Neurosurg Rev (2019) 42:49–58
DOI 10.1007/s10143-017-0892-2

REVIEW

Recurrence of endovascularly and microsurgically treated intracranial aneurysms—review of the putative role of aneurysm wall biology

Serge Marbacher[1,2] · **Mika Niemelä**[1] · **Juha Hernesniemi**[1] · **Juhana Frösén**[1,3]

Received: 19 April 2017 / Revised: 10 July 2017 / Accepted: 4 August 2017 / Published online: 17 August 2017

Abstract Although endovascular therapy has been proven safe and has become in many centers the primary method of treatment for intracranial aneurysms, the long-term durability of endovascular embolization remains a concern; at least for some aneurysms despite initial good result. While healing after clipping relies on mechanical occlusion, restoration after endovascular occlusion mainly requires the induction of a biological response. Healing after embolization depends on the growth of new tissue over the thrombus formed by the embolization material, or alternatively, on the organization of thrombus into fibrous tissue. This review highlights the fundamental importance of aneurysm wall biology on the healing process and long-term occlusion after intracranial aneurysm (IA) treatment. It seems likely that the effect of luminal thrombus on the IA wall, as well as the IA wall condition at the time of thrombosis, determine if thrombus organizes into scar tissue (neointima formation by infiltration of cells originating from the IA wall) or if the wall undergoes continuous remodeling, which is primarily destructive (loss of mural cells). In the latter, intraluminal thrombus organization fails and the impaired healing increases the chance of recurrence. Mechanisms underlying IA reopening, the influence of intraluminal thrombosis on the IA wall, and clinical implications of the IA wall condition are discussed in detail, along with how knowledge of IA wall biology can offer new solutions for IA treatment and affect the patient selection for and follow-up after endovascular treatment.

Keywords Intracranial aneurysm · Clipping · Coiling · Aneurysm wall biology · Thrombosis · Recurrence

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10143-017-0892-2) contains supplementary material, which is available to authorized users.

✉ Serge Marbacher
serge.marbacher@ksa.ch

[1] Neurosurgery Research Group, Biomedicum Helsinki, Helsinki, Finland

[2] Department of Neurosurgery, Kantonspital Aarau, 5000 Aarau, Switzerland

[3] Hemorrhagic Brain Pathology Research Group, Kuopio University Hospital, Kuopio, Finland

Introduction

Intracranial aneurysms (IA) must be isolated from the cerebral circulation to prevent rupture and subsequent devastating intracranial hemorrhage. This was originally performed by ligating the artery at the site where the aneurysm originated. With the development of microneurosurgical techniques, occlusion of the aneurysm neck with a microsurgical clip (clipping) became the golden standard for treatment. Later, due to safe catheterization techniques for cerebral vessels and surgical angiography, endovascular embolization with thrombogenic coils (coiling) evolved and eliminated the need for craniotomy and related manipulation of the brain itself. One-year results of the largest randomized controlled trial comparing clipping and coiling found less dependency or death for patients with ruptured small anterior circulation IA of good neurological grade [61]. Despite its criticism, the results of the study led to increased use of endovascular therapy and eventually surpassed clipping as the most popular therapeutic approach for IAs. Although endovascular therapy has been proven safe and effective, recurrence may occur even after perfect packing of the aneurysm with coils (Table 1). The variation in healing and long-term outcomes of embolized aneurysms may be explained by aneurysm wall biology,

Table 1 Recurrence in relation to IA rupture status

Authors (year)	Follow-up (months)	UIA *n*/*n* (% of recurrence)	Ruptured IA *n*/*n* (% of recurrence)
Cognard et al. [13] (1999)	3–48	4/54 (7)	16/94 (17)
Raymond et al. [74] (2003)	12 (mean)	52/190 (27)	76/191 (40)
Ngyen et al. [67] (2007)	20 (mean)	16/72 (22)	23/44 (52)
Tan et al. [91] (2011)	20–25 (mean)	10/49 (20)	19/47 (40)
Vanzin et al. [97] (2012)	21 (mean)	42/194 (22)	80/261 (31)
Abdihalim et al. [1] (2014)	9 (mean)	5/92 (5)	24/120 (20)

After EVT using mainly standard coils

which is fundamental to the healing of embolized aneurysms and long-term success of endovascular therapy. Regarding the term endovascular treatment (EVT), this review is mainly focused on standard coil embolization. Since, histological data of the healing response induced by more recent embolization devices is relatively scarce. The available published data, nevertheless, demonstrates a similar healing response after novel intrasaccular thrombogenic flow disruptive devices as after standard coil embolization [19, 52, 58, 60]. Moreover, clinical series demonstrate similar neck remnant and recanalization problems after application of intrasaccular flow disruptive devices, as after standard coil embolization [5, 74, 73, 88].

Initial occlusion does not guarantee long-term healing—a problem of embolized aneurysms

The long-term success of any current therapy used to prevent IA rupture is dependent on permanent occlusion of the IA from the circulation. Embolized IA recur relatively frequently despite good initial treatment results (Tables 1 and 2; Supplementary Table 1). Many factors affect the risk of IA recurrence after embolization [13, 65, 72, 78], and the natural history of IA recurrence after embolization is poorly known. However, it is clear that IA recurrence after embolization is associated with a risk of rupture (although very low) and necessitates a higher rate of retreatment [9, 48, 63, 71]—or at the minimum, additional follow-up that is prone to cause anxiety in the patient [24].

Angiographic occlusion after EVT or after clipping is not to be equated with biological healing [3, 50, 76, 80, 92, 93]. In a long-term digital subtraction angiography study after coiling, over 40% of patients with adequate IA occlusion at short-term follow-up (< 36 months) demonstrated IA recurrence and 26% of these patients required retreatment [10]. Recurrence and retreatment rates are even higher for patients with known recurrence at short-term follow-up, 67 and 49%, respectively [10].

Animal studies revealed significant discrepancy between angiographic and histological findings resulting in overrated radiologic occlusion after coil embolization [50, 80, 89]. Human histopathological studies confirmed these results and demonstrated that half of IA deemed completely occluded on angiography show tiny open spaces between the coils at the neck [3]. When reviewing all published literature on human

Table 2 Recurrence in relation to IA size

Authors (year)	Follow-up (months)	Small IA < 10 mm *n*/*n* (% of recurrence)	Large IA > 10 to ≤ 25 mm *n*/*n* (% of recurrence)	Giant IA > 25 mm *n*/*n* (% of recurrence)
Byrne et al. [7] (1999)	6–12	24/176 (14)	12/81 (15)	2/2 (100)
Tateshima et al. [92] (2000)	19 (mean)	2/24 (8)	4/10 (40)	4/8 (50)
Raymond et al. [74] (2003)	12 (mean)	47/221 (21)	81/160 (51)	–
Murayama et al. [62] (2003)	6–12	66/579 (11)	70/198 (35)	43/73 (59)
Standhardt et al. [86] (2008)[a]	35 (mean)	22/163 (14)	5/20 (25)	9/19 (45)
Plowman et al. [70] (2011)	6	88/345 (26)	27/97 (28)	4/10 (40)
Gao et al. [32] (2012)[b]	38 (mean)	–	6/53 (11)	10/28 (36)
Dorfer et al. [19] (2012)	6–18	61/403 (15)	66/173 (38)	–
Chalouhi et al. [11] (2014)[c]	6–60	62/177 (35)	29/62 (47)	11/21 (52)

After EVT using mainly standard coils

[a] Small (< 12 mm) and large (13–24 mm) angiographic FU were available for 76% of all aneurysms

[b] Large (15–25 mm)

[c] Small (10–14 mm) and large (15–24 mm)

histopathology after EVT, it can be concluded that transformation of intraluminal thrombosis into scar formation and re-endothelialization of the luminal surface after EVT seems to be the exception rather than the rule (Supplementary Table 2).

