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ABSTRACT

BACKGROUND AND PURPOSE: Stent-assisted coiling has expanded the treatment of intracranial aneurysms. With the use of continuously compiled data, we reviewed the role and drawbacks of stent-assisted coiling.

MATERIALS AND METHODS: We compiled data from consecutive patients from 2003–2012 who underwent coiling, with or without stent assistance. Clinical and angiographic results were analyzed retrospectively.

RESULTS: Of 1815 saccular aneurysms in 1505 patients, 323 (17.8%) were treated with stents (299 procedures) and 1492 (82.2%) without stents (1400 procedures). Procedure-related complications occurred in 9.4% with stents versus 5.6% without stents ($P = .016$, relative risk 1.5; 95% CI, 1.1–2.7). Ischemic complications were more frequent in the stent group than in the no-stent group (7.0% versus 3.5%; $P = .005$; relative risk, 1.7; 95% CI 1.2–2.5), as were hemorrhagic complications (2.3% versus 1.9%, $P = .64$). Procedure-induced mortality occurred in 2.7% (8/299) with stents versus 1.1% (15/1400) without stents ($P = .029$; relative risk, 2.0; 95% CI, 1.1–3.5). Logistic regression analysis identified wide-neck aneurysms as the most significant independent predictor of complications. A total of 64.1% (207/323) of aneurysms treated with stents and 70.3% (1049/1492) treated without stents have been followed, disclosing angiographic recurrence in 15.5% (32/207) versus 35.5% (372/1049), respectively ($P < .0001$). Logistic regression analysis showed that the presence of a stent was the most important factor for the reduction of angiographic recurrence ($P < .0001$; relative risk, 2.3; 95% CI, 1.6–3.3).

CONCLUSIONS: The stent-assisted coiling technique is associated with a significant decrease in recurrences but a significant increase in complications. The treatment of wide-neck aneurysms remains hazardous.

The stent-assisted coiling technique has broadened the indication for coil embolization, and numerous reports have depicted the value of stents in the treatment of cerebral aneurysms.^{1–6}

We present herein the clinical and angiographic results of a consecutive series of 1815 aneurysms treated over a 9-year period. The aims of this retrospective study were to place the role of stent-assisted coiling into perspective and to determine the factors associated with procedural complications.

MATERIALS AND METHODS

Data Collection

From a prospectively gathered data base of all patients with intracranial saccular aneurysms (with no prior endovascular treat-

ment) who were treated with coils in our institution between January 2003 (when we initiated the use of self-expandable stents) and March 2012, 1505 patients were identified and constituted our study population. The data base included data on the patient (age, sex), the endovascular procedure technique (balloon-assisted, stent-assisted, stand-alone coiling), aneurysm status (ruptured or not), procedure-related morbidity and mortality, immediate and follow-up angiographic results, and the rate of (re-)hemorrhage. All data were reviewed and statistically analyzed. Institutional review board acceptance was obtained for this retrospective study, and the need for informed consent was waived.

Endovascular Procedures

Coiling was performed under general anesthesia and full anticoagulation with heparin in all cases. In all patients with no history of subarachnoid hemorrhage within the previous 4 weeks, 250 mg aspirin was given intravenously. Heparin was discontinued after embolization in most patients. Whenever stent placement was anticipated, patients were given dual antiplatelet therapy before surgery (75–150 mg clopidogrel, 250 mg aspirin daily initiated 15

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Table 1: Baseline demographics and procedures

