EDITOR'S CHOICE

ORIGINAL RESEARCH

A single center comparison of coiling versus stent assisted coiling in 90 consecutive paraophthalmic region aneurysms

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ABSTRACT

Introduction Aneurysm recurrence is a principle limitation of endovascular coiling procedures, with recurrence rates reported of >30%. The adjunct use of self-expandable stents has revolutionized the treatment of intracranial aneurysms, especially for complex morphologies, wide necks or unfavorable dome to neck ratios. However, further investigation into the durability and outcomes of stent assisted coiling procedures is required.

Methods The records of a prospective single center aneurysm database were retrospectively reviewed, and 90 consecutive patients with paraophthalmic aneurysms who underwent coil embolization were identified, 30 of which included stent placement. Patient demographics, aneurysm characteristics, coil packing density, angiographic results (initial and follow-up) and complications were analyzed.

Results Complete aneurysm occlusion was obtained on initial angiography in 13/30 (43.3%) stented and 19/60 (31.7%) non-stented patients. At ≤24 months (mean follow-up 12.8±6.2 months for stented and 12.8±6.6 months for non-stented group), aneurysm recurrence occurred in 3/26 (11.5%) stented and 14/39 (35.9%) non-stented patients ($p<0.05$). At the longest follow-up (mean 14.5±12.5 months for stented and 37.6±35.3 months for non-stented), aneurysm recurrence occurred in 4/26 (15.4%) stented and 17/41 (41.5%) non-stented patients ($p<0.03$). There was no statistically significant correlation between recurrence and aneurysm size or coiling packing.

Conclusions Following endovascular coil embolization of paraophthalmic region aneurysms, recurrence rates at 2 years were significantly lower in patients who had stent assisted coiling (11.5%) compared with patients who had coiling procedures without the use of a stent (35.9%). Aneurysm size and coiling packing density did not significantly affect recurrence in our study population.

INTRODUCTION

Endovascular coil embolization is widely accepted as an important technique for the treatment of intracranial aneurysms. Aneurysm recurrence, or recanalization, has been a principle limitation of coiling procedures, with historical recurrence rates as high as 33.6% at approximately 1 year.[1] The adjunct use of vascular reconstruction devices, particularly self-expandable stents, has revolutionized the endovascular treatment of intracranial aneurysms, especially for aneurysms with complex morphologies, wide necks or unfavorable dome to neck ratios.

Intracranial stents have a multifactorial role in aneurysm embolization. Stents provide a mechanical scaffold for microcoils within an aneurysm, allowing for increased packing density, improved neck coverage and prevention of coil protrusion into the parent artery.[2] Additionally, the operator can position the microcatheter between the aneurysm vessel wall and the stent ('jailing') for more stable access during coil placement. Furthermore, stents have flow diverting properties and induce changes in intra-aneurysmal hemodynamics that are thought to facilitate aneurysm thrombosis and durability of coil emblization.[3–5] Finally, stents provide a scaffold for endothelization and growth of fibroelastic tissue at the aneurysm neck, which may lead to isolation and eventual obliteration of the aneurysm sac.[6]

Various published series and case reports have demonstrated clinical success using stent assisted aneurysm coiling.[7–14] In this study, we present a single institution series of 90 paraophthalmic aneurysms that were treated with endovascular coil embolization, 30 of which were treated with the adjunct use of a stent. Furthermore, we demonstrate that the use of a stent is linked to a lower aneurysm recurrence rate in this population.

METHODS

Patient selection

We retrospectively reviewed the records of a prospective single center aneurysm database to identify consecutive patients with paraophthalmic aneurysms who underwent catheter angiography and coil embolization. Ninety patients, representing 90 paraophthalmic aneurysms, were treated at our institution between May 1992 and March 2009. All 90 aneurysms were embolized with detachable coils, and for 30 of these aneurysms, a self-expandable stent was used. More than 10 interventionalists participated in the treatment of these patients during the study period, making this series an institutional experience.

