms should be secured and that the risk of treating them is low. The symptomatic aneurysm should be treated first and the others can be treated in the same setting or alternatively later on. The localization of blood on the CT scan can help to identify the aneurysm responsible for the SAH. Nehls et al. (1985) showed that in patients presenting with multiple aneurysms and SAH the ruptured aneurysm could be correctly identified in 97.5% on the basis of clinical, CT and angiographic data. However, there is also evidence in the literature that blood distribution on CT does not enable identification of the site of the ruptured aneurysms.

Other hints may be: The larger and more irregularly shaped aneurysm is usually the one which has ruptured. If there are two aneurysms at one artery the most proximal and large aneurysm is the one that usually has ruptured.

However, little is known of the overall management outcome of multiple aneurysms. In an unselected series of 302 patients with multiple intracranial aneurysms Rinne et al. (1995) reported the management outcome one year after treatment significantly

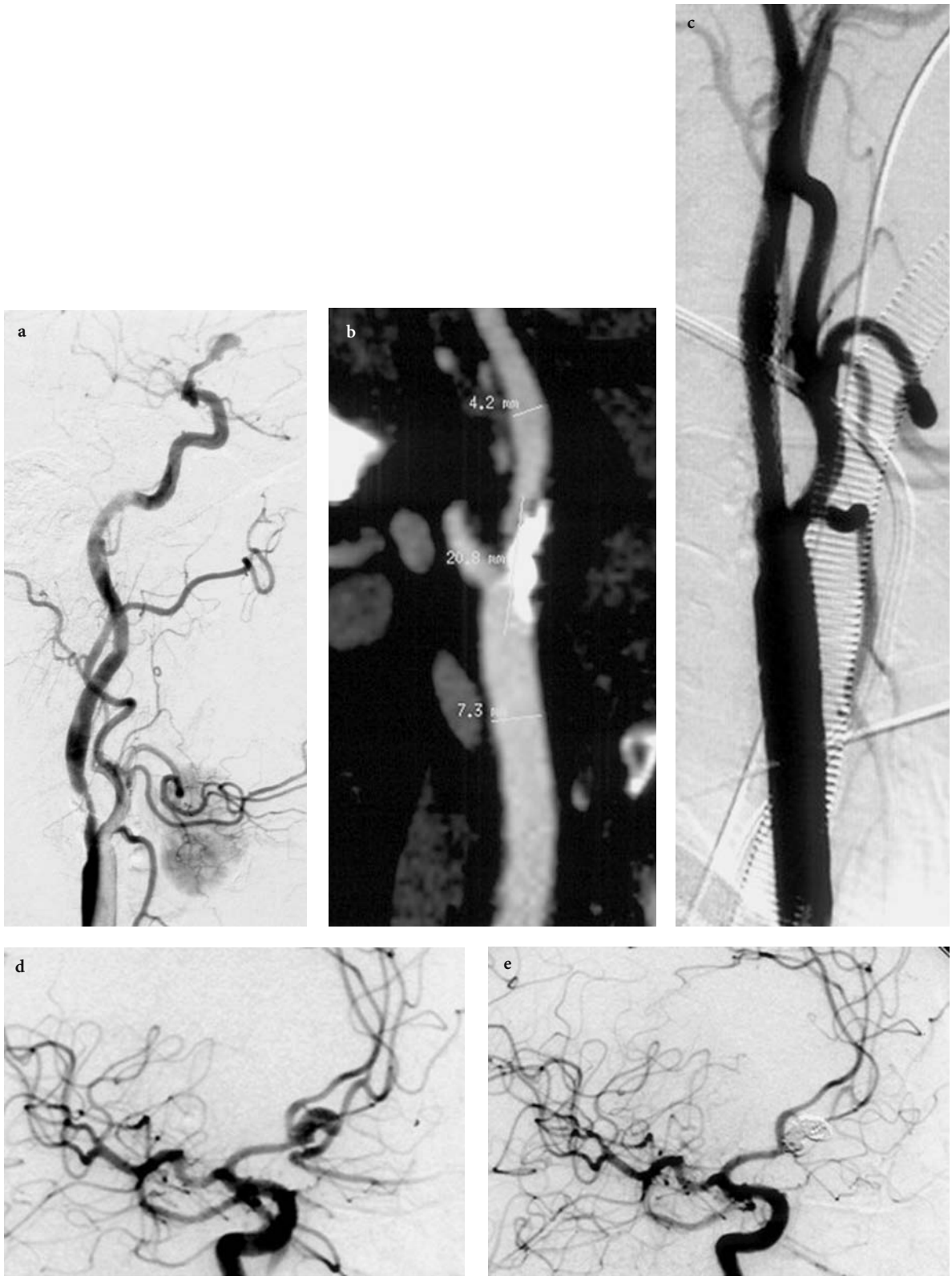


Fig. 5.4.46a–e. High-grade ICA stenosis due to atheromatous plaques in a patient with a ruptured Acom aneurysm. After stenting of the stenosis under heparin the Acom aneurysm was successfully embolized, the patient got antiplatelet therapy immediately after this two-step procedure

poorer for patients with multiple than for those with single intracranial aneurysms. The frequency of poor outcome (GCS 3–5) was most evident in patients with Hunt and Hess Grades II and III (29%), compared to patients with a single aneurysm (19%) in the same clinical grade (Rinne et al. 1995). The authors attribute their results mainly to the increased manipulation of cerebral arteries and brain tissue associated with increased delayed neurologic deficits in this patient group. This is comparable with the data by Vajda (1992) reporting a 26% frequency of poor outcome during long-term follow-up in patients with multiple intracranial aneurysms. However, most surgical series have opposite results, with equal results in patients with multiple and single cerebral aneurysms (Inagawa 1991; Mizoi et al. 1989; Yasargil 1984).

A major advantage of endovascular therapy is the possibility to treat more than one aneurysm in a single procedure. Additionally, the increased manipulation of cerebral arteries and brain tissue during surgery can be avoided by the endovascular approach. There are recommendations to treat only one aneurysm of the same artery or vascular territory within a single procedure. This is not the policy in our institution. On a case-by-case selection our policy is to treat any further aneurysm during the same procedure, independent of the anatomic location, if the first symptomatic (ruptured) non-giant aneurysm was quickly treated without difficulties. This is in accordance with the results reported by Solander et al. (1999) evaluating their results of GDC treatment of multiple aneurysms in single-stage procedures. The authors reported 38 consecutive patients with 101 cerebral aneurysms, 79 of which were treated with GDC, 14 neurosurgically, and eight left untreated. A total of 25 patients (66%) underwent treatment for all aneurysms within 3 days after admission. Follow up angiographic studies demonstrated unchanged or improved results in 94% of patients and an overall excellent clinical outcome in 89%. The authors conclude that endovascular GDC treatment of multiple cerebral aneurysms, regardless of their location, can be performed safely in one session. In the same way, this single-staged procedure may protect patients from rebleeding and eliminates the risk of mistakenly treating only the unruptured aneurysm (Solander et al. 1999).

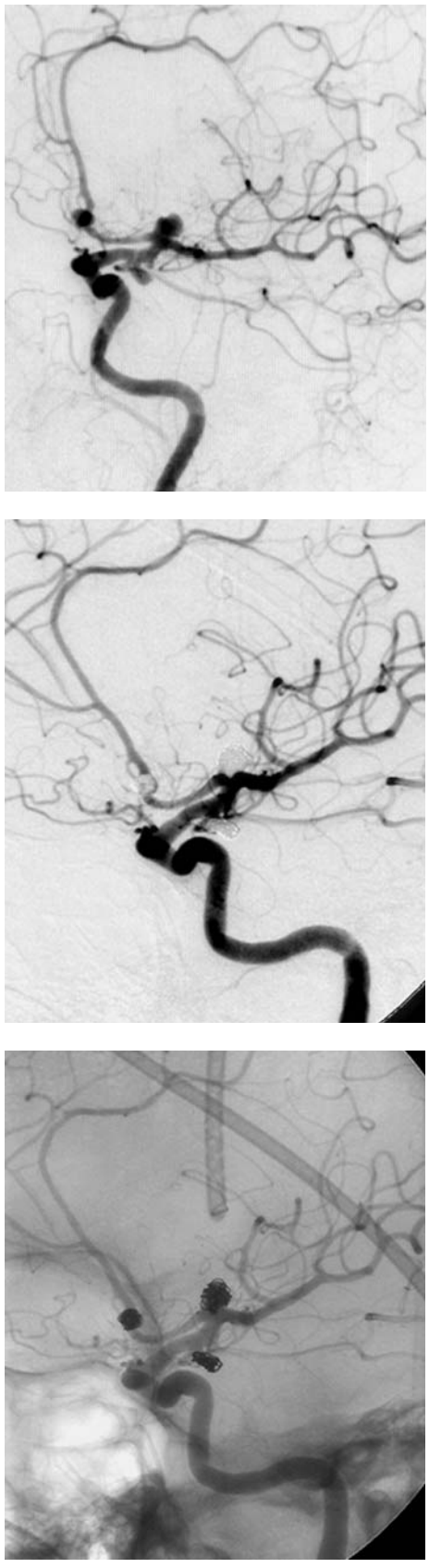
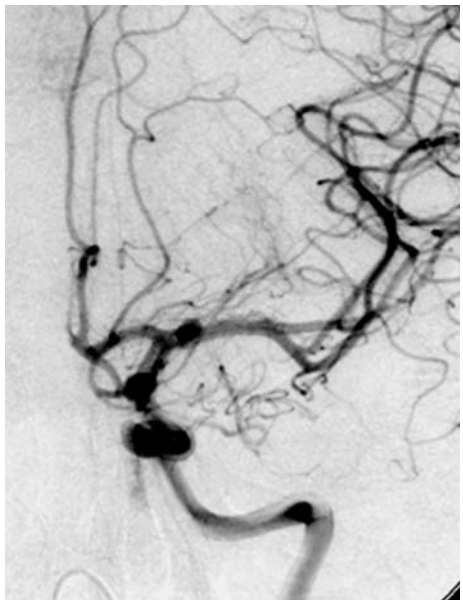
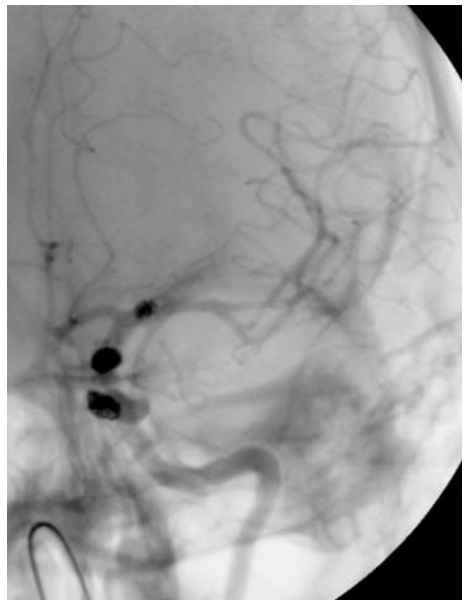


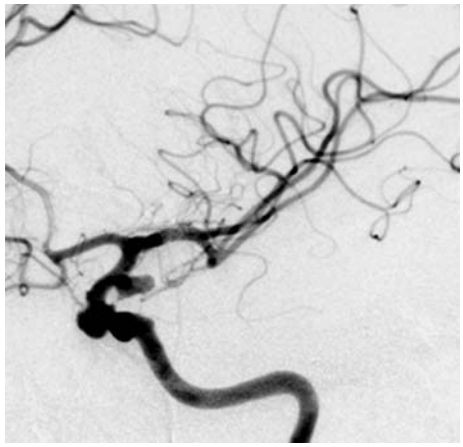
Fig. 5.4.47a–c. Coil embolization of multiple aneurysms in one procedure: Acom, Pcom and carotid-T aneurysm before and after coil embolization



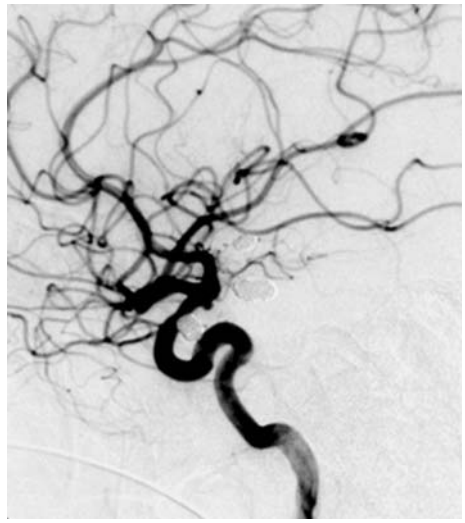
a



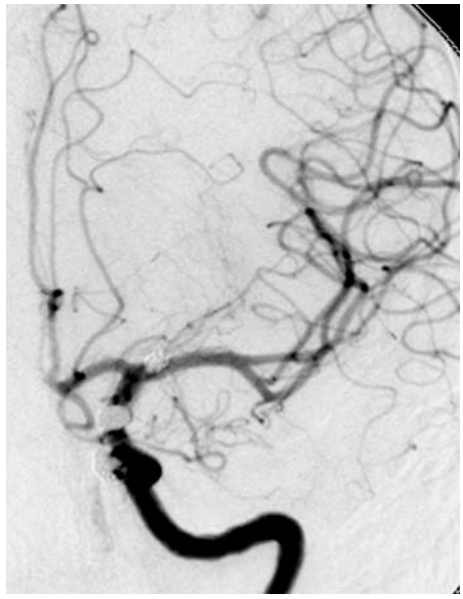
d



b



e



c

Fig. 5.4.48a–e. Coil embolization of multiple aneurysms in one procedure: Cavernous aneurysm, Pcom and carotid-T aneurysm before and after coil embolization

Pierot et al. (1997) reported their experience of 53 patients with a total of 128 aneurysms. Endovascular treatment was performed in 67 aneurysms in 46 patients, resulting in complete occlusion in 58 aneurysms and partial occlusion in nine. Permanent neurologic complications occured in 6.5%, one patient rebled. In patients with multiple unruptured aneurysms the authors treated two aneurysms at the same time if endovascular treatment proves easy (Pierot et al. 1997).

Because of the patients poor grade, old age, or difficult aneurysms it is not always possible to occlude all aneurysms in one setting. In the series of Rinne et al. (1995) only 58% of all patients with multiple aneurysms had all aneurysms clipped or treated endovascularly.

5.4.10.5 Incompletely Treated Aneurysms/Aneurysm Remnants

Although postoperative angiography is the only objective method for confirming the absence of any aneurysmal remnant, the widespread trend is not to perform postoperative angiography after microsurgical clipping. Since intraoperative techniques like checking exact clip location and absence of neighbouring perforators under the microscope, and needle puncture of the aneurysm are standard parts of aneurysm surgery the need of postoperative angiography may be questioned. The usefulness versus potential complications and costs have to be evaluated and its legitimacy discussed. However, we think that postoperative angiography is at least justified in all "difficult" and large aneurysms. Our institutional policy is to routinely perform postoperative angiography in all patients treated neurosurgically.

This is the only way to make completely sure that there is no remaining aneurysm or aneurysm remnant. Even opening of the aneurysm sac after clipping, a standard procedure in many neurosurgical institutions, does not exclude residual neck remnants proximal to the clip. Additionally, imperfect clip placement or delayed clip dislocation may remain unrecognized until postoperative angiography is performed.

There is another perspective that recommends postoperative angiograms in all patients: Sometimes the incomplete clipped aneurysm offers a new opportunity for the endovascular approach. A broad neck may be pretty small after incomplete clipping, a giant aneurysm may be turned into a just large one or the anatomy may have become clearer after inspection.

In up to 4% of patients postoperative angiograms reveal an expected or unexpected aneurysm residuum due to incomplete clipping (Lin et al. 1989). In a consecutive series of 305 clipped aneurysms, Sindou et al. (1998) reported an incomplete clipping in 18 out of 305 aneurysms (5.9%), with only a neck remnant in 3.9% and neck and sac remnant in 1.9%, amenable for complementary retreatment. A recent clinical data review of six series of clipped aneurysms which were checked by early postoperative angiography, revealed that 82 aneurysms (5.2%) out of a total of 1397 patients demonstrated residual filling (Thornton et al. 2000b).

Data on cerebral aneurysms treated by an endovascular approach also confirmed that a significant number of cases had either a residual or recurrent aneurysm. Vinuela et al. reported a multi-centre study on the results of GDC treatment for cerebral aneurysms in 403 patients. They reported an aneurysm remnant in an aneurysm-size dependent fashion: 25.6% of small aneurysms with a small neck, 52% of small aneurysms with a wide neck, 62.1% of large aneurysms and 50% of giant aneurysms demonstrated a remnant after initial treatment. During follow-up to 36 months after treatment, nine patients (2.2%) with incompletely embolized aneurysms rebled (Vinuela et al. 1997). In another review by Byrne and coworkers (1999) 36% of cases had an aneurysm remnant of variable size after initial treatment, 14.7% of aneurysm remnants had enlarged to some degree. Giant aneurysms had a 100% recurrence rate (Byrne et al. 1999).

The incidence of aneurysm regrowing after incomplete treatment may have been underestimated. Even a small portion of aneurysm neck has the potential to enlarge over time. Although small aneurysm remnants measuring from 1 to 2 mm may not justify retreatment, the risk of progressive enlargement to a dangerous aneurysm should be considered. Long-term angiographic – preferentially done with MR – reassessment may be valuable not to miss aneurysm enlargement (Sindou et al. 1998).

Incomplete treatment of an aneurysm, either by clipping or endovascular, may result in recurrent hemorrhage with serious or devastating consequences (Drake and Allcock 1973; Ebina et al. 1982; Le Roux et al. 1998; Lin et al. 1989). The risk of rebleeding from an aneurysm remnant has not been statistically studied in a larger series of patients. One might assume that these lesions might have at least the same risk of rupture as asymptomatic aneurysms, which has been evaluated at an average of 0.5% per year (Giannotta and Litofsky 1995;

Le Roux et al. 1998; Thielen et al. 1997). Feuerberg et al. (1987) looked at the natural history of these remnants and concluded that the rebleeding risk is between 0.38 and 0.79% per year. Lin and coworkers (1989) reported 19 patients who had an enlargement of a previously documented small aneurysm remnant after surgical clipping with 14 of these patients presenting with rebleeding.