	Total	Stent-Assisted	No Stent	P
No. of aneurysms	1815	323	1492	—
Age, y, mean \pm SD	50.5 \pm 12.9	51.8 \pm 11.5	50.3 \pm 13.1	.009
Ruptured aneurysm, n (%)	767 (42.3)	38 (11.8)	729 (48.9)	<.0001
Female, n (%)	986 (65.5)	196 (68.8)	790 (64.8)	.20
Location, n (%)				
ICA	647 (35.6)	134 (41.5)	513 (34.4)	.015
MCA	489 (26.9)	94 (29.1)	395 (26.5)	.34
AcomA	446 (24.6)	49 (15.2)	397 (26.6)	<.0001
Vertebrobasilar	160 (8.8)	42 (13.0)	118 (7.9)	.003
Pericallosal	59 (3.3)	2 (0.6)	57 (3.8)	.003
PCA	14 (0.8)	2 (0.6)	12 (0.8)	.73
Aneurysm size, mm, mean \pm SD	7.1 \pm 4.0	8.2 \pm 4.7	6.8 \pm 3.8	<.0001
Neck size, mm, mean \pm SD	3.8 \pm 1.9	5.0 \pm 2.6	3.6 \pm 1.6	<.0001
Multiple, n (%)	1078 (59.4)	147 (45.5)	931 (62.4)	.004
AVM-related, n (%)	36 (2.0)	2 (0.6)	34 (2.3)	.052
No. of procedures	1699	299	1400	—
No. of aneurysms treated in same EVT, n (%)				
1	1591 (93.6)	275 (92.0)	1316 (94.0)	
2	100 (5.9)	24 (8.0)	76 (5.4)	
3	8 (0.5)	0	8 (0.6)	
Balloon-assisted, n (%)	1017 (56.0)	149 (46.1)	868 (58.2)	<.0001
Packing density, %, mean \pm SD	26.8 \pm 12.3	24.6 \pm 11.1	27.3 \pm 12.5	<.0001

Note:—AcomA indicates anterior communicating artery; EVT, endovascular treatment; PCA, posterior cerebral artery.

days before the procedure and continued for 6 months). There were no strict exclusion criteria, but a massive subarachnoid hemorrhage potentially requiring ventricular drainage was considered to be a contraindication to stent placement.

Follow-Up Protocol

Our standard follow-up protocol consisted of fixed angiographic follow-up, the first follow-up being performed at 1–6 months after endovascular treatment (depending of the quality of the initial angiographic occlusion and the presentation). The second angiographic follow-up was performed 12 months after the first follow-up, and the third follow-up was performed 24 months after the second follow-up. In the case of angiographic recurrence and/or associated aneurysms left untreated, the follow-up was continued on a yearly basis. A single reader prospectively evaluated all angiograms. The degree of aneurysm occlusion was classified according to the Montreal simplified classification.⁷ Aneurysm recurrence was dichotomized as absent or present. At follow-up, an aneurysm was considered recurrent if a previously totally occluded aneurysm (class 1) had a partial recurrence of the neck (class 2) and/or the sac (class 3). An aneurysm was considered remnant regrowth if a subtotally occluded aneurysm (class 2 or 3) was found to have an increasing neck remnant or residual aneurysm. Aneurysm dimensions were determined on 3D images derived from rotational angiography. Indication for retreatment (class 3 angiographic results) was decided on a case-to-case basis, depending on the patient age and medical history. Aneurysm retreatments were noted.

Statistical Analysis

Data are presented as means for continuous variables and frequencies for categoric variables. Statistical analysis of categoric variables was carried out by use of χ^2 and Wilcoxon tests. Analysis of variance followed by Bonferroni post hoc testing was used to assess differences between the stent-assisted and no-stent groups.

A multivariable logistic regression analysis was carried out to determine predictors of procedural complications and aneurysm recanalization. *P* values of $\leq .05$ were considered statistically significant. Statistical analysis was carried out with R software version 2.15 (<http://www.r-project.org/>).

RESULTS

Baseline Demographics and Procedures

Among 1505 consecutive patients, 1815 intracranial aneurysms were treated by coil embolization in 1699 procedures. A total of 323 aneurysms were treated with the assistance of self-expandable stents in 299 procedures; 1492 aneurysms were treated without stent assistance in 1400 procedures. The baseline demographics of all of the aneurysms according to stent use are shown in Table 1.

In the stent-assisted group, 76.2% (246 aneurysms) had single stent placement and 23.8% (77 aneurysms) had multiple stent placement (Y, X, or straight overlapping configuration). A balloon-assisted technique was used in 46.1% in the stent-assisted group (the stent was deployed after coiling), including 6.8% (22/323) of bailed-out stent placement, versus 58.2% in the no-stent group ($P < .0001$). In 53.3% of aneurysms (172/323), the stents were delivered before coiling (145 trans-cell, 16 jailed-catheter, and 11 stent-jack techniques).

