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INTERVENTIONAL NEURORADIOLOGY

# Stent-assisted embolization of recurrent or residual intracranial aneurysms

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**Abstract**
*Introduction* Intracranial stents have theoretical advantages in the treatment of wide-necked intracranial aneurysms, but the usability of intracranial stents in the retreatment of recurrent intracranial aneurysms is relatively unknown. In this study, we aim to evaluate the safety and efficacy of stent-assisted embolization in the retreatment of recurrent or residual intracranial aneurysms.
*Methods* Retrospective evaluation was carried out for 55 consecutive patients (17 men and 38 women; mean age 51.5 years), with 56 recurrent or residual intracranial aneurysms electively retreated with stent-assisted embolization.
*Results* The technical success rate was 91 % (50/55 patients). Procedural complications were encountered with six patients (11 %). Angiographic and clinical follow-up data were available for 51 patients (93 %), with a mean follow-up period of 28.1 months. No rebleedings were encountered during the study period. The clinical outcome was favorable in 50 patients (91 %), with a Glasgow Outcome Score of 4 ($N$=14) or 5 ($N$=36) at the end of the study period. Poor clinical outcome correlated with very large (>2 cm) total aneurysm size ($P$=0.002), large (>10 mm) recurrent aneurysm size ($P$=0.011), and occurrence of periprocedural complications ($P$<0.001).
*Conclusion* Stent-assisted coil embolization is beneficial for the retreatment of wide-necked recurrent or residual intracranial aneurysms, but stability and permanent occlusion of the recurrent aneurysm is unlikely if the aneurysm exceeds 2 cm in diameter, the recurrent diameter of the aneurysm exceeds 10 mm, or if mass effect is present with the recurrent aneurysm.

**Keywords** Intracranial aneurysms · Embolization therapy · Stents

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## Introduction

Angiographic recurrence after coil embolization of intracranial aneurysms is relatively common, with reported incidences of up to 33.6 % [1–6]. The small but notable risk of bleeding from partially occluded aneurysms must be balanced against the procedure-related risks of retreatment [7–10]. Additional coiling of previously coiled aneurysms has been reported to have a low procedural complication rate and to lead to sufficient occlusion in most aneurysms [8, 11, 12]. The residual or recurrent aneurysm, however, occasionally has a wide-necked profile; coil embolization of the recurrent aneurysm may be challenging, since the coils may protrude into the parent artery. Balloon-assisted remodeling may be useful in preventing coil protrusion [13, 14], but additional support to the aneurysm neck provided by an intracranial stent may also be advantageous in the retreatment of these challenging aneurysms [15–19].

There are several theoretical advantages in using stents in conjunction with coils as follows: the presence of the stent reduces the risk of coil protrusion, the stent disturbs the inflow jet to the aneurysm sac, thus promoting aneurysm thrombosis, and the stent provides a physical matrix for possible endothelial growth. Stent implantation seems beneficial with respect to reducing the recanalization rate of recurrent intracranial aneurysms, but the published data remains scarce [20]. In this retrospective study, we evaluate the safety and efficacy of stent-assisted embolization in the retreatment of recurrent or residual intracranial aneurysms. Clinical and angiographic outcomes including midterm follow-up data, safety of the technique, and factors associated with poor outcome are also presented.

## Methods

### Study design and size

We retrospectively analyzed patient records and angiographic data for all consecutive patients with recurrent or residual intracranial aneurysms treated with stent-assisted coil embolization in three tertiary care centers in Finland from February 2003 to June 2011. We estimated that a total of 4,300 patients were treated either with coil embolization or surgical clipping in our centers between October 1997 and July 2008, about 440 of which were evaluated to necessitate retreatment (i.e., 20 % of the endovascular group). From this population, a total of 59 patients with 60 aneurysms treated with stent-assisted re-embolization were identified. Patients treated in the acute phase (≤72 h; $N$=2) or late subacute stage (<4 weeks; $N$=2) of subarachnoid hemorrhage (SAH) were excluded due to the differences in the treatment regimens in (sub)acute and chronic phase of SAH, resulting in a study group of 55 patients with 56 aneurysms initially treated by coil embolization ($N$=51) or surgical ligation ($N$=5) between October 1997 and July 2008 (Fig. 1). The institutional review board of Tampere University Hospital and the Ministry of Social Affairs and Health of Finland approved this multicenter study. The need to obtain informed consent was waived. None of the authors received financial support for this study.