There are some predisposing factors for postoperative aneurysm remnants such as aneurysm size and topographic peculiarities: Large or giant aneurysms are associated with a higher frequency of aneurysm remnants as well as neurosurgical difficult anatomic localizations such as carotido-ophthalmic region, which requires removal of the clinoid.

Since nowadays endovascular aneurysm therapy is an important part in the management of SAH, comparison of surgical and endovascular methods regarding completeness of obliteration is of major importance. The reported results with coil embolization are very variable according to the series, techniques used and aneurysmal size. In Raymond and Roy's (1997) series a neck remnant was present in 37%. The study by Vinuela et al. (1997) in 403 patients clearly demonstrated that the completeness of aneurysm occlusion is strongly dependent on aneurysm size. In small aneurysms the complete occlusion rate was 70.8%, whereas in large or giant aneurysms it was in the range of 50%. Using the "remodeling technique" for wide-necked aneurysms Moret et al. (1997) reported aneurysm remnants in 17% of the cases and incomplete occlusion in only 6%.

This leads to the further question concerning the management of the aneurysm remnant or residual neck: again surgical, or endovascular, or no therapy? Feuerberg and colleagues (1987) found that the incidence of rehemorrhage of an aneurysm remnant is 3.7%, and the risk of rupture is up to 0.8% per year, warranting retreatment of the residual aneurysm at least in young patients. However, Feuerberg et al. (1987) reported that up to 50% of neurosurgeons believe that a second surgical approach would not improve the situation. Perioperative scarring, the frequent need to remove the primary surgical clip, increased incidence of intraoperative rupture all add to the increased risk of such a repeat operation (Boet et al. 2001). In any case, this remains a difficult field and a complex group of patients. However, we recommend performing postoperative angiography in all patients after clipping and considering the endovascular route for those patients with aneurysm remnants. For coiled patients it is even more important to have follow-up imaging at least for 3 years.

5.4.10.6 Combined Therapies

Neurosurgery and interventional neuroradiology are not competitive therapies, but the complementary nature of techniques offers the best chance to reduce treatment morbidity and improve long-term outcome in difficult aneurysms. The primary modality of treatment, the anatomy and configuration of the aneurysm, the radiologist's and the neurosurgeon's opinion and the ease or difficulty of the retreatment procedure using either method and the risks involved with each, all have to be considered in the decision making process. However, since ISAT, the endovascular modality should clearly be the first choice, if – and this should be borne very much in mind – the endovascular expertise is available.

For complex aneurysms a combined approach of endovascular and surgical treatment may use the strength of both methods in a synergistic way. There are different management paradigms of such a combined philosophy available:

- Clipping after partial endovascular occlusion
- Coiling after partial surgical clipping
- Temporary balloon occlusion during clipping (see Fig. 5.4.17)
- Superselective angiography prior to aneurysm surgery

5.4.10.6.1 Clipping After Partial Endovascular Occlusion

GDC treatment does not exclude subsequent surgical clipping. Graves et al. (1995) reported two patients in whom surgical clipping of incompletely embolized aneurysms was performed without significant problems (Graves et al. 1995). However, in some cases clipping after coiling might be difficult, often requiring prolonged temporary vessel occlusion. Additionally, opening of the aneurysm for coil extraction might become necessary for final clip placement (Asgari et al. 2002; Batjer and Samson 1992; Solomon et al. 1996).

The primary goal of endovascular aneurysm therapy is to completely obliterate the aneurysm. However, for acutely ruptured and complex aneurysms in poor grade patients a therapeutic alternative might be a combined sequential approach: first to treat the aneurysm by partial coil embolization without the demand of achieving complete aneurysm obliteration. This way one might achieve a temporary protection against early rebleeding, give the patient the chance for clinical recovery and offer the final and definite occlusion later on.

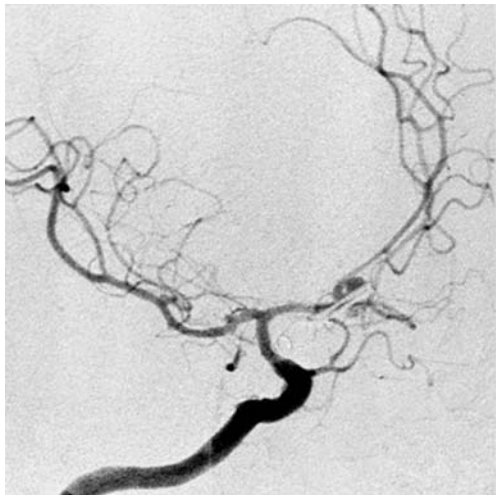
5.4.10.6.2 Coiling After Partial Surgical Clipping

There have been several reports on completion of aneurysm occlusion by endovascular technique after partial clipping (Forsting et al. 1996; Fraser et al. 1994). In this setting, the reduced neck size after incomplete clipping may represent a technical advantage for endovascular therapy. Wide-neck aneurysms might thereby be transformed into small-neck aneurysms. For complex aneurysms which cannot be treated by either modality alone, this staged procedure of initial partial clipping with narrowing of the aneurysm neck and subsequent endovascular aneurysm obliteration may be considered as therapy.

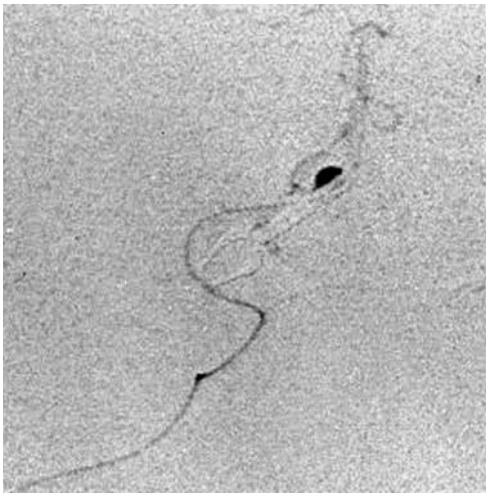
Entering the aneurysm with the microcatheter might sometimes represent a problem, which can be overcome in most cases by appropriate shaping of the wire and microcatheter. However, there will remain some patients in whom the partially clipped aneurysm neck may be too small to allow the microcatheter to enter the sac or too wide to retain the coils.

5.4.10.6.3 Coiling After Coiling

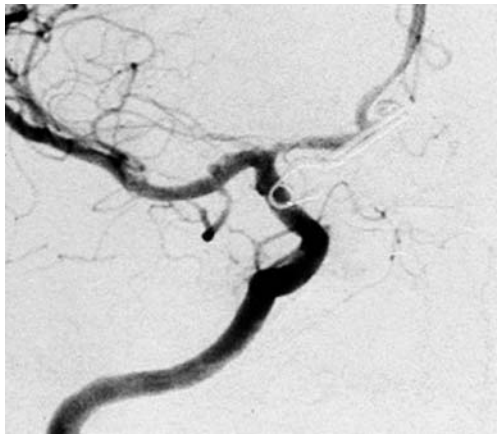
Surgery of a partially coiled or recanalized aneurysm can be difficult and some authors consider it to be associated with increased risk and higher morbidity (Horowitz et al. 1999). If at all possible, our recommendation is, if anatomy is favourable, to retreat all previously coiled, but recurrent aneurysms by a second endovascular approach. If the remnant or recurrent aneurysm is of a reasonable size the 2nd endovascular attempt is possible in the majority of patients. The decision to treat (or not to treat) is sometimes more difficult than the treatment itself. Is it really necessary to retreat a previously unruptured aneurysm with a 3-mm remmant? Probably not, if this remnant is stable during follow-up. The situation is different if a previously ruptured aneurysm reveals a growing remnant over 6–12 months. But you can probably imagine, that there is a number of patients just in between both extremes.



a

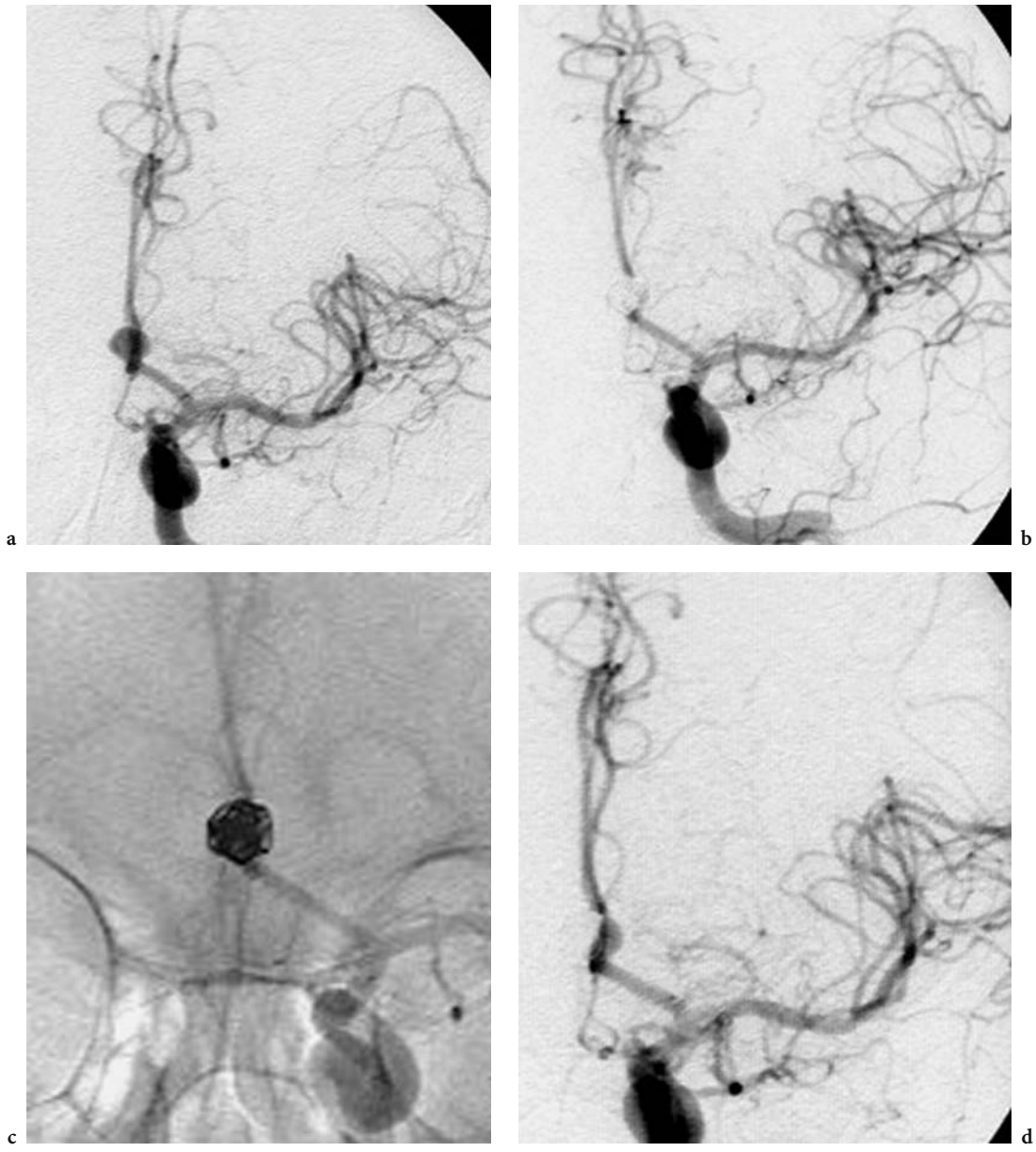


b



c

Fig. 5.4.49a–c. Coiling after clipping. Endovascular treatment of a small Acom aneurysm remnant after incomplete clipping.



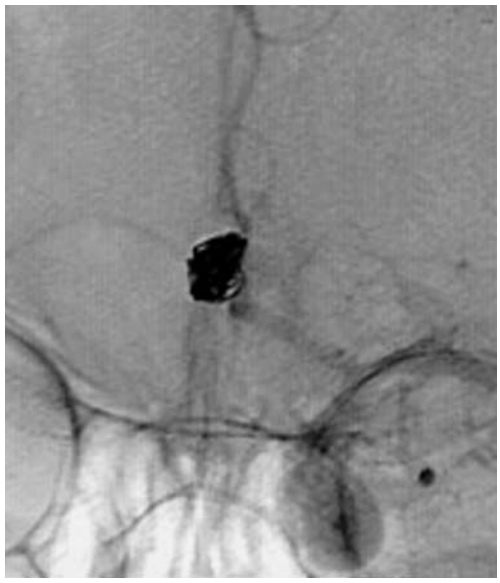
5.4.10.7 Complications of Endovascular Therapy

Endovascular treatment is potentially associated with procedural complications induced by the treatment itself. Mainly, there are two categories of complications: thromboembolic events and aneurysm rupture.

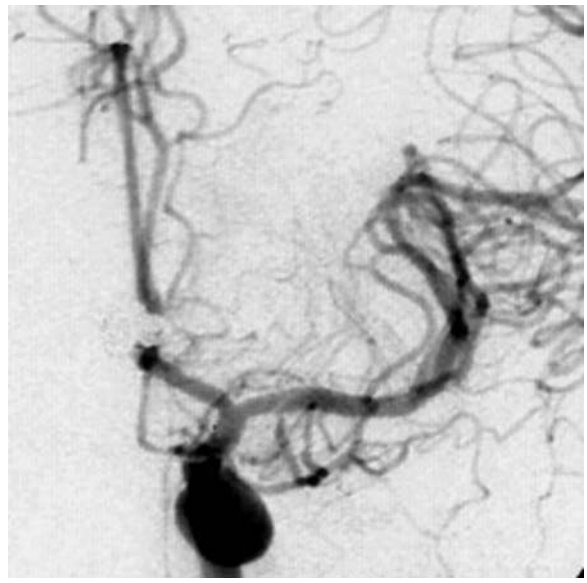
Ischemic complications are either due to a thrombosis of the aneurysm bearing arterial segment or due to an embolus either into the aneurysm bearing artery or into another artery.

Thrombosis of the parent artery probably develops at the interface of the platinum coils due to aggregation of platelets. This complication is observed more often in broad based aneurysms, e.g. in giant aneurysms of the ICA. On the other hand, an embolus generates most often in the guiding catheter system. Since this complication can occur away from the aneurysm, it is important to perform control angiograms during the intervention using a large field of view to cover all relevant vessels.

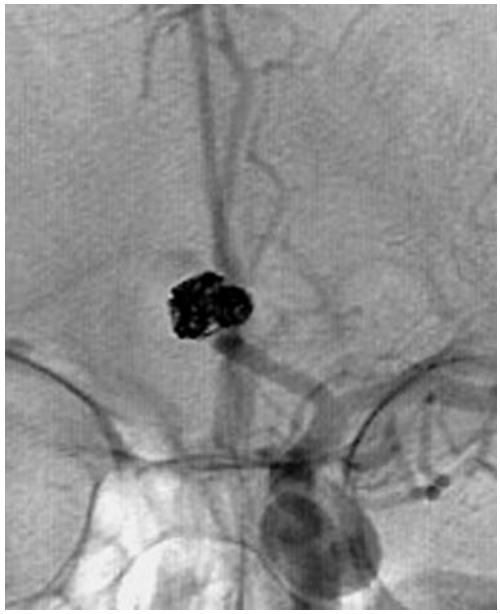
Procedural morbidity of endovascular treatment ranges between 3.7% and about 10%, mortal-



e



f



g

Fig. 5.4.50a–g. Retreatment after coil compaction („coiling after coiling"). Before and after endovascular treatment of an Acom aneurysm with complete obliteration, 6-month follow-up demonstrated partial aneurysm recanalization due to coil compaction. Retreatment was successfully performed

ity between 0% and 2.1%. These numbers are well evaluated in patients with unruptured aneurysm to exclude complications due to the SAH itself (Cognard et al. 1997; Johnston et al. 2000; Qureshi et al. 2000; Wanke et al. 2002). Johnston et al. (2000) reported about a very high number (10%) of cranial nerve palsies after endovascular therapy. This can only be explained by the large number of giant aneurysms treated with coils resulting in compression of a cranial nerve by the coil mass (Johnston et al. 2000). However, thromboembolic complications do not necessarily lead to neurologic deterioration of the patient. Qureshi et al. (2000) had 8.2% thromboembolic events during coiling which resulted in neurological deterioration in only 5.4% of the patients.

While analysing data about complications of endovascular therapy aneurysm localization plays an important role. It turns out that treating an aneurysms at the site of the MCA bifurcation is associated with a higher complication rate than treating an aneurysm at another location (7% versus 3% for Acom aneurysms (Cognard et al. 1997). Probably the complex anatomy of the MCA bifurcation might be the reason for this circumstance.

To reduce the risk of thromboembolic events, most of the neurointerventional centres anticoagulate the patient periprocedurally. Thereby, most of the groups at least double the ACT to 250–300 s. Postprocedural heparinization reduces the incidence of thromboembolic events from 9.3% to 5.9% (Qureshi et al. 2000) and is usually maintained for another 24–48 h after intervention. Although no scientific data exist about antiplatelet therapy and prevention of thromboembolic events during or after endovascular treatment, administration of low dose aspirin might (e.g. 100 mg per day) reduce symptomatic ischemic events.

If, beside this regimen, clotting occurs, elevation of blood pressure (mean arterial blood pressure 90-100mmHg), reassurance of efficient heparinization and "wait and see" for a couple of minutes is the first step. If control angiogram shows growing thrombus or no improvement occurs within 10 min and if no retrograde collateralization of the occluded vessel is visible, administration of a GPIIb/IIIa antagonist, e. g. abciximab, might be necessary. Administration should be performed in bolus fractions of 2 mg, either intra-arterial – however, this is an off-label use – or intravenously, up to 10 mg and if diminishing of the thrombus is noted, low-dose abciximab infusion should be continued. GPIIb/IIIa antagonists may induce thrombocytopenia that is probably attributed to an immunological phenomena, therefore, platelets should be monitored.