Recurrence after clipping—are problems with long-term durability also associated with clipping?

In general, the reopening rate is lower in clipped than in coiled IA [63, 90]. The largest study to date with the longest follow-up data (mean, 7.2 ± 4.7 years) found that the risk of recurrence after clip ligation is 0.14% (1/699) and 13.6% (8/59) in IA without residual and with residual neck on postoperative imaging [6]. Previous series on long-term angiographic follow-up (mean, 4.4 ± 1.6 years) found comparable increase of IA recurrence with increase of residual aneurysm, 1.5% (2/135), 25% (2/8), and 75% (3/4) in completely clipped IA, known dog-ear, and broad-based remnant, respectively [16]. When a significant portion of the aneurysm wall is incorporated into the reconstructed vessel segment, the chance of delayed recurrence is as high as 30% [102]. Drake and Vanderlinden reported 0% (0/45), 17% (2/12), and 23% (3/13) late rebleeding after surgical IA treatment with complete obliteration, small remnant, or large remnant on postoperative angiography [21].

Histological analysis of clipped human IA demonstrated that complete re-endothelialization and neointima formation across the aneurysm neck occurred only in those IA with 100% exclusion of the diseased vessel wall (Supplementary Table 2) [46]. This data demonstrates that IA clipping shares many of the challenges of IA coiling. If microsurgical clipping fails to realign normal arterial tissue, recurrence rate is similar that found after endovascular coiling.

Clipping vs. coiling—mechanical vs. biological healing

There is a fundamental difference in the way clipping and coiling prevent IA rupture. Aneurysm clips exclude the diseased vessel segment, close the aneurysm neck and realign healthy arterial walls (Fig. 1). When successful, the clip blades pull the opposing healthy vessel walls towards each other (if the parent artery segment is not diseased), immediately reconstituting the affected vessel segment. Conventional histological and electron microscopy results after experimental clipping show a completely reconstructed normal vessel wall, with endothelialization across the aneurysm neck directly below the clip blades [50]. However, in clipped human IA, the effectiveness of treatment is mainly related to the mechanics of vessel reconstruction rather than the slow biological healing process (endothelialization and neointima formation) [46].

In embolization, the aneurysm sac is filled with material that will induce thrombosis but – at least initially – keeps the aneurysm neck open, separates adjacent healthy tissue and prevents realignment of the endothelium of the diseased arterial segment (Fig. 1). Healing after embolization requires the growth of new tissue over the thrombus, or the organization of the thrombus into fibrous tissue (Supplementary Table 2). In summary, healing after clipping relies on mechanical occlusion, whereas healing after coiling mainly requires the induction of a biological response.

Mechanisms for recurrence of embolized aneurysms—a mechanical or biological problem?

The mechanisms underlying reopening are poorly understood. Most hypotheses are based on subjective interpretation of morphological IA changes. IA volume-oriented mechanisms include coil compaction, coil migration into intraluminal thrombus, and resorption of pre-existing intraluminal thrombus [8, 42, 50, 100].

Human histopathological studies after Guglielmi detachable coil (GDC) embolization revealed that the unorganized intraluminal thrombus organizes itself by creating granulation tissue; first at the aneurysm wall, followed by the expansion of the endothelial cell lining over the granulation tissue at the aneurysm neck [3]. Based upon these findings and the

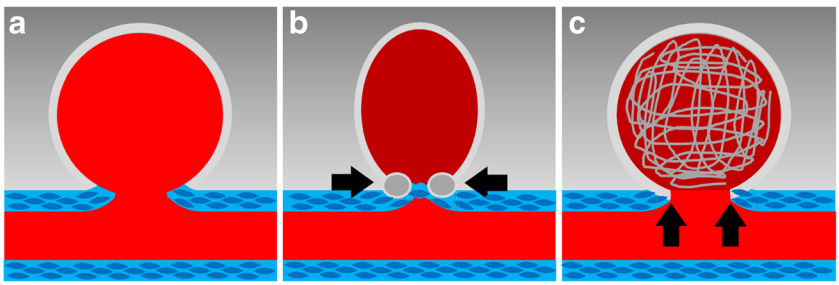

Fig. 1 Aneurysm healing after clipping vs. after coiling. **a** Schematic illustration of an IA with healthy parent arteries (*blue vessel wall*) and diseased bulging segment (*thinner gray aneurysm wall*). **b** Aneurysm clips exclude the diseased vessel segment, close the aneurysm neck, realign healthy arterial walls (*black arrows*), and exclude the thrombosed IA lumen from the circulation. **c** In IA coiling, the healthy transition zone at the neck is not realigned (*black arrows*). The coils hold the neck open, induce intraluminal thrombosis, and prevent exclusion of the diseased arterial segment until neointima forms over the aneurysm orifice or the thrombus organizes into fibrous tissue. In summary, healing after clipping requires mechanical occlusion while healing after coiling mainly depends on the induction of a biological response

confirmation of the healing processes in experimental settings, deficient fibrosis, insufficient neointima, and lack of endothelialization may tentatively be seen as mechanisms of IA recurrence [14, 15, 17, 50, 79].

Based on extensive experience with canine carotid bifurcation aneurysm models, Raymond et al. found that, following GDC occlusion, thrombus organization, endothelialization, and neointima formation take place at the same time as IA recurrence. They presented an alternative concept and proposed that connective tissue contraction leads to fibrosed cavity shrinkage [76]. This results in displacement towards the fundus, the opening of recurring space, progressive enlargement, and coil compaction. Cognard et al. [13] found regrowth after subtotal occlusion to be more frequent than true recurrences and emphasized that aneurysm growth might be an important factor for IA recurrence. They hypothesized that IA growth is related to coil compaction in that regrowth may produce changes in the coil mesh, or conversely, that round coil compaction could lead to recanalization of the neck and restart the IA growth process.

Rigorous three-dimensional image analysis of IA reopening revealed that not only coil compaction but also aneurysm growth is an important mechanism for recurrence of initially complete or near-complete obliteration [35]. Comparison of coil mass and the area surrounding aneurysm sacs in 29 patients with significant IA recurrence (24/29 patients with ruptured IA status) points to IA growth as the leading cause in more than half of the cases (62%; 18 patients) [1]. A study minimizing image analysis bias by using non-recurrence control subjects and automated image analysis protocols demonstrated that aneurysm sac growth is the predominant etiology of IA recurrence after coil embolization [39]. The fact that recurrence in patients with multiple aneurysm is higher than the subpopulation of patients with single IA supports the hypotheses that biological processes are responsible for IA recurrence after EVT using standard coils [101].