### Participants

The necessity for treatment and the form of retreatment were individually evaluated via a consensus between an experienced vascular neurosurgeon and a neurointerventional radiologist. The patients were informed about the treatment options and their risks. Numerous factors influenced the retreatment decision, including the recurrence size of the aneurysm, growth of the recurrence size during follow-up, and the estimated risks of various retreatment options versus the estimated lifetime risk of rupture of the recurrent aneurysm. Unstable recurrent aneurysms (growth of the recurrence size during follow-up) were typically retreated, and previously ruptured aneurysms were more likely to be retreated than nonruptured aneurysms. The size criteria for the recurrence size that indicate retreatment depend considerably on the initial aneurysm size and shape. Very small (<2 mm in diameter) recurrences were, however, not retreated due to a low risk of rebleeding and the difficulty of the re-embolization procedure, whereas recurrences exceeding 4 mm in diameter were typically selected for retreatment. Stent-assisted embolization was selected only if surgical ligation or unassisted or balloon-assisted embolization were not

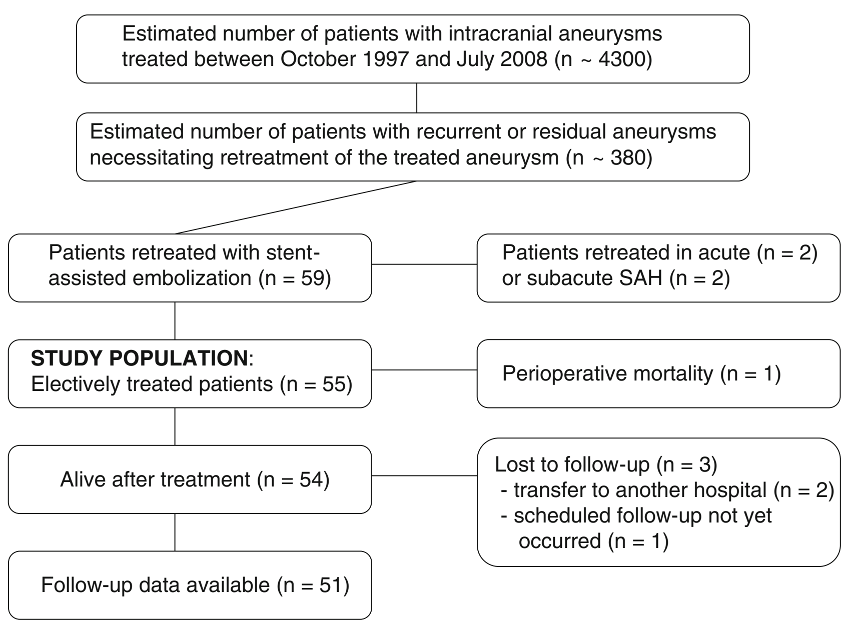


**Fig. 1** Flow chart of patient selection and available follow-up

considered feasible due to the wide-necked profile or difficult morphology of the recurrent aneurysm.

## Patient demographics and aneurysm characteristics

Thirty-eight out of 55 patients (69 %) were women, and 17 patients (31 %) were men, with a mean age of 51.5 years (range 32–75 years). Most of the patients (45/55; 82 %) had a history of SAH. The time interval between SAH and stent-assisted treatment of the ruptured aneurysm varied from 8 weeks to 10 years and 5 months. Ventriculostomy was performed in nine patients (16 %), all of whom had a history of SAH.

The largest diameter of the recurrent or residual portion of the aneurysm varied from 2 to 20 mm (mean 5.5 mm), and the largest diameter of the entire aneurysm ranged from 4 to 27 mm (mean 10.4 mm). The recurrent or residual aneurysms were wide-necked, with a neck of ≥4 mm in 35 of 56 (63 %) and dome/neck ratio of <2 in 55 of 56 (98 %) treated aneurysms. More than one prior treatment session had been performed in 21 aneurysms (38 %), while four or more treatment sessions were carried out for four aneurysms (7 %). Patient demographics, preceding therapies, and angiographic characteristics of the aneurysms are presented in Table 1.

## Stenting procedure

Unilateral femoral access was used in all interventions. A 90-cm guiding catheter (Boston Scientific, Fremont, CA, USA) was inserted into the relevant carotid or vertebral artery. A microcatheter (Excelsior SL-10; Boston Scientific/Target Therapeutics, Fremont, CA, USA) was navigated past the aneurysm with the help of a standard (180 cm) microguide wire, which was usually also used in the deployment of the stent (Neuroform; Boston Scientific/Target Therapeutics). Aneurysms were packed with Guglielmi detachable coils and/or Matrix coils (Boston Scientific) in earlier phase of the study and with Target (Stryker Neurovascular, Fremont, CA, USA) or Axium coils (ev3 Neurovascular, Irvine, CA, USA) in later cases (Fig. 2).

## Antithrombotic medication

Combination of antiplatelet therapy was initiated 10 days prior to the procedure with clopidogrel bisulphate (75 mg daily, Plavix; Sanofi Pharma Bristol-Meyers Squibb, Paris, France) and acetylsalicylic acid (100 mg daily). The patients were hospitalized the day before the procedure, and response to the antiplatelet therapy was confirmed via the VerifyNow system (Accumetrics, San Diego, CA, USA) after this device