If the thrombus does not resolve local intra-arterial lysis might be necessary. In unruptured aneurysms, fibrinolytic agents are an obvious option. In ruptured aneurysms, fibrinolytic agents should be used with extreme caution because rebleeding might end in a catastrophic situation even if the aneurysm is completely occluded on DSA.

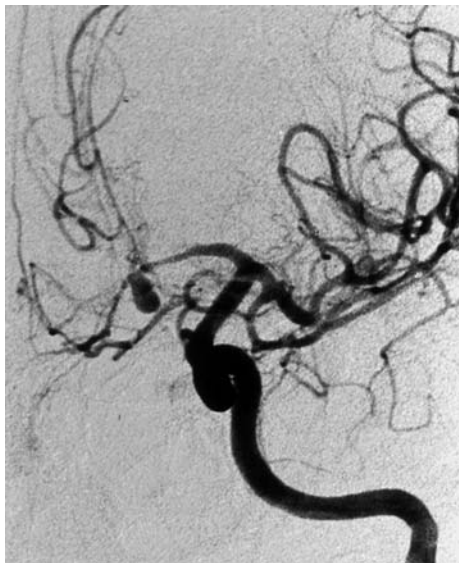
Aneurysm rupture is another complication which can occur during the intervention. Aneurysm rupture has continued to be one of the most feared complications of endovascular aneurysm therapy. Although any interventional neuroradiologist treating acutely ruptured aneurysms may be confronted with this complication, only few data regarding frequency, causes, management and outcome of such ruptures during endovascular treatment are available (Halbach et al. 1991; McDougall et al. 1998; Ricolfi et al. 1998). However, aneurysmal rupture during endovascular treatment could represent a devastating complication. There are many possible mechanisms of aneurysm rupture during treatment: rupture can occur coincidentally during diagnostic angiography or endovascular treatment. Increased blood pressure during injection of contrast may contribute to rerupture of an acutely ruptured aneurysm (Saitoh et al. 1995). Aneurysm rupture might also be due to perforation with the guidewire or microcatheter, or might occur during coil placement. Clinical sequelae may be variable, ranging from slight leakage of contrast into the subarachnoid space to massive SAH or intraparenchymal hematoma with severe intracranial hypertension.

Embolization of the aneurysm can be continued in most cases, and the majority of patients with treatment-related SAH survive without serious sequelae and with a better outcome than anticipated (Doerfler et al. 2001). In our experience the degree of vasospasms – these can occur immediately – is the most important predictor of patient's outcome: immediate severe vasospasms correlate with a bad clinical outcome. Anyway, it is extremely helpful in this situation to have the external CSF drainage in place before endovascular therapy starts.

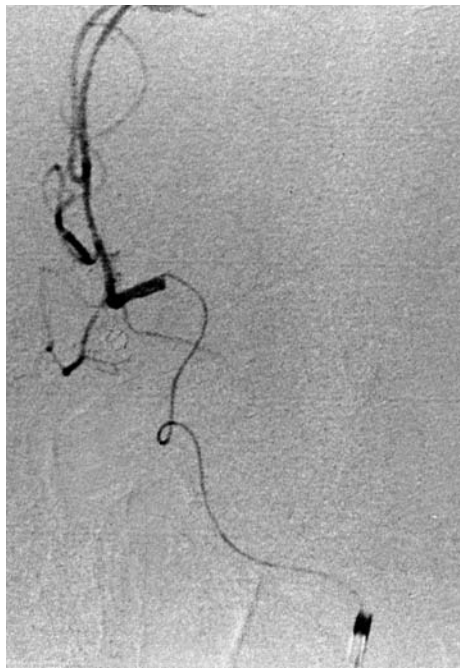
5.4.10.8 Monitoring and Therapy of Vasospasm

Transcranial Doppler sonography (TCD) is a useful non-invasive monitoring tool in SAH patients. The detection of vasospasm is possible with transcranial Doppler, by means of increased blood flow velocity from arterial narrowing in the middle cerebral artery and the posterior circulation. However, there is uncertainty about the diagnostic specificity of TCD. Only velocities above 120–200 cm/s are highly predictive for the diagnosis of vasospasm (Vora et al. 1999). Compared to angiography, the sensitivity and specificity of TCD is good for the middle cerebral artery. For all other arteries there is a lack of evidence of accuracy or of usefulness of TCD. Additionally, TCD cannot distinguish symptomatic from asymptomatic vasospasm. The crucial point for the patient is to be in the hand's of an excellent ICU physician, preferentially a neurosurgeon or a neurologist. Both are familiar with acute or slow onset of neurological deficits and it is the clinical history that leads to an endovascular approach for vasospasm.

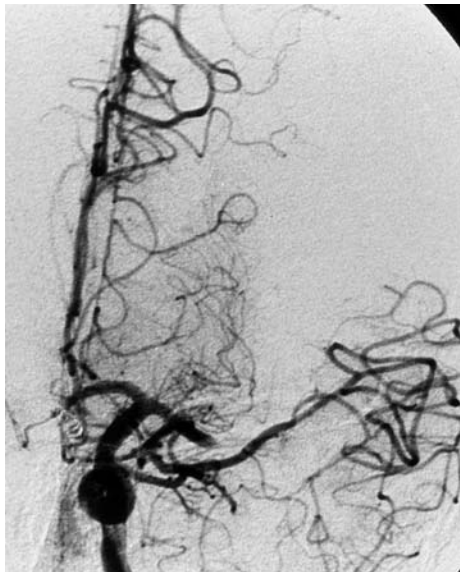
Quantification of cerebral tissue perfusion and earlier detection of ischemic injury would be nice to have in order to guide therapy in SAH patients with vasospasm. New imaging techniques, such as perfusion (PWI)- and diffusion (DWI)-weighted magnetic resonance imaging might enable very early identification of ischemic areas (Minematsu et al. 1992; Moseley et al. 1990; Warach et al. 1992). PWI is a non-invasive method often used to demonstrate the perfusion reduction in focal ischemia in animal



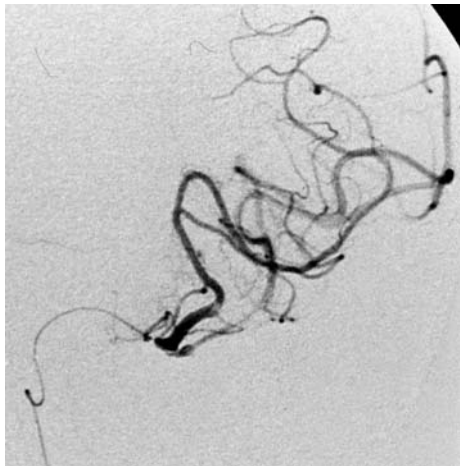
a



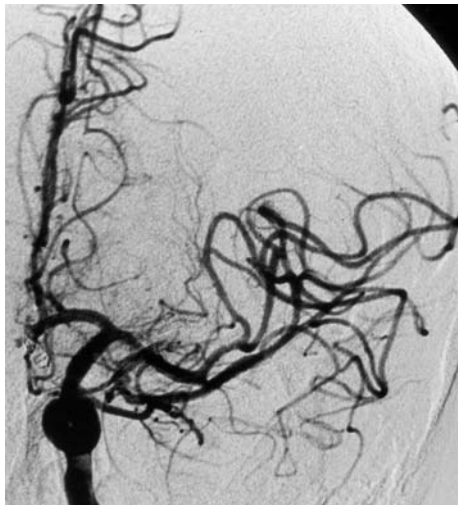
b



c

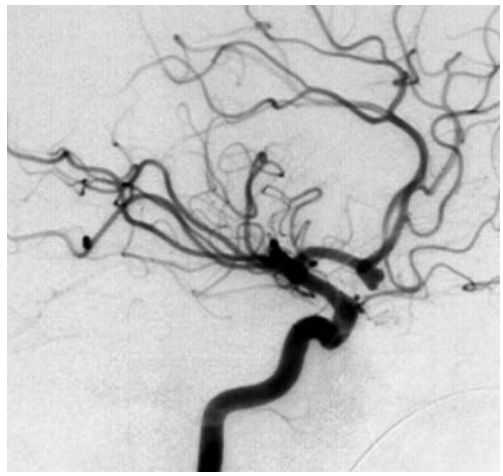


d

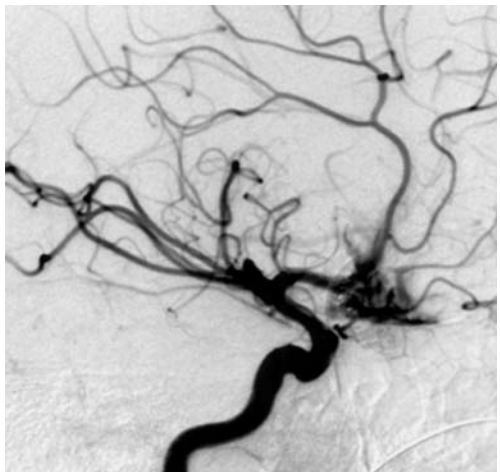


e

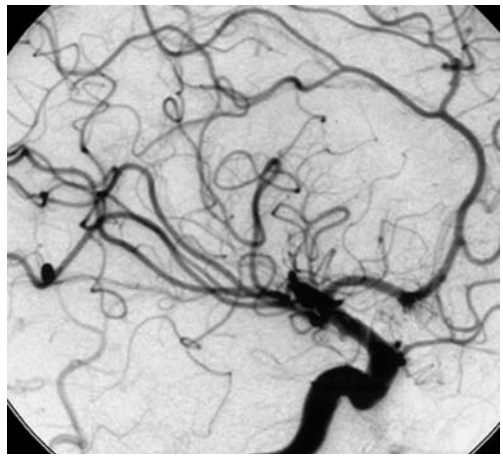
Fig. 5.4.51a–e. The MCA was occluded during embolization of an Acom aneurysm. Thrombolysis was performed using 10 mg rt-PA



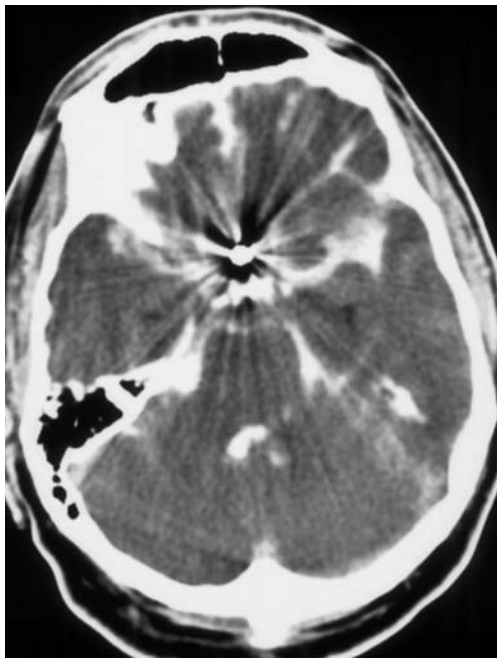
a



b



c



d

Fig. 5.4.52a–d. During embolization of an unruptured Acom aneurysm perforation occurred while introducing a coil. **b, d** DSA and CT demonstrated extravasation of blood. **c** Rapid embolization was continued and bleeding stopped immediately after complete insertion of the first coil. Patient recovered without clinical sequelae

studies and stroke patients (de Crespigny et al. 1993; Moseley et al. 1990). DWI provides potentially unique information on the viability of brain tissue and has been shown to be sensitive to early cerebral ischemia (Dardzinski et al. 1993; Moseley et al. 1990; Reith et al. 1995).

Since DWI is extremely sensitive to ischemic lesions it can be used to non-invasively assess the safety and efficacy of endovascular aneurysm therapy. DWI might be of particular help in those patients in whom clinical examination is difficult (Biondi et al. 2000).

Shimoda et al. (2001) used serial magnetic resonance imaging to prospectively investigate the incidence of infarction caused by vasospasm with or without a delayed ischemic neurological deficit in 125 patients with subarachnoid hemorrhage. The authors defined an infarct from vasospasm as a new lesion not present on the initial MRI within 3 days after SAH and therefore not attributable to primary brain damage or surgical complications. A new infarct on MRI was evident in 34% (43 patients), whereas 4% (five patients) showed no new lesion but had a delayed ischemic neurological deficit. However, 29 patients (23%) showed a new asymptomatic infarct but no delayed ischemic neurological deficit (Shimoda et al. 2001).

Vasospasms secondary to subarachnoid hemorrhage are responsible for severe ischemic complications. Condette-Auliac and colleagues (2001)

studied asymptomatic vasospasms in seven patients with aneurysmal SAH to assess whether DWI provides predictive markers of silent ischemic lesions and/or progression toward symptomatic ischemia. Additionally, three patients with symptomatic vasospasm, and four patients with SAH but without vasospasm were studied at regular intervals by DWI, and their apparent diffusion coefficients (ADCs) were calculated. All patients with vasospasm including those without symptoms presented abnormalities on DWI with a reduction of the ADC prevalently in the white matter. No such abnormalities were observed in patients without vasospasm. Correlation of abnormalities on DWI with parenchymal involvement in asymptomatic patients would be of considerable clinical significance. Larger studies might be able to determine whether the ADC has a reversibility threshold, because this would facilitate patient management (Condette-Auliac et al. 2001).

Monitoring of patients with vasospasm after SAH using a combination of serial PWI and DWI might yield insight into the hemodynamics and temporal evolution of vasospasms and delayed cerebral ischemia (Rordorf et al. 1999). DWI and PWI might thereby improve our pathophysiologic understanding of the mechanisms underlying the evolution of vasospasm and delayed cerebral ischemia. Rordorf and colleagues (1999) tried to identify early ischemic injury with combined diffusion-weighted and perfusion-weighted MRI in patients with vasospasm after SAH. In patients with symptomatic vasospasm the authors found small, sometimes multiple, ischemic lesions on DWI encircled by a large area of decreased cerebral blood flow and increased mean transit time. MR images were normal in asymptomatic patients with angiographic vasospasm and patients with a normal angiogram and no clinical signs of vasospasm. This combined technique could become a useful tool in the clinical management of patients with SAH (Rordorf et al. 1999). However, at the moment the application of these techniques in SAH patients is a matter of research and not clinical routine.

Cerebral vasospasm continues to be the leading cause of morbidity and mortality following aneurysmal subarachnoid hemorrhage. Roughly 40% of patients with aneurysmal SAH develop angiographically visible vasospasm, about 20% have neurologic signs of vasospasm and 10% present with vasospasm related infarction. If vasospasm is present at the time of patient administration and before treatment of the aneurysm a combined approach might be necessary in order to occlude the aneurysm and to resolve vasospasm (Wanke et al. 2000).

After treatment of the ruptured aneurysm approaches to treat aneurysmal vasospasm currently include medical treatment with Ca-antagonists, "triple-H" therapy and endovascular methods.

Nimodipine is recommended prophylactically for all patients. Several randomized trials have demonstrated that nimodipine reduces poor outcome due to vasospasm in all grades of patients. These results are summarized by Feigin et al. (2000) who analyzed eight controlled trials on efficacy of nimodipine with 1574 randomized patients.

Aggressive hypertensive, hemodilutional, hypervolemic therapy is also recommended prophylactically and is – at least – indicated for symptomatic vasospasm. Triple-H therapy is an effective modality for elevating and sustaining CBF after SAH. In combination with early and definite aneurysm occlusion as a prerequisite for this regimen, it can minimize delayed cerebral ischemia and lead to an improved overall outcome (King and Martin 1994; Origitano et al. 1990; Seifert 1997). Assessing trial quality there exist only studies with optional recommendations for this therapy. The efficacy of triple-H therapy has yet not been demonstrated in randomized clinical trials.

The same is valid for the use of the endovascular methods. The two main endovascular treatment methods are balloon angioplasty and intra-arterial infusion of spasmolytic agents. If clinical deterioration is progressive despite intravenous medical therapy, endovascular methods to treat vasospasm should be used.

Balloon angioplasty is superior to papaverine for treatment of proximal vessel vasospasm and has a more sustained effect on the vessels. Up to date there are no series documenting a *significance* of cerebral blood flow increase or improvement of delayed ischemic neurologic deficits induced by vasospasm compared to controls, but our clinical experience and single case studies suggest that balloon angioplasty does reverse vasospasms and – if performed early enough – can improve the patient's condition.

Song et al. (1997) reported in early and aggressive treatment with balloon angioplasty clinical improvement in about two-thirds of their patients suffering from neurological deficits attributable to vasospasm. In a rabbit model an increase in endothelial proliferation and decrease in the thickness of the tunica media was shown suggesting, that angioplasty damages endothelial and smooth-muscle cells. This may be the basis for the observation that vasospastic arteries do not reconstrict after angioplasty (Macdonald et al. 1995).

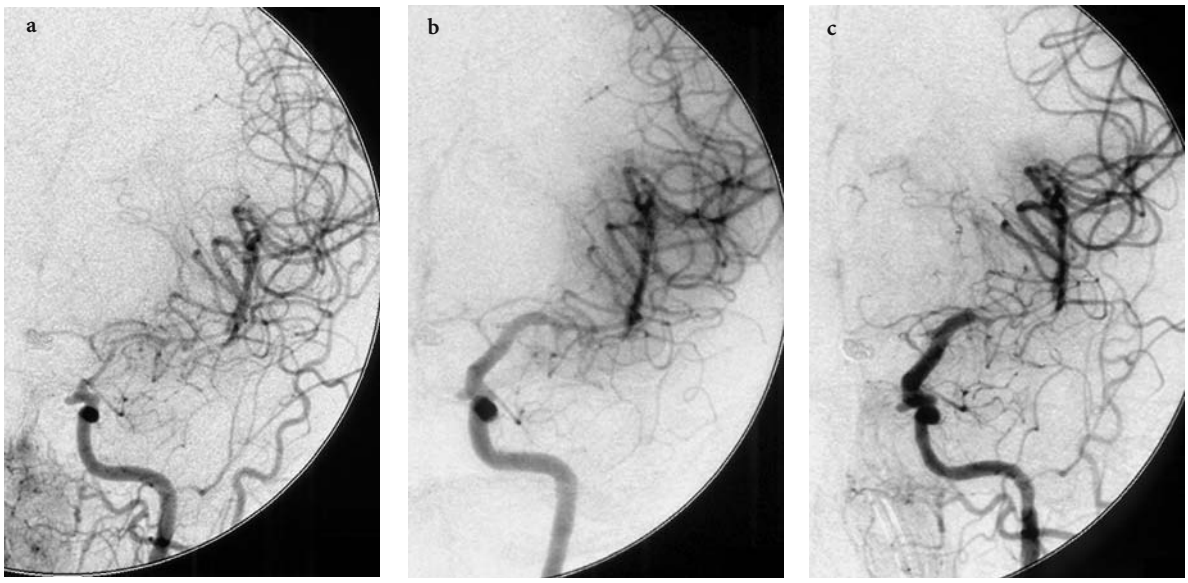


Fig. 5.4.53. a Severe vasospasm after rupture of an Acom aneurysm. **b** After balloon angioplasty and papaverine infusion. **c** Severe vasospasm 1 day later was noted of the previously not dilated vessels

Papaverine can be useful as an adjunct to balloon angioplasty and also for the treatment of distal vessels that are not accessible for balloon angioplasty (Newell et al. 1999).

