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CLINICAL ARTICLE

Partially thrombosed intracranial aneurysms: symptoms, evolution, and therapeutic management

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Abstract
Background Partially thrombosed intracranial aneurysms (PTIAs) are different from saccular or nonthrombosed giant or large aneurysms, as they are characterized by multiple intramural thrombotic phenomena related to recurrent vessel wall dissections.
Methods We retrospectively reviewed clinical and radiological files of 23 consecutive patients with PTIAs (mean age 49.3 years). Twenty-two lesions were studied by magnetic resonance imaging (MRI). Patients were managed by endovascular treatments, medically with steroids, or conservatively.
Results Thirteen patients presented with progressive neurological symptoms. Subarachnoid hemorrhage was suspected but not proven in three. At MRI, 90.9% of PTIAs caused mass effect; perilesional T2 hypersignal compatible with edema was evident in 13.6%. Aneurysmal wall enhancement was detectable in 63.2% of the PTIAs and considered a marker of inflammatory processes. Parent artery occlusion was performed in seven patients with clinical improvement in six. Selective coiling was proposed in three patients (one improved, one remained stable, and one experienced symptoms progression). Three patients were treated with steroids and improved. Ten patients were managed conservatively: eight because spontaneous thrombosis of the lesion had been diagnosed and two because of clinical and radiological stability.
Conclusions The natural history of PTIAs is different from other aneurysms. They most commonly present with progressive neurological symptoms due to mass effect. MRI properly diagnoses PTIAs and allows precise follow-up, more accurately than angiography because it detects prominent "abluminal" features indicating inflammation and neovascularization. Spontaneous thrombosis is part of the natural history of PTIAs and it should be taken in consideration when discussing the therapeutic management.

Keywords Intracranial aneurysm · Intracranial dissecting aneurysm · Partially thrombosed cerebral aneurysm · Therapeutic embolization

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Introduction

Partially thrombosed intracranial aneurysms (PTIAs) are rare entities among the spectrum of intracranial arterial aneurysms (AA), most often presenting with progressive neurological symptoms and rarely causing subarachnoid hemorrhage (SAH) [28]. At pathology, PTIAs harbor thrombi inside the vessel wall (i.e., intramural) and not in the vascular lumen of the aneurysm (i.e., intraluminal). It has therefore been suggested that at neuroimaging, PTIAs are characterized by an overall diameter (as detected by

cross-sectional imaging) that is larger than the diameter of the perfused lumen [12]. PTIAs have circulating portions that may be small and do not correspond to the overall size of the lesion itself, mostly related to its thickened arterial wall. The latter has been considered as the center of biological phenomena that is responsible for the evolution of the lesion [13]. PTIAs might thus be considered as "abluminal" aneurysmal vasculopathies with pathological processes occurring at the adventitial surface of the aneurysm playing a role in lesion growth by vasa vasorum involvement and recurrent vessel wall dissecting phenomena [24]. Enlargement of PTIAs and clinical symptom progression have been described despite complete exclusion of the aneurysm lumen from circulation by endovascular parent artery occlusion [9]. We report the retrospective review of our series of 23 consecutive patients with PTIA seen between 2001 and 2008 and detail their clinical symptoms, the evolution and natural history of their lesion, the therapeutic strategy chosen, and the clinical outcome.

Materials and methods

Subjects

We reviewed the radiological and clinical files of 23 consecutive patients with PTIAs (14 women and 9 men; mean age 49.3 years; age range 17–73 years) followed in our institution for a mean of 45.5 months (median 28 months; range 1–164 months). Only patients with PTIAs were considered in this study. Patients with non-thrombosed saccular aneurysms or with lesions harboring a clot inside the lumen were not considered.

Neuroimaging

Magnetic resonance imaging (MRI) and/or computed tomography (CT) was available in all patients. Sixteen patients were examined by MRI in our institution on a 1.5-T magnet (HD General Electric, USA) with an imaging protocol including T1-weighted images (WIs) (TR 560 ms, TE 13 ms, slice thickness 6 mm), fast spine echo T2-WIs (TR 7,000 ms, TE 75 ms, slice thickness 5 mm), fluid-attenuated inversion recovery (FLAIR) (TR 8,400 ms, TE 173 ms, slice thickness 5 mm), and T1 fast SPGR (TR 10.5 ms, TE 3 ms, slice thickness 0.6 mm) obtained after gadolinium-based contrast injection. Contrast-enhanced 3D MR angiography was obtained in 16 patients. Six patients had MR studies performed in outside institutions with T1-WIs and T2-WIs. In three of these patients, gadolinium-enhanced T1-WIs were available. One patient was only studied by CT.

MRIs of 22 patients were independently reviewed by two neuroradiologists to define the signal characteristics of the lesion, signs of mass effect, and presence of perilesional hyperintensity zones on T2-WIs. The presence of aneurysmal wall enhancement was evaluated on gadolinium-enhanced T1-WIs in 19 patients.

Treatment

The treatment strategy was based on clinical symptoms (stable or progressive), characteristics of the lesional architecture and of the regional vascular anatomy, MRI evidence of mass effect, and presence of edema. Surgery was not considered in these patients neither by our neurosurgical group nor by the referring neurosurgeons because of the size of the lesions and their relationships with the surrounding brain. Embolization was always favored when invasive treatment was warranted. Endovascular options included parent artery occlusion (PAO), when regional vascular anatomy allowed the sacrifice of the parent vessel, or selective coiling of the circulating portion of the PTIAs.

When embolization was not considered feasible, the patients were treated with corticosteroids if there was clinical and/or radiological evidence of symptoms progression or mass effect increase with suffering of the surrounding brain. If clinically and radiologically stable, no invasive treatment was proposed and patients were followed up.

Results

Patient demographics

Twenty-three patients with PTIAs were registered in our series. Demographic and clinical data of the patients are reported in Table 1. Thirteen patients presented with progressive neurological symptoms, and seven patients presented with isolated, acute symptoms, among which three were suspected to be related to SAH because of acute episodes of headaches. SAH was, however, not documented in the foreign countries from which the patients were referred and no definitive proof of the subarachnoid bleed could ever be obtained. Two patients presented with seizures (one partial and one generalized). One PTIA was incidentally found in a patient during evaluation of a head trauma.