Immediate and Follow-Up Angiographic Results

Immediately, there were more complete obliterations in the no-stent group and more residual aneurysms in the stent-assisted group, but this trend was reversed at last follow-up (Table 2).

Angiographic follow-up was available for 1256 of 1815 aneurysms (69.2%) (Table 3). The no-stent group had a longer mean follow-up ($P = .0004$). The stent-assisted group had fewer angiographic recurrences ($P < .0001$). Of the 1492 aneurysms treated with coils, 140 (9.4%) were retreated, whereas 20 (6.2%) of the 323 stent-assisted coiled aneurysms were retreated ($P = .084$).

Risk Factors for Angiographic Recurrence

In the univariate analysis, the risk factors for angiographic recurrence were ruptured status at presentation, larger aneurysm size, no stent, wider neck, younger age, and lower coil packing attenuation (Table 4). The identified reductive factor for angiographic recurrence was multiple aneurysms. In the logistic regression analysis, the independent variables were ruptured status at presentation, absence of stent, larger aneurysm size, lower packing attenuation, younger age, and wider neck (Table 4). In the univariate analysis, the risk factors for aneurysm retreatment were larger aneurysm, lower packing attenuation, and incomplete initial aneurysm occlusion. In the logistic regression analysis, the independent variables favoring retreatment were larger aneurysm size, absence of stent, hemorrhagic presentation, lower packing attenuation, and initial incomplete occlusion (Table 5).

Table 2: Immediate and follow-up angiographic results

	Total	Stent-Assisted	No Stent	P
Immediate result, n (%)	(n = 1815)	(n = 323)	(n = 1492)	–
Class 1 ^a	1083 (59.7)	165 (51.1)	918 (61.5)	<.001
Class 2 ^b	307 (16.9)	44 (13.6)	263 (17.6)	.08
Class 3 ^c	425 (23.4)	114 (35.3)	311 (20.8)	<.0001
Last follow-up result, n (%)	(n = 1254)	(n = 207)	(n = 1047)	–
Class 1 ^a	718 (57.3)	152 (73.4)	566 (54.1)	<.0001
Class 2 ^b	319 (25.4)	30 (14.5)	289 (27.6)	<.0001
Class 3 ^c	217 (17.4)	25 (12.1)	192 (18.3)	.04

^a Complete obliteration (Reference 7).^b Residual neck (Reference 7).^c Residual aneurysm (Reference 7).**Table 3: Angiographic recurrence**

	Total	Stent-Assisted	No Stent	P
No. of aneurysms followed	1254	207	1047	–
Cumulative follow-up, mo, median (range)	20.0 (1–122)	16.0 (1–69)	21.0 (1–122)	.0004
Recurrence, n (%)	404 (32.2)	32 (15.5)	372 (35.5)	<.0001

Table 4: Risk factors for angiographic recurrence

	Univariate P	Relative Risk	95% CI	Logistic Regression P
Younger age	.004			.008
Location				
ICA	.056	0.84	0.70–1.00	
MCA	.72	1.04	0.86–1.25	
AcomA	.39	1.09	0.90–1.32	
Vertebrobasilar	.82	1.05	0.78–1.37	
Pericallosal	.054	1.50	0.99–2.03	
PCA	.50	0.56	0.10–1.63	
Sac size	<.0001			<.00001
Neck size	.001			.02
Packing density	.013			.005
Cumulative follow-up period	.33			
Balloon-assisted	.82	0.98	0.83–1.16	
SAH	<.0001	1.72	1.46–2.02	<.00001
No stent	<.0001	2.30	1.65–3.28	<.00001

Note:—AcomA indicates anterior communicating artery; PCA, posterior cerebral artery.**Table 5: Risk factors for retreatment**

	Univariate P	Logistic Regression P
Sac size	<.001	<.001
Stent	.084	.0039
SAH	.098	.0024
Packing density	<.001	.019
Initial occlusion	<.001	<.001

Procedure-Related Complications

The procedure-related complications were counted for any intracranial hemorrhages (including a wire perforation or an aneurysm rupture) and any ischemic events (that resulted in patient morbidity or mortality). Hydrocephalus after the treatment of unruptured aneurysms was also counted as a complication. In the no-stent group, procedure-related complications occurred in 5.6% of procedures,