The fundamental difference between ruptured and unruptured IA

Raymond et al. studied IA recurrence after embolization and was not able to explain the significant difference in recurrence between unruptured and ruptured IA based on factors such as aneurysm size, neck width, or quality of initial angiographic results [78]. They therefore assumed that biological differences must exist. The difference in recurrence rate after EVT between ruptured and unruptured IAs is a solid finding (Table 1) [1, 13, 70, 78, 95, 101]. Analysis of a matched (aneurysm location, diameter, and neck size) cohort demonstrated not only an overall higher risk of recanalization in ruptured IA but also shorter period and higher degrees of recanalization and a higher percentage of retreatment when compared with unruptured IA [95]. It is increasingly recognized that the need of retreatment after GDC embolization are more common in ruptured than unruptured IA [20, 38, 64, 71, 72].

Ruptured and unruptured IAs most likely represent different biological entities. Human histopathological series clearly demonstrate underlying differences in aneurysm morphology between ruptured and unruptured IA. Ruptured aneurysms are associated with wall degeneration and some exhibit extremely thin thrombosis-lined hypo- to acellular walls, with degenerated extracellular matrix and loss of endothelial cells [29, 44]. We hypothesize that this type of IAs with loss of smooth muscle cells (SMC) are not only prone to growth and rupture [27] but also lack the capacity to organize thrombus, which could explain the significantly higher recurrence rate after embolization of ruptured IA.

Intraluminal thrombosis destabilizes the IA wall and influence healing

Acute thrombus induction has been linked to mural destabilization not only in experimental aneurysms [4, 56, 57, 77] but also in clinical settings after endovascular therapy [23, 34, 51, 66]. Various degrees of inflammation may exist depending on both the volume of induced thrombus and the IA wall condition at the time of EVT (wall enhancement is less common in ruptured than unruptured IA) [23]. Aneurysm wall enhancement is found in 32–64% after EVT and may not be pathological per se but rather part of a normal healing response [23, 91]. Increased aneurysm size and the associated large thrombus volume after GDC embolization is an independent predictor of IA wall enhancement [23, 40, 91]. Aneurysm wall and perianeurysmal inflammation is frequently encountered in partially thrombosed aneurysms which provide further evidence that intraluminal thrombosis contributes significantly to IA wall inflammation [23, 49].

Approximately 70% of aneurysm volume is filled with thrombus following coil embolization [12, 83, 94]. Recanalization has been linked to a packing volume with higher recurrence rates in aneurysms in over 80% of intraluminal thrombus [41, 45, 53, 81, 86, 94, 97, 100]. Increasing packing volumes is more difficult to achieve in larger aneurysms. Packing density is inversely related to aneurysm volume with higher amounts of thrombus in larger aneurysms [47, 86, 98]. In experimental aneurysms, volume was negatively correlated with packing density, and histological healing was negatively correlated with aneurysm size [18]. Both thrombus organization and neointima formation were superior in aneurysms with less thrombus. Small aneurysm size was found to be associated with stable long-term results after coiling, irrespective of IA location [87]. Histologically, confirmed complete healing after coiling tends to be found only in small IA (Supplementary Table 2).

Coil packing density is particularly poor in large and giant aneurysms which leads to > 95% of intraluminal thrombus and recurrence rates of > 50% [7, 11, 25, 62, 85, 96, 99]. Overall, recurrence rates for small aneurysms (4–10 mm) are reported to be 5–20%, depending on neck size [65]. This increases to 35–50% in large (10–25 mm) and 60–90% in giant aneurysms (Table 2) [32, 33, 65, 78]. The presence of intraluminal thrombosis alone is a possible risk factor for a coiled IA reopening [25, 69, 71, 72, 96, 100, 102]. Large aneurysm size is not only a risk factor for IA recurrence but also raises the need for retreatment after EVT [9, 71, 72].

Overall, it seems likely that the effect of luminal thrombus on the IA wall as well as the IA wall condition at the time of thrombosis determine if thrombus organizes into scar tissue (neointima formation by infiltration of SMC or myofibroblasts) or if the wall will undergo continuous remodeling (driven by inflammatory processes which are primarily destructive). In the latter case, intraluminal thrombus organization fails and impaired healing makes the IA more susceptible to recurrence.

Implications of wall pathology on aneurysm healing—an explanation for posttreatment recurrence?

In experimental models of saccular aneurysm, most thrombus organizing neointima cells are derived from the aneurysm wall—with a possible negligible contribution from circulating bone marrow cells [28, 37]. The finding that intraluminal unorganized thrombus is mainly organized by IA wall cells is in line with human histological studies after GDC embolization which found that granulation tissue response starts at the periphery of the luminal clot adjacent to the aneurysm wall (Supplementary Table 2) [2, 3, 62, 68, 84]. However, many processes of aneurysm healing are not well understood and remain controversial. Recent studies suggest that also bone marrow-derived endothelial progenitor and not only parent artery endothelial cells contribute to re-endothelialization at the aneurysm neck [54, 103]. Furthermore, in a murine elastase saccular model, monocyte chemotactic protein-1-coated coils were capable to recruit bone marrow-derived fibroblasts and macrophages via macrophage inflammatory protein-dependent pathways [36].