Aneurysm characteristics

The location of the PTIAs is detailed in Table 1. Mean overall maximum diameter of the PTIAs at cross-sectional imaging was 29.9 mm (range 55–8 mm) with a mean diameter of the circulating portion of 12.4 mm (range 34–0 mm).

At MR imaging, the PTIAs were responsible for mass effect on the surrounding cerebral structures in 20 patients

Table 1 Demographic and clinical data of the 23 patients harboring PTIAs included in the study

Patient	Age	Sex	PTIA location	Symptoms	PTIA enhancement	Treatment
1	21	M	Basilar artery	Acute headache (suspicion of SAH, unproven)	+	Steroids
2	73	M	Pericallosal artery	Progressive gait disturbances	NA	Conservative (ST)
3	61	F	MCA	Acute headache (suspicion of SAH, unproven)	+	Conservative (ST)
4	36	F	MCA	Partial seizures	NA	Conservative (ST)
5	63	F	ICA (cavernous)	Progressive diplopia	+	Sacrifice (PAO) with balloon
6	61	F	ACOM	Progressive visual loss	+	Conservative (ST)
7	58	F	ICA (cavernous)	Progressive diplopia, trigeminal neuralgia	+	Sacrifice (PAO) with balloon
8	61	F	PCA (P1)	Progressive hemiparesis	+	Steroids
9	54	F	ACOM	Fortuitous discovery	+	Conservative (ST)
10	51	F	ICA (ophthalmic)	Progressive visual loss	+	Coiling with GDC
11	55	M	PCA (P2)	Progressive paresthesia	NA	Conservative (ST)
12	38	F	VA-BA	Progressive diplopia, hemiparesis	+	Sacrifice (PAO) with GDC
13	61	F	ICA (cavernous)	Acute opthalmoplegia	E	Steroids
14	61	M	ICA (cavernous)	Progressive diplopia, retroorbital pain	NA	Conservative (ST)
15	25	M	PCA (P3)	Progressive headaches	+	Conservative (ST)
16	43	F	ICA (cavernous)	Acute diplopia, headaches	+	Sacrifice (PAO) with balloon
17	67	F	Basilar artery	Progressive diplopia	−	Coiling with GDC
18	72	F	ICA (cavernous)	Acute CCF (exophthalmus, opthalmoplegia)	E	Coiling with GDC (on ST lesion)
19	31	M	ACA (A2)	Generalized seizures	+	Conservative
20	17	M	ICA (cavernous)	Acute diplopia	E	Sacrifice (PAO) with balloon
21	37	F	ICA (cavernous)	Progressive diplopia	E	Sacrifice (PAO) with balloon
22	59	M	VA (V4)	Progressive hearing loss	−	Sacrifice (PAO) with GDC
23	29	M	ACA (A2)	Acute headache (suspicion of SAH, unproven)	−	Conservative

The presence or absence of contrast enhancement as detected on post-gadolinium T1-WI is reported in the table

NA postcontrast images not available for review, *E* the presence of PTIAs enhancement could not clearly be differentiated from the dura and was thus rated "equivocal", *SAH* subarachnoid hemorrhage, *ST* spontaneous thrombosis, *PAO* parent artery occlusion, *GDC* Guglielmi detachable coils, *CCF* carotid cavernous fistula, *MCA* middle cerebral artery, *ACOM* anterior communicating artery, *ICA* internal carotid artery, *PCA* posterior cerebral artery, *VA* vertebral artery, *BA* basilar artery, *ACA* anterior cerebral artery

(90.9%). Hyperintense perilesional brain tissue on T2-WIs, compatible with perianeurysmal edema, was evident in three patients (13.6% of patients). Aneurysmal wall enhancement was evident in 12 PTIAs (63.2%) (Table 1). Wall enhancement was typically at the periphery of the PTIA and was classified as "thin rim" in eight and "thick rim" in four (Fig. 1). In four PTIAs, all located in the cavernous segment aneurysm, the PTIA wall enhancement could not clearly be distinguished from the dural envelope.

MRI typically showed heterogeneous signal intensities in the aneurysm wall on T1 and T2-WIs reflecting the presence of thrombosed blood at different stages of evolution. A classical "onion-skin like" aspect could thus be described in aneurysms with thick walls (Figs. 2 and 3).

Spontaneous thrombosis

Nine PTIAs spontaneously thrombosed (39.1%) during evolution. Total exclusion, or exclusion with a minimal residue at the neck of the lesion that did not require any therapy, was observed in eight patients (Fig. 3). The moment at which the thrombosis occurred could not be determined as it could not be related to any definite clinical event. The spontaneous thrombosis was discovered incidentally at the time patients were sent for pretherapeutic evaluation of their PTIAs. A carotid cavernous fistula linked to an intracavernous PTIA in a 72-year-old lady spontaneously thrombosed, and the remaining circulating portion of the lesion was secondarily coiled. All these patients have clinically normalized or stabilized.

In one patient, partial recanalization of the intracavernous PTIA, associated to trigeminal neuralgia, occurred at 12 months of follow-up. Sacrifice of the internal carotid artery (ICA) was then performed by another team.

Therapeutic management and results

Endovascular treatment was performed in ten patients. PAO was performed in seven of them after proper evaluation of the collateral circulation by an occlusion test or precise