**Table 1** Characteristics of the patients and treated aneurysms

| | Ruptured aneurysms | Non-ruptured aneurysms | All patients |
|---|---|---|---|
| Patient age in years, mean (range) | 50.8 (32–75) | 54.3 (44–65) | 51.5 (32–75) |
| Patient sex, N (%)[a] | | | |
| Male | 14 (31) | 3 (30) | 17 (31) |
| Female | 31 (69) | 7 (70) | 38 (69) |
| Angiographic features of the recurrent aneurysm, mean (range) | | | |
| Largest patent diameter in mm[b] | 5.6 (3–20) | 5.4 (2–9) | 5.5 (2–20) |
| Patent dome height in mm[b] | 4.4 (2–20) | 3.6 (2–6) | 4.2 (2–20) |
| Neck width in mm[b] | 4.0 (2–9) | 4.3 (2–7) | 4.1 (2–9) |
| Dome/neck ratio[b] | 1.1 (0.4–5) | 0.86 (0.6–1.5) | 1.1 (0.4–5.0) |
| Largest total diameter in mm[c] | 10.4 (5–27) | 10.7 (4–27) | 10.4 (4–27) |
| Total dome height in mm[c] | 9.8 (4–25) | 10.7 (3–24) | 9.9 (3–25) |
| Fill ratio[d] | 0.44 (0.2–1.0) | 0.40 (0.2–0.8) | 0.44 (0.2–1.0) |
| Multiple aneurysms, N(%)[a] | | | |
| Yes | 17 (38) | 6 (60) | 23 (42) |
| No | 28 (62) | 4 (40) | 32 (58) |
| Prior treatment approach, N(%)[a] | | | |
| Endovascular | 41 (91) | 7 (70) | 51 (86) |
| Surgical | 1 (2) | 2 (20) | 4 (7) |
| Both endovascular and surgical | 3 (7) | 1 (10) | 4 (7) |
| Clinical outcome, N(%)[a] | | | |
| Favorable (GOS 4–5) | 41 (91) | 9 (90) | 50 (91) |
| Poor (GOS 1–3) | 4 (9) | 1 (10) | 5 (9) |
| Total | 45 | 10 | 55 |

[a] Corresponding column percentage. Percentages may not sum to 100 % due to rounding

[b] Largest patent diameter and patent dome height (residual/recurrent part of the aneurysm)

[c] Largest diameter and dome height, including the occluded part of the aneurysm

[d] Ratio of the patent aneurysm dome height to the total dome height of the aneurysm

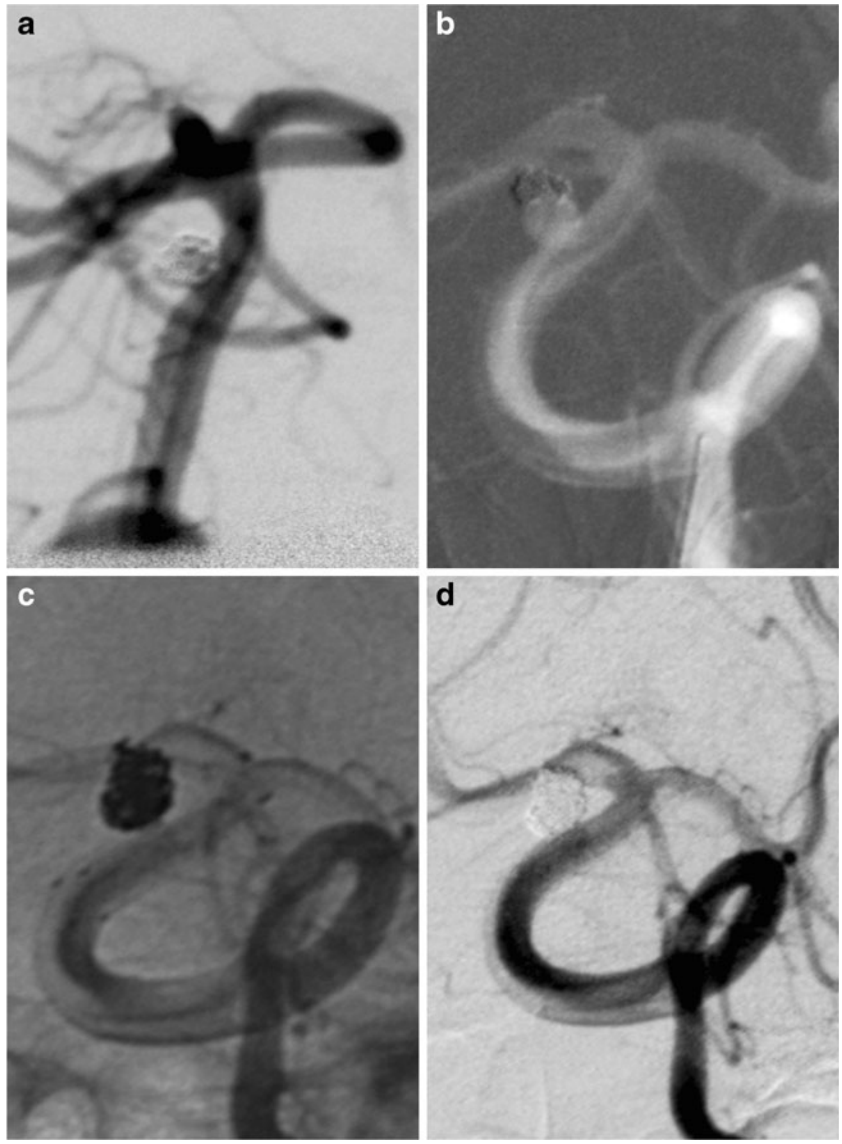


**Fig. 2** Digital subtraction angiography of a ruptured aneurysm of the basilar artery, which was initially embolized with an adequate occlusion rate (**a**). Marked coil compaction and wide-necked recurrent aneurysm formation were observed via digital subtraction angiography 8 months later (**b**), and a stent-assisted re-embolization was performed (**c**). The angiographic result remained stable after retreatment of the aneurysm; complete occlusion of the aneurysm was observed via digital subtraction angiography 38 months after the stent-assisted retreatment (**d**)