Table 6: Procedure-related complications

	Total	Stent-Assisted	No Stent	χ^2
No. of procedures	1699	299	1400	–
Complications, n (%)	107 (6.3)	28 (9.4)	79 (5.6)	0.016 ^a
Ischemia	70 (4.1)	21 (7.0)	49 (3.5)	0.005 ^a
Hemorrhage	34 (2.0)	7 (2.3)	27 (1.9)	0.64
Hydrocephalus	3 (0.2)	0	3 (0.2)	0.42
Complication-related deaths, n (%)	23 (1.4)	8 (2.7)	15 (1.1)	0.029 ^a

^a Significant value.

including complication-related deaths in 1.1% (Table 6). The 49 ischemic complications resulted in 5 deaths, and the 27 perforations resulted in 10 deaths. There were 3 hydrocephali after treatment of unruptured aneurysms with hydrogel-coated coils.

In the stent-assisted group, complications occurred in 9.4% of procedures and led to 8 deaths (2.7%). The 21 ischemic events led to 5 deaths, and the 7 hemorrhagic events led to 3 deaths. Overall, there were significantly more complications in the stent-assisted group than in the no-stent group (9.4% versus 5.6%; $P = .016$).

In the univariate analysis, the risk factors for procedure-related complications were wider neck, stent-assisted coiling, MCA location, and larger aneurysm. In logistic regression analysis, the independent variable was a wider neck. Stent-assisted coiling and aneurysm size were related to neck width (Table 7).

(Re-)Bleeding After Coiling

Only 21 of 1815 aneurysms (1.2%) bled after endovascular treatment (Table 8). The rates of (re-)bleeding were 0.3% in the stent-assisted group and 1.4% in the no-stent group. In the stent-assisted group, 2 patients bled after treatment of unruptured aneurysms (1 from the aneurysm 12 months after the treatment; the second was readmitted 3 weeks after the treatment with a remote intraparenchymal hematoma). No rebleeding was seen from previously ruptured aneurysms. In the no-stent group, 1 unruptured aneurysm bled 12 months after coiling (modified Rankin Scale 4). Nineteen rebleedings occurred after coil embolization of 729 ruptured aneurysms (2.6%) and led to 13 deaths.

DISCUSSION

Stent-assisted coiling creates a mechanical scaffold to prevent coil protrusion into the parent vessels. Thus, the indication for this technique had mostly been motivated by aneurysm morphology (large neck). Accordingly, our stent-assisted group included aneurysms with wider necks. Ruptured aneurysms were underrepresented to avoid antiplatelet therapy in the setting of subarachnoid hemorrhage. In the stent-assisted group, internal carotid and MCA aneurysms were overrepresented, whereas posterior circulation and pericallosal aneurysms were scarce, explained by a lower incidence of wide-neck aneurysms in these locations. Multiple aneurysms, which were more often treated with coiling alone, tended to have a smaller size, a narrower neck, and fewer ruptured aneurysms compared with the group of single aneurysms.

Immediate and Follow-Up Angiographic Results

Immediate angiographic complete occlusions were obtained less frequently in the stent-assisted than in the no-stent group (51.1% versus 61.5%). This is because larger aneurysms were more frequent in the

stent-assisted group and because dual antiplatelet therapy affected the immediate intra-aneurysmal thrombosis. Catheter kickback out of the stent also affected tight packing. Conversely, at follow-up, complete occlusions increased to 73.4% in the stent-assisted group, whereas these diminished to 54.0% in the no-stent group. For stent-assisted coiling, numerous articles have reported a broad range (13.2–94.4%) of immediate complete occlusion.^{1,2,8–13} However, similar to the present series, most mid-to-long-term follow-up series have reported augmented rates of angiographic complete occlusion at follow-up (range, 54–81%).^{8–14}

Angiographic Recurrences

Recurrences were statistically less likely in the stent-assisted group (15.5% versus 35.5%; $P < .0001$). Low rates of recurrence for stent-assisted coiling have also been reported in other recent studies (range, 0–15.2%).^{8,10,11,13–15} In line with our findings, rup-

tured aneurysms, larger size, lower packing attenuation, and wide necks are well-established risk factors for recurrence.^{7,16–20} We also identified younger age to be a risk factor for recurrence. The effect of age is not yet clear, but younger age was one of the predicting factors of late retreatment in the International Subarachnoid Aneurysm Trial.²¹

Multiple aneurysms reduced the likelihood of recurrence, but these aneurysms were generally smaller, had narrower necks, and had fewer ruptured lesions.