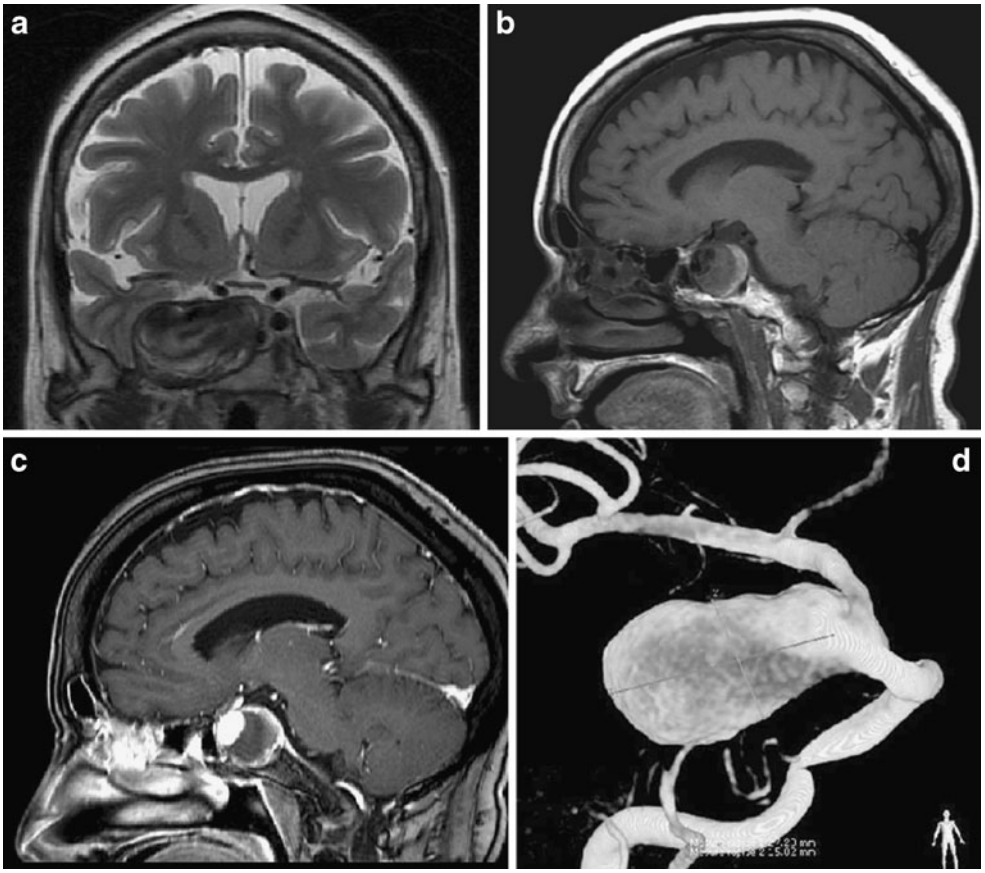

Fig. 1 A 63-year-old female with a PTIA located in the ICA cavernous segment causing diplopia. A coronal T2-WI demonstrates the mass effect on the adjacent temporal lobe (**a**). A sagittal unenhanced T1-WI demonstrates the intramural thrombosed portion of the lesion with a crescent-shaped spontaneous hyperintensity (**b**) indicating recent bleeding which is located far from the perfused lumen of the lesion detectable as a hypointense flow void. After contrast injection, on T1 sagittal pictures (**c**), enhancement of the circulating lumen is detected, as of the external rim of the lesion suggesting inflammatory phenomena at that level. 3D angiography (**d**) confirms the circulating portion of the PTIA

anatomical analysis of the collateral circulation: in five intracavernous ICA PTIAs, PAO was achieved with detachable balloons (CathNet-Science, Paris, France or Balt, Montmorency, France); in two intradural vertebral artery PTIAs, PAO was performed with GDC coils (Boston Scientific, Fremont, CA, USA). Selective coiling of the circulating lumen of the aneurysm was performed with GDC coils (Boston Scientific) in three patients (Table 1).

Six of the seven patients treated by PAO improved. In one patient with an ICA PTIA, a left motor deficit appeared 12 h after PAO despite well-tolerated occlusion test due to difficulties in maintaining appropriate blood pressure values in the intensive care unit. The patient recovered with a mild residual deficit, MR images showing watershed ischemic lesions.

Among the three patients treated by selective coiling, one remained stable and one improved (Fig. 2). In one 67-year-old lady, progressive increase in size of a basilar tip PTIA revealed by a third cranial nerve palsy was seen over 6 years, despite initial partial coiling of the circulating lumen by another team. Complementary coiling was performed because of progressive motor deficit due to mass effect on the upper brain stem and excluded totally the lesion. A transitory episode of dysarthria and motor impairment occurred 8 days after the procedure and recovered under anticoagulation therapy. The patient stabilized without recovery but died of massive middle cerebral artery stroke unrelated to the PTIA 1 year later.

Medical management with steroids was decided in three patients with PTIAs (Table 1). All these patients improved: one is asymptomatic, after a 55-month follow-up, complaining only of intermittent mild headaches; one is currently stable with mild residual hemiparesis due to the mass effect on the brain stem by the PTIA at a 41-month follow-up (Fig. 4); and one died of cancer 69 months later.

Ten patients were managed conservatively: eight because spontaneous thrombosis had been confirmed and two because of clinical and radiological stability. These patients are followed up.

Discussion

PTIAs correspond to a distinct subgroup of intracranial AA which should be differentiated from nonthrombosed large or giant lesions and from aneurysms containing intraluminal clots. A definition of large or giant AAs exclusively based on their size may bring confusion in the unequivocal recognition of PTIAs. In fact, an aneurysm is labeled large (or giant) when its diameter is more than 2 cm (or 2.5 cm). This definition does not consider the difference between an aneurysm of large or giant size with a completely circulating