became available in our centers in January 2010. If at least 40 % change from the baseline platelet aggregation level was not registered, additional doses of clopidogrel bisulphate or prasugrel hydrochloride (Efient; Eli Lilly Nederland BV, RA Houten, The Netherlands) were administered, followed by repeated laboratory measurements. All of the patients were heparinized during the procedure with an activated clotting time target of about 240 s. Combination therapy with clopidogrel bisulphate (75 mg daily for 3 months) and acetylsalicylic acid (100 mg daily for a minimum of 6 months) was continued post-procedurally.

## Statistical methods

For statistical analysis (IBM SPSS Statistics, version 19, 2010; SPSS Inc., Chicago, IL, USA), clinical outcome was dichotomized into favorable (Glasgow Outcome Score (GOS) 4 and 5) and poor (GOS 1–3) outcomes. The effect of total aneurysm size on clinical outcome was evaluated with Kruskal–Wallis one-way analysis and after categorization into small (<10 mm), large (10–24 mm), and giant (≥25 mm) aneurysms. The recurrence sizes of the treated aneurysms were also divided into three groups (<5, 5–10, and >10 mm). Dichotomous and other categorical variables were compared with the $\chi^2$ test or Fisher's exact test, and after univariate analysis, a binomial regression analysis was performed.

## Variables and data measurement

All clinical parameters were studied on a per patient basis. The dimensions of the treated recurrent or residual aneurysm were measured from perioperative digital subtraction angiography (DSA) images, preferably from 3D reformations when available ($N$=25; 45 %). Technical success of the procedure was recorded if the recurrent or residual aneurysm was successfully stented and re-embolized with a satisfactory initial angiographic result (complete occlusion or a small neck remnant as described by the modified Raymond classification [21]). For the evaluation of angiographic results, all available follow-up images were also studied and categorized into the following groups: primary angiographic success (adequate occlusion and stability of the aneurysm; no additional therapies), secondary angiographic success (adequate occlusion and stability of the aneurysm achieved by additional therapies), and angiographic failure (residual aneurysm and/or instability of the treated aneurysm). The patients were clinically assessed using the Glasgow Outcome Scale. Procedural complications were recorded if clinical deterioration of the patient was observed post-procedurally. Administration of abciximab in the treatment of periprocedural thromboembolic events and deliveries of additional stents were recorded as adjunctive therapies if there were no post-procedural clinical sequelae.

### Follow-up data and data analysis

Technical success, follow-up images, angiographic results, and complications were evaluated by a radiologist, and all clinical parameters were reviewed by an experienced neurosurgeon. All images and patient records were studied in January 2013. Follow-up imaging was primarily performed by DSA. MR angiography (contrast enhanced and three-dimensional time-of-flight MR angiography) was utilized only in selected cases, if the initial postoperative angiographic result was adequate and the risk of aneurysm recurrence was small ($N$=4), or if adequate occlusion and stability of the treated aneurysm was already detected in DSA ($N$=20) [22].

## Results

### Technical success

The technical success rate was 91 % (50/55 patients). Delivery of the intracranial stent failed due to tortuosity of the target vessel in one patient (2 %). Surgical ligation was successfully performed on this ruptured, large posterior communicating artery aneurysm remnant, which had been only partially embolized during the acute phase of SAH 3 months earlier. Technical failures also included four patients (7 %), in whom adequate coil embolization was not achieved after stenting either due to small size of the recurrent or remnant aneurysm (dome height 2 mm; $N$=1) or difficult target anatomy and/or limited visibility ($N$=3).

### Adjunctive therapies and procedural complications

Intraprocedural adjunctive therapies were required in five patients (9 %): two cases (4 %) of minor periprocedural thromboembolism successfully treated with intra-arterial abciximab, two cases (4 %) of presumable iatrogenic vertebral dissections that were successfully stented, and one case (2 %) where insertion of an additional intracranial stent was required due to suboptimal placement of the primary stent. Clinical sequelae or procedure-related radiographic findings were not detected in these patients postoperatively or during the available follow-up.

Procedural complications were encountered in six patients (11 %), including three cases (5 %) of perioperative aneurysm perforation, one case (2 %) of postoperative retroperitoneal and intra-abdominal hemorrhage, and two cases (4 %) in which an embolized large basilar tip aneurysm presented with progressive brain stem compression symptoms postoperatively. Procedural complications almost invariably resulted in permanent neurological deterioration ($N$=4) or death ($N$=1) of the patient; only the patient with retroperitoneal and intra-abdominal hemorrhage recovered without sequelae.