Although isolated series documenting clinical successes have prompted the increased use of papaverine as a treatment for vasospasm after SAH, some authors found, as it is currently being used, the drug does not provide added benefits, compared with medical treatment of vasospasm alone but do not preclude the possibility that alterations in the timing of or indications for drug treatment might produce beneficial effects (Polin et al. 1998).

5.4.10.9 Follow-Up and Outcome

5.4.10.9.1 Follow-Up After Endovascular Therapy

The goal of intracranial aneurysm treatment is to achieve complete aneurysm occlusion in order to avoid rebleeding. The total occlusion rate after clipping is higher than after endovascular therapy. In most of the neurosurgical centers control angiography after surgery is not performed. However, in the literature the range of incompletely clipped aneurysms range from 4% up to 17% (Byrne et al. 1999; Feuerberg et al. 1987; Macdonald et al. 1993). A large series of postoperatively examined patients with a total of 837 aneurysms revealed residual aneurysms in 7.09% (Suzuki et al. 1980).

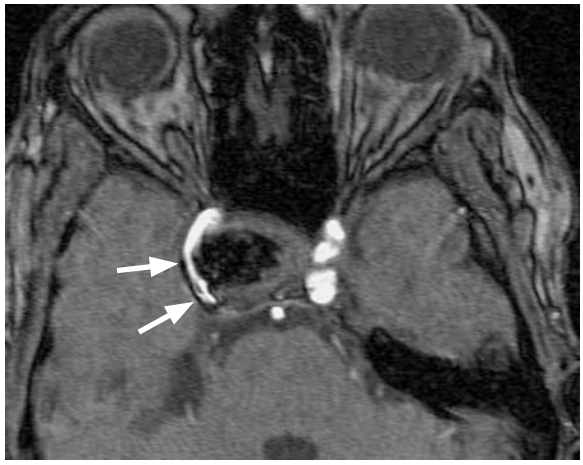
Especially for small neck aneurysms endovascular coil embolization has become a therapeutic alternative to microneurosurgical clipping (Johnston et al. 1999; Koivisto et al. 2000; Murayama et al. 1999; Raaymakers et al. 1998). However, one problem that might occur in endovascularly treated aneurysms is the relatively high number of suboptimal obliterated aneurysms with a tendency to recanalize (Byrne et al. 1999; Cognard et al. 1999). Therefore, careful follow-up after endovascular treatment in order to detect recurrent aneurysm is of major importance.

Up to now digital subtraction angiography (DSA) has been considered the gold standard for evaluation of residual or recurrent aneurysms. Since it is an expensive procedure and carries the risk of a permanent neurologic deficit (Grzyska et al. 1990; Hankey et al. 1990) a non-invasive and more cost-effective modality would be more than nice to have. Magnetic resonance angiography (MRA) using time-of-flight (TOF) technique has an excellent spatial resolution and is – although not routinely – used for detection of both unruptured and ruptured intracranial aneurysms (Bosmans et al. 1995; Gouliamos et al. 1992; Houkin et al. 1994; Jager et al. 2000; Raaymakers et al. 1999; Ross et al. 1990; Sevick et al. 1990). However, in neurosurgically clipped patients MRA is clearly not the diagnostic tool of choice to determine occlu-

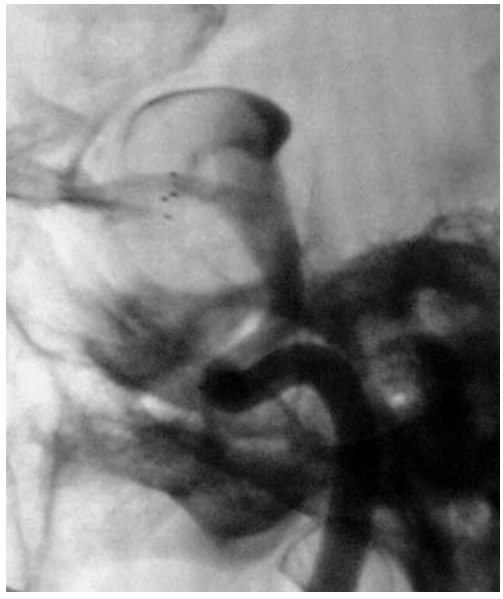
sion rate due to severe artefacts of the titanium clips (Grieve et al. 1999; Hartman et al. 1997).

However, there are still controversial studies about the value of MRA after coiling of aneurysms. Some authors report severe artefacts, others report excellent diagnostic results without producing artefacts (Anzalone et al. 2000; Derdeyn et al. 1997; Hartman et al. 1997; Brunereau 1999; Kahara et al. 1999; Shellock et al. 1997).

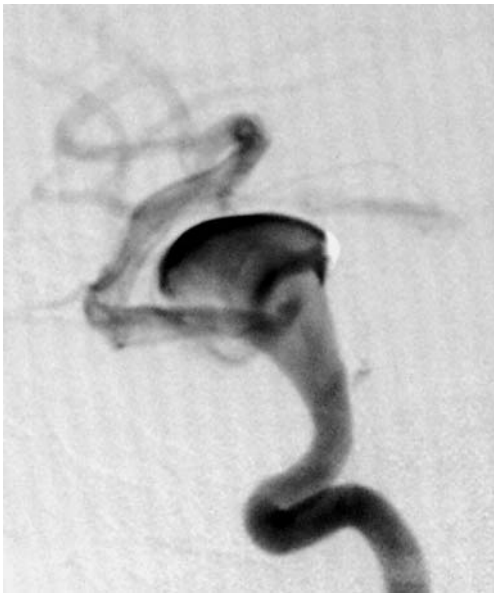
In our experience MRA is very reliable to detect recurrent aneurysms. Platinum coils do of course alter the MR signal, but not produce artefacts interfering with the evaluation of aneurysm obliteration. As always, the patient should be in a reasonable clinical condition to cooperate during the time of scanning and vasospasm and subarachnoid blood clots should not be present. The same is true if platinum coils are used in combination with a neurostent (Neuroform). Although the stent is visible on MRA source images and produces some signal loss vessel patency and aneurysm obliteration can be evaluated.



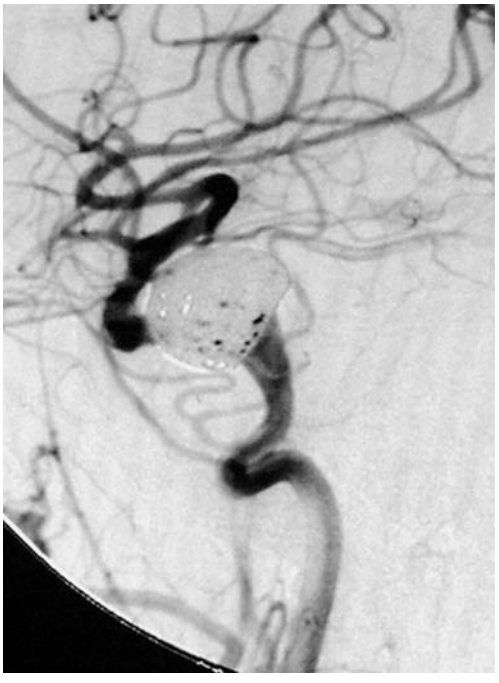
a



c

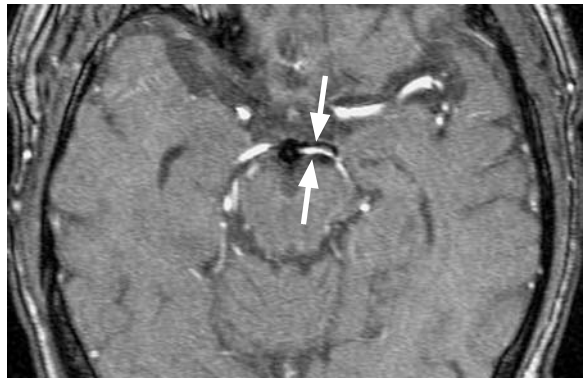


b

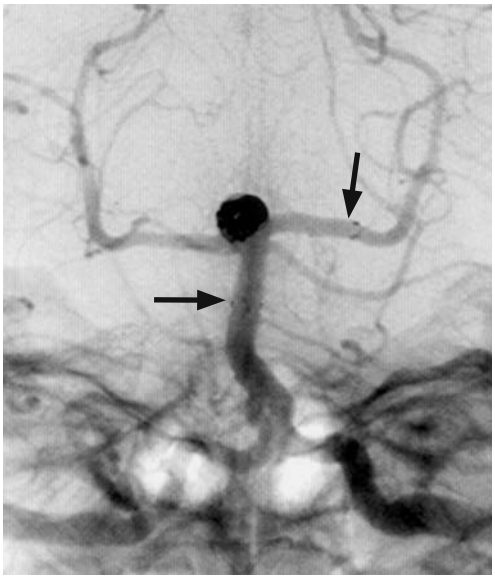


d

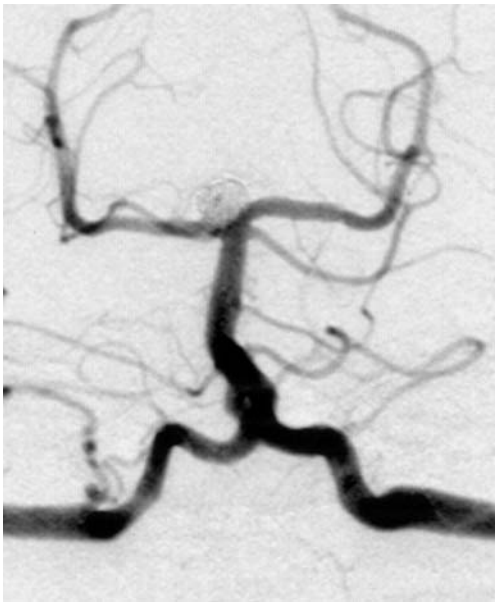
Fig. 5.4.54a–d. Giant broad-based ICA aneurysm: TOF axial source image demonstrating signal loss at the vessel wall at the site of the implanted stent (*arrows*). while the parent artery is patent. Although there is no flow after coiling the giant aneurysm is partially thrombosed. **b** DSA demonstrated the broad base of the aneurysm, and after (**c**) stent placement the aneurysm could be (**d**) embolized through the stent-interstices



a



b



c

Fig. 5.4.55. **a** Broad-based basilar tip aneurysm encroaching the P1 segment. TOF axial source images revealed patency of the basilar artery as well as of the P1 segment of the left. The implanted stent is producing signal loss at the vessel wall (*arrows*). **b, c** DSA delineate the position of the proximal and distal markers of the stent (*arrows*) and complete obliteration of the aneurysm

If there is a good correlation between DSA and MRA in the first control after endovascular intervention – usually 3–6 months later – MRA seems promising as a sufficient tool for follow-up of a patient with a coiled intracranial aneurysm initially larger than 2 mm to select those who should undergo further intervention. Nevertheless, pitfalls such as aneurysm position in acquisition plane (e.g. at the basilar tip) and extraordinary vascular disease should be taken into account. To reliably evaluate aneurysmal recurrence analysis of the MRA-TOF source images is mandatory; evaluation of the 3D MIP images alone is not sufficient. However, in a series of more than 200 patients up to now we never missed an aneurysm remnant or regrowth requiring new therapy. Therefore, we consider MRA as a sufficient tool for follow-up patients after endovascular therapy of intracranial aneurysms.

5.4.10.10 Final Remarks

Aneurysm therapy has changed in recent last years. At some centers already before ISAT and in many since ISAT, endovascular therapy is the method of choice for those aneurysms that are suitable for this technique. In specialized centers, up to 70–80% of aneurysms could be treated via the endovascular approach. The remaining aneurysms are difficult and it will be a major challenge to maintain neurosurgical expertise for exactly these "non-coilable" aneurysms. However, despite all the technical improvements, occlusion of a ruptured aneurysm is often not the most difficult part of the therapy! The disease is the *subarachnoid hemorrhage* and that determines patient outcome. Instead of fighting about "who should do what" all disciplines should now focus on the remaining problems of the disease. There is still a long way ahead to overcome these difficulties.

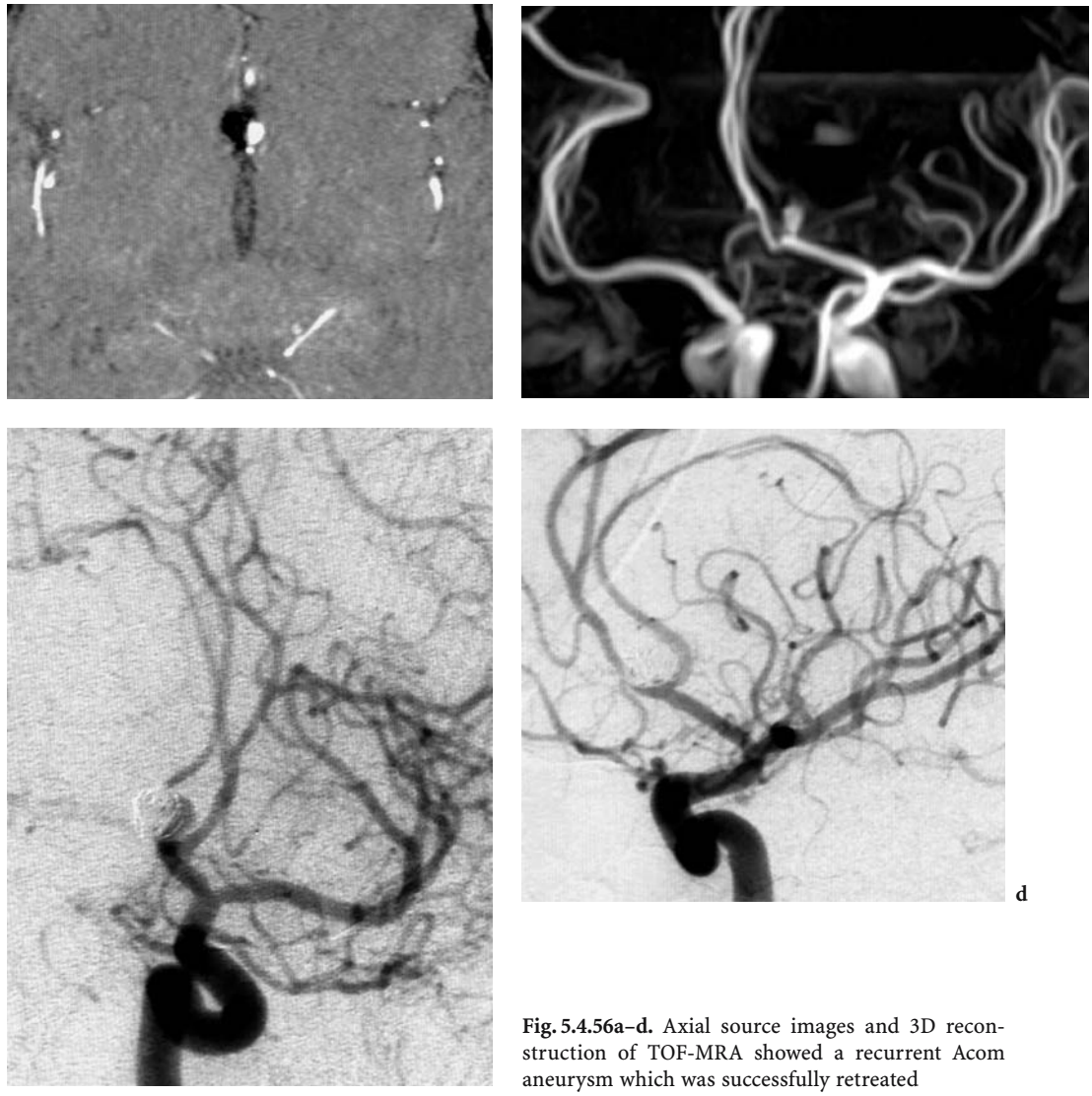


Fig. 5.4.56a–d. Axial source images and 3D reconstruction of TOF-MRA showed a recurrent Acom aneurysm which was successfully retreated

References

Abrahams JM, Diamond SL, Hurst RW, Zager EL, Grady MS (2000) Topic review: surface modifications enhancing biological activity of Guglielmi detachable coils in treating intracranial aneurysms. Surg Neurol 54:34-40; discussion 40-31

Abrahams JM, Forman MS, Grady MS, Diamond SL (2001a) Delivery of human vascular endothelial growth factor with platinum coils enhances wall thickening and coil impregnation in a rat aneurysm model. AJNR Am J Neuroradiol 22:1410-1417

Abrahams JM, Forman MS, Grady MS, Diamond SL (2001b) Biodegradable polyglycolide endovascular coils promote wall thickening and drug delivery in a rat aneurysm model. Neurosurgery 49:1187-1193; discussion 1193-1185

Adams HP Jr, Kassell NF, Torner JC, Sahs AL (1983) CT and clinical correlations in recent aneurysmal subarachnoid hemorrhage: a preliminary report of the Cooperative Aneurysm Study. Neurology 33:981-988