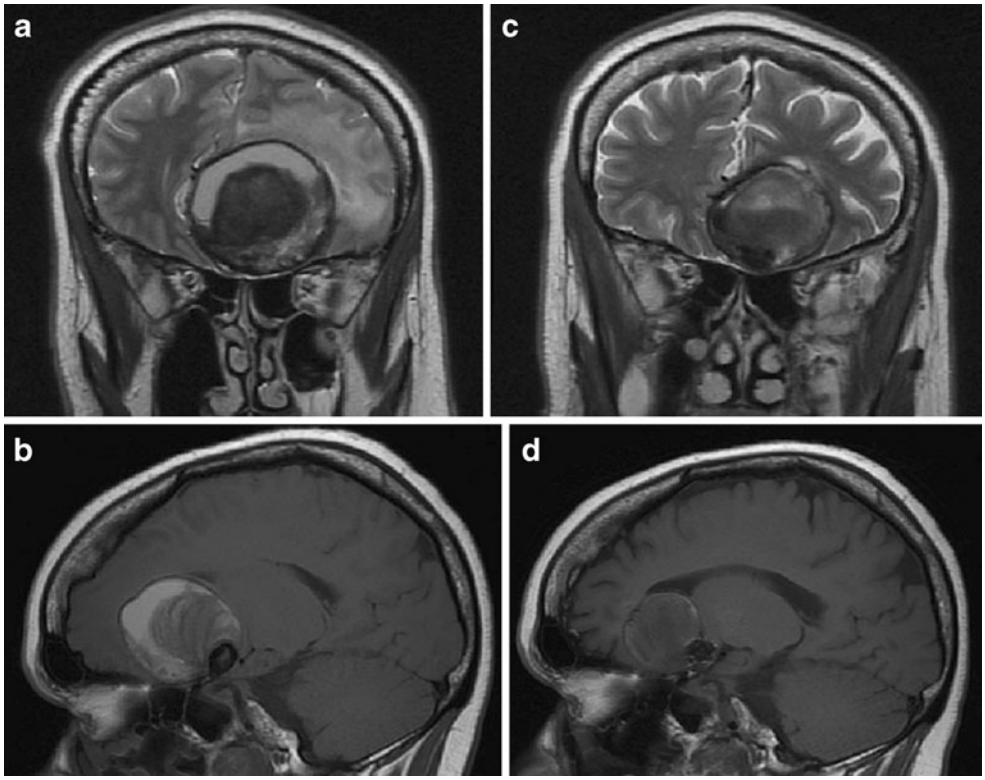

Fig. 2 A 51-year-old female with left progressive visual loss due to mass effect on the optic nerve of a carotido-ophthalmic PTIA. Coronal T2-WI discloses a large area of hyperintense signal surrounding the lesion and corresponding to brain edema (**a**). Unenhanced sagittal T1-WI demonstrates typical "onion-skin" appearance of the intramural thrombus of different ages, with spontaneous hyperintensity at the periphery suggesting recent bleeding (**b**); the circulating portion of the lesion corresponds to the hypointense flow void zone. The patient was treated with selective coiling of the lesion with detachable coils. A follow-up MR obtained after 36 months demonstrates a reduction of the size of the lesion, decrease of the mass effect, and disappearance of the surrounding edema on T2-WI (**c**). Also note the changes of signal intensity on unenhanced sagittal T1-WI with disappearance of the previous spontaneous hyperintensity at the periphery of the lesion testifying the aging of the intramural thrombus (**d**). The patient improved after embolization and remained stable at 42 months follow-up

lumen and an aneurysm with a thick, thrombosed arterial wall (and not necessarily a large circulating portion) that also reaches the size required to be classified as large (or giant) aneurysm but that is most likely a different pathological entity.

This recognition has important clinical and therapeutic consequences, as the natural history of PTIAs is different. Unfortunately, precise data on the natural history of PTIAs are lacking as those available in the literature are mostly derived from small studies or are often inappropriately linked to berry aneurysms, which are biologically different [29], introducing thus some confusion in the understanding of these diseases. Our series exclusively concerns PTIAs and does not consider any other type of aneurysm.

Schubiger in 1980 classified giant aneurysms into non-thrombosed, partially thrombosed, and completely thrombosed lesions using contrast-enhanced CT, enabling the in vivo study of pathological features such as blood clots at the periphery of the lesion. Ring enhancement at the outer margin of the aneurysm was found in totally or partially thrombosed giant aneurysms, suggesting that aneurysms were associated with a dense vasa vasorum vascularization [23]. Concomitantly, minute vessels on the surface of these aneurysms have been described during neurosurgical procedures, and pathology has confirmed the presence of small arterial networks compatible with vasa vasorum on their adventitial surface. It has been thus suggested that adventitial neovascularization could be recognized as a potential source of blood supply to PTIAs and as a source for intracranial bleedings [3]. Other pathology studies of PTIAs described the presence of multiple intrathrombotic vascular channels lined by endothelial cells [20] and of transmural vascular connections between subadventitial vasa vasorum and the thrombosed portion of the aneurysm [9]. It was hypothesized that establishment of blood flow between the parent artery and these channels may play a role in the growth of thrombosed aneurysms.

MRI has helped to better understand these lesions. Cross-sectional pictures were used to define PTIAs as aneurysms characterized by a thickened arterial wall with intramural thrombosis and an overall diameter that is larger than the diameter of the perfused lumen [12].