Endovascular treatment

Coiling procedures were performed on a biplane angiographic system under general anesthesia. Systemic anticoagulation with heparin was used for all procedures that involved stenting. Systemic heparinization was performed after the dome was secured in patients with subarachnoid hemorrhage. When stenting was anticipated prior to elective procedures, patients received preoperative treatment with aspirin (325 mg daily) and clopidogrel (300 mg loading followed by 75 mg daily maintenance × 7 days) followed by 6 months of postoperative aspirin and plavix treatment. For subarachnoid hemorrhage patients, aspirin and plavix were loaded intraprocedure prior to stent placement. Stents were typically used for aneurysms with wide necks (in general, neck to dome ratio >1) and for aneurysms that involved significant circumferential portions of the parent vessel. Stents were avoided in patients with subarachnoid hemorrhage, when possible, although there are some of these patients reflected in the series.

Follow-up protocol

Angiographic images obtained immediately after embolization for each patient were compared with those images obtained at each follow-up visit. For follow-up imaging, patients had either conventional digital subtraction angiography, MR angiography, or both. Digital subtraction angiography was used for sole analysis whenever available.

Data collection and statistical analysis

Patient age, gender, aneurysm size, presence of multiple aneurysms, aneurysm status (ruptured vs unruptured) and admission Hunt and Hess grade (for ruptured aneurysms) were examined. Initial angiographic results were classified as previously described by Roy *et al*.[15] Recurrence rates were examined using two radiographic follow-up periods: 0–24 months and longest to date. The volume of coils was calculated using the Cerebral Aneurysm Calculator (AngioCalc, http://www.angiocalc.com/). Packing was calculated as the ratio of coil volume to aneurysm volume. Technical complications, including thromboembolic events, coil protrusion, parent artery occlusion and stent occlusion, were evaluated. Periprocedural cranial nerve palsies and changes in vision were also recorded. Two tailed Student t tests were used to compare means and Fisher exact tests were used to compare proportions. A probability value of <0.05 was considered statistically significant.

RESULTS

Ninety patients with paraophthalmic aneurysms were treated with endovascular coiling. Thirty of these aneurysms were treated with adjunct use of a self-expandable stent. Patient demographics and aneurysm characteristics are shown in table 1. Mean ages in the stented and non-stented groups were 53.2±12.5 years and 52.4±10.7 years, respectively. Approximately 90% of the patients in each group were women, with multiple aneurysms in 40% of patients in the stented group and in 20% of patients in the non-stented group. Mean aneurysm size in the stented group was 7.0±4.7 mm and 8.8±5.2 mm in the non-stented group, with mean neck sizes of 4.1±1.2 mm and 3.3±1.3 mm in the stented and non-stented groups, respectively. Two of the 30 aneurysms in the stented group were ruptured, with both patients presenting as Hunt and Hess grade 3. Twelve of the 60 aneurysms in the non-stented group were ruptured, with most patients presenting as either Hunt and Hess grade 1 or 3. Of the 30 stented aneurysms, Neuroform stents (Boston Scientific, Natick, Massachusetts, USA) were used in 14 and Enterprise stents (Cordis, Miami Lakes, Florida, USA) in 15 of the cases. The stent type used for one of the aneurysms was unknown.

Table 1 Demographics

	Stented	Non-stented	p Value
No of aneurysms	30	60	1.00
Age (years) (mean±SD)	53.2±12.5	52.4±10.7	0.76
Female gender (n (%))	27 (90.0)	55 (91.7)	1.00
Multiple aneurysms (n (%))	12 (40)	12 (20)	0.08
Aneurysm size (mm) (mean±SD)	7.0±4.7	8.8±5.2	0.11
Neck size (mm) (mean±SD)	4.1±1.2	3.3±1.3	0.10
Aneurysm status, ruptured (n (%))	2 (6.7)	12 (20)	0.13
Hunt and Hess grade (n (%))			
Grade 1	0	5 (41.7)	0.51
Grade 2	0	1 (8.3)	1.00
Grade 3	2 (100)	4 (33.3)	0.16
Grade 4	0	1 (8.3)	1.00
Grade 5	0	1 (8.3)	1.00