Adams WM, Laitt RD, Jackson A (2000) The role of MR angiography in the pretreatment assessment of intracranial aneurysms: a comparative study. AJNR Am J Neuroradiol 21:1618-1628

Aletich VA, Debrun GM, Misra M, Charbel F, Ausman JI (2000) The remodeling technique of balloon-assisted Guglielmi detachable coil placement in wide-necked aneurysms: experience at the University of Illinois at Chicago. J Neurosurg 93:388-396

Allison JW, Davis PC, Sato Y, James CA, Haque SS, Angtuaco EJ, Glasier CM (1998) Intracranial aneurysms in infants and children. Pediatr Radiol 28:223-229

Amirjamshidi A, Rahmat H, Abbassioun K (1996) Traumatic aneurysms and arteriovenous fistulas of intracranial vessels associated with penetrating head injuries occurring during war: principles and pitfalls in diagnosis and management. A survey of 31 cases and review of the literature. J Neurosurg 84:769-780

Andrews RJ, Spiegel PK (1979) Intracranial aneurysms. Age, sex, blood pressure, and multiplicity in an unselected series of patients. J Neurosurg 51:27-32

Anson JA, Lawton MT, Spetzler RF (1996) Characteristics and surgical treatment of dolichoectatic and fusiform aneurysms. J Neurosurg 84:185-193

Anxionnat R, Bracard S, Ducrocq X, Trousset Y, Launay L, Kerrien E, Braun M, Vaillant R, Scomazzoni F, Lebedinsky A, Picard L (2001) Intracranial aneurysms: clinical value of 3D digital subtraction angiography in the therapeutic decision and endovascular treatment. Radiology 218:799-808

Anzalone N, Righi C, Simionato F, Scomazzoni F, Pagani G, Calori G, Santino P, Scotti G (2000) Three-dimensional time-of-flight MR angiography in the evaluation of intracranial aneurysms treated with Guglielmi detachable coils. AJNR Am J Neuroradiol 21:746-752

Arnold H, Schwachenwald R, Nowak G, Schwachenwald D (1994) Aneurysm surgery in poor grade patients. Results, and value of external ventricular drainage. Neurol Res 16: 45-48

Asgari S, Doerfler A, Wanke I, Schoch B, Forsting M, Stolke D (2002) Complementary management of partially occluded aneurysms by using surgical or endovascular therapy. J Neurosurg 97:843-850

Atlas SW, Sheppard L, Goldberg HI, Hurst RW, Listerud J, Flamm E (1997) Intracranial aneurysms: detection and characterization with MR angiography with use of an advanced postprocessing technique in a blinded-reader study. Radiology 203:807-814

Barrow DL, Prats AR (1990) Infectious intracranial aneurysms: comparison of groups with and without endocarditis. Neurosurgery 27:562-572; discussion 572-563

Batjer HH, Samson DS (1992) Reoperation for aneurysms and vascular malformations. Clin Neurosurg 39:140-171

Bavinzski G, Killer M, Gruber A, Reinprecht A, Gross CE, Richling B (1999) Treatment of basilar artery bifurcation aneurysms by using Guglielmi detachable coils: a 6-year experience. J Neurosurg 90:843-852

Becker G, Perez J, Krone A, Demuth K, Lindner A, Hofmann E, Winkler J, Bogdahn U (1992) Transcranial color-coded real-time sonography in the evaluation of intracranial neoplasms and arteriovenous malformations. Neurosurgery 31:420-428

Benson PJ, Sung JH (1989) Cerebral aneurysms following radiotherapy for medulloblastoma. J Neurosurg 70:545-550

Berenstein A, Ransohoff J, Kupersmith M, Flamm E, Graeb D (1984) Transvascular treatment of giant aneurysms of the cavernous carotid and vertebral arteries. Functional investigation and embolization. Surg Neurol 21:3-12

Bigelow NH (1955) Multiple intracranial arterial aneurysms; an analysis of their significance. AMA Arch Neurol Psychiatry 73:76-99

Biller J, Godersky JC, Adams HP Jr (1988) Management of aneurysmal subarachnoid hemorrhage. Stroke 19:1300-1305

Biondi A, Oppenheim C, Vivas E, Casasco A, Lalam T, Sourour N, Jean LL, Dormont D, Marsault C (2000) Cerebral aneurysms treated by Guglielmi detachable coils: evaluation with diffusion-weighted MR imaging. AJNR Am J Neuroradiol 21:957-963

Birchall D, Khangure MS, McAuliffe W (1999) Resolution of third nerve paresis after endovascular management of aneurysms of the posterior communicating artery. AJNR Am J Neuroradiol 20:411-413

Birchall D, Khangure M, McAuliffe W, Apsimon H, Knuckey N (2001) Endovascular treatment of posterior circulation aneurysms. Br J Neurosurg 15:39-43

Blanc R, Weill A, Piotin M, Ross IB, Moret J (2001) Delayed stroke secondary to increasing mass effect after endovascular treatment of a giant aneurysm by parent vessel occlusion. AJNR Am J Neuroradiol 22:1841-1843

Boet R, Poon WS, Yu SC (2001) The management of residual and recurrent intracranial aneurysms after previous endovascular or surgical treatment – a report of eighteen cases. Acta Neurochir (Wien) 143:1093-1101

Bohmfalk GL, Story JL, Wissinger JP, Brown WE Jr (1978) Bacterial intracranial aneurysm. J Neurosurg 48:369-382

Bornstein RA, Weir BK, Petruk KC, Disney LB (1987) Neuropsychological function in patients after subarachnoid hemorrhage. Neurosurgery 21:651-654

Bosmans H, Wilms G, Marchal G, Demaerel P, Baert AL (1995) Characterisation of intracranial aneurysms with MR angiography. Neuroradiology 37:262-266

Brilstra EH, Hop JW, Rinkel GJ (1997) Quality of life after perimesencephalic haemorrhage. J Neurol Neurosurg Psychiatry 63:382-384

Brilstra EH, Rinkel GJ, van der Graaf Y, van Rooij WJ, Algra A (1999) Treatment of intracranial aneurysms by embolization with coils: a systematic review. Stroke 30:470-476

Brown JH, Lustrin ES, Lev MH, Ogilvy CS, Taveras JM (1999) Reduction of aneurysm clip artifacts on CT angiograms: a technical note. AJNR Am J Neuroradiol 20:694-696

Brown RD, Jr., Wiebers DO, Forbes GS (1990) Unruptured intracranial aneurysms and arteriovenous malformations: frequency of intracranial hemorrhage and relationship of lesions. J Neurosurg 73:859-863

Brunberg JA, Frey KA, Horton JA, Deveikis JP, Ross DA, Koeppe RA (1994) [15O]H2O positron emission tomography determination of cerebral blood flow during balloon test occlusion of the internal carotid artery. AJNR Am J Neuroradiol 15:725-732

Brunereau L, Cottier JP, Sonier CB, Medioni B, Bertrand P, Rouleau P, Sirinelli D, Herbreteau D (1999) Prospective evaluation of time-of-flight MR angiography in the follow-up of intracranial saccular aneurysms treated with Guglielmi detachable coils. J Comput Assist Tomogr 23:216-223

Brust JC, Dickinson PC, Hughes JE, Holtzman RN (1990) The diagnosis and treatment of cerebral mycotic aneurysms. Ann Neurol 27:238-246

Byrne JV, Sohn MJ, Molyneux AJ, Chir B (1999) Five-year experience in using coil embolization for ruptured intracranial aneurysms: outcomes and incidence of late rebleeding. J Neurosurg 90:656-663

Byrne JV, Bashiri M, Pasco A, Morris JH (2000) A novel flexible endovascular stent for use in small and tortuous vessels. Neuroradiology 42:56-61

Canhao P, Ferro JM, Pinto AN, Melo TP, Campos JG (1995) Perimesencephalic and nonperimesencephalic subarachnoid haemorrhages with negative angiograms. Acta Neurochir 132:14-19

Carey J, Numaguchi Y, Nadell J (1990) Subarachnoid hemorrhage in sickle cell disease. Childs Nerv Syst 6:47-50
Chapot R, Houdart E, Saint-Maurice JP, Aymard A, Mounayer C, Lot G, Merland JJ (2002) Endovascular treatment of cerebral mycotic aneurysms. Radiology 222:389-396
Chason J, Hindman W (1958) Berry aneurysms of the circle of Willis: results of a planned autopsy study. Neurology 8: 41-44
Church W (1869) Aneurysm of the right cerebral artery in a boy of thirteen. Trans Pathol Soc Lond 20:109
Chyatte D, Reilly J, Tilson MD (1990) Morphometric analysis of reticular and elastin fibers in the cerebral arteries of patients with intracranial aneurysms. Neurosurgery 26: 939-943
Ciceri EF, Klucznik RP, Grossman RG, Rose JE, Mawad ME (2001) Aneurysms of the posterior cerebral artery: classification and endovascular treatment. AJNR Am J Neuroradiol 22:27-34
Clare CE, Barrow DL (1992) Infectious intracranial aneurysms. Neurosurg Clin North Am 3:551-566
Cognard C, Gobin YP, Pierot L, Bailly AL, Houdart E, Casasco A, Chiras J, Merland JJ (1995) Cerebral dural arteriovenous fistulas: clinical and angiographic correlation with a revised classification of venous drainage. Radiology 194: 671-680
Cognard C, Pierot L, Boulin A, Weill A, Tovi M, Castaings L, Rey A, Moret J, Toevi M (1997) Intracranial aneurysms: endovascular treatment with mechanical detachable spirals in 60 aneurysms. Radiology 202:783-792
Cognard C, Weill A, Spelle L, Piotin M, Castaings L, Rey A, Moret J (1999) Long-term angiographic follow-up of 169 intracranial berry aneurysms occluded with detachable coils. Radiology 212:348-356
Condette-Auliac S, Bracard S, Anxionnat R, Schmitt E, Lacour JC, Braun M, Meloneto J, Cordebar A, Yin L, Picard L (2001) Vasospasm after subarachnoid hemorrhage: interest in diffusion-weighted MR imaging. Stroke 32:1818-1824
Conway JE, Hutchins GM, Tamargo RJ (1999) Marfan syndrome is not associated with intracranial aneurysms. Stroke 30:1632-1636
Conway JE, Hutchins GM, Tamargo RJ (2001) Lack of evidence for an association between neurofibromatosis type I and intracranial aneurysms: autopsy study and review of the literature. Stroke 32:2481-2485
Crompton MR (1966) The comparative pathology of cerebral aneurysms. Brain 89:789-796
Dardzinski BJ, Sotak CH, Fisher M, Hasegawa Y, Li L, Minematsu K (1993) Apparent diffusion coefficient mapping of experimental focal cerebral ischemia using diffusion-weighted echo-planar imaging. Magn Reson Med 30: 318-325
Dawson RC, Krisht AF, Barrow DL, Joseph GJ, Shengelaia GG, Bonner G (1995) Treatment of experimental aneurysms using collagen-coated microcoils. Neurosurgery 36:133-139; discussion 139-140
De Crespigny AJ, Tsuura M, Moseley ME, Kucharczyk J (1993) Perfusion and diffusion MR imaging of thromboembolic stroke. J Magn Reson Imaging 3:746-754
Debrun G, Fox A, Drake C, Peerless S, Girvin J, Ferguson G (1981) Giant unclippable aneurysms: treatment with detachable balloons. AJNR Am J Neuroradiol 2:167-173
Derdeyn CP, Graves VB, Turski PA, Masaryk AM, Strother CM (1997) MR angiography of saccular aneurysms after treatment with Guglielmi detachable coils: preliminary experience. AJNR Am J Neuroradiol 18:279-286
Derdeyn CP, Barr JD, Berenstein A, Connors JJ, Dion JE, Duckwiler GR, Higashida RT, Strother CM, Tomsick TA, Turski P (2003) The International Subarachnoid Aneurysm Trial (ISAT): a position statement from the Executive Committee of the American Society of Interventional and Therapeutic Neuroradiology and the American Society of Neuroradiology. AJNR Am J Neuroradiol 24:1404-1408
Doerfler A, Wanke I, Egelhof T, Dietrich U, Asgari S, Stolke D, Forsting M (2001) Aneurysmal rupture during embolization with Guglielmi detachable coils: causes, management, and outcome. AJNR Am J Neuroradiol 22:1825-1832
Drake CG (1965) On the surgical treatment of ruptured intracranial aneurysms. Clin Neurosurg 13:122-155
Drake CG (1977) Intracranial aneurysms. Acta Neurol Latinoam 23:43-68
Drake CG, Allcock JM (1973) Postoperative angiography and the „slipped" clip. J Neurosurg 39:683-689
Drake CG, Peerless SJ (1997) Giant fusiform intracranial aneurysms: review of 120 patients treated surgically from 1965 to 1992. J Neurosurg 87:141-162
Ebina K, Suzuki M, Andoh A, Saitoh K, Iwabuchi T (1982) Recurrence of cerebral aneurysm after initial neck clipping. Neurosurgery 11:764-768
Eckard DA, Purdy PD, Bonte FJ (1992) Temporary balloon occlusion of the carotid artery combined with brain blood flow imaging as a test to predict tolerance prior to permanent carotid sacrifice. AJNR Am J Neuroradiol 13: 1565-1569
Ellenbogen BK (1970) Subarachnoid haemorrhage in the elderly. Gerontol Clin 12:115-120
Elliott JP, Le Roux PD (1998) Subarachnoid hemorrhage and cerebral aneurysms in the elderly. Neurosurg Clin North Am 9:587-594
Endo S, Nishijima M, Nomura H, Takaku A, Okada E (1993) A pathological study of intracranial posterior circulation dissecting aneurysms with subarachnoid hemorrhage: report of three autopsied cases and review of the literature. Neurosurgery 33:732-738
Eskridge JM (1989) Interventional neuroradiology. Radiology 172:991-1006
Fahrig R, Moreau M, Holdsworth DW (1997) Three-dimensional computed tomographic reconstruction using a C-arm mounted XRII: correction of image intensifier distortion. Med Phys 24:1097-1106
Feigin VL, Rinkel GJ, Algra A, Vermeulen M, van Gijn J (2000) Calcium antagonists for aneurysmal subarachnoid haemorrhage. Cochrane Database Syst Rev. 2002;(4):CD000277
Ferrante L, Fortuna A, Celli P, Santoro A, Fraioli B (1988) Intracranial arterial aneurysms in early childhood. Surg Neurol 29:39-56
Feuerberg I, Lindquist C, Lindqvist M, Steiner L (1987) Natural history of postoperative aneurysm rests. J Neurosurg 66: 30-34
Findlay JM, Kassell NF, Weir BK, Haley EC Jr., Kongable G, Germanson T, Truskowski L, Alves WM, Holness RO, Knuckey NW, et al. (1995) A randomized trial of intraoperative, intracisternal tissue plasminogen activator for the prevention of vasospasm. Neurosurgery 37:168–76; discussion 177–8
Findlay JM, Hao C, Emery D (2002) Non-atherosclerotic fusiform cerebral aneurysms. Can J Neurol Sci 29:41-48

Fisher CM, Kistler JP, Davis JM (1980) Relation of cerebral vasospasm to subarachnoid hemorrhage visualized by computerized tomographic scanning. Neurosurgery 6:1-9

Forsting M, Albert FK, Jansen O, von Kummer R, Aschoff A, Kunze S, Sartor K (1996) Coil placement after clipping: endovascular treatment of incompletely clipped cerebral aneurysms. Report of two cases. J Neurosurg 85:966-969

Fox AJ, Pelz DM, Vinuela F, Barnett HJ, Peerless SJ (1986) Results of the international extracranial/intracranial bypass study. Implications for neuroradiologists. Acta Radiol Suppl 369:77-78

Fox AJ, Vinuela F, Pelz DM, Peerless SJ, Ferguson GG, Drake CG, Debrun G (1987) Use of detachable balloons for proximal artery occlusion in the treatment of unclippable cerebral aneurysms. J Neurosurg 66:40-46

Fraser KW, Halbach VV, Teitelbaum GP, Smith TP, Higashida RT, Dowd CF, Wilson CB, Hieshima GB (1994) Endovascular platinum coil embolization of incompletely surgically clipped cerebral aneurysms. Surg Neurol 41:4-8

Fridriksson SM, Hillman J, Saveland H, Brandt L (1995) Intracranial aneurysm surgery in the 8th and 9th decades of life: impact on population-based management outcome. Neurosurgery 37:627-631; discussion 631-622

Friedman WA, Grundy BL (1987) Monitoring of sensory evoked potentials is highly reliable and helpful in the operating room. J Clin Monit 3:38-44

Friedman WA, Kaplan BL, Day AL, Sypert GW, Curran MT (1987) Evoked potential monitoring during aneurysm operation: observations after fifty cases. Neurosurgery 20: 678-687

Friedman WA, Chadwick GM, Verhoeven FJ, Mahla M, Day AL (1991) Monitoring of somatosensory evoked potentials during surgery for middle cerebral artery aneurysms. Neurosurgery 29:83-88

Fujii Y, Takeuchi S, Sasaki O, Minakawa T, Koike T, Tanaka R (1996) Ultra-early rebleeding in spontaneous subarachnoid hemorrhage. J Neurosurg 84:35-42

Furuya K, Sasaki T, Yoshimoto Y, Okada Y, Fujimaki T, Kirino T (1995) Histologically verified cerebral aneurysm formation secondary to embolism from cardiac myxoma. Case report. J Neurosurg 83:170-173

Gailloud P, Fasel JH, Muster M, de Tribolet N, Rufenacht DA (1997) A case in favor of aneurysmographic studies: a perforating artery originating from the dome of a basilar tip aneurysm. AJNR Am J Neuroradiol 18:1691-1694

Gallagher JP (1963) Obliteration of intracranial aneurysms by pilojection. JAMA 183:231-236

Gallagher JP (1964) Pilojection for Intracranial Aneurysms. Report of progress. J Neurosurg 21:129-134

Gallagher JP, Baiz T (1964) Pilojection for Carotid Aneurysm in the Cavernous Sinus. JAMA 188:1156-1158