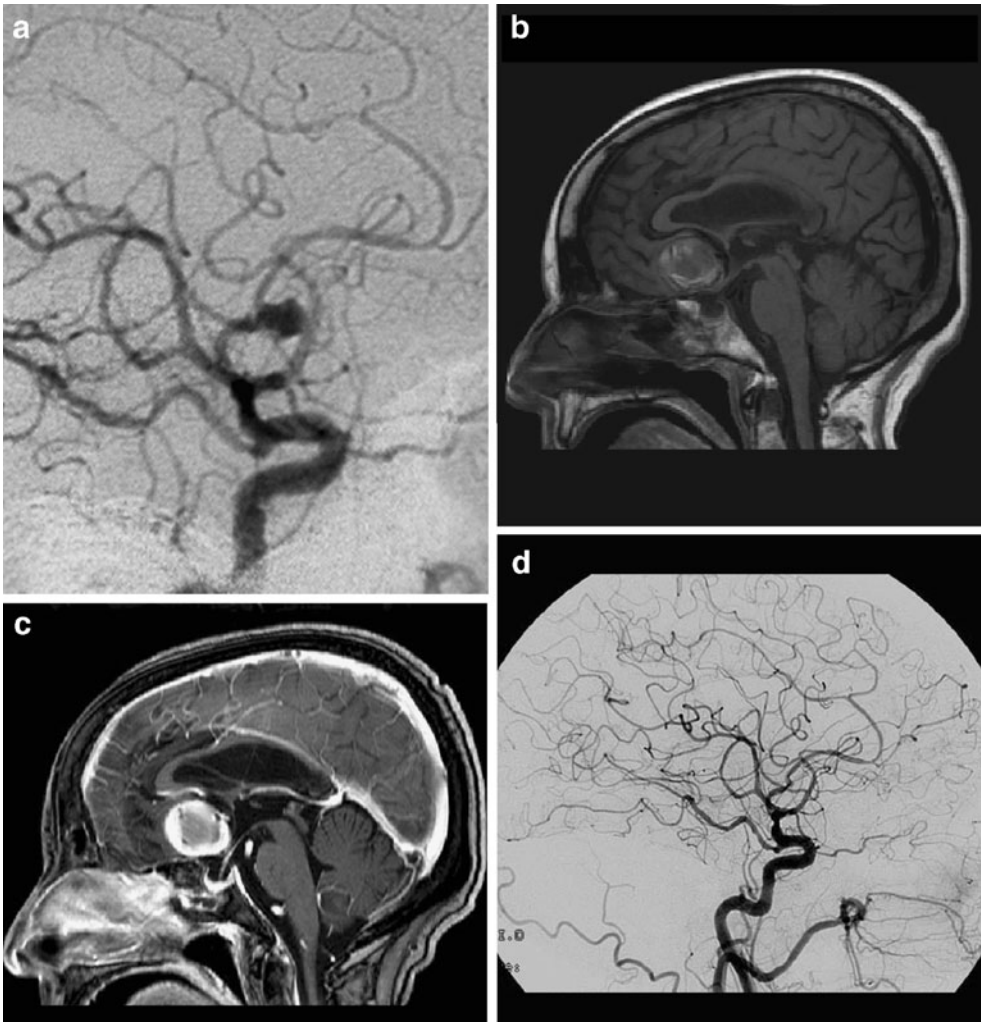

Fig. 3 A 61-year-old female presenting with progressive visual loss. MR performed in her home country diagnosed a PTIA on the midline, and angiography confirmed the circulating portion of the lesion located on the anterior communicating artery (**a**). The patient was sent to our institution for endovascular treatment. MR performed at admission confirmed the diagnosis of PTIA: sagittal T1-WI (**b**) showed the lesion with organized intramural thrombi and no circulating portion at that stage. Contrast injection confirmed these data and detected intense rim enhancements corresponding to what was interpreted as inflammatory and hypervascularization related to vasa vasorum reaction in the vessel wall (**c**). A control angiography confirmed the total thrombosis of the circulating portion of the PTIA (**d**). No treatment was proposed and the patient remained stable and is scheduled for further MR controls

The morphology of the aneurysm reflected the pathological hallmark of PTIAs which is prominent arterial wall pathology with intramural layers of clots of different ages and in different stages of evolution. Immunohistological studies have further detailed the complex biological phenomena that characterize PTIAs, as the role of "abluminal" factors and of a dysfunctional adventitia with vasa vasorum external neovascularization and inflammatory processes in the pathogenesis of PTIAs [13, 31]. These observations served as background for a theory on the growth mechanisms of PTIAs that would result from recurrent hemorrhages into the lesion from sprouting capillaries, the highly vascularized wall of PTIAs behaving like the membrane of a chronic subdural hematoma [24]. MRI investigations of patients with PTIAs identified the thrombotic phenomena along the aneurysmal wall by employing MR pulse sequences to define the age of different areas within the thrombosed portion of the aneurysm [4]. About 80% of the partially thrombosed aneurysms present an "onion-skin" appearance on noncontrast T1-WIs and a low signal inside the thrombus from the susceptibility effect of blood degradation products on T2-WIs [25]. Moreover, after gadolinium injection, peripheral enhancement has been reported in PTIAs, a feature compatible with the previously described adventitial neovascularization and presence of inflammatory phenomena in the adventitia [12, 31]. All the patients studied by MRI in our series had images compatible with intramural thrombus with signal intensity indicating different stages of evolution, with typical peripheral contrast enhancement in 63.2% of patients.

MRI described thus in vivo that the biological center of PTIAs is the vessel wall and that these pathological entities should be viewed as "aneurysms with intramural hemorrhage". Even if consensus on the pathological mechanism leading to the formation and growth of PTIAs is not fully achieved, it has been suggested that partially thrombosed aneurysms could originate from recurrent nontransmural dissections leading to repeated intramural bleeding and progressive enlargement of the aneurysm [11, 19].

Clinical manifestations of PTIAs can be acute or progressive. SAH is rare and has been reported in around 9% to 25% of cases [12, 24, 28]. Thus, according to published data,