In our study, the use of a balloon-assisted technique had no influence on recurrence. Conversely, Shapiro et al²² found both initial and follow-up aneurysm occlusion rates to be higher in balloon-assisted cases. In our study, an absence of a stent was identified as one of the most relevant factors for recurrence. Our results help to confirm the evidence that stent-assisted coiling augments treatment durability and contributes to progressive occlusion.^{10,23,24} This durability can be explained by the combination of biologic, geometric, and hemodynamic mechanisms.^{25–27}

Procedural Complications

Our no-stent results show occurrences of complications (5.6%) and mortality (1.1%) similar to various other series without stents.^{28–31} Henkes et al²⁸ reported procedural morbidity of 5.0% and mortality of 1.5%. van Rooij et al³⁰ reported procedural complications with a morbidity rate of 3.2% and a mortality rate of 2.6%. A recent meta-analysis for unruptured aneurysms (mainly of studies without the use of stents) found a morbidity rate of 4.8% and a mortality rate of 1.2%.²⁹ Our complication and mortality

Table 7: Risk factors for procedure-related complications

	Univariate <i>P</i>	Relative Risk	95% CI	Logistic Regression <i>P</i>
Age	.16			
Location				
MCA	.01	1.67	1.15–2.43	.058
Vertebrobasilar	.08	0.40	0.15–1.07	–
ICA	.84	0.94	0.64–1.38	–
AcomA	.48	0.83	0.53–1.30	–
Pericallosal	1.00	0.85	0.28–2.50	–
PCA	.71	NA		–
No. of aneurysms in same EVT (multiple vs single)	.98	1.04	0.58–1.79	–
Size	.04			.94
Neck	<.001			.02 ^a
Balloon-assisted	1.00	1.02	0.70–1.47	–
SAH	.98	1.01	0.70–1.47	–
Stent	.016	1.66	1.07–2.55	0.15
Single (vs Y) stenting	.36	1.59	0.73–3.47	–

Note:—AcomA indicates anterior communicating artery; EVT, endovascular treatment; NA, not available for the small sample numbers; PCA, posterior cerebral artery.

^a Significant value.

Table 8: Aneurysm (re)-bleeding summary

Case/Sex/Age	Presentation	Use of Antiplatelet	Initial Aneurysm Occlusion	Stent	(Re)-Bleeding Delay	Outcome (mRS)
1/F/71	SAH	None	1	None	Day 1	6
2/F/68	Fortuitous	None	1	None	12 mo	4
3/M/46	SAH	None	3	None	Day 10	6
4/F/48	SAH	None	3	None	Day 10	6
5/F/65	SAH	8 mg i.a. of abciximab during procedure	1	None	Hour 14	6
6/F/57	SAH	None	1	None	Day 1	4
7/M/35	SAH	None	1	None	Hour 6	6
8/M/48	SAH	None	3	None	Hour 8	6
9/F/55	SAH	None	3	None	89 mo	6
10/F/37	SAH	None	2	None	57 mo	6
11/F/52	SAH	None	1	None	17 mo	1
12/F/81	SAH	None	3	None	Day 4	6
13/F/55	SAH	None	3	None	4 mo	6
14/M/52	Fortuitous	Clopidogrel + aspirin	2	Yes	12 mo	1
15/M/41	SAH	None	1	None	Day 18	6
16/M/52	SAH	4 mg i.a. of abciximab during procedure	1	None	Day 1	6
17/F/51	SAH	4 mg i.a. of abciximab during procedure	1	None	Hour 4	6
18/M/20	SAH	No	1	None	Day 22	1
19/M/69	Fortuitous	Clopidogrel + aspirin	1	Yes	Day 21	6
20/F/56	SAH	No	3	None	Day 1	6
21/F/56	SAH	No	3	None	2 mo	1