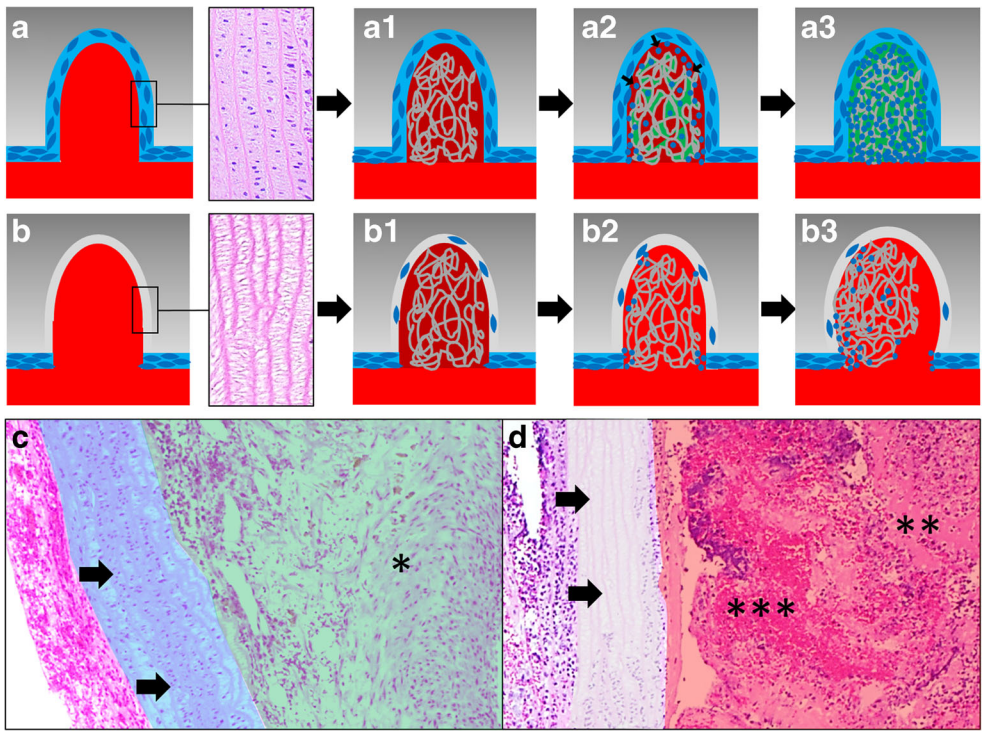

Fig. 2 The natural course of aneurysm healing after coiling is not solely dictated by the angioarchitecture of the aneurysm; it is largely determined by the condition of the aneurysm wall. Schematic illustration comparing healing after coiling in IA with many functioning SMC (**a**, *thick blue aneurysm wall*) and IA with highly degenerated walls and loss of SMC (**b**, *thin gray aneurysm wall*). In healthy wall IA, coiling induces intraluminal thrombosis (*a1*, *dark red areas*), SMC undergo phenotypic modulation, migrate into the thrombus (*a2*, *blue dots*), and transform it into scar tissue (*a3*, *green areas*). EVT also induces intraluminal thrombosis in IAs with a degenerated wall (*b1*, *dark red areas*). Missing mural cells, however, prevent thrombus organization and recanalization (*b2*, *red areas*) and may further damage the aneurysm wall which potentially cause progression of the disease (*b3*, *enlargement and recurrence*). **c** Histology of a healed rat sidewall aneurysm (*green area with intraluminal connective tissue formation* (*asterisk*)) with a vital wall full of SMCs (*black arrows*). **d** Unorganized thrombus (*red area with fibrin mesh* (*double asterisks*) and red blood cells (*triple asterisks*)) in an experimental aneurysm with missing mural cells (*black arrows*)

Many IA walls lack the SMCs that are meant to organize the thrombus induced by embolization and thus permanently heal the embolized aneurysm [27, 29, 44]. This loss of SMCs slows thrombus organization, causing the embolized IA to remain in an unstable state of continuous coagulation cascade—with subsequent activation of clot lysis pathways. This can eventually lead to clot lysis, recanalization, and IA recurrence. Moreover, experimental models have demonstrated that continuous exposure of the unorganized thrombus to the circulation can promote recruitment of neutrophils and inflammatory cells [55, 57], which increase proteolytic injury to the IA wall [30]. Unruptured IAs tend to have more viable SMCs in their walls, providing unruptured IAs increased opportunity to heal after embolization. This could explain why unruptured IAs have lower rebleeding rates [20, 75], necessitate less retreatment [20, 31, 38, 71, 72, 82], and are more stable after GCD embolization than ruptured IAs [1, 13, 26, 43, 70–72, 78, 95, 101].

We demonstrated in an experimental aneurysm model how the loss of SMCs from the aneurysm wall leads to growth and rupture, with concomitant wall inflammation and neutrophil recruitment [57], as well as how thrombus organization and prevention of aneurysm growth and rupture is significantly dependent on the presence of healthy SMCs in the aneurysm wall [55]. The contribution of bone marrow-derived cells to intra-aneurysmal tissue healing might vary in relation to the aneurysm wall condition (loss of mural cells).

The experimental data confirms the importance of aneurysm wall SMCs and—together with histopathological data from human IAs—strongly suggests that loss of this particular cell population could explain the failure of EVT in patients. IAs with a decellularized wall are less likely to heal properly after EVT as they lack the capacity for thrombus organization (Fig. 2).

Why knowledge of aneurysm wall biology can offer new solutions

The biology of the aneurysm wall determines the risk of rupture as well as the biological potential for healing. Although risk factors influencing IA recurrence and the need for retreatment have been identified [71, 72], it remains difficult to determine which IA will reopen after EVT and which will not. A growing body of evidence emphasizes the paramount importance of the aneurysm wall condition in IA growth and recurrence after EVT.

IA walls can be imaged with modern MRI techniques already available for clinical use [22, 59, 67]. This enables us to study different aspects of their biology and condition in patients in a clinical setting. Gadolinium uptake on T1 was more frequently observed in unstable IA [22] and has been associated with major recurrence after embolization [23].

Other MRI techniques able to identify IA walls with mural SMC loss have considerable potential as diagnostic tools to help designate patients for endovascular or microsurgical intervention. In cases where endovascular intervention has been selected, they could help identify which embolized IAs are likely to recur and necessitate retreatment. The development of MRI or other imaging methods to identify decellularized IA walls with loss of SMCs is urgently needed.

Compliance with ethical standards

Ethical statement We hereby confirm that no funds were received for this work. Ethical approval and informed consent are not applicable for this review.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Abdihalim M, Watanabe M, Chaudhry SA, Jagadeesan B, Suri MF, Qureshi AI (2014) Are coil compaction and aneurysmal growth two distinct etiologies leading to recurrence following endovascular treatment of intracranial aneurysm? Journal of Neuroimaging: Official Journal of the American Society of Neuroimaging 24:171–175. doi:10.1111/j.1552-6569.2012.00786.x
2. Asai J, Suzuki R, Fujimoto T, Miyo T, Nagashima G, Hokaku H, Takei A, Chang CW, Kurata A (2000) Correlation of magnetic resonance imaging and histological findings in a large basilar tip aneurysm after coil embolization—case report. Neurol Med Chir (Tokyo) 40:519–523
3. Bavinzski G, Talazoglu V, Killer M, Richling B, Gruber A, Gross CE, Plenk H Jr (1999) Gross and microscopic histopathological findings in aneurysms of the human brain treated with Guglielmi detachable coils. J Neurosurg 91:284–293. doi:10.3171/jns.1999.91.2.0284
4. Becker TA, Preul MC, Bichard WD, Kipke DR, McDougall CG (2007) Preliminary investigation of calcium alginate gel as a biocompatible material for endovascular aneurysm embolization in vivo. Neurosurgery 60:1119–1127; discussion 1127–1118. doi:10.1227/01.NEU.0000255447.90106.12
5. Bozzetto Ambrosi P, Gory B, Sivan-Hoffmann R, Riva R, Signorelli F, Labeyrie PE, Eldesouky I, Sadeh-Gonike U, Armoiry X, Turjman F (2015) Endovascular treatment of bifurcation intracranial aneurysms with the WEB SL/SLS: 6-month clinical and angiographic results. Interv Neuroradiol 21:462–469. doi:10.1177/1591019915590083
6. Brown MA, Parish J, Guandique CF, Payner TD, Horner T, Leipzig T, Rupani KV, Kim R, Bohnstedt BN, Cohen-Gadol AA (2016) A long-term study of durability and risk factors for aneurysm recurrence after microsurgical clip ligation. J Neurosurg:1–6. doi:10.3171/2016.2.JNS152059
7. Byrne JV, Adams CB, Kerr RS, Molyneux AJ (1995) Endosaccular treatment of inoperable intracranial aneurysms with platinum coils. Br J Neurosurg 9:585–592
8. 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