Giannotta SL, Litofsky NS (1995) Reoperative management of intracranial aneurysms. J Neurosurg 83:387-393

Gobin YP, Vinuela F, Gurian JH, Guglielmi G, Duckwiler GR, Massoud TF, Martin NA (1996) Treatment of large and giant fusiform intracranial aneurysms with Guglielmi detachable coils. J Neurosurg 84:55-62

Gonner F, Lovblad KO, Heid O, Remonda L, Guzman R, Barth A, Schroth G (2002) Magnetic resonance angiography with ultrashort echo times reduces the artefact of aneurysm clips. Neuroradiology 44:755-758

Gouliamos A, Gotsis E, Vlahos L, Samara C, Kapsalaki E, Rologis D, Kapsalakis Z, Papavasiliou C (1992) Magnetic resonance angiography compared to intra-arterial digital subtraction angiography in patients with subarachnoid haemorrhage. Neuroradiology 35:46-49

Graves VB, Strother CM, Duff TA, Perl J 2nd (1995) Early treatment of ruptured aneurysms with Guglielmi detachable coils: effect on subsequent bleeding. Neurosurgery 37: 640-647; discussion 647-648

Grieve JP, Stacey R, Moore E, Kitchen ND, Jager HR (1999) Artefact on MRA following aneurysm clipping: an in vitro study and prospective comparison with conventional angiography. Neuroradiology 41:680-686

Griewing B, Motsch L, Piek J, Schminke U, Brassel F, Kessler C (1998) Transcranial power mode Doppler duplex sonography of intracranial aneurysms. J Neuroimaging 8:155-158

Grosset DG, Straiton J, du Trevou M, Bullock R (1992) Prediction of symptomatic vasospasm after subarachnoid hemorrhage by rapidly increasing transcranial Doppler velocity and cerebral blood flow changes. Stroke 23:674-679

Grote E, Hassler W (1988) The critical first minutes after subarachnoid hemorrhage. Neurosurgery 22:654-661

Grzyska U, Freitag J, Zeumer H (1990) Selective cerebral intraarterial DSA. Complication rate and control of risk factors. Neuroradiology 32:296-299

Guglielmi G, Vinuela F, Sepetka I, Macellari V (1991a) Electrothrombosis of saccular aneurysms via endovascular approach, part 1. Electrochemical basis, technique, and experimental results. J Neurosurg 75:1-7

Guglielmi G, Vinuela F, Dion J, Duckwiler G (1991b) Electrothrombosis of saccular aneurysms via endovascular approach, part 2. Preliminary clinical experience. J Neurosurg 75:8-14

Guglielmi G, Vinuela F, Duckwiler G, Dion J, Lylyk P, Berenstein A, Strother C, Graves V, Halbach V, Nichols D et al (1992) Endovascular treatment of posterior circulation aneurysms by electrothrombosis using electrically detachable coils. J Neurosurg 77:515-524

Hademenos GJ, Massoud TF, Turjman F, Sayre JW (1998) Anatomical and morphological factors correlating with rupture of intracranial aneurysms in patients referred for endovascular treatment. Neuroradiology 40:755-760

Halbach VV, Higashida RT, Dowd CF, Barnwell SL, Hieshima GB (1991) Management of vascular perforations that occur during neurointerventional procedures. AJNR Am J Neuroradiol 12:319-327

Haley EC Jr, Kassell NF, Apperson-Hansen C, Maile MH, Alves WM (1997) A randomized, double-blind, vehicle-controlled trial of tirilazad mesylate in patients with aneurysmal subarachnoid hemorrhage: a cooperative study in North America. J Neurosurg 86:467-474

Hamada J, Morioka M, Miura M, Fujioka S, Marubayashi T, Ushio Y (2001) Management outcome for ruptured anterior circulation aneurysms with a Hunt and Hess clinical grade of III in patients in the 9th decade of life. Surg Neurol 56:294-300

Hankey GJ, Warlow CP, Sellar RJ (1990) Cerebral angiographic risk in mild cerebrovascular disease. Stroke 21:209-222

Hartman J, Nguyen T, Larsen D, Teitelbaum GP (1997) MR artifacts, heat production, and ferromagnetism of Guglielmi detachable coils. AJNR Am J Neuroradiol 18:497-501

Hauerberg J, Andersen BB, Eskesen V, Rosenorn J, Schmidt K (1991) Importance of the recognition of a warning leak as a sign of a ruptured intracranial aneurysm. Acta Neurol Scand 83:61-64

Hecht ST, Horton JA, Yonas H (1991) Growth of a thrombosed giant vertebral artery aneurysm after parent artery occlusion. AJNR Am J Neuroradiol 12:449-451

Heiserman JE, Dean BL, Hodak JA, Flom RA, Bird CR, Drayer BP, Fram EK (1994) Neurologic complications of cerebral angiography. AJNR Am J Neuroradiol 15:1401-1407; discussion 1408-1411

Heiskanen O (1989) Ruptured intracranial arterial aneurysms of children and adolescents. Surgical and total management results. Childs Nerv Syst 5:66-70

Hieshima GB, Grinnell VS, Mehringer CM (1981) A detachable balloon for therapeutic transcatheter occlusions. Radiology 138:227-228

Higashida RT, Halbach VV, Cahan LD, Hieshima GB, Konishi Y (1989) Detachable balloon embolization therapy of posterior circulation intracranial aneurysms. J Neurosurg 71: 512-519

Higashida RT, Halbach VV, Barnwell SL, Dowd C, Dormandy B, Bell J, Hieshima GB (1990) Treatment of intracranial aneurysms with preservation of the parent vessel: results of percutaneous balloon embolization in 84 patients. AJNR Am J Neuroradiol 11:633-640

Higashida RT, Halbach VV, Dowd CF, Barnwell SL, Hieshima GB (1991) Intracranial aneurysms: interventional neurovascular treatment with detachable balloons–results in 215 cases. Radiology 178:663-670

Higashida RT, Smith W, Gress D, Urwin R, Dowd CF, Balousek PA, Halbach VV (1997) Intravascular stent and endovascular coil placement for a ruptured fusiform aneurysm of the basilar artery. Case report and review of the literature. J Neurosurg 87:944-949

Hijdra A, Vermeulen M, van Gijn J, van Crevel H (1987) Rerupture of intracranial aneurysms: a clinicoanatomic study. J Neurosurg 67:29-33

Hijdra A, Brouwers PJ, Vermeulen M, van Gijn J (1990) Grading the amount of blood on computed tomograms after subarachnoid hemorrhage. Stroke 21:1156-1161

Hoh BL, Rabinov JD, Pryor JC, Carter BS, Barker FG 2nd (2003) In-hospital morbidity and mortality after endovascular treatment of unruptured intracranial aneurysms in the United States, 1996-2000: effect of hospital and physician volume. AJNR Am J Neuroradiol 24:1409-1420

Holmes B, Harbaugh RE (1993) Traumatic intracranial aneurysms: a contemporary review. J Trauma 35:855-860

Hop JW, Rinkel GJ, Algra A, van Gijn J (1999) Initial loss of consciousness and risk of delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage. Stroke 30: 2268-2271

Horikoshi T, Nukui H, Yagishita T, Nishigaya K, Fukasawa I, Sasaki H (1999) Oculomotor nerve palsy after surgery for upper basilar artery aneurysms. Neurosurgery 44:705-710; discussion 710-701

Horowitz M, Purdy P, Kopitnik T, Dutton K, Samson D (1999) Aneurysm retreatment after Guglielmi detachable coil and nondetachable coil embolization: report of nine cases and review of the literature. Neurosurgery 44:712-719; discussion 719-720

Horowitz MB, Levy EI, Koebbe CJ, Jungreis CC (2001) Transluminal stent-assisted coil embolization of a vertebral confluence aneurysm: technique report. Surg Neurol 55:291-296

Houkin K, Aoki T, Takahashi A, Abe H, Koiwa M, Kashiwaba T (1994) Magnetic resonance angiography (MRA) of ruptured cerebral aneurysm. Acta Neurochir 128:132-136

Housepian E, Pool J (1958) A systematic analysis of intracranial aneurysms from the autopsy file of the Presbyterian Hospital, 1914 to 1956. J Neuropathol Exp Neurol 17: 409-423

Hughes RL (1992) Identification and treatment of cerebral aneurysms after sentinel headache. Neurology 42:1118-1119

Inagawa T (1991) Surgical treatment of multiple intracranial aneurysms. Acta Neurochir 108:22-29

Inagawa T, Hirano A (1990) Autopsy study of unruptured incidental intracranial aneurysms. Surg Neurol 34:361-365

Inagawa T, Hada H, Katoh Y (1992) Unruptured intracranial aneurysms in elderly patients. Surg Neurol 38:364-370

Inci S, Erbengi A, Ozgen T (1998) Aneurysms of the distal anterior cerebral artery: report of 14 cases and a review of the literature. Surg Neurol 50:130-139; discussion 139-140

Jager HR, Mansmann U, Hausmann O, Partzsch U, Moseley IF, Taylor WJ (2000) MRA versus digital subtraction angiography in acute subarachnoid haemorrhage: a blinded multireader study of prospectively recruited patients. Neuroradiology 42:313-326

Jarus-Dziedzic K, Zub W, Wronski J, Juniewicz H, Kasper E (2000) The relationship between cerebral blood flow velocities and the amount of blood clots in computed tomography after subarachnoid haemorrhage. Acta Neurochir 142:309-318

Johnston SC, Dudley RA, Gress DR, Ono L (1999a) Surgical and endovascular treatment of unruptured cerebral aneurysms at university hospitals. Neurology 52:1799-1805

Johnston SC, Gress DR, Kahn JG (1999b) Which unruptured cerebral aneurysms should be treated? A cost-utility analysis. Neurology 52:1806-1815

Johnston SC, Wilson CB, Halbach VV, Higashida RT, Dowd CF, McDermott MW, Applebury CB, Farley TL, Gress DR (2000) Endovascular and surgical treatment of unruptured cerebral aneurysms: comparison of risks. Ann Neurol 48: 11-19

Juvela S, Poussa K, Porras M (2001) Factors affecting formation and growth of intracranial aneurysms: a long-term follow-up study. Stroke 32:485-491

Kahara VJ, Seppanen SK, Ryymin PS, Mattila P, Kuurne T, Laasonen EM (1999) MR angiography with three-dimensional time-of-flight and targeted maximum-intensity-projection reconstructions in the follow-up of intracranial aneurysms embolized with Guglielmi detachable coils. AJNR Am J Neuroradiol 20:1470-1475

Kallmes DF, Fujiwara NH (2002) New expandable hydrogel-platinum coil hybrid device for aneurysm embolization. AJNR Am J Neuroradiol 23:1580-1588

Kallmes DF, Williams AD, Cloft HJ, Lopes MB, Hankins GR, Helm GA (1998) Platinum coil-mediated implantation of growth factor-secreting endovascular tissue grafts: an in vivo study. Radiology 207:519-523

Kandel EI (1980) Complete excision of arteriovenous malformations of the cervical cord. Surg Neurol 13:135-139

Kassell NF, Torner JC (1983) Size of intracranial aneurysms. Neurosurgery 12:291-297

Kassell NF, Torner JC, Haley EC Jr, Jane JA, Adams HP, Kongable GL (1990a) The International Cooperative Study on the Timing of Aneurysm Surgery, part 1. Overall management results. J Neurosurg 73:18-36

Kassell NF, Torner JC, Jane JA, Haley EC Jr, Adams HP (1990b) The International Cooperative Study on the Timing of

Aneurysm Surgery, part 2. Surgical results. J Neurosurg 73:37-47
Kerr R, Molyneux A (2003) Results from the ISAT study, 16-19 Febr 2003, Phoenix, AZ
King WA, Martin NA (1994) Critical care of patients with subarachnoid hemorrhage. Neurosurg Clin North Am 5: 767-787
Klucznik RP, Carrier DA, Pyka R, Haid RW (1993) Placement of a ferromagnetic intracerebral aneurysm clip in a magnetic field with a fatal outcome. Radiology 187:855-856
Koivisto T, Vanninen R, Hurskainen H, Saari T, Hernesniemi J, Vapalahti M (2000) Outcomes of early endovascular versus surgical treatment of ruptured cerebral aneurysms. A prospective randomized study. Stroke 31:2369-2377
Kojima M, Nagasawa S, Lee YE, Takeichi Y, Tsuda E, Mabuchi N (1998) Asymptomatic familial cerebral aneurysms. Neurosurgery 43:776-781
Korogi Y, Takahashi M, Mabuchi N, Nakagawa T, Fujiwara S, Horikawa Y, Miki H, O'Uchi T, Shiga H, Shiokawa Y, Watabe T, Furuse M (1996) Intracranial aneurysms: diagnostic accuracy of MR angiography with evaluation of maximum intensity projection and source images. Radiology 199: 199-207
Korogi Y, Takahashi M, Katada K, Ogura Y, Hasuo K, Ochi M, Utsunomiya H, Abe T, Imakita S (1999) Intracranial aneurysms: detection with three-dimensional CT angiography with volume rendering – comparison with conventional angiographic and surgical findings. Radiology 211:497-506
Kupersmith MJ, Berenstein A, Choi IS, Ransohoff J, Flamm ES (1984) Percutaneous transvascular treatment of giant carotid aneurysms: neuro- ophthalmologic findings. Neurology 34:328-335
Landtblom AM, Fridriksson S, Boivie J, Hillman J, Johansson G, Johansson I (2002) Sudden onset headache: a prospective study of features, incidence and causes. Cephalalgia 22:354-360
Lanzino G, Kassell NF (1999) Double-blind, randomized, vehicle-controlled study of high-dose tirilazad mesylate in women with aneurysmal subarachnoid hemorrhage, part II. A cooperative study in North America. J Neurosurg 90: 1018-1024
Lanzino G, Kassell NF, Dorsch NW, Pasqualin A, Brandt L, Schmiedek P, Truskowski LL, Alves WM (1999a) Double-blind, randomized, vehicle-controlled study of high-dose tirilazad mesylate in women with aneurysmal subarachnoid hemorrhage, part I. A cooperative study in Europe, Australia, New Zealand, and South Africa. J Neurosurg 90: 1011-1017
Lanzino G, Wakhloo AK, Fessler RD, Hartney ML, Guterman LR, Hopkins LN (1999b) Efficacy and current limitations of intravascular stents for intracranial internal carotid, vertebral, and basilar artery aneurysms. J Neurosurg 91: 538-546
Larson JJ, Tew JM Jr, Tomsick TA, van Loveren HR (1995) Treatment of aneurysms of the internal carotid artery by intravascular balloon occlusion: long-term follow-up of 58 patients. Neurosurgery 36:26-30; discussion 30
Lau AH, Takeshita M, Ishii N (1991) Mycotic (Aspergillus) arteritis resulting in fatal subarachnoid hemorrhage: a case report. Angiology 42:251-255
Leblanc R (1996) Familial cerebral aneurysms. A bias for women. Stroke 27:1050-1054
Lee EK, Hecht ST, Lie JT (1998) Multiple intracranial and systemic aneurysms associated with infantile- onset arterial fibromuscular dysplasia. Neurology 50:828-829
Lee KC, Joo JY, Lee KS, Shin YS (1999) Recanalization of completely thrombosed giant aneurysm: case report. Surg Neurol 51:94-98
Le Roux PD, Winn HR (1998) Management of the ruptured aneurysm. Neurosurg Clin North Am 9:525-540
Le Roux PD, Elliott JP, Eskridge JM, Cohen W, Winn HR (1998) Risks and benefits of diagnostic angiography after aneurysm surgery: a retrospective analysis of 597 studies. Neurosurgery 42:1248-1254; discussion 1254-1245
Levine SR, Brust JC, Futrell N, Ho KL, Blake D, Millikan CH, Brass LM, Fayad P, Schultz LR, Selwa JF et al (1990) Cerebrovascular complications of the use of the „crack" form of alkaloidal cocaine. N Engl J Med 323:699-704
Levine SR, Brust JC, Futrell N, Brass LM, Blake D, Fayad P, Schultz LR, Millikan CH, Ho KL, Welch KM (1991) A comparative study of the cerebrovascular complications of cocaine: alkaloidal versus hydrochloride – a review. Neurology 41:1173-1177
Levy DI (1997) Embolization of wide-necked anterior communicating artery aneurysm: technical note. Neurosurgery 41:979-982
Liang EY, Chan M, Hsiang JH, Walkden SB, Poon WS, Lam WW, Metreweli C (1995) Detection and assessment of intracranial aneurysms: value of CT angiography with shaded-surface display. AJR Am J Roentgenol 165:1497-1502
Lin T, Fox AJ, Drake CG (1989) Regrowth of aneurysm sacs from residual neck following aneurysm clipping. J Neurosurg 70:556-560
Linn FH, Rinkel GJ, Algra A, van Gijn J (1998) Headache characteristics in subarachnoid haemorrhage and benign thunderclap headache. J Neurol Neurosurg Psychiatry 65: 791-793
Linskey ME, Sekhar LN, Hirsch WL Jr, Yonas H, Horton JA (1990) Aneurysms of the intracavernous carotid artery: natural history and indications for treatment. Neurosurgery 26:933-937; discussion 937-938
Linskey ME, Jungreis CA, Yonas H, Hirsch WL Jr, Sekhar LN, Horton JA, Janosky JE (1994) Stroke risk after abrupt internal carotid artery sacrifice: accuracy of preoperative assessment with balloon test occlusion and stable xenon- enhanced CT. AJNR Am J Neuroradiol 15:829-843
Locksley HB, Sahs AL, Knowler L (1966) Report on the cooperative study of intracranial aneurysms and subarachnoid hemorrhage. Section II. General survey of cases in the central registry and characteristics of the sample population. J Neurosurg 24:922-932
Longstreth WT Jr, Koepsell TD, Yerby MS, van Belle G (1985) Risk factors for subarachnoid hemorrhage. Stroke 16: 377-385
Lownie SP, Pelz DM, Fox AJ (2000) Endovascular therapy of a large vertebral artery aneurysm using stent and coils. Can J Neurol Sci 27:162-165
Lozano AM, Leblanc R (1987) Familial intracranial aneurysms. J Neurosurg 66:522-528
Luginbuhl M, Remonda L (1999) Interventional neuroradiology. Recent developments and anaesthesiologic aspects. Minerva Anestesiol 65:445-454
Lussenhop AJ, Spence WT (1960) Artificial embolization of cerebral arteries. Report of use in a case of arteriovenous