### Angiographic results

Initial post-procedural angiographic results were as follows: complete occlusion of the stented aneurysm in 30 aneurysms (30/56 aneurysms; 54 %), neck remnant in 21 aneurysms (38 %), and residual aneurysm ($N$=3) or no coiling ($N$=2) in 5 aneurysms (9 %), including 1 case (2 %) with unsuccessful stent deployment. After combining post-procedural angiographic results with all available follow-up images, adequate angiographic results were observed at the end of the follow-up period in 51 aneurysms (91 %), with either complete occlusion of the stented aneurysm (59 %) or a small neck remnant (32 %). Partial occlusion of the recurrent aneurysm was detected in four aneurysms (7 %), and the recurrent size (dome height 2 mm and neck width 3 mm) of one small anterior communicating artery aneurysm was completely unoccluded due to unsuccessful embolization of the aneurysm after deployment of the stent. Further treatment of these five (9 %) unsecured aneurysms has not been decided.

### Follow-up and re-embolizations

Angiographic and clinical follow-up data were available for 51 patients (93 %; 52 aneurysms), with a mean follow-up period of 28.1 months (range 3–114 months). Two (4 %) patients were lost to follow-up due to a transfer to another hospital, and the scheduled clinical and angiographic follow-up of one patient (2 %) had not yet occurred. After the stent-assisted embolization, additional endovascular treatment was performed in nine patients (16 %) due to the additional coil compaction and regrowth of the recurrent aneurysm volume ($N$=7; 13 %) or suboptimal initial occlusion of the recurrent aneurysm ($N$=2; 4 %), including one case (2 %) in which two additional embolizations were performed to a rapidly growing basilar tip aneurysm. However, an adequate angiographic result was not achieved in this patient; this patient was also one of the patients who developed brain stem compression symptoms from the embolized aneurysm (Fig. 3).

## Outcome data and main results

The clinical outcome was favorable in 50 patients (91 %) with GOSs of 4 ($N$=14) or 5 ($N$=36). Poor clinical outcome was recorded in five (9 %) patients, with a GOS of 3 in three patients (5 %) and mortality rate of 3 % ($N$=2). Perioperative mortality rate was 2 % ($N$=1). There were no rebleedings from the treated aneurysms during the available follow-up.

Statistically significant correlations were detected between poor clinical outcome and an exceedingly large (>25 mm) total aneurysm size ($P$=0.002), a large (>10 mm) recurrent aneurysm size ($P$=0.011), and the occurrence of periprocedural complications ($P$<0.001). Further analysis revealed significantly worse prognoses for aneurysms exceeding 2 cm in diameter versus smaller aneurysms ($P$=0.012). In a binomial regression analysis, the only independent factor related to poor clinical outcome was the occurrence of periprocedural complications ($P$=0.017) due to a strong intercorrelation between recurrence size and total aneurysm size ($P$=0.006). Although four of the five patients (80 %) with poor clinical outcome had a medical history of SAH, no statistically significant correlation between poor clinical outcome and SAH was found (Table 2).