9. Campi A, Ramzi N, Molyneux AJ, Summers PE, Kerr RS, Sneade M, Yarnold JA, Rischmiller J, Byrne JV (2007) Retreatment of ruptured cerebral aneurysms in patients randomized by coiling or clipping in the international subarachnoid aneurysm trial (ISAT). Stroke 38:1538–1544. doi:10.1161/STROKEAHA.106.466987
10. Chalouhi N, Bovenzi CD, Thakkar V, Dressler J, Jabbour P, Starke RM, Teufack S, Gonzalez LF, Dalyai R, Dumont AS, Rosenwasser R, Tjoumakaris S (2014) Long-term catheter angiography after aneurysm coil therapy: results of 209 patients and predictors of delayed recurrence and retreatment. J Neurosurg 121:1102–1106. doi:10.3171/2014.7.JNS132433
11. Chalouhi N, Tjoumakaris S, Gonzalez LF, Dumont AS, Starke RM, Hasan D, Wu C, Singhal S, Moukarzel LA, Rosenwasser R, Jabbour P (2013) Coiling of large and giant aneurysms: complications and long-term results of 334 cases. AJNR Am J Neuroradiol. doi:10.3174/ajnr.A3696
12. Cloft HJ, Kallmes DF (2004) Aneurysm packing with HydroCoil embolic system versus platinum coils: initial clinical experience. AJNR Am J Neuroradiol 25:60–62
13. 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. doi:10.1148/radiology.212.2.r99jl47348
14. Dai D, Ding YH, Danielson MA, Kadirvel R, Lewis DA, Cloft HJ, Kallmes DF (2005) Histopathologic and immunohistochemical comparison of human, rabbit, and swine aneurysms embolized with platinum coils. AJNR Am J Neuroradiol 26(10):2560–8
15. Dai D, Ding YH, Kadirvel R, Danielson MA, Lewis DA, Cloft HJ, Kallmes DF (2006) A longitudinal immunohistochemical study of the healing of experimental aneurysms after embolization with platinum coils. AJNR Am J Neuroradiol 27:736-741. Doi:27/4/736 [pii]
16. David CA, Vishteh AG, Spetzler RF, Lemole M, Lawton MT, Partovi S (1999) Late angiographic follow-up review of surgically treated aneurysms. J Neurosurg 91:396–401. doi:10.3171/jns.1999.91.3.0396
17. Desfaits AC, Raymond J, Muizelaar JP (2000) Growth factors stimulate Neointimal cells in vitro and increase the thickness of the Neointima formed at the neck of porcine aneurysms treated by embolization. Editorial comment. Stroke 31:498–507. doi:10.1161/01.str.31.2.498
18. Ding YH, Dai D, Kadirvel R, Lewis DA, Cloft HJ, Kallmes DF (2008) Relationship between aneurysm volume and histologic healing after coil embolization in elastase-induced aneurysms: a retrospective study. AJNR Am J Neuroradiol 29:98–101. doi:10.3174/ajnr.A0752
19. Ding YH, Lewis DA, Kadirvel R, Dai D, Kallmes DF (2011) The woven EndoBridge: a new aneurysm occlusion device. AJNR Am J Neuroradiol 32:607–611. doi:10.3174/ajnr.A2399
20. Dos Santos MP, Sabri A, Dowlatshahi D, Bakkai AM, Elallegy A, Lesiuk H, Lum C (2015) Survival analysis of risk factors for major recurrence of intracranial aneurysms after coiling. The Canadian Journal of Neurological Sciences [Le journal canadien des sciences neurologiques] 42:40–47. doi:10.1017/cjn.2014.126
21. Drake CG, Vanderlinden RG (1967) The late consequences of incomplete surgical treatment of cerebral aneurysms. J Neurosurg 27:226–238. doi:10.3171/jns.1967.27.3.0226
22. Edjlali M, Gentric JC, Regent-Rodriguez C, Trystram D, Hassen WB, Lion S, Nataf F, Raymond J, Wieben O, Turski P, Meder JF, Oppenheim C, Naggara O (2014) Does aneurysmal wall enhancement on vessel wall MRI help to distinguish stable from unstable intracranial aneurysms? Stroke 45:3704–3706. doi:10.1161/STROKEAHA.114.006626
23. Fanning NF, Willinsky RA, ter Brugge KG (2008) Wall enhancement, edema, and hydrocephalus after endovascular coil occlusion of intradural cerebral aneurysms. J Neurosurg 108:1074–1086. doi:10.3171/jns/2008/108/6/1074
24. Ferns SP, Nieuwkerk PT, van Rooij WJ, Rinkel GJ, Majoie CB (2011) Long-term MRA follow-up after coiling of intracranial aneurysms: impact on mood and anxiety. Neuroradiology 53:343–348. doi:10.1007/s00234-010-0726-1
25. 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 31:1197–1205. doi:10.3174/ajnr.A2057
26. Finitsis S, Anxionnat R, Lebedinsky A, Albuquerque PC, Clayton MF, Picard L, Bracard S (2010) Endovascular treatment of ACom intracranial aneurysms. Report on series of 280 patients. Interv Neuroradiol 16:7–16
27. Frosen J (2014) Smooth muscle cells and the formation, degeneration, and rupture of saccular intracranial Aneurysm Wall—a review of current pathophysiological knowledge. Transl Stroke Res 5:347–356. doi:10.1007/s12975-014-0340-3
28. Frosen J, Marjamaa J, Myllarniemi M, Abo-Ramadan U, Tulamo R, Niemela M, Hernesniemi J, Jaaskelainen J (2006) Contribution of mural and bone marrow-derived neointimal cells to thrombus organization and wall remodeling in a microsurgical murine saccular aneurysm model. Neurosurgery 58:936–944; discussion 936-944. doi:10.1227/01.NEU.0000210260.55124.A4
29. Frosen J, Piippo A, Paetau A, Kangasniemi M, Niemela M, Hernesniemi J, Jaaskelainen J (2004) Remodeling of saccular cerebral artery aneurysm wall is associated with rupture: histological analysis of 24 unruptured and 42 ruptured cases. Stroke 35:2287–2293. doi:10.1161/01.STR.0000140636.30204.da
30. Frosen J, Tulamo R, Paetau A, Laaksamo E, Korja M, Laakso A, Niemela M, Hernesniemi J (2012) Saccular intracranial aneurysm: pathology and mechanisms. Acta Neuropathol 123:773–786. doi:10.1007/s00401-011-0939-3
31. Gallas S, Januel AC, Pasco A, Drouineau J, Gabrillargues J, Gaston A, Cognard C, Herbreteau D (2009) Long-term follow-up of 1036 cerebral aneurysms treated by bare coils: a multicentric cohort treated between 1998 and 2003. AJNR Am J Neuroradiol 30:1986–1992. doi:10.3174/ajnr.A1744
32. Gao X, Liang G, Li Z, Wei X, Cao P (2012) A single-centre experience and follow-up of patients with endovascular coiling of large and giant intracranial aneurysms with parent artery preservation. J Clin Neurosci 19:364–369. doi:10.1016/j.jocn.2011.03.038
33. Gruber A, Killer M, Bavinzski G, Richling B (1999) Clinical and angiographic results of endosaccular coiling treatment of giant and very large intracranial aneurysms: a 7-year, single-center experience. Neurosurgery 45:793–803 discussion 803-794
34. Hampton T, Walsh D, Tolias C, Fiorella D (2011) Mural destabilization after aneurysm treatment with a flow-diverting device: a report of two cases. Journal of Neurointerventional Surgery 3:167–171. doi:10.1136/jnis.2010.002873
35. Hasan DM, Nadareyshvili AI, Hoppe AL, Mahaney KB, Kung DK, Raghavan ML (2012) Cerebral aneurysm sac growth as the etiology of recurrence after successful coil embolization. Stroke 43:866–868. doi:10.1161/STROKEAHA.111.637827
36. Hoh BL, Hosaka K, Downes DP, Nowicki KW, Fernandez CE, Batich CD, Scott EW (2011) Monocyte chemotactic protein-1 promotes inflammatory vascular repair of murine carotid aneurysms via a macrophage inflammatory protein-1alpha and macrophage inflammatory protein-2-dependent pathway. Circulation 124:2243–2252. doi:10.1161/CIRCULATIONAHA.111.036061
37. Hoh BL, Velat GJ, Wilmer EN, Hosaka K, Fisher RC, Scott EW (2010) A novel murine elastase saccular aneurysm model for studying bone marrow progenitor-derived cell-mediated processes