malformation. JAMA 12; 172:1153–1155
Lusseveld E, Brilstra EH, Nijssen PC, van Rooij WJ, Sluzewski M, Tulleken CA, Wijnalda D, Schellens RL, van der Graaf Y, Rinkel GJ (2002) Endovascular coiling versus neurosurgical clipping in patients with a ruptured basilar tip aneurysm. J Neurol Neurosurg Psychiatry 73:591-593
Lylyk P, Ceratto R, Hurvitz D, Basso A (1998) Treatment of a vertebral dissecting aneurysm with stents and coils: technical case report. Neurosurgery 43:385-388
Lylyk P, Cohen JE, Ceratto R, Ferrario A, Miranda C (2001) Combined endovascular treatment of dissecting vertebral artery aneurysms by using stents and coils. J Neurosurg 94:427-432
MacDonald A, Mendelow AD (1988) Xanthochromia revisited: a re-evaluation of lumbar puncture and CT scanning in the diagnosis of subarachnoid haemorrhage. J Neurol Neurosurg Psychiatry 51:342-344
Macdonald RL, Wallace MC, Kestle JR (1993) Role of angiography following aneurysm surgery. J Neurosurg 79:826-832
Macdonald RL, Wallace MC, Montanera WJ, Glen JA (1995) Pathological effects of angioplasty on vasospastic carotid arteries in a rabbit model. J Neurosurg 83:111-117
Macdonald RL, Mojtahedi S, Johns L, Kowalczuk A (1998) Randomized comparison of Guglielmi detachable coils and cellulose acetate polymer for treatment of aneurysms in dogs. Stroke 29:478-485; discussion 485-476
Malek AM, Halbach VV, Phatouros CC, Lempert TE, Meyers PM, Dowd CF, Higashida RT (2000) Balloon-assist technique for endovascular coil embolization of geometrically difficult intracranial aneurysms. Neurosurgery 46:1397-1406; discussion 1406-1397
Massoud TF, Turjman F, Ji C, Vinuela F, Guglielmi G, Gobin YP, Duckwiler GR (1995) Endovascular treatment of fusiform aneurysms with stents and coils: technical feasibility in a swine model. AJNR Am J Neuroradiol 16:1953-1963
Mathis JM, Barr JD, Jungreis CA, Yonas H, Sekhar LN, Vincent D, Pentheny SL, Horton JA (1995) Temporary balloon test occlusion of the internal carotid artery: experience in 500 cases. AJNR Am J Neuroradiol 16:749-754
Mattle H, Kohler S, Huber P, Rohner M, Steinsiepe KF (1989) Anticoagulation-related intracranial extracerebral haemorrhage. J Neurol Neurosurg Psychiatry 52:829-837
Mawad ME, Klucznik RP (1995) Giant serpentine aneurysms: radiographic features and endovascular treatment. AJNR Am J Neuroradiol 16:1053-1060
Mayfrank L, Hutter BO, Kohorst Y, Kreitschmann-Andermahr I, Rohde V, Thron A, Gilsbach JM (2001) Influence of intraventricular hemorrhage on outcome after rupture of intracranial aneurysm. Neurosurg Rev 24:185-191
McCormick WF, Acosta-Rua GJ (1970) The size of intracranial saccular aneurysms. An autopsy study. J Neurosurg 33:422-427
McDougall CG, Halbach VV, Dowd CF, Higashida RT, Larsen DW, Hieshima GB (1998) Causes and management of aneurysmal hemorrhage occurring during embolization with Guglielmi detachable coils. J Neurosurg 89:87-92
McKissock W, Richardson A, Walsh L, Owen E (1964) Multiple intracranial aneurysms. Lancet 15:623-626
Menovsky T, van Rooij WJ, Sluzewski M, Wijnalda D (2002) Coiling of ruptured pericallosal artery aneurysms. Neurosurgery 50:11–14; discussion 14–15
Mericle RA, Wakhloo AK, Rodriguez R, Guterman LR, Hopkins LN (1997) Temporary balloon protection as an adjunct to endosaccular coiling of wide-necked cerebral aneurysms: technical note. Neurosurgery 41:975-978
Mericle RA, Lanzino G, Wakhloo AK, Guterman LR, Hopkins LN (1998) Stenting and secondary coiling of intracranial internal carotid artery aneurysm: technical case report. Neurosurgery 43:1229-1234
Minematsu K, Li L, Fisher M, Sotak CH, Davis MA, Fiandaca MS (1992) Diffusion-weighted magnetic resonance imaging: rapid and quantitative detection of focal brain ischemia. Neurology 42:235-240
Mizoi K, Suzuki J, Yoshimoto T (1989) Surgical treatment of multiple aneurysms. Review of experience with 372 cases. Acta Neurochir (Wien) 96:8-14
Mizoi K, Yoshimoto T, Nagamine Y, Kayama T, Koshu K (1995) How to treat incidental cerebral aneurysms: a review of 139 consecutive cases. Surg Neurol 44:114-120; discussion 120-111
Mohsenipour I, Ortler M, Twerdy K, Schmutzhard E, Attlmayr G, Aichner F (1994) Isolated aneurysm of a spinal radicular artery presenting as spinal subarachnoid haemorrhage. J Neurol Neurosurg Psychiatry 57:767-768
Molyneux A, Kerr R, Stratton I, Sandercock P, Clarke M, Shrimpton J, Holman R (2002) International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. Lancet 360:1267-1274
Moret J, Pierot L, Boulin A, Castaings L, Rey A (1996) Endovascular treatment of anterior communicating artery aneurysms using Guglielmi detachable coils. Neuroradiology 38:800-805
Moret J, Cognard C, Weill A, Castaings L, Rey A (1997) Reconstruction technic in the treatment of wide-neck intracranial aneurysms. Long-term angiographic and clinical results. Apropos of 56 cases. J Neuroradiol 24:30-44
Moseley ME, Mintorovitch J, Cohen Y, Asgari HS, Derugin N, Norman D, Kucharczyk J (1990) Early detection of ischemic injury: comparison of spectroscopy, diffusion-, T2-, and magnetic susceptibility-weighted MRI in cats. Acta Neurochir (Wien) [Suppl] 51:207-209
Murayama Y, Vinuela F, Suzuki Y, Do HM, Massoud TF, Guglielmi G, Ji C, Iwaki M, Kusakabe M, Kamio M, Abe T (1997) Ion implantation and protein coating of detachable coils for endovascular treatment of cerebral aneurysms: concepts and preliminary results in swine models. Neurosurgery 40:1233-1243; discussion 1243-1234
Murayama Y, Vinuela F, Duckwiler GR, Gobin YP, Guglielmi G (1999) Embolization of incidental cerebral aneurysms by using the Guglielmi detachable coil system. J Neurosurg 90:207-214
Murayama Y, Vinuela F, Tateshima S, Vinuela F Jr, Akiba Y (2000) Endovascular treatment of experimental aneurysms by use of a combination of liquid embolic agents and protective devices. AJNR Am J Neuroradiol 21:1726-1735
Murayama Y, Vinuela F, Tateshima S, Song JK, Gonzalez NR, Wallace MP (2001) Bioabsorbable polymeric material coils for embolization of intracranial aneurysms: a preliminary experimental study. J Neurosurg 94:454-463
Nakahara I, Taki W, Kikuchi H, Sakai N, Isaka F, Oowaki H, Kondo A, Iwasaki K, Nishi S (1999) Endovascular treatment of aneurysms on the feeding arteries of intracranial arteriovenous malformations. Neuroradiology 41:60-66
Nanda A, Vannemreddy PS, Polin RS, Willis BK (2000) Intra-

cranial aneurysms and cocaine abuse: analysis of prognostic indicators. Neurosurgery 46:1063-1067; discussion 1067-1069

Nehls DG, Flom RA, Carter LP, Spetzler RF (1985) Multiple intracranial aneurysms: determining the site of rupture. J Neurosurg 63:342-348

Nelson PK (1998) Neurointerventional management of intracranial aneurysms. Neurosurg Clin North Am 9:879-895

Nelson PK, Levy DI (2001) Balloon-assisted coil embolization of wide-necked aneurysms of the internal carotid artery: medium-term angiographic and clinical follow-up in 22 patients. AJNR Am J Neuroradiol 22:19-26

Newell DW, Elliott JP, Eskridge JM, Winn HR (1999) Endovascular therapy for aneurysmal vasospasm. Crit Care Clin 15:685-699, v

Noguchi K, Ogawa T, Inugami A, Toyoshima H, Sugawara S, Hatazawa J, Fujita H, Shimosegawa E, Kanno I, Okudera T et al (1995) Acute subarachnoid hemorrhage: MR imaging with fluid-attenuated inversion recovery pulse sequences. Radiology 196:773-777

Nornes H (1973) The role of intracranial pressure in the arrest of hemorrhage in patients with ruptured intracranial aneurysm. J Neurosurg 39:226-234

Nowak G, Schwachenwald R, Arnold H (1994) Early management in poor grade aneurysm patients. Acta Neurochir (Wien) 126:33-37

Okahara M, Kiyosue H, Yamashita M, Nagatomi H, Hata H, Saginoya T, Sagara Y, Mori H (2002) Diagnostic accuracy of magnetic resonance angiography for cerebral aneurysms in correlation with 3D-digital subtraction angiographic images: a study of 133 aneurysms. Stroke 33:1803–8

Okamoto K, Horisawa R, Kawamura T, Asai A, Ogino M, Takagi T, Ohno Y (2003) Family history and risk of subarachnoid hemorrhage: a case-control study in Nagoya, Japan. Stroke 34:422-426

Origitano TC, Wascher TM, Reichman OH, Anderson DE (1990) Sustained increased cerebral blood flow with prophylactic hypertensive hypervolemic hemodilution («triple-H» therapy) after subarachnoid hemorrhage. Neurosurgery 27:729-739; discussion 739-740

Ostergaard JR (1991) Headache as a warning symptom of impending aneurysmal subarachnoid haemorrhage. Cephalalgia 11:53-55

Padolecchia R, Guglielmi G, Puglioli M, Castagna M, Nardini V, Collavoli P, Guidetti G, Dazzi M, Zucchi V, Narducci P (2001) Role of electrothrombosis in aneurysm treatment with Guglielmi detachable coils: an in vitro scanning electron microscopic study. AJNR Am J Neuoradiol 22: 1757-1760

Pasqualin A, Battaglia R, Scienza R, Da Pian R (1988) Italian cooperative study on giant intracranial aneurysms: 3. Modalities of treatment. Acta Neurochir (Wien) [Suppl] 42:60-64

Patel AN, Richardson AE (1971) Ruptured intracranial aneurysms in the first two decades of life. A study of 58 patients. J Neurosurg 35:571-576

Peerless SJ, Ferguson GG, Drake CG (1982) Extracranial-intracranial (EC/IC) bypass in the treatment of giant intracranial aneurysms. Neurosurg Rev 5:77-81

Peerless SJ, Nemoto S, Drake CG (1987) Acute surgery for ruptured posterior circulation aneurysms. Adv Tech Stand Neurosurg 15:115-129

Peerless SJ, Hernesniemi JA, Gutman FB, Drake CG (1994) Early surgery for ruptured vertebrobasilar aneurysms. J Neurosurg 80:643-649

Perneczky A, Czech T (1984) Prognosis of oculomotor palsy following subarachnoid hemorrhage due to aneurysms of the posterior communicating artery. Zentralbl Neurochir 45:189-195

Phillips LH 2nd, Whisnant JP, O'Fallon WM, Sundt TM Jr (1980) The unchanging pattern of subarachnoid hemorrhage in a community. Neurology 30:1034-1040

Phuong LK, Link M, Wijdicks E (2002) Management of intracranial infectious aneurysms: a series of 16 cases. Neurosurgery 51:1145-1151; discussion 1151-1142

Pierot L, Boulin A, Castaings L, Rey A, Moret J (1996) Selective occlusion of basilar artery aneurysms using controlled detachable coils: report of 35 cases. Neurosurgery 38:948-953; discussion 953-944

Pierot L, Boulin A, Castaings L, Rey A, Moret J (1997) The endovascular approach in the management of patients with multiple intracranial aneurysms. Neuroradiology 39:361-366

Polin RS, Hansen CA, German P, Chadduck JB, Kassell NF (1998) Intra-arterially administered papaverine for the treatment of symptomatic cerebral vasospasm. Neurosurgery 42:1256-1264; discussion 1264-1257

Proust F, Toussaint P, Hannequin D, Rabenenoina C, Le Gars D, Freger P (1997) Outcome in 43 patients with distal anterior cerebral artery aneurysms. Stroke 28:2405-2409

Qureshi AI, Mohammad Y, Yahia AM, Luft AR, Sharma M, Tamargo RJ, Frankel MR (2000a) Ischemic events associated with unruptured intracranial aneurysms: multicenter clinical study and review of the literature. Neurosurgery 46: 282-289; discussion 289-290

Qureshi AI, Luft AR, Sharma M, Guterman LR, Hopkins LN (2000b) Prevention and treatment of thromboembolic and ischemic complications associated with endovascular procedures, part II. Clinical aspects and recommendations. Neurosurgery 46:1360-1375; discussion 1375-1366

Qureshi AI, Suri MF, Khan J, Kim SH, Fessler RD, Ringer AJ, Guterman LR, Hopkins LN (2001) Endovascular treatment of intracranial aneurysms by using Guglielmi detachable coils in awake patients: safety and feasibility. J Neurosurg 94:880-885

Raaymakers T (1999) Aneurysms in relatives of patients with subarachnoid hemorrhage: frequency and risk factors. MARS study group. Magnetic Resonance Angiography in relatives of patients with subarachnoid hemorrhage. Neurology 53:982-988

Raaymakers T (2000) Functional outcome and quality of life after angiography and operation for unruptured intracranial aneurysms. On behalf of the MARS Study Group. J Neurol Neurosurg Psychiatry 68:571-576

Raaymakers T, Rinkel G, Limburg M, Algra A (1998a) Mortality and morbidity of surgery for unruptured intracranial aneurysms. Stroke 29:1531-1538

Raaymakers TW, Rinkel GJ, Ramos LM (1998b) Initial and follow-up screening for aneurysms in families with familial subarachnoid hemorrhage. Neurology 51:1125-1130

Raaymakers TW, Buys PC, Verbeeten B Jr, Ramos LM, Witkamp TD, Hulsmans FJ, Mali WP, Algra A, Bonsel GJ, Bossuyt PM, Vonk CM, Buskens E, Limburg M, van Gijn J, Gorissen A, Greebe P, Albrecht KW, Tulleken CA, Rinkel GJ (1999) MR angiography as a screening tool for intracranial aneurysms: feasibility, test characteristics, and interobserver agreement. AJR Am J Roentgenol 173:1469-1475

Raymond J, Roy D (1997) Safety and efficacy of endovascular treatment of acutely ruptured aneurysms. Neurosurgery 41:1235-1245; discussion 1245-1236

Regli L, Uske A, de Tribolet N (1999) Endovascular coil placement compared with surgical clipping for the treatment of unruptured middle cerebral artery aneurysms: a consecutive series. J Neurosurg 90:1025-1030

Reith W, Hasegawa Y, Latour LL, Dardzinski BJ, Sotak CH, Fisher M (1995) Multislice diffusion mapping for 3-D evolution of cerebral ischemia in a rat stroke model. Neurology 45:172-177

Rice BJ, Peerless SJ, Drake CG (1990) Surgical treatment of unruptured aneurysms of the posterior circulation. J Neurosurg 73:165-173

Richling B, Gruber A, Bavinzski G, Killer M (1995) GDC-system embolization for brain aneurysms – location and follow-up. Acta Neurochir 134:177-183

Ricolfi F, Le Guerinel C, Blustajn J, Combes C, Brugieres P, Melon E, Gaston A (1998) Rupture during treatment of recently ruptured aneurysms with Guglielmi electrodetachable coils. AJNR Am J Neuroradiol 19:1653-1658

Rinkel GJ, Wijdicks EF, Hasan D, Kienstra GE, Franke CL, Hageman LM, Vermeulen M, van Gijn J (1991) Outcome in patients with subarachnoid haemorrhage and negative angiography according to pattern of haemorrhage on computed tomography. Lancet 338:964-968

Rinkel GJ, Prins NE, Algra A (1997) Outcome of aneurysmal subarachnoid hemorrhage in patients on anticoagulant treatment. Stroke 28:6-9

Rinkel GJ, Djibuti M, Algra A, van Gijn J (1998) Prevalence and risk of rupture of intracranial aneurysms: a systematic review. Stroke 29:251-256

Rinne J, Hernesniemi J, Puranen M, Saari T (1994) Multiple intracranial aneurysms in a defined population: prospective angiographic and clinical study. Neurosurgery 35:803-808

Rinne J, Hernesniemi J, Niskanen M, Vapalahti M (1995) Management outcome for multiple intracranial aneurysms. Neurosurgery 36:31-37; discussion 37-38

Ronkainen A, Hernesniemi J, Puranen M, Niemitukia L, Vanninen R, Ryynanen M, Kuivaniemi H, Tromp G (1997) Familial intracranial aneurysms. Lancet 349:380-384

Roos YB, Hasan D, Vermeulen M (1995) Outcome in patients with large intraventricular haemorrhages: a volumetric study. J Neurol Neurosurg Psychiatry 58:622-624

Roos YB, de Haan RJ, Beenen LF, Groen RJ, Albrecht KW, Vermeulen M (2000) Complications and outcome in patients with aneurysmal subarachnoid haemorrhage: a prospective hospital based cohort study in the Netherlands. J Neurol Neurosurg Psychiatry 68:337-341

Rordorf G, Koroshetz WJ, Copen WA, Gonzalez G, Yamada K, Schaefer PW, Schwamm LH, Ogilvy CS, Sorensen AG (1999) Diffusion- and perfusion-weighted imaging in vasospasm after subarachnoid hemorrhage. Stroke 30:599-605