Note:—i.a. indicates intra-arterial.

rates in the stent-assisted group were 9.4% and 2.7%, respectively. These are similar to other series of stent-assisted coiling that have reported 2.9–11% morbidity rate and 0–4.8% mortality rate.^{1,3,5,8,32,33} Overall, our complication rate in the stent-assisted group was higher than in the stand-alone coiling series (9.4% versus 5.6%; $P = .016$). The use of a stent was linked to a significantly higher morbidity in our series, but not as an independent factor because stents were generally used in aneurysms with wider necks.

Three cases (0.2%) of hydrocephalus occurred after the treatment of unruptured aneurysms with hydrogel-coated coils, and there were no cases in the smaller stent-assisted group. The HELPS trial also reported that there was no significant difference in the occurrence of hydrocephalus between the hydrogel-coated and bare-platinum coil groups.³⁴

A large aneurysm size was identified as a risk factor for complications but was not identified as an independent value, unlike neck width, which also appeared to be an independent factor. In the CLARITY study, aneurysms >10 mm had a higher risk of thromboembolic events, with higher morbidity-mortality rates compared with smaller lesions.³⁵ Similar results have also been reported in the ATENA study.³³ Moreover, the amount of procedural aneurysmal ruptures was significantly higher for smaller aneurysms.^{33,36} In CLARITY, the morbidity-mortality secondary to thromboembolic events was higher in the group of aneurysms for which the neck was >4 mm.³⁵ In the same study, a neck >4 mm was also identified as an independent risk factor of intraoperative rupture.³⁵

As in our study, age was not identified as a risk factor for complications in the series from van Rooij et al.³⁰ However, Sedat et al¹⁴ reported that thromboembolic events were more frequent among elderly patients, whereas in the CLARITY study, procedural ruptures were more likely to occur in patients <65 years of age.³⁵ As did van Rooij et al,³⁰ we did not find any specific locations to be linked with complications. However, we found that MCA location was a risk factor in the univariate analysis. Similarly, the CLARITY study reported that thromboembolic events were more likely to occur in MCA aneurysms than in aneurysms in other locations, such as intraoperative ruptures.³⁵ The treatment of several aneurysms during the same procedure was not found to result in more complications, as was previously found in the CLARITY study.³⁵ However, only 6.4% of our procedures were multiple aneurysm treatments. The balloon-assisted technique was not identified as a risk factor for complications, unlike in some previous reports.^{28,30,37} However, the ATENA and CLARITY studies showed that the balloon-assisted technique was as safe as conventional coiling.^{33,35} A ruptured aneurysm was not found to be a significant risk factor for complications in the current study. However, this is contrary to various other studies. For example, Ng et al¹⁸ reported that intraprocedural ruptures occurred more frequently for ruptured aneurysms than for unruptured aneurysms. Ishibashi et al³⁸ reported that hyper intensities were seen more frequently on diffusion-weighted MRI after the treatment of ruptured than unruptured aneurysms. Also, Ross and Dhillon³⁹ reported that the risks of vessel or aneurysm rupture or thromboembolic stroke were greater during the treatment of ruptured aneurysms. Similarly, Park et al³⁶ reported that pro-

cedural morbidity and mortality rates were higher for ruptured than unruptured aneurysms. We cannot postulate as to why our results are different from these studies.

(Re-)Bleeding

The (re-)bleeding rates were low for both stented and nonstented aneurysms, which is in line with previous reports.^{40–43} None of the ruptured aneurysms that were treated with stent-assisted coiling rebled. However, no definitive conclusions can be drawn because of the small number of ruptured aneurysms that were treated with stents.

Study Limitations

Our study has the inherent limitations of a retrospective study. The duration of follow-up was shorter for stented aneurysms because most of the stents were implanted during the last 6 years. Moreover, the rate of aneurysms followed by angiography was lower.

CONCLUSIONS

The stent-assisted coiling technique was associated with a significant decrease in recurrences but a significant increase in complications. The treatment of wide-neck aneurysms remains more hazardous.

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