Table 2 Immediate angiographic results

	Stented (n=30)	Non-stented (n=60)	p Value
Complete occlusion (n (%))	13 (43.3)	19 (31.7)	0.29
Neck remnant (n (%))	14 (46.7)	26 (43.3)	0.77
Sac remnant (n (%))	3 (10.0)	15 (15.0)	0.06

Immediate angiographic results

Immediate angiographic results following the embolization procedure were analyzed and the results are summarized in table 2. Complete aneurysm occlusion was obtained in 13/30 (43.3%) of the stented patients and in 19/60 (31.7%) of the non-stented patients. Neck remnants were present in 14/30 (46.7%) in the stented group and in 26/60 (43.3%) in the non-stented group. Sac remnant was present in 3/30 (10%) in the stented group and in 15/60 (15%) in the non-stented group. Although a larger percentage of patients in the stented group achieved complete occlusion or neck remnant, this result was not statistically significant.

Aneurysm recurrence, size and packing

Angiographic follow-up time ranged from 3 to 24 months in the stented group and from 3 to 29 months in the non-stented groups. At 2 years (≤24 months) post-embolization, 26/30 stented (86.7%) and 39/60 (65.0%) non-stented patients had repeat imaging (table 3). Mean angiographic follow-up in these patients was 12.8±6.2 months for the stented group and 12.8±6.6 months for the non-stented group ($p=1$). As shown in table 3, aneurysm recurrence was found in 3/26 (11.5%) stented and 14/39 (35.9%) non-stented patients ($p<0.05$), whereas 23/26 (88.5%) stented patients and 25/39 (64.1%) non-stented patients were stable. The lower incidence of aneurysm recurrence in the stented group was statistically significant.

When all follow-up dates post-embolization were analyzed, 26/30 (86.7%) stented patients and 41/60 (68.3%) non-stented patients had follow-up imaging ($p=0.12$), with a mean time of 14.5±12.5 months for the stented patients and 37.6±35.3 months for the non-stented patients (table 4). In this group, aneurysm recurrence was found in 4/26 (15.4%) stented and 17/41 (41.5%) non-stented ($p<0.03$) patients whereas 22/26

Table 3 Aneurysm recurrence (≤24 months of follow-up)

	Stented	Non-stented	p Value
Angiographic follow-up (n (%))	26 (86.7)	39 (65.0)	<0.05
Mean angiographic follow-up (months)	12.8±6.2	12.8±6.6	1
Stable aneurysm size (n (%))	23 (88.5)	25 (64.1)	<0.05
Aneurysm recurrence (n (%))	3 (11.5)	14 (35.9)	<0.05

Table 4 Aneurysm recurrence (longest follow-up)

	Stented	Non-stented	p Value
Angiographic follow-up (n (%))	26 (86.7)	41 (68.3)	0.12
Mean angiographic follow-up (months)	14.5±12.5	37.6±35.3	<0.05
Stable aneurysm size (n (%))	22 (84.6)	24 (58.5)	<0.03
Aneurysm recurrence (n (%))	4 (15.4)	17 (41.5)	<0.03

(84.6%) stented patients and 24/ 41 (58.5%) non-stented patients were stable (p<0.03). There was a statistically significant lower rate of recurrence at the longest follow-up in those aneurysms that had stent assisted coiling versus those with coiling alone.

Recurrence according to initial aneurysm size was analyzed as shown in table 5. In the group of patients with angiographic follow-up at ≤24 months, stented patients with stable follow-up imaging had a mean initial aneurysm size of 6.5±4.2 mm whereas those patients with recurrence had a size of 11.3±7.6 mm (p=0.40). Non-stented patients with stable follow-up had a mean initial aneurysm size of 8.9±5.7 mm, and patients with recurrence had aneurysm sizes of 8.5±3.5 mm (p=0.78). Although the stented aneurysms that recurred following coiling tended to be larger than those that did not recur, there was no statistically significant difference in recurrence according to initial aneurysm size in either the stented or non-stented group.