in aneurysm formation. Neurosurgery 66:544–550; discussion 550. doi:10.1227/01.NEU.0000365616.46414.2B
38. Holmin S, Krings T, Ozanne A, Alt JP, Claes A, Zhao W, Alvarez H, Rodesch G, Lasjaunias P (2008) Intradural saccular aneurysms treated by Guglielmi detachable bare coils at a single institution between 1993 and 2005: clinical long-term follow-up for a total of 1810 patient-years in relation to morphological treatment results. Stroke 39:2288–2297. doi:10.1161/STROKEAHA.107.508234
39. Hoppe AL, Raghavan ML, Hasan DM (2015) Comparison of the association of sac growth and coil compaction with recurrence in coil embolized cerebral aneurysms. PLoS One 10:e0123017. doi:10.1371/journal.pone.0123017
40. Horie N, Kitagawa N, Morikawa M, Tsutsumi K, Kaminogo M, Nagata I (2007) Progressive perianeurysmal edema induced after endovascular coil embolization. Report of three cases and review of the literature. J Neurosurg 106:916–920. doi:10.3171/jns.2007.106.5.916
41. Kai Y, Hamada J, Morioka M, Yano S, Kuratsu J (2005) Evaluation of the stability of small ruptured aneurysms with a small neck after embolization with Guglielmi detachable coils: correlation between coil packing ratio and coil compaction. Neurosurgery 56:785–792 discussion 785–792
42. Kang H-S, Han MH, Kwon BJ, Kwon O-K, Kim SH (2006) Repeat endovascular treatment in post-embolization recurrent intracranial aneurysms. Neurosurgery 58:60–70 discussion 60–70
43. Kang HS, Kwon BJ, Kwon OK, Jung C, Kim JE, Oh CW, Han MH (2009) Endovascular coil embolization of anterior choroidal artery aneurysms. Clinical article. J Neurosurg 111:963–969. doi:10.3171/2009.4.JNS08934
44. Kataoka K, Taneda M, Asai T, Kinoshita A, Ito M, Kuroda R (1999) Structural fragility and inflammatory response of ruptured cerebral aneurysms. A comparative study between ruptured and unruptured cerebral aneursyms. Stroke 30:1396–1401
45. Kawanabe Y, Sadato A, Taki W, Hashimoto N (2001) Endovascular occlusion of intracranial aneurysms with Guglielmi detachable coils: correlation between coil packing density and coil compaction. Acta Neurochir 143:451–455
46. Killer-Oberpfalzer M, Aichholzer M, Weis S, Richling B, Jones R, Virmani R, Cruise GM (2012) Histological analysis of clipped human intracranial aneurysms and parent arteries with short-term follow-up. Cardiovascular Pathology: the Official Journal of the Society for Cardiovascular Pathology 21:299–306. doi:10.1016/j.carpath.2011.09.010
47. Knap D, Gruszczynska K, Partyka R, Ptak D, Korzekwa M, Zbroszczyk M, Baron J (2013) Results of endovascular treatment of aneurysms depending on their size, volume and coil packing density. Neurol Neurochir Pol 47:467–475
48. Korja M (2015) ISAT: end of the debate on coiling versus clipping? Lancet 385:2250–2251. doi:10.1016/s0140-6736(15)61059-5
49. Krings T, Alvarez H, Reinacher P, Ozanne A, Baccin CE, Gandolfo C, Zhao WY, Reinges MH, Lasjaunias P (2007) Growth and rupture mechanism of partially thrombosed aneurysms. Interv Neuroradiol 13:117–126
50. Krings T, Busch C, Sellhaus B, Drexler AY, Bovi M, Hermanns-Sachweh B, Scherer K, Gilsbach JM, Thron A, Hans FJ (2006) Long-term histological and scanning electron microscopy results of endovascular and operative treatments of experimentally induced aneurysms in the rabbit. Neurosurgery 59:911–923; discussion 923–914. doi:10.1227/01.NEU.0000232841.08876.DA
51. Kulcsar Z, Houdart E, Bonafe A, Parker G, Millar J, Goddard AJ, Renowden S, Gal G, Turowski B, Mitchell K, Gray F, Rodriguez M, van den Berg R, Gruber A, Desal H, Wanke I, Rufenacht DA (2011) Intra-aneurysmal thrombosis as a possible cause of delayed aneurysm rupture after flow-diversion treatment. AJNR Am J Neuroradiol 32:20–25. doi:10.3174/ajnr.A2370
52. Kwon SC, Ding YH, Dai D, Kadirvel R, Lewis DA, Kallmes DF (2011) Preliminary results of the luna aneurysm embolization system in a rabbit model: a new intrasaccular aneurysm occlusion device. AJNR Am J Neuroradiol 32:602–606. doi:10.3174/ajnr.A2314
53. Li MH, Gao BL, Fang C, Gu BX, Cheng YS, Wang W, Scotti G (2006) Angiographic follow-up of cerebral aneurysms treated with Guglielmi detachable coils: an analysis of 162 cases with 173 aneurysms. AJNR Am J Neuroradiol 27:1107–1112
54. Li ZF, Fang XG, Yang PF, Huang QH, Zhao WY, Liang C, Zhao R, Liu JM (2013) Endothelial progenitor cells contribute to neointima formation in rabbit elastase-induced aneurysm after flow diverter treatment. CNS Neuroscience & Therapeutics 19:352–357. doi:10.1111/cns.12086
55. Marbacher S, Frosen J, Marjamaa J, Anisimov A, Honkanen P, von Gunten M, Abo-Ramadan U, Hernesniemi J, Niemela M (2014) Intraluminal cell transplantation prevents growth and rupture in a model of rupture-prone saccular aneurysms. Stroke 45:3684–3690. doi:10.1161/STROKEAHA.114.006600
56. Marbacher S, Frosen J, Marjamaa J, Anisimov A, Honkanen P, Von Gunten M, Abo-Ramadan U, Hernesniemi J, Niemela M (2014) Intraluminal cell transplantation prevents growth and rupture in a model of rupture-prone saccular aneurysms. Stroke (in press)
57. Marbacher S, Marjamaa J, Bradacova K, von Gunten M, Honkanen P, Abo-Ramadan U, Hernesniemi J, Niemela M, Frosen J (2014) Loss of mural cells leads to wall degeneration, aneurysm growth, and eventual rupture in a rat aneurysm model. Stroke 45:248–254. doi:10.1161/STROKEAHA.113.002745
58. Marotta TR, Riina HA, McDougall I, Ricci DR, Killer-Oberpfalzer M (2017) Physiological remodeling of bifurcation aneurysms: preclinical results of the eCLIPs device. J Neurosurg:1–7. doi:10.3171/2016.10.JNS162024
59. Matouk CC, Mandell DM, Gunel M, Bulsara KR, Malhotra A, Hebert R, Johnson MH, Mikulis DJ, Minja FJ (2013) Vessel wall magnetic resonance imaging identifies the site of rupture in patients with multiple intracranial aneurysms: proof of principle. Neurosurgery 72:492–496; discussion 496. doi:10.1227/NEU.0b013e31827d1012
60. Moftakhar R, Xu F, Aagaard-Kienitz B, Consigny DW, Grinde JR, Hart K, Flanagan CE, Crone WC, Masters KS (2015) Preliminary in vivo evaluation of a novel intrasaccular cerebral aneurysm occlusion device. Journal of Neurointerventional Surgery 7:584–590. doi:10.1136/neurintsurg-2014-011179
61. 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
62. Molyneux AJ, Ellison DW, Morris J, Byrne JV (1995) Histological findings in giant aneurysms treated with Guglielmi detachable coils. Reports of two cases with autopsy correlation. J Neurosurg 83:129–132. doi:10.3171/jns.1995.83.1.0129
63. Molyneux AJ, Kerr RS, Yu LM, Clarke M, Sneade M, Yarnold JA, Sandercock P, International Subarachnoid Aneurysm Trial Collaborative G (2005) International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. Lancet 366:809–817. doi:10.1016/S0140-6736(05)67214-5
64. Mortimer AM, Bradley MD, Mews P, Molyneux AJ, Renowden SA (2014) Endovascular treatment of 300 consecutive middle cerebral artery aneurysms: clinical and radiologic outcomes. AJNR Am J Neuroradiol 35:706–714. doi:10.3174/ajnr.A3776