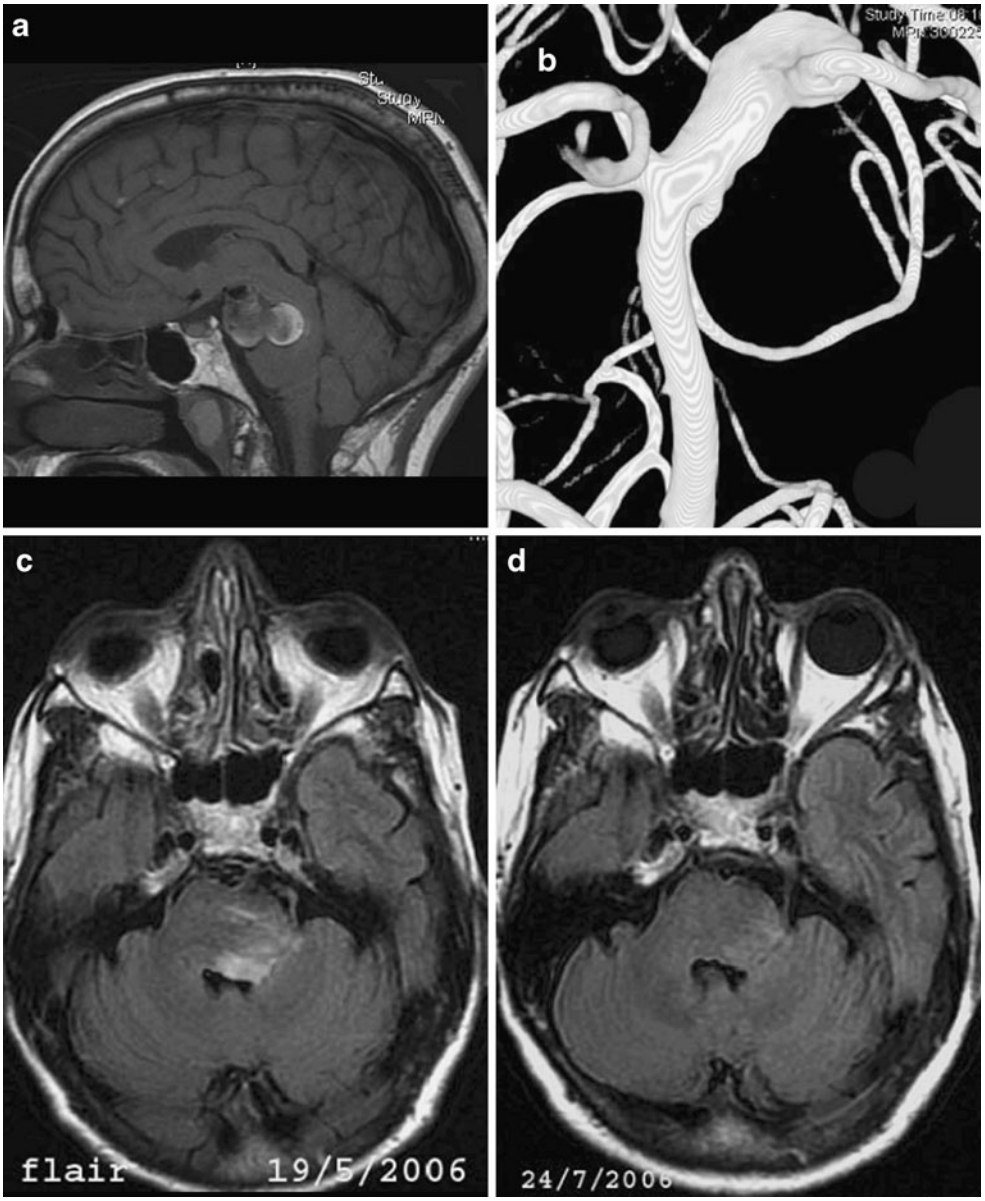

Fig. 4 A 61-year-old lady complaining of progressive moderate hemiparesis with rapid impairment within a month before consultation. Nonenhanced sagittal MR T1-WI diagnosed a PTIA with a small circulating flow void lumen and a large thrombosed noncirculating portion embedded in the brain stem with a recent intramural hematoma that could be responsible for the clinical worsening (**a**). 3D angiography confirmed that the circulating portion corresponded to the cranial P1 segment of the left posterior cerebral artery (**b**). No endovascular or surgical therapy could be proposed. Axial FLAIR images demonstrated hyperintense signal in the pons that was considered to correspond to edematous reaction linked to the PTIA (**c**). The patient was treated by corticosteroids. She clinically improved and returned to her previous chronic status. Control MR 2 months later showed regression of the edema on axial FLAIR pictures (**d**)

thrombosis of the aneurysm does not completely protect from SAH as SAH in PTIAs can be caused by further transmural dissections [30]. Acute neurological symptoms can also be related to focal acute dissections in the vessel wall (Fig. 4). In these cases, the dissection may be responsible for intense headaches mimicking the clinical features of a SAH. MRI depicts properly the hematoma in the outer layer of the vessel wall and the edematous reaction of the surrounding brain to the acute intramural dissection (Fig. 4). The three patients of our series in whom no SAH could be proven at brain imaging were suspected of having suffered from acute dissections.

Most patients in our series presented with progressive neurological symptoms, mainly related to the mass effect of the PTIAs. The inflammatory phenomena occurring at the outer layer of the aneurismal wall may be responsible for edematous reactions of the nervous tissue that can be detected at MRI on T2-WIs and that we observed in 13.6% of patients. Different treatment options exist for the management of PTIAs. The pathophysiological model of aneurysms growth supported by blood supply through a dense adventitial vascular network with apposition of new layers of thrombus from the periphery of the aneurysms supports the role of surgical "aneurysmectomy" as the most reliable method for the cure of PTIAs and relief of their mass effect. However, surgical management of these lesions is often difficult and remains a therapeutic challenge [8]. When feasible, microneurosurgical clipping can offer permanent exclusion of the aneurysm from the arterial lumen as well as the possibility of mass effect removal.

Not all PTIAs can be managed by clipping and "clippability" is constrained by anatomic features of the

lesion; the presence of neck calcifications or atherosclerosis can impede proper positioning of the clip at the aneurysm neck [21]; moreover, clipping can be impracticable in coiled PTIA aneurysms with coiling extending to the neck [14]. In "unclippable" aneurysms, alternative surgical strategies can be planned and include thrombectomy with clip reconstruction or bypass vessel occlusion. The former option can present different risks as the surgeon works while the patient's brain remains ischemic and reperfusion is possible only when neck repair is completed; back bleeding can be present if the aneurysm is not completely isolated by temporary clips and the dissection of adherent arteries can be complicated. Bypass vessel occlusion can be the preferred alternative surgical strategy, and different types of bypass may be proposed as a treatment option in patients that fail parent artery occlusion [14, 22]. These techniques have not been considered in our patient population.

Endovascular procedures are considered as valid therapeutic options in the treatment of intracranial aneurysms, but their importance for PTIAs has till now not been fully assessed as they deal indeed with the vascular lumen and not with the vessel wall. In one of the patients seen in our series and treated initially by another team, the control MRI pictures clearly demonstrated that the growth was linked to progressive mural dissections independent from the selectively coiled lumen.

Our series demonstrates that embolization can manage PTIAs in various ways. PAO can be performed if favorable anatomy and angioarchitecture allows it. It excludes the PTIA from the vasculature and induces thrombosis of the circulating portion and secondary regression of the lesion itself within some months, allowing then the resolution of the clinical symptoms, as seen in six patients of our series. One recent study confirmed these data and demonstrated that results of PAO were considered superior to those obtained with selective coiling of these aneurysms [6].