Recurrence according to initial aneurysm packing was analyzed, as shown in table 6. In the group of patients with follow-up at ≤24 months, stented patients with stable follow-up imaging had mean packing of 27.9±14.7% whereas those patients with recurrence had packing of 18.9±11.9% (p=0.32). Non-stented patients with stable follow-up had mean packing of 22.3±10.8%, and patients with recurrence had packing of 26.4±15.3% (p=0.45). There was no statistically significant difference in recurrence according to initial aneurysm packing in either the stented or non-stented group.

Complications

Complications during the initial embolization procedure were analyzed in the stented and non-stented patients (table 7). Thromboembolism occurred in 0/30 (0%) stented patients and in 2/60 (3.3%) non-stented patients (p=0.55). Parent artery occlusion occurred in 2/30 (6.7%) stented patients and in 4/60 (6.7%) non-stented patients (p=1.0). Coil protrusion occurred in 1/30 (3.3%) and 4/60 (6.7%) of the stented and non-stented patients, respectively (p=0.66). Stent migration occurred in 1/30 (3.3%) patients.

Furthermore, periprocedural cranial nerve palsies and changes in vision were assessed in the two patient groups (table 8). Cranial nerve palsy occurred in 1/30 (3.3%) stented patients and in 2/60 (3.3%) non-stented patients (p=1.0). Worsening of vision occurred in 1/30 (3.3%) of the stented patients and in 4/60 (6.7%) of the non-stented patients (p=0.66). Subarachnoid hemorrhage was believed to be responsible for worsening of vision in the one stented patient and in two of the four non-stented patients with vision changes.

Table 5 Recurrence (≤24 months of follow-up) according to initial aneurysm size

Mean aneurysm size (mm)	Stable	Recurrence	p Value
Stented	6.5±4.2	11.3±7.6	0.40
Non-stented	8.9±5.7	8.5±3.5	0.78

Table 6 Recurrence (≤24 months of follow-up) according to aneurysm packing

Packing (%)	Stable	Recurrence	p Value
Stented	27.9±14.7	18.9±11.9	0.32
Non-stented	22.3±10.8	26.4±15.3	0.45

DISCUSSION

Angiographic recurrence continues to be a major limitation following endovascular coil embolization of aneurysms.[16] In a series of 501 aneurysms treated solely with coil embolization, Raymond *et al* demonstrated recurrence in 33.6% of aneurysms that appeared at a mean time of 12.31±11.33 months. Aneurysm recurrence following coil embolization without the use of a stent was associated with aneurysm size of ≥10 mm, neck size >4 mm, length of follow-up period, incomplete occlusion on initial angiography and treatment during the acute phase following aneurysm rupture.[1] Murayama *et al* also found higher rates of recurrence with larger and giant aneurysms. Although aneurysm location had no statistically significant effect on recurrence in the study from Raymond *et al*, the recurrence rates ranged from 25% for anterior communicating artery aneurysms to 39.4% for basilar bifurcation aneurysm. Ophthalmic carotid aneurysms treated in this study had a recurrence in 26% of cases. The authors suggested that failure to find a statistically significant linkage between location and recurrence may be secondary to insufficient statistical power.[1 17] Further investigation into the endovascular management of paraophthalmic aneurysms is extremely important as aneurysms at this location are considered at many institutions to be surgically challenging and of higher risk secondary to the anatomical complexity of the paraclinoid region.[1 18 19]