65. Murayama Y, Nien YL, Duckwiler G, Gobin YP, Jahan R, Frazee J, Martin N, Vinuela F (2003) Guglielmi detachable coil embolization of cerebral aneurysms: 11 years' experience. J Neurosurg 98: 959–966. doi:10.3171/jns.2003.98.5.0959
66. Mustafa W, Kadziolka K, Anxionnat R, Pierot L (2010) Direct carotid-cavernous fistula following intracavernous carotid aneurysm treatment with a flow-diverter stent. A case report. Interv Neuroradiol 16:447–450
67. Nagahata S, Nagahata M, Obara M, Kondo R, Minagawa N, Sato S, Sato S, Mouri W, Saito S, Kayama T (2014) Wall enhancement of the intracranial aneurysms revealed by magnetic resonance Vessel Wall imaging using three-dimensional turbo spin-Echo sequence with motion-sensitized driven-equilibrium: a sign of ruptured aneurysm? Clin Neuroradiol. doi:10.1007/s00062-014-0353-z
68. Nakahara T, Sakamoto S, Hamasaki O, Sakoda K (2003) Postmortem pathological examination of two patients after intraaneurysmal embolization using guglielmi detachable coils. Interv Neuroradiol 9:57–62
69. Ng P, Khangure MS, Phatouros CC, Bynevelt M, ApSimon H, McAuliffe W (2002) Endovascular treatment of intracranial aneurysms with Guglielmi detachable coils: analysis of midterm angiographic and clinical outcomes. Stroke 33:210–217
70. Nguyen TN, Hoh BL, Amin-Hanjani S, Pryor JC, Ogilvy CS (2007) Comparison of ruptured vs unruptured aneurysms in recanalization after coil embolization. Surg Neurol 68:19–23. doi:10.1016/j.surneu.2006.10.021
71. Ogilvy CS, Chua MH, Fusco MR, Griessenauer CJ, Harrigan MR, Sonig A, Siddiqui AH, Levy EI, Snyder K, Avery M, Mitha A, Shores J, Hoh BL, Thomas AJ (2015) Validation of a system to predict recanalization after endovascular treatment of intracranial aneurysms. Neurosurgery. doi:10.1227/NEU.0000000000000744
72. Ogilvy CS, Chua MH, Fusco MR, Reddy AS, Thomas AJ (2015) Stratification of recanalization for patients with endovascular treatment of intracranial aneurysms. Neurosurgery. doi:10.1227/NEU.0000000000000651
73. Papagiannaki C, Spelle L, Januel AC, Benaissa A, Gauvrit JY, Costalat V, Desal H, Turjman F, Velasco S, Barreau X, Courtheoux P, Cognard C, Herbreteau D, Moret J, Pierot L (2014) WEB intrasaccular flow disruptor-prospective, multicenter experience in 83 patients with 85 aneurysms. AJNR Am J Neuroradiol 35:2106–2111. doi:10.3174/ajnr.A4028
74. Pierot L, Costalat V, Moret J, Szikora I, Klisch J, Herbreteau D, Holtmannspotter M, Weber W, Januel AC, Liebig T, Sychra V, Strasilla C, Cognard C, Bonafe A, Molyneux A, Byrne JV, Spelle L (2016) Safety and efficacy of aneurysm treatment with WEB: results of the WEBCAST study. J Neurosurg 124:1250–1256. doi:10.3171/2015.2.JNS142634
75. Pyysalo LM, Keski-Nisula LH, Niskakangas TT, Kahara VJ, Ohman JE (2010) Long-term follow-up study of endovascularly treated intracranial aneurysms. Interv Neuroradiol 16:231–239
76. Raymond J, Darsaut T, Salazkin I, Gevry G, Bouzeghrane F (2008) Mechanisms of occlusion and recanalization in canine carotid bifurcation aneurysms embolized with platinum coils: an alternative concept. AJNR Am J Neuroradiol 29:745–752. doi:10.3174/ajnr.A0902
77. Raymond J, Darsaut TE, Kotowski M, Makoyeva A, Gevry G, Berthelet F, Salazkin I (2013) Thrombosis heralding aneurysmal rupture: an exploration of potential mechanisms in a novel giant swine aneurysm model. AJNR Am J Neuroradiol 34:346–353. doi:10.3174/ajnr.A3407
78. Raymond J, Guilbert F, Weill A, Georganos SA, Juravsky L, Lambert A, Lamoureux J, Chagnon M, Roy D (2003) Long-term angiographic recurrences after selective endovascular treatment of aneurysms with detachable coils. Stroke 34:1398–1403. doi:10.1161/01.STR.0000073841.88563.E9
79. Raymond J, Venne D, Allas S, Roy D, Oliva VL, Denbow N, Salazkin I, Leclerc G (1999) Healing mechanisms in experimental aneurysms. I. Vascular smooth muscle cells and neointima formation. Journal of Neuroradiology [Journal de neuroradiologie] 26: 7–20
80. Reul J, Weis J, Spetzger U, Konert T, Fricke C, Thron A (1997) Long-term angiographic and histopathologic findings in experimental aneurysms of the carotid bifurcation embolized with platinum and tungsten coils. AJNR Am J Neuroradiol 18:35–42
81. Satoh K, Matsubara S, Hondoh H, Nagahiro S (1997) Intracranial aneurysm embolization using interlocking detachable coils. Correlation between Volume Embolization Rate and Coil Compaction Interv Neuroradiol 3(Suppl 2):125–128
82. Sedat J, Chau Y, Moubarak K, Vargas J, Lonjon M (2012) Endovascular treatment of recurrent coiled aneurysms: assessment of complications and rebleeding during a decade in a single center. Interv Neuroradiol 18:14–19
83. Sherif C, Plenk H Jr, Grossschmidt K, Kanz F, Bavinzski G (2006) Computer-assisted quantification of occlusion and coil densities on angiographic and histological images of experimental aneurysms. Neurosurgery 58:559–566; discussion 559-566. doi:10.1227/01.NEU.0000197490.60670.A8
84. Shimizu S, Kurata A, Takano M, Takagi H, Yamazaki H, Miyasaka Y, Fujii K (1999) Tissue response of a small saccular aneurysm after incomplete occlusion with a Guglielmi detachable coil. AJNR Am J Neuroradiol 20:546–548
85. Sluzewski M, Menovsky T, van Rooij WJ, Wijnalda D (2003) Coiling of very large or giant cerebral aneurysms: long-term clinical and serial angiographic results. AJNR Am J Neuroradiol 24: 257–262
86. Sluzewski M, van Rooij WJ, Slob MJ, Bescos JO, Slump CH, Wijnalda D (2004) Relation between aneurysm volume, packing, and compaction in 145 cerebral aneurysms treated with coils. Radiology 231:653–658. doi:10.1148/radiol.2313030460
87. Songsaeng D, Geibprasert S, ter Brugge KG, Willinsky R, Tymianski M, Krings T (2011) Impact of individual intracranial arterial aneurysm morphology on initial obliteration and recurrence rates of endovascular treatments: a multivariate analysis. J Neurosurg 114:994–1002. doi:10.3171/2010.8.JNS10241
88. Sourour NA, Vande Perre S, Maria FD, Papagiannaki C, Gabrieli J, Pistocchi S, Bartolini B, Degos V, Carpentier A, Chiras J, Clarencon F (2017) Medina(R) embolization device for the treatment of intracranial aneurysms: safety and angiographic effectiveness at 6 months. Neurosurgery. doi:10.1093/neuros/nyx161
89. Spetzger U, Reul J, Weis J, Bertalanffy H, Thron A, Gilsbach JM (1996) Microsurgically produced bifurcation aneurysms in a rabbit model for endovascular coil embolization. J Neurosurg 85: 488–495. doi:10.3171/jns.1996.85.3.0488
90. Spetzler RF, McDougall CG, Albuquerque FC, Zabramski JM, Hills NK, Partovi S, Nakaji P, Wallace RC (2013) The barrow ruptured aneurysm trial: 3-year results. J Neurosurg 119:146–157. doi:10.3171/2013.3.JNS12683
91. Su IC, Willinsky RA, Fanning NF, Agid R (2014) Aneurysmal wall enhancement and perianeurysmal edema after endovascular treatment of unruptured cerebral aneurysms. Neuroradiology 56: 487–495. doi:10.1007/s00234-014-1355-x
92. Szikora I, Seifert P, Hanzely Z, Kulcsar Z, Berentei Z, Marosfoi M, Czirjak S, Vajda J, Nyary I (2006) Histopathologic evaluation of aneurysms treated with Guglielmi detachable coils or matrix detachable microcoils. AJNR Am J Neuroradiol 27:283–288
93. Szikora I, Turanyi E, Marosfoi M (2015) Evolution of flow-diverter endothelialization and thrombus organization in giant fusiform aneurysms after flow diversion: a histopathologic study. AJNR Am J Neuroradiol. doi:10.3174/ajnr.A4336
94. Tamatani S, Ito Y, Abe H, Koike T, Takeuchi S, Tanaka R (2002) Evaluation of the stability of aneurysms after embolization using