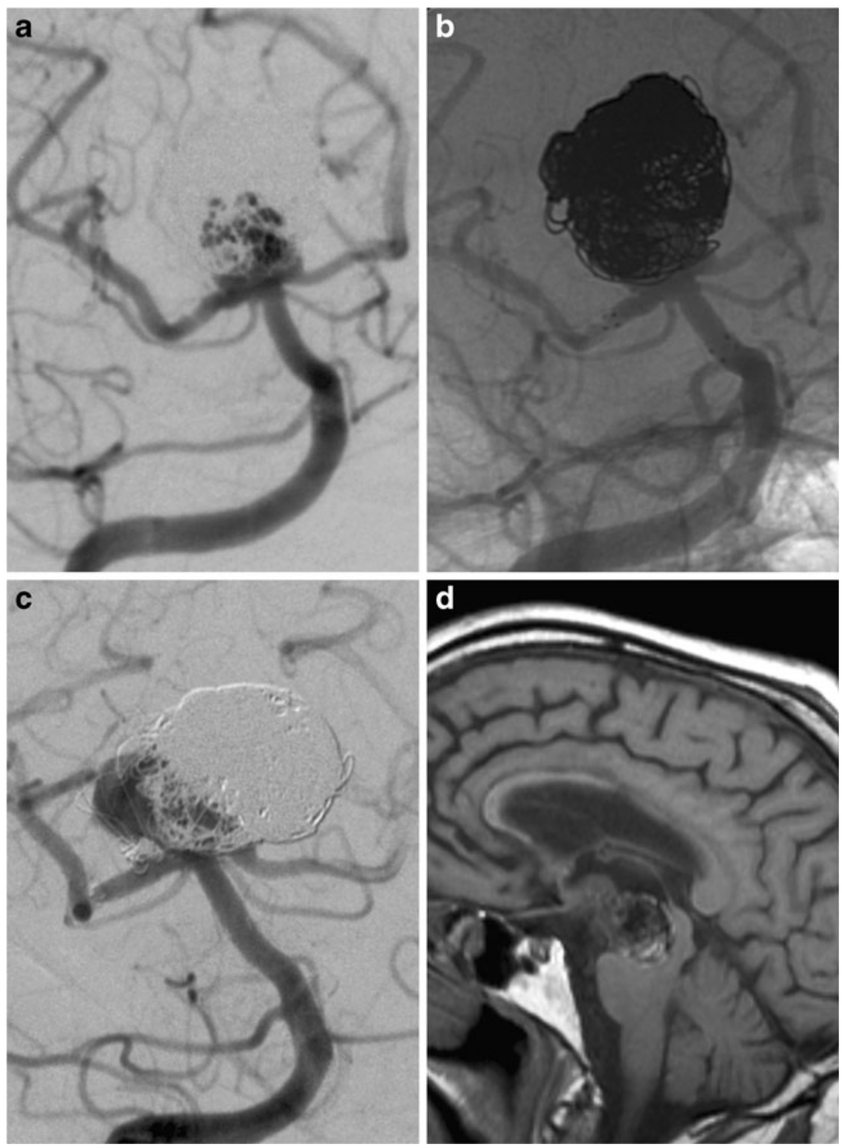


**Fig. 3** Two re-embolizations were performed on this ruptured basilar tip aneurysm 4 and 15 months after the initial coil embolization (**a**). Thirty-three months after the second re-embolization, coil compaction, and recanalization of the aneurysm were revealed via digital subtraction angiography (**b**). The Neuroform stent had become available at this time, allowing stent-assisted re-embolization of the aneurysm. Re-embolization was performed again 31 months after the stent-assisted embolization, but 30 months after the fifth embolization, marked recanalization of the aneurysm was again observed (**c**). At this time, severe compression to the brain stem was associated with the aneurysm, as seen via sagittal T1-weighted magnetic resonance imaging (**d**); the patient died within 1 month. This unstable giant basilar tip aneurysm could not be controlled with a conventional intracranial stent. Flow-diverting stents were not available at the time of treatment

**Table 2** Factors associated with clinical outcome

| | GOS[a] 1–3 | GOS[a] 4–5 | All patients | *P* value[b] |
|---|---|---|---|---|
| Total aneurysm size, N(%)[c] | | | | |
| Small (<10 mm) | 2 (40) | 25 (50) | 27 (49) | 0.002 |
| Large (10–24 mm) | 1 (20) | 24 (48) | 25 (46) | |
| Giant (≥25 mm) | 2 (40) | 1 (2) | 3 (6) | |
| Median (range) | 10 (8–27) | 9 (4–27) | 10 (4–27) | |
| Recurrent/residual aneurysm size, N (%)[c] | | | | |
| <5 mm | 2 (40) | 23 (46) | 25 (46) | 0.011 |
| 5–10 mm | 1 (20) | 25 (50) | 26 (47) | |
| >10 mm | 2 (40) | 2 (4) | 4 (7) | |
| Median (range) | 9 (4–20) | 5 (2–11) | 5 (2–20) | |
| Periprocedural complication, N (%)[c] | | | | |
| Yes | 4 (80) | 2 (4) | 6 (11) | <0.001 |
| No | 1 (20) | 48 (96) | 49 (89) | |
| Periprocedural adjunctive therapy, N (%)[c] | | | | |
| Yes | 0 | 5 (10) | 5 (9) | 1.000 |
| No | 5 (100) | 45 (90) | 50 (91) | |
| Initial angiographic result, N (%)[c] | | | | |
| Complete occlusion | 4 (80) | 26 (52) | 30 (55) | 0.669 |
| Neck remnant | 1 (20) | 19 (38) | 20 (36) | |
| Partial occlusion/no coiling | 0 | 5 (10) | 5 (9) | |
| # of previous treatment sessions, N (%)[c] | | | | |
| 1 | 2 (40) | 32 (64) | 34 (62) | 0.104 |
| 2–4 | 2 (40) | 17 (34) | 19 (35) | |
| ≥5 | 1 (20) | 1 (2) | 2 (4) | |
| History of SAH, N (%) | | | | |
| Yes | 4 (80) | 41 (82) | 45 (82) | 1.000 |
| No | 1 (20) | 9 (18) | 10 (18) | |
| Total | 5 | 50 | 55 | |

[a] Glasgow Outcome Scale *1* dead, *2* vegetative state, *3* severe disability, *4* moderate disability, *5* good recovery

[b] For difference between groups (when applicable)

[c] Corresponding column percentage. Percentages may not sum to 100 % due to rounding

## Discussion

Re-embolization of a previously treated intracranial aneurysm is often considerably more technically challenging than the initial treatment. Although additional coiling of the previously coiled aneurysms has been reported to be associated with a low procedural complication rate and sufficient occlusion in most aneurysms, a small subgroup of challenging residual or recurrent aneurysms requires advanced endovascular therapies and/or multiple retreatment sessions. The risk of complications is increased in the endovascular treatment of these aneurysms, and durable occlusion of the recurrent aneurysm is unlikely, if the diameter of the recurrent aneurysms is over 2 cm, recurrence size is over 10 mm in diameter, or if mass effect is present with a large or giant partially thrombosed aneurysm.