Selective coiling of the lumen of PTIAs is from a theoretical point of view not an ideal therapeutic solution as it acts on the lumen and not on the wall [1]. This technique has been chosen in our patients when sacrifice of the parent vessel was not considered feasible, but angioarchitecture of the aneurysm allowed it. Relief of the symptoms and/or stabilization of the clinical evolution could be obtained in all three patients that we selectively coiled, with decrease of the AA size in one patient. We believe that the reduction of pulsatility of PTIA improved the "hammer effect" on the surrounding nervous structures, allowing clinical recovery [7]. Coiling of the patent lumen may also reduce the shear stresses associated to the circulating flow, avoid further mural dissections, and allow exclusion of the AA from the global circulation. If these endoluminal vascular disconnections do not target the "abluminal" compartments, representing the main center of the disease, they may remain of some indirect therapeutic interest. Post-therapeutic bleeds linked to vasa vasorum or continuous growth of the lesion has indeed at this stage not been encountered after we have performed embolization.

Coil compaction has often been a concern after AA embolization [27]. This phenomenon has been described as more prone to occur in thrombosed aneurysms because the coils would compact inside the soft intraluminal clots. This theory could be probably inexact in PTIAs as the clots are within the vessel wall. This type of compaction has not been seen in our series if dense packing could be obtained.

Flow diverter stents are considered currently as an appropriate treatment option [16]. This new endovascular material is supposed to modify the intraaneurysmal hemodynamics, allowing thus the indirect exclusion of the sac from the vasculature and producing intraluminal thrombosis. Attractive at first sight, the use of this new device remains in our opinion with a theoretical limitation as the outer wall of the PTIA is not targeted. Moreover, data on safety and on efficacy of these devices are still scare or detail high rates of complications that have to be taken into consideration when one deals with a disease which has this type of natural history [26]. Even if thrombotic phenomena are intramural, clots of platelets can theoretically form inside the often anfranctuous lumen of PTIAs because of turbulent flow. Patients are therefore often treated by antiplatelet therapy in order to avoid ischemic complications related to distal emboli. These events were never described in our series. They are furthermore reported as rare in the literature [28] and probably not more frequent in patients with PTIAs than in patients with nonthrombosed aneuryms [18].

Total spontaneous thrombosis (ST) has been observed in our series in 39.1% of patients. We consider thus ST as part of the natural history of these lesions, even if its occurrence and timing is unpredictable. Although ST has been reported by several authors [23, 28] as total or partial in up to, respectively, 20% and 50% of giant aneurysms during their evolution, review of these papers confirms that these phenomena concerned aneurysms that were from the beginning on PTIAs already. This confirms thus the difference between giant "circulating" aneurysms and giant partially thrombosed aneurysms that are of different pathologies with different outcomes [23]. We believe, therefore, that the risks involved in the therapeutic management of PTIAs have to be precisely evaluated and, thus, put in balance with the pathophysiology and natural history of these lesions. We should remember that even after complete angiographic exclusion, PTIAs have still to be regarded as dynamic, potentially unstable lesions. Moreover, aneurysm growth from subadventitial neovessels hemorrhage with associated clinical deterioration can occur

also without patency of the parent artery lumen [5, 9]. MRI allows the investigation of intramural thrombotic phenomena, adventitial neovascularisation, and inflammation and should be considered the modality of choice for the follow-up of patients with PTIAs. The growth potential of PTIAs in the posterior circulation after treatment seems to be lower when contrast enhancement at the rim of the AA is not present [10].

Recanalization of thrombosed lesions remains rare [2, 15] and cannot be anticipated. We considered steroid treatment helpful in patients that were clinically "active" and for which no other treatment could be safely proposed. This medical treatment allowed resorption of the perilesional edematous inflammatory reaction with clinical recovery of the patients. In three patients of our series, symptoms resolved after administration of corticosteroids as sole therapy. Regression of the PTIAs related brain edema could be detected by MRI. Patients remain under follow-up and retreated if needed. We acknowledge that steroids were empirically prescribed and that observations on their beneficial role on stabilization of vessel wall pathology are largely speculative. Studies investigating the mechanisms of vascular adventitial inflammation will shed light on the role that antiinflammatory or antiangiogenic strategies might play in the management of these lesions [17]. Steroid treatment gave interesting results in our patients and we consider it a potential adjuvant therapy.

Conclusions

PTIAs must be classified as pathological entities different from other aneurysms. They are characterized by the presence of multiple intramural thrombotic phenomena and are related to prominent abluminal pathology with adventitial inflammation and neovascularization. They most commonly present with neurological symptoms due to mass effect and less frequently with SAH. At MRI, PTIAs are characterized by a thickened arterial wall with intramural thrombosis and an overall diameter that is larger than the diameter of the perfused lumen. Among the MRI features of this aneurysm, peripheral enhancement and perilesional brain tissue signal changes on T2-WIs might be markers of inflammation and neovascularization.

The "abluminal pathology" model of PTIA pathogenesis can explain the limited efficacy of treatments targeting only luminal aspect of the aneurysm. Available treatment strategies should thus propose complete exclusion of the aneurysm from the circulation. These lesions might, however, continue to grow even if excluded from the flow and have to remain followed up by MRI. Spontaneous thrombosis, being an important part of the natural history of these diseases, should be taken into consideration when discussing the therapeutic management and risks involved in the procedures. Antiinflammatory medical treatment may be considered as therapeutic adjuvant. The place of antiangiogenic therapy for PTIAs will have to be determined.

Conflicts of interest None.