detachable coils: correlation between stability of aneurysms and embolized volume of aneurysms. AJNR Am J Neuroradiol 23: 762–767
95. Tan IY, Agid RF, Willinsky RA (2011) Recanalization rates after endovascular coil embolization in a cohort of matched ruptured and unruptured cerebral aneurysms. Interv Neuroradiol 17:27–35
96. 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
97. Uchiyama N, Kida S, Nomura M, Hasegawa M, Yamashima T, Yamashita J, Matsui O (2000) Significance of volume embolization ratio as a predictor of recanalization on endovascular treatment of cerebral aneurysms with guglielmi detachable coils. Interv Neuroradiol 6(Suppl 1):59–63
98. van Rooij WJ, Sluzewski M (2006) Packing density in coiling of small intracranial aneurysms. AJNR Am J Neuroradiol 27:725–726 author reply 726
99. van Rooij WJ, Sluzewski M (2007) Coiling of very large and giant basilar tip aneurysms: midterm clinical and angiographic results. AJNR Am J Neuroradiol 28:1405–1408. doi:10.3174/ajnr.A0556
100. van Rooij WJ, Sprengers ME, Sluzewski M, Beute GN (2007) Intracranial aneurysms that repeatedly reopen over time after coiling: imaging characteristics and treatment outcome. Neuroradiology 49:343–349. doi:10.1007/s00234-006-0200-2
101. Vanzin JR, Mounayer C, Abud DG, D'Agostini Annes R, Moret J (2012) Angiographic results in intracranial aneurysms treated with inert platinum coils. Interv Neuroradiol 18:391–400
102. Yang K, Park JC, Ahn JS, Kwon DH, Kwun BD, Kim CJ (2014) Characteristics and outcomes of varied treatment modalities for partially thrombosed intracranial aneurysms: a review of 35 cases. Acta Neurochir 156:1669–1675. doi:10.1007/s00701-014-2147-0
103. Zhang S, An Q, Li Q, Huang J, Chen X, Chen X, Zhang J, Wang Y, Yang GY, Zhu W (2014) Therapeutic benefit of bone marrow-derived endothelial progenitor cell transplantation after experimental aneurysm embolization with coil in rats. PLoS One 9:e90069. doi: 10.1371/journal.pone.0090069