In the International Subarachnoid Aneurysm Trial, retreatment of the primarily embolized aneurysm was performed in 17.4 % of patients (191 of 1,096). Younger patient age, larger lumen size, and incomplete aneurysm occlusion were risk factors for late retreatment after endovascular therapy [3, 9]. In a large meta-analysis, Ferns et al. [5] estimated that approximately 20 % of all coiled aneurysms recur, and half of those go on to be retreated; aneurysm recurrence depended on the initial size and previous rupture status of the aneurysm. In the CARAT study [7], 19 post-procedural re-ruptures occurred among 1,001 patients with ruptured intracranial aneurysms treated with coil embolization or surgical clipping. The median time to re-rupture was 3 days, and the degree of aneurysm occlusion after the initial treatment was strongly associated with the risk of re-rupture, justifying attempts to completely occlude ruptured aneurysms.

The low rate of procedural complications associated with additional coiling of previously embolized aneurysms does not negate the advantage of initial coil embolization [4, 11, 12]. In our study, the risks associated with stent-assisted retreatment were markedly higher than in previous reports of aneurysm re-embolization. However, our study group consisted of complex and wide-necked recurrent aneurysms in which visibility of the target area was often limited and conventional re-embolization therapy had been attempted and/or was regarded infeasible. Three out of the six procedural complications encountered in our series were not specifically device related; in addition to the retroperitoneal hemorrhage encountered in one patient, the progressive brain stem compressions encountered postoperatively in two patients were not device related but rather accentuated the limitations of endovascular therapy in general in the retreatment of large or giant recurrent intracranial aneurysms. Ringer et al. [10] evaluated the risks of retreatment for recurrent or residual aneurysms by endovascular coiling in a multicenter study and discovered that two of the three treatment-related deaths and the single case of permanent major disability occurred in patients who underwent treatment for recurrence more than once. A small subset of patients with aneurysms that are prone to recurrence may exist, and failure of a single retreatment, either with coil embolization or with stent-assisted embolization, was suggested to be an indication for surgery. Ferns et al. [23] assessed late adverse effects in a large series of 124 ruptured aneurysms with incomplete occlusion 6 months after coil embolization; 88 of these aneurysms were selected for retreatment. All but one of the aneurysms (7/8; 88 %) that underwent late complications were 15 mm in size or larger, and the risk of rebleeding or regrowth of the aneurysm was associated with large aneurysm size, aneurysm location in the posterior circulation, and aneurysm re-permeabilization. Another study demonstrated that in partially thrombosed aneurysms presenting with mass effect, the results of parent vessel occlusion were much better than those of selective coiling [24].

Our observations are in agreement with these studies to a large extent. Although there was no statistically significant correlation between the number of treatment sessions and clinical outcome, significant correlations occurred between clinical outcome and aneurysm as well as recurrence size.