References

1. Alvarez H (2009) Etiology of giant aneurysms and their treatment. AJNR Am J Neuroradiol 30:E8
2. Atkinson JL, Lane JI, Colbassani HJ, Llewellyn DM (1993) Spontaneous thrombosis of posterior cerebral artery aneurysm with angiographic reappearance. Case report. J Neurosurg 79:434–437
3. Atkinson JL, Okazaki H, Sundt TM Jr, Nichols DA, Rufenacht DA (1991) Intracranial cerebrovascular vasa vasorum associated with atherosclerosis and large thick-walled aneurysms. Surg Neurol 36:365–369
4. Atlas SW, Grossman RI, Goldberg HI, Hackney DB, Bilaniuk LT, Zimmerman RA (1987) Partially thrombosed giant intracranial aneurysms: correlation of MR and pathologic findings. Radiology 162:111–114
5. Dehdashti AR, Thines L, Willinsky RA, Tymianski M (2009) Symptomatic enlargement of an occluded giant carotido-ophthalmic aneurysm after endovascular treatment: the vasa vasorum theory. Acta Neurochir (Wien) 151:1153–1158
6. Ferns SP, van Rooij WJ, Sluzewski M, van den Berg R, Majoie CB (2010) Partially thrombosed intracranial aneurysms presenting with mass effect: long-term clinical and imaging follow-up after endovascular treatment. AJNR Am J Neuroradiol. doi:10.3174/ajnr.A2057
7. Halbach VV, Higashida RT, Dowd CF, Barnwell SL, Fraser KW, Smith TP, Teitelbaum GP, Hieshima GB (1994) The efficacy of endosaccular aneurysm occlusion in alleviating neurological deficits produced by mass effect. J Neurosurg 80:659–666
8. Hanel RA, Spetzler RF (2008) Surgical treatment of complex intracranial aneurysms. Neurosurgery 62:1289–1297
9. Iihara K, Murao K, Sakai N, Soeda A, Ishibashi-Ueda H, Yutani C, Yamada N, Nagata I (2003) Continued growth of and increased symptoms from a thrombosed giant aneurysm of the vertebral artery after complete endovascular occlusion and trapping: the role of vasa vasorum. Case report. J Neurosurg 98:407–413
10. Iihara K, Murao K, Yamada N, Takahashi JC, Nakajima N, Satow T, Hishikawa T, Nagata I, Miyamoto S (2008) Growth potential and response to multimodality treatment of partially thrombosed large or giant aneurysms in the posterior circulation. Neurosurgery 63:832–842
11. Jissendi Tchofo P, Rodesch G, Duret M, Baleriaux D (2002) Natural evolution of an aneurysm of the V4 segment of the vertebral artery into a giant aneurysm. A case report. J Neuroradiol 29:275–280
12. Krings T, Alvarez H, Reinacher P et al (2007) Growth and rupture mechanism of partially thrombosed aneurysms. Interv Neuroradiol 13:117–126
13. Krings T, Piske RL, Lasjaunias PL (2005) Intracranial arterial aneurysm vasculopathies: targeting the outer vessel wall. Neuroradiology 47:931–937
14. Lawton MT, Quinones-Hinojosa A, Chang EF, Yu T (2005) Thrombotic intracranial aneurysms: classification scheme and management strategies in 68 patients. Neurosurgery 56:441–454

15. Lee KC, Joo JY, Lee KS, Shin YS (1999) Recanalization of completely thrombosed giant aneurysm: case report. Surg Neurol 51:94–98
16. Lylyk P, Miranda C, Ceratto R, Ferrario A, Scrivano E, Luna HR, Berez AL, Tran Q, Nelson PK, Fiorella D (2009) Curative endovascular reconstruction of cerebral aneurysms with the pipeline embolization device: the Buenos Aires experience. Neurosurgery 64:632–642
17. Maiellaro K, Taylor WR (2007) The role of the adventitia in vascular inflammation. Cardiovasc Res 75:640–648
18. McLaughlin N, Bojanowski MW (2008) Unruptured cerebral aneurysms presenting with ischemic events. Can J Neurol Sci 35:588–592
19. Mizutani T, Miki Y, Kojima H, Suzuki H (1999) Proposed classification of nonatherosclerotic cerebral fusiform and dissecting aneurysms. Neurosurgery 45:253–259
20. Nagahiro S, Takada A, Goto S, Kai Y, Ushio Y (1995) Thrombosed growing giant aneurysms of the vertebral artery: growth mechanism and management. J Neurosurg 82:796–801
21. Navratil O, Lehecka M, Lehto H, Dashti R, Kivisaari R, Niemela M, Hernesniemi JA (2009) Vascular clamp-assisted clipping of thick-walled giant aneurysms. Neurosurgery 64:113–120
22. Patel HC, Teo M, Higgins N, Kirkpatrick PJ (2010) High flow extra-cranial to intra-cranial bypass for complex internal carotid aneurysms. Br J Neurosurg 24:173–178
23. Schubiger O, Valavanis A, Hayek J (1980) Computed tomography in cerebral aneurysms with special emphasis on giant intracranial aneurysms. J Comput Assist Tomogr 4:24–32
24. Schubiger O, Valavanis A, Wichmann W (1987) Growth-mechanism of giant intracranial aneurysms; demonstration by CT and MR imaging. Neuroradiology 29:266–271
25. Teng MM, Nasir Qadri SM, Luo CB, Lirng JF, Chen SS, Chang CY (2003) MR imaging of giant intracranial aneurysm. J Clin Neurosci 10:460–464
26. Turowski B, Macht S, Kulcsár Z, Hänggi D, Stummer W (2010) Early fatal hemorrhage after endovascular cerebral aneurysm treatment with a flow diverter (SILK-Stent): do we need to rethink our concepts? Neuroradiology. doi:10.1007/s00234-010-0676-7
27. van Rooij WJ, Sluzewski M (2009) Endovascular treatment of large and giant aneurysms. AJNR Am J Neuroradiol 30:12–18
28. Whittle IR, Dorsch NW, Besser M (1982) Spontaneous thrombosis in giant intracranial aneurysms. J Neurol Neurosurg Psychiatry 45:1040–1047
29. Wiebers DO, 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, International Study of Unruptured Intracranial Aneurysms Investigators (2003) Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet 362:103–110
30. Yasui T, Sakamoto H, Kishi H, Komiyama M, Iwai Y, Yamanaka K, Nishikawa M, Nakajima H, Kobayashi Y, Inoue T (1998) Rupture mechanism of a thrombosed slow-growing giant aneurysm of the vertebral artery—case report. Neurol Med Chir (Tokyo) 38:860–864
31. Zhao L, Moos MP, Gräbner R, Pédrono F, Fan J, Kaiser B, John N, Schmidt S, Spanbroek R, Lötzer K, Huang L, Cui J, Rader DJ, Evans JF, Habenicht AJ, Funk CD (2004) The 5-lipoxygenase pathway promotes pathogenesis of hyperlipidemia-dependent aortic aneurysm. Nat Med 10:966–973