The adjunct use of vascular reconstruction devices, in particular self-expandable stents, has been shown to significantly lower aneurysm recurrence rates although published rates of recurrence are still variable. In a large series by Piotin *et al*, angiographic recurrence occurred in 14.9% (17 of 114) of stented aneurysms and in 33.5% (259 or 774) of aneurysms treated without stents at a mean period of 8 months and 12 months, respectively.[14] In a smaller study of 42 patients with intracranial wide neck aneurysms treated with stent assisted coiling, regrowth was observed in four (9.5%) patients.[13] Fiorella *et al* reported an overall recanalization rate of 23.0% at an average follow-up time of 4.6 months.[11] In our series, we demonstrated that paraophthalmic aneurysms treated with stent assisted coiling had a significantly lower recurrence rate than aneurysms treated with coils alone within a 24 month follow-up period (11.5% vs 35.9%, p<0.05) and at the longest follow-up available (15.4% vs 41.5%, p<0.03). Our recurrence rates are comparable with other published series. One limitation of the current study is the difference in angiographic follow-up time points available for stented patients (mean longest follow-up 14.5±12.5 months) versus non-stented patients (mean longest follow-up 37.6±35.3 months). The shorter follow-up period for stented patients was primarily due to the more recent adoption of stenting as routine practice in our institution. Additionally, it is

Table 7 Complications during the initial embolization procedure

	Stented (n=30)	Non-stented (n=60)	p Value
Thromboembolism (n (%))	0 (0)	2 (3.3)	0.55
Parent artery occlusion (n (%))	2 (6.7)	4 (6.7)	1.0
Coil protrusion (n (%))	1 (3.3)	4 (6.7)	0.66

Table 8 Cranial nerve palsies and changes in vision

	Stented (n=30)	Non-stented (n=60)	p Value
Cranial nerve palsy (n (%))	1 (3.3)*	2 (3.3)†	1.0
Worsening of vision (n (%))	1 (3.3)‡	4 (6.7)§	0.66

*One patient with unilateral oculomotor nerve palsy.
†Two patients with unilateral abducens nerve palsy.
‡One patient with worsening vision attributed to subarachnoid hemorrhage, not the embolization procedure.
§One patient with Terson syndrome, one patient with temporary unilateral visual loss that returned to baseline after 1 week of decadron therapy, one patient with unilateral visual loss and one patient with posterior ischemic optic neuropathy, likely secondary to the subarachnoid hemorrhage.

possible that stent usage might change the time to recurrence rather than the absolute recurrence rate. This question remains to be answered in the literature, and additional studies with even longer follow-up data will be required to appropriately address it.

In our series, there was no statistically significant difference in aneurysm size between aneurysms with recurrence versus those that were stable on follow-up for both the stented (11.3±7.6 mm vs 6.5±4.2 mm, p=0.40) and the non-stented (8.5±3.5 mm vs 8.9±5.7 mm, p=0.78) groups. Although not statistically significant, the aneurysms with recurrence in the stented group trended towards larger size. In general, reported rates of recanalization are higher for larger aneurysms regardless of whether a vascular reconstruction device is used, as these lesions are often more technically challenging to treat. For large aneurysms (>10 mm) treated with stent assisted coiling, Fiorella *et al* reported recanalization rates of 36.8% and Piotin *et al* reported rates of 32.6%.[11 14] In a series of very large unruptured aneurysms (>2 cm), Hauck *et al* demonstrated that achieving complete occlusion remains challenging. They reported complete occlusion of 20% (3/15 patients) on follow-up angiography, with occlusion attributed to parent vessel occlusion in one patient and parent vessel sacrifice after stent problems in another.[20]

Aneurysm recanalization following coiling results, at least partially, from compaction of the coil mass. Higher packing density has been correlated with decreased coil compaction and this theoretically reduces recurrence rates.[21 22] In clinical studies, there have been conflicting results regarding the correlation between packing density and aneurysm recanalization. In a study of coil embolization of 25 small (<7 mm) intracranial aneurysms, Goddard *et al* demonstrated that low mean packing density of 8.2% was sufficient for aneurysm stability at an average follow-up of 30.8 months.[23] Other groups, including Kawanabe *et al* and Sluzewski *et al*, have demonstrated that compaction is correlated with lower packing density and that packing densities of 20–25% are needed to protect against recurrence.[21 22] Piotin *et al*, however, demonstrated no significant association between packing density and aneurysm recurrence in a study of aneurysms of various sizes.[24]