Ross JS, Masaryk TJ, Modic MT, Ruggieri PM, Haacke EM, Selman WR (1990) Intracranial aneurysms: evaluation by MR angiography. AJNR Am J Neuroradiol 11:449-455

Rowe JG, Molyneux AJ, Byrne JV, Renowden S, Aziz TZ (1996) Endovascular treatment of intracranial aneurysms: a minimally invasive approach with advantages for elderly patients. Age Ageing 25:372-376

Rumboldt Z, Kalousek M, Castillo M (2003) Hyperacute subarachnoid hemorrhage on T2-weighted MR images. AJNR Am J Neuroradiol 24:472-475

Sacco RL, Wolf PA, Bharucha NE, Meeks SL, Kannel WB, Charette LJ, McNamara PM, Palmer EP, D'Agostino R (1984) Subarachnoid and intracerebral hemorrhage: natural history, prognosis, and precursive factors in the Framingham Study. Neurology 34:847-854

Saitoh H, Hayakawa K, Nishimura K, Okuno Y, Teraura T, Yumitori K, Okumura A (1995) Rerupture of cerebral aneurysms during angiography. AJNR Am J Neuroradiol 16:539-542

Sakata S, Fujii K, Matsushima T, Fujiwara S, Fukui M, Matsubara T, Nagatomi H, Kuromatsu C, Kamikaseda K (1993) Aneurysm of the posterior cerebral artery: report of eleven cases – surgical approaches and procedures. Neurosurgery 32:163-167; discussion 167-168

Sasaki O, Ogawa H, Koike T, Koizumi T, Tanaka R (1991) A clinicopathological study of dissecting aneurysms of the intracranial vertebral artery. J Neurosurg 75:874-882

Schievink WI (1997) Genetics of intracranial aneurysms. Neurosurgery 40:651-662; discussion 662-653

Schievink WI (2001) Spontaneous dissection of the carotid and vertebral arteries. N Engl J Med 344:898-906

Schievink WI, Wijdicks EF, Piepgras DG, Chu CP, O'Fallon WM, Whisnant JP (1995) The poor prognosis of ruptured intracranial aneurysms of the posterior circulation. J Neurosurg 82:791-795

Schievink WI, Parisi JE, Piepgras DG (1997) Familial intracranial aneurysms: an autopsy study. Neurosurgery 41:1247-1251; discussion 1251-1242

Schwartz RB, Tice HM, Hooten SM, Hsu L, Stieg PE (1994) Evaluation of cerebral aneurysms with helical CT: correlation with conventional angiography and MR angiography. Radiology 192:717-722

Schwartz TH, Solomon RA (1996) Perimesencephalic nonaneurysmal subarachnoid hemorrhage: review of the literature. Neurosurgery 39:433-440; discussion 440

Seifert V (1997) Neurosurgical therapy of subarachnoid hemorrhage. Wien Med Wochenschr 147:152-158

Sekhon LH, Morgan MK, Sorby W, Grinnell V (1998) Combined endovascular stent implantation and endosaccular coil placement for the treatment of a wide-necked vertebral artery aneurysm: technical case report. Neurosurgery 43: 380-383; discussion 384

Serbinenko FA (1974a) Balloon occlusion of saccular aneurysms of the cerebral arteries. Vopr Neirokhir. 1974 Jul-Aug; (4):8-15

Serbinenko FA (1974b) Balloon catheterization and occlusion of major cerebral vessels. J Neurosurg 41:125-145

Sethi H, Moore A, Dervin J, Clifton A, MacSweeney JE (2000) Hydrocephalus: comparison of clipping and embolization in aneurysm treatment. J Neurosurg 92:991-994

Sevick RJ, Tsuruda JS, Schmalbrock P (1990) Three-dimensional time-of-flight MR angiography in the evaluation of cerebral aneurysms. J Comput Assist Tomogr 14:874-881

Shellock FG, Detrick MS, Brant-Zawadski MN (1997) MR compatibility of Guglielmi detachable coils. Radiology 203:568-570

Shimoda M, Takeuchi M, Tominaga J, Oda S, Kumasaka A, Tsugane R (2001) Asymptomatic versus symptomatic infarcts from vasospasm in patients with subarachnoid hemorrhage: serial magnetic resonance imaging. Neurosurgery 49:1341-1348; discussion 1348-1350

Sindou M, Pelissou-Guyotat I, Mertens P, Keravel Y, Athayde AA (1988) Pericallosal aneurysms. Surg Neurol 30:434-440

Sindou M, Acevedo JC, Turjman F (1998) Aneurysmal remnants

after microsurgical clipping: classification and results from a prospective angiographic study (in a consecutive series of 305 operated intracranial aneurysms). Acta Neurochir (Wien) 140:1153-1159

Solander S, Ulhoa A, Vinuela F, Duckwiler GR, Gobin YP, Martin NA, Frazee JG, Guglielmi G (1999) Endovascular treatment of multiple intracranial aneurysms by using Guglielmi detachable coils. J Neurosurg 90:857-864

Solomon RA, Mayer SA, Tarmey JJ (1996) Relationship between the volume of craniotomies for cerebral aneurysm performed at New York state hospitals and in-hospital mortality. Stroke 27:13-17

Song JK, Elliott JP, Eskridge JM (1997) Neuroradiologic diagnosis and treatment of vasospasm. Neuroimaging Clin North Am 7:819-835

Standard SC, Ahuja A, Guterman LR, Chavis TD, Gibbons KJ, Barth AP, Hopkins LN (1995) Balloon test occlusion of the internal carotid artery with hypotensive challenge. AJNR Am J Neuroradiol 16:1453-1458

Stapf C, Mohr JP, Pile-Spellman J, Sciacca RR, Hartmann A, Schumacher HC, Mast H (2002) Concurrent arterial aneurysms in brain arteriovenous malformations with haemorrhagic presentation. J Neurol Neurosurg Psychiatry 73:294-298

Stehbens WE (1989) Etiology of intracranial berry aneurysms. J Neurosurg 70:823-831

Steinberg GK, Guppy KH, Adler JR, Silverberg GD (1992) Stereotactic, angiography-guided clipping of a distal, mycotic intracranial aneurysm using the Cosman-Roberts-Wells system: technical note. Neurosurgery 30:408-411

Suzuki J, Komatsu S, Sato T, Sakurai Y (1980) Correlation between CT findings and subsequent development of cerebral infarction due to vasospasm in subarachnoid haemorrhage. Acta Neurochir (Wien) 55:63-70

Suzuki J, Kwak R, Katakura R (1980) Review of incompletely occluded surgically treated cerebral aneurysms. Surg Neurol 13:306-310

Szikora I, Guterman LR, Wells KM, Hopkins LN (1994) Combined use of stents and coils to treat experimental wide-necked carotid aneurysms: preliminary results. AJNR Am J Neuroradiol 15:1091-1102

Tan WS, Jafar JJ, Abejo R, Spigos DG, Crowell RM, Capek V (1986) Regional cerebral blood flow assessment prior to balloon detachment in the treatment of intracranial giant aneurysms. Acta Radiol [Suppl] 369:116-119

Tateshima S, Murayama Y, Gobin YP, Duckwiler GR, Guglielmi G, Vinuela F (2000) Endovascular treatment of basilar tip aneurysms using Guglielmi detachable coils: anatomic and clinical outcomes in 73 patients from a single institution. Neurosurgery 47:1332-1339; discussion 1339-1342

Taylor CL, Yuan Z, Selman WR, Ratcheson RA, Rimm AA (1995) Cerebral arterial aneurysm formation and rupture in 20,767 elderly patients: hypertension and other risk factors. J Neurosurg 83:812-819

Teunissen LL, Rinkel GJ, Algra A, van Gijn J (1996) Risk factors for subarachnoid hemorrhage: a systematic review. Stroke 27:544-549

Thielen KR, Nichols DA, Fulgham JR, Piepgras DG (1997) Endovascular treatment of cerebral aneurysms following incomplete clipping. J Neurosurg 87:184-189

Thompson RC, Steinberg GK, Levy RP, Marks MP (1998) The management of patients with arteriovenous malformations and associated intracranial aneurysms. Neurosurgery 43:202-211; discussion 211-202

Thornton J, Aletich VA, Debrun GM, Alazzaz A, Misra M, Charbel F, Ausman JI (2000a) Endovascular treatment of paraclinoid aneurysms. Surg Neurol 54:288-299

Thornton J, Bashir Q, Aletich VA, Debrun GM, Ausman JI, Charbel FT (2000b) What percentage of surgically clipped intracranial aneurysms have residual necks? Neurosurgery 46:1294-1298; discussion 1298-1300

Timperman PE, Tomsick TA, Tew JM Jr, van Loveren HR (1995) Aneurysm formation after carotid occlusion. AJNR Am J Neuroradiol 16:329-331

Tokunaga K, Kinugasa K, Mandai S, Handa A, Hirotsune N, Ohmoto T (1998) Partial thrombosis of canine carotid bifurcation aneurysms with cellulose acetate polymer. Neurosurgery 42:1135-1142; discussion 1142-1134

Tong FC, Cloft HJ, Dion JE (2000) Endovascular treatment of intracranial aneurysms with Guglielmi detachable coils: emphasis on new techniques. J Clin Neurosci 7:244-253

Torner JC, Kassell NF, Wallace RB, Adams HP Jr (1981) Preoperative prognostic factors for rebleeding and survival in aneurysm patients receiving antifibrinolytic therapy: report of the Cooperative Aneurysm Study. Neurosurgery 9:506-513

Turjman F, Massoud TF, Vinuela F, Sayre JW, Guglielmi G, Duckwiler G (1994) Aneurysms related to cerebral arteriovenous malformations: superselective angiographic assessment in 58 patients. AJNR Am J Neuroradiol 15:1601-1605

Uda K, Murayama Y, Gobin YP, Duckwiler GR, Vinuela F (2001) Endovascular treatment of basilar artery trunk aneurysms with Guglielmi detachable coils: clinical experience with 41 aneurysms in 39 patients. J Neurosurg 95:624-632

Vajda J (1992) Multiple intracranial aneurysms: a high risk condition. Acta Neurochir (Wien) 118:59-75

Vallee JN, Aymard A, Vicaut E, Reis M, Merland JJ (2003) Endovascular treatment of basilar tip aneurysms with Guglielmi detachable coils: predictors of immediate and long-term results with multivariate analysis 6-year experience. Radiology 226:867-879

Van der Wee N, Rinkel GJ, Hasan D, van Gijn J (1995) Detection of subarachnoid haemorrhage on early CT: is lumbar puncture still needed after a negative scan? J Neurol Neurosurg Psychiatry 58:357-359

Van Gijn J, van Dongen KJ (1982) The time course of aneurysmal haemorrhage on computed tomograms. Neuroradiology 23:153-156

Van Rooij WJ, Sluzewski M, Metz NH, Nijssen PC, Wijnalda D, Rinkel GJ, Tulleken CA (2000) Carotid balloon occlusion for large and giant aneurysms: evaluation of a new test occlusion protocol. Neurosurgery 47:116-121; discussion 122

Van Rooij WJ, Sluzewski M, Menovsky T, Wijnalda D (2003) Coiling of saccular basilar trunk aneurysms. Neuroradiology 45:19-21

Vermeulen M, van Gijn J, Hijdra A, van Crevel H (1984) Causes of acute deterioration in patients with a ruptured intracranial aneurysm. A prospective study with serial CT scanning. J Neurosurg 60:935-939

Vermeulen M, Hasan D, Blijenberg BG, Hijdra A, van Gijn J (1989) Xanthochromia after subarachnoid haemorrhage needs no revisitation. J Neurol Neurosurg Psychiatry 52: 826-828

Vieco PT, Shuman WP, Alsofrom GF, Gross CE (1995) Detec-

tion of circle of Willis aneurysms in patients with acute subarachnoid hemorrhage: a comparison of CT angiography and digital subtraction angiography. AJR Am J Roentgenol 165:425-430

Vieco PT, Morin EE 3rd, Gross CE (1996) CT angiography in the examination of patients with aneurysm clips. AJNR Am J Neuroradiol 17:455-457

Vinuela F, Duckwiler G, Mawad M (1997) Guglielmi detachable coil embolization of acute intracranial aneurysm: perioperative anatomical and clinical outcome in 403 patients. J Neurosurg 86:475-482

Vora YY, Suarez-Almazor M, Steinke DE, Martin ML, Findlay JM (1999) Role of transcranial Doppler monitoring in the diagnosis of cerebral vasospasm after subarachnoid hemorrhage. Neurosurgery 44:1237-1247; discussion 1247-1238

Wanke I, Dorfler A, Dietrich U, Aalders T, Forsting M (2000) Combined endovascular therapy of ruptured aneurysms and cerebral vasospasm. Neuroradiology 42:926-929

Wanke I, Doerfler A, Dietrich U, Egelhof T, Schoch B, Stolke D, Forsting M (2002) Endovascular treatment of unruptured intracranial aneurysms. AJNR Am J Neuroradiol 23: 756-761

Wanke I, Doerfler A, Schoch B, Stolke D, Forsting M (2003) Treatment of wide-necked intracranial aneurysms with a self-expanding stent system: initial clinical experience. AJNR Am J Neuroradiol 24:1192-1199

Warach S, Chien D, Li W, Ronthal M, Edelman RR (1992) Fast magnetic resonance diffusion-weighted imaging of acute human stroke. Neurology 42:1717-1723

Wardlaw J, White P (2000) The detection and management of unruptured intracranial aneurysms. Brain 123:205-221

Wardlaw JM, Cannon JC (1996) Color transcranial „power" Doppler ultrasound of intracranial aneurysms. J Neurosurg 84:459-461

Wardlaw JM, White PM (2000) The detection and management of unruptured intracranial aneurysms. Brain 123:205-221

Weaver JP, Fisher M (1994) Subarachnoid hemorrhage: an update of pathogenesis, diagnosis and management. J Neurol Sci 125:119-131

Weber W, Henkes H, Kuhne D (2000) Stent implantation into the basilar artery for supporting endovascular aneurysm treatment. Nervenarzt 71:843-848

Weber W, Yousry TA, Felber SR, Henkes H, Nahser HC, Roer N, Kuhne D (2001) Noninvasive follow-up of GDC-treated saccular aneurysms by MR angiography. Eur Radiol 11: 1792-1797

Weir B, MacDonald N, Mielke B (1978) Intracranial vascular complications of choriocarcinoma. Neurosurgery 2:138-142

Weir BK, Kongable GL, Kassell NF, Schultz JR, Truskowski LL, Sigrest A (1998) Cigarette smoking as a cause of aneurysmal subarachnoid hemorrhage and risk for vasospasm: a report of the Cooperative Aneurysm Study. J Neurosurg 89:405-411

White PM, Wardlaw JM, Easton V (2000) Can noninvasive imaging accurately depict intracranial aneurysms? A systematic review. Radiology 217:361-370

White PM, Wardlaw JM, Teasdale E, Sloss S, Cannon J, Easton V (2001) Power transcranial Doppler ultrasound in the detection of intracranial aneurysms. Stroke 32:1291-1297

Wiebers D (1998) Unruptured intracranial aneurysms – risk of rupture and risks of surgical intervention. The international study of unruptured intracranial aneurysms investigators. New Engl J Med 339:1725-1733

Wiebers D, Whisnant JP, O'Fallon WM (1981) The natural history of unruptured intracranial aneurysms. N Engl J Med 304:696-698

Wiebers D, Torner J, Meissner I (1992) Impact of unruptured intracranial aneurysms on public health in the United States. Stroke 23:1416-1419

Wiebers D, Whisnant JP, Huston J 3rd, Meissner I, Brown RD Jr, Piepgras DG, Forbes GS, Thielen K, Nichols D, O'Fallon WM, Peacock J, Jaeger L, Kassell NF, Kongable-Beckman GL, Torner JC (2003) Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet 362:103-110

Wiesmann M, Mayer TE, Yousry I, Medele R, Hamann GF, Bruckmann H (2002) Detection of hyperacute subarachnoid hemorrhage of the brain by using magnetic resonance imaging. J Neurosurg 96:684-689

Winn HR, Richardson AE, Jane JA (1977) The long-term prognosis in untreated cerebral aneurysms I. The incidence of late hemorrhage in cerebral aneurysm: a 10-year evaluation of 364 patients. Ann Neurol 1:358-370

Winn HR, Almaani WS, Berga SL, Jane JA, Richardson AE (1983) The long-term outcome in patients with multiple aneurysms. Incidence of late hemorrhage and implications for treatment of incidental aneurysms. J Neurosurg 59:642-651

Wintermark M, Uske A, Chalaron M, Regli L, Maeder P, Meuli R, Schnyder P, Binaghi S (2003) Multislice computerized tomography angiography in the evaluation of intracranial aneurysms: a comparison with intraarterial digital subtraction angiography. J Neurosurg 98:828-836

Yalamanchili K, Rosenwasser RH, Thomas JE, Liebman K, McMorrow C, Gannon P (1998) Frequency of cerebral vasospasm in patients treated with endovascular occlusion of intracranial aneurysms. AJNR Am J Neuroradiol 19:553-558

Yamaura A, Ono J, Hirai S (2000) Clinical picture of intracranial non-traumatic dissecting aneurysm. Neuropathology 20:85-90

Yasargil MG (1984) Multiple aneurysms in microneurosurgery, vol 1. Thieme, Stuttgart, pp 305-328

Yasui N, Suzuki A, Nishimura H, Suzuki K, Abe T (1997) Long-term follow-up study of unruptured intracranial aneurysms. Neurosurgery 40:1155-1159; discussion 1159-1160

Yonas H, Linskey M, Johnson DW, Horton JA, Janecka IP, Witt JP, Jungreis C, Hirsch WL, Sekhar LN (1992) Internal carotid balloon test occlusion does require quantitative CBF. AJNR Am J Neuroradiol 13:1147-1152

Yong-Zhong G, van Alphen HA (1990) Pathogenesis and histopathology of saccular aneurysms: review of the literature. Neurol Res 12:249-255