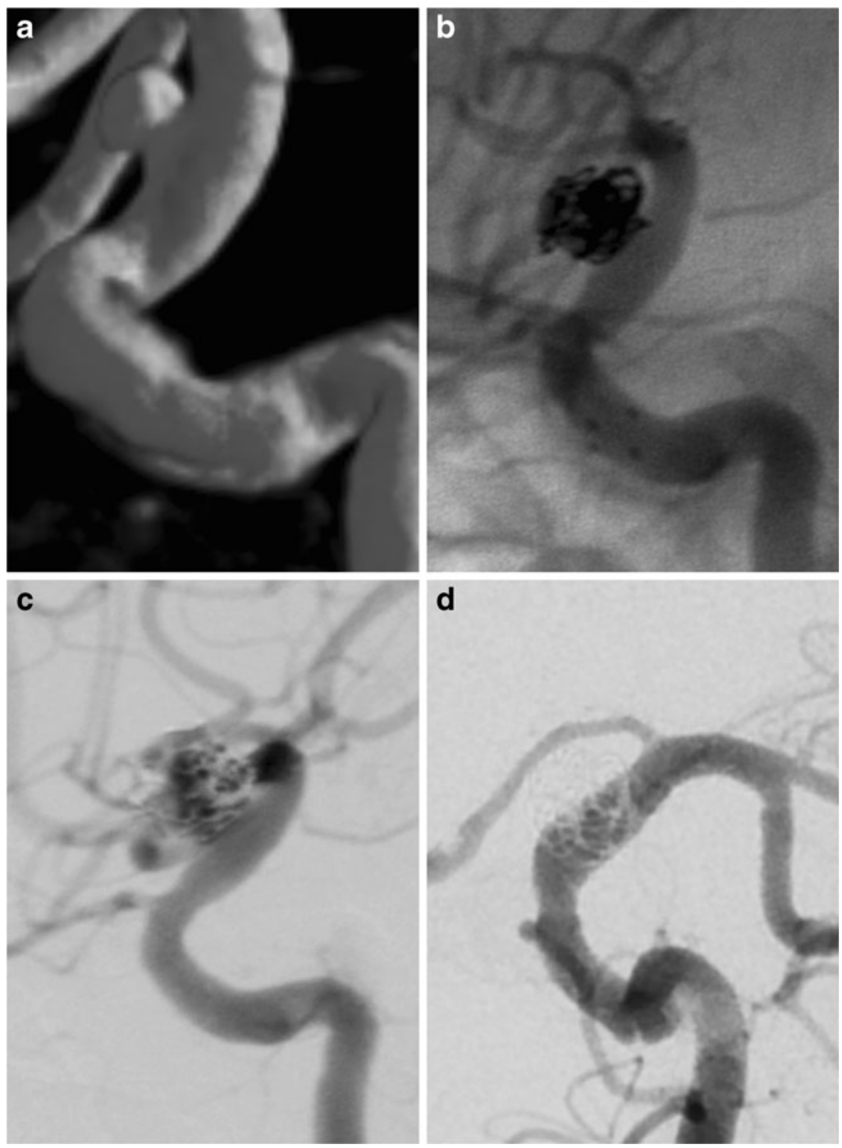


**Fig. 4** A ruptured internal carotid artery aneurysm was visualized in a preoperative three-dimensional digital subtraction angiography reformation (**a**). The aneurysm was adequately occluded with balloon-assisted embolization. One month later, coil compression and recurrent aneurysm formation were observed, and the aneurysm was re-embolized via a stent-assisted technique (**b**). One month later, however, a control digital subtraction angiograph indicated that recanalization of the aneurysm had occurred again (**c**), motivating treatment of the aneurysm with a flow-diverting stent (Silk; Balt Extrusion, Montmorency, France). Complete occlusion of the aneurysm is detected in control DSA images taken 3 months later (**d**). The rapid recanalization of the aneurysm after the insertion of a conventional intracranial stent predicted poor outcome in this patient; the selection of a flow-diverting device was presumably advantageous in this case

Durable occlusion of the recurrent aneurysm was observed in only one of the four aneurysms (25 %), in which the largest diameter of the recurrence volume exceeded 10 mm, and at least two of the three (67 %) of the giant aneurysms in our series were clearly unstable with poor clinical and angiographic results despite multiple treatment sessions and insertion of a stent. Although intracranial stents have several theoretical advantages for the treatment of wide-necked or instable recurrent aneurysms, the stent does not by itself guarantee adequate occlusion or stability of the aneurysm [5, 15, 16, 19]. If progressive mass effect is present with a large or giant partially thrombosed aneurysm, an alternative treatment approach (parent vessel occlusion, surgical clipping, or treatment with a flow-diverting device) may also be preferable (Fig. 4) [25–31].

Although conventional intracranial stents induce marked flow reduction in the inflow jet entering the aneurysm sac, and high obliteration rates at follow-up have been observed despite modest packing of stented aneurysms [32–34], an intracranial stent does not intrinsically warrant adequate flow diversion or thrombosis of the aneurysm. Flow-diverting stents, on the other hand, offer interesting opportunities for the treatment of segmentally diseased vessels, including neck remnants and recurrent aneurysms. The initial results of flow-diverting devices were promising, but major limitations still exist, including the risk of thromboembolic events and the risk of unexplained aneurysm rupture after treatment [31, 35–39]. Since the safety of flow-diverting devices is still equivocal, we have used flow-diverting devices for the treatment of complex intracranial aneurysms only when conventional endovascular or surgical treatment options are not applicable [38].

This retrospective multicenter study has several potential limitations including selection bias, since the treatment decisions for recurrent aneurysms may vary markedly between centers and individual operators [40]. However, the form of treatment for each patient was selected based on a consensus between a neurosurgeon and an interventional radiologist who evaluated the data with similar guidelines. A stent-assisted technique is rarely necessary for the re-embolization of recurrent intracranial aneurysms, limiting the number of patients in this study. In particular, the number of recurrent giant cerebral aneurysms was low in our study, even though their relative proportion was fairly high due to patient selection. The Neuroform stent was the first available intracranial stent and exclusively used in this series. Due to the semi-open cell structure of the Neuroform stent, it kinks rarely and usually opens out adequately also in tortuous target vessels, but stents with closed cell design are re-sheathable and may provide better protection of the aneurysm neck and other intracranial stents (Enterprise; Cordis Neurovascular/Johnson & Johnson and Acclino; Acandis GmbH & Co. KG, Pforzheim, Germany) are now also frequently utilized in our centers. It may also be debatable whether the attributes of the recurrent aneurysms in Finnish population can be directly extrapolated to other populations, since the risk of aneurysm rupture is higher in Finnish and Japanese populations compared to other countries [41].

## Conclusion

According to our midterm results, stent-assisted coil embolization is beneficial for the treatment of wide-necked recurrent or residual intracranial aneurysms. However, stability and permanent occlusion of the recurrent aneurysm is unlikely if the aneurysm exceeds 2 cm in diameter or the recurrent diameter of the aneurysm exceeds 10 mm. A different treatment method (parent vessel occlusion, surgical clipping, or treatment with a flow-diverting device) may also be preferable if mass effect is present with a large or giant partially thrombosed aneurysm. It is important to keep an open mind regarding the treatment of residual or recurrent aneurysms, since surgical and endovascular procedures are often complementary.

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**Conflict of interest** We declare that we have no conflict of interest.

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