In our study, there was no statistically significant difference between packing density for recurrence versus stable aneurysms in either the stented or non-stented group. However, there was a trend towards higher packing density in stented aneurysms that were stable (27.9%) versus those that recurred (18.9%). Using an in vitro model for aneurysm coil embolization, Bendok *et al* demonstrated that use of a vascular reconstruction device provided an absolute increase in coil packing density of greater than 10%, and increased effective coil neck coverage from 28.1% to 30.6%.[2] Stent placement across an aneurysm has also been shown to change intra-aneurysmal hemodynamics in vitro, significantly reducing intra-aneurysmal flow velocity.[5 25 26] The combination of these factors may assist aneurysm thrombosis and help to prevent recurrence.

Stent assisted aneurysm coil embolization procedures are generally associated with higher rates of thromboembolic complications than coiling procedures done without the use of a stent.[14 27] This is generally attributed to platelet aggregation and activation on the stent surface. Yahia *et al* reported thromboembolic events in three of 65 patients (4.6%) with stent assisted coil embolization of an intracranial aneurysm.[27] In-stent thrombosis rates using Neuroform stents (Stryker/Boston Scientific Neurovascular) have ranged from 0.7% to 19%, with a recent study by Mocco *et al* reporting in-stent thrombosis in 1 in 139 stent deployments (0.7%).[28] Piotin *et al*, in a series of 216 aneurysms treated with stent assisted coiling, reported permanent neurological complications in 7.4% (16 of 216) of the procedures with stents versus 3.8% (42 of 1109) of the procedures without stents. These complications were presumably secondary to thrombotic or ischemic events.[14] In the present study, there was no statistically significant difference in complications between those patients with stents and those without. Furthermore, this study demonstrated overall low rates of cranial nerve palsy (3.3% in both groups) and visual disturbance (3.3% in the stented group and 6.7% in the non-stented group). There was no statistically significant difference in cranial nerve palsy or visual disturbance between patients treated with a stent and those treated without. Additionally, if visual changes secondary to subarachnoid hemorrhage were excluded, none of the stented patients and only 2/60 (3.3%) of the non-stented patients had worsening vision.

CONCLUSIONS

We have reported a retrospective review of 90 consecutive patients with paraophthalmic aneurysms who had coil embolization, 30 of which included use of a stent. Stent use was associated with a significant reduction in aneurysm recurrence at 2 years and at the longest follow-up. There was no statistically significant correlation between recurrence and aneurysm size or coiling packing density. Furthermore, complication rates, including cranial nerve palsy and visual disturbance, were low and consistent with other reported series. This report demonstrates that use of a stent is an important adjunct to coil embolization of paraophthalmic aneurysms, with good initial evidence for reducing aneurysm recurrence.

Key messages

Endovascular coil embolization is a widely accepted and useful treatment modality for intracranial aneurysms but the principal limitation of this technique has been aneurysm recurrence over time (>30% at 1 year). The adjunct use of stents for coil embolization procedures has revolutionized the field of endovascular aneurysm management but the long term effects of stent use on aneurysm recurrence is not fully known, particularly at specific aneurysm locations. This study demonstrates that use of a stent during coil embolization of paraophthalmic aneurysms significantly reduces the aneurysm recurrence rate at 2 years (from 35.9% to 11.5%). This difference was not dependent on packing density or aneurysm size in our study. Furthermore, stent use was not associated with increased procedural complications, including thromboembolic events, visual changes or cranial nerve palsies.

Competing interests None.

Ethics approval This study was conducted with the approval of the the Institutional Review Board of Johns Hopkins Hospital.

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