Clin Neuroradiol (2018) 28:569–577
DOI 10.1007/s00062-017-0612-x

ORIGINAL ARTICLE

Progressive Occlusion of Small Saccular Aneurysms Incompletely Occluded After Stent-Assisted Coil Embolization

Analysis of Related Factors and Long-Term Outcomes

Jeong Wook Lim[1] · Jeongjun Lee[2] · Young Dae Cho[2]

Received: 19 April 2017 / Accepted: 18 July 2017 / Published online: 8 August 2017

Abstract
Purpose Incompletely occluded aneurysms after coil embolization are subject to recanalization but occasionally progress to a totally occluded state. Deployed stents may actually promote thrombosis of coiled aneurysms. We evaluated outcomes of small aneurysms (<10 mm) wherein saccular filling with contrast medium was evident after stent-assisted coiling, assessing factors implicated in subsequent progressive occlusion.
Methods Between September 2012 and June 2016, a total of 463 intracranial aneurysms were treated by stent-assisted coil embolization. Of these, 132 small saccular aneurysms displayed saccular filling with contrast medium in the immediate aftermath of coiling. Progressive thrombosis was defined as complete aneurysmal occlusion at the 6-month follow-up point. Rates of progressive occlusion and factors predisposing to this were analyzed via binary logistic regression.
Results In 101 (76.5%) of the 132 intracranial aneurysms, complete occlusion was observed in follow-up imaging studies at 6 months. Binary logistic regression analysis indicated that progressive occlusion was linked to smaller neck diameter (odds ratio [OR] = 1.533; p = 0.003), hyperlipidemia (OR = 3.329; p = 0.036) and stent type (p = 0.031). The LVIS stent is especially susceptible to progressive thrombosis, more so than Neuroform (OR = 0.098; p = 0.008) or Enterprise (OR = 0.317; p = 0.098) stents. In 57 instances of progressive thrombosis, followed for ≥12 months (mean 25.0 ± 10.7 months), 56 (98.2%) were stable, with minor recanalization noted once (1.8%) and no major recanalization.
Conclusion Aneurysms associated with smaller diameter necks, hyperlipidemic states and LVIS stent deployment may be inclined to possible thrombosis, if occlusion immediately after stent-assisted coil embolization is incomplete. In such instances, excellent long-term durability is anticipated.

Keywords Aneurysm · Coil embolization · Stent · Recanalization · Progressive occlusion

Introduction

In coil embolization of intracranial aneurysms, complete occlusion is critical to reduce the potential for recanalization (and retreatment) and to avoid possible rebleeding at a later time [1, 2]; however, despite saccular opacification (i.e. contrast medium filling) in immediate postcoiling studies, complete occlusion may ultimately materialize. This phenomenon is known as progressive thrombosis or progressive occlusion. For some aneurysms with unfavorable configurations and/or complex angioanatomic features refractory to all efforts, the prospect of progressive thrombosis is a clear advantage, offering positive outcome under difficult conditions. Stent usage also considerably broadens the scope of endovascular treatment in therapeutically challenging lesions. Stenting provides mechanical support

Electronic supplementary material The online version of this article (doi: 10.1007/s00062-017-0612-x) contains supplementary material, which is available to authorized users.

✉ Young Dae Cho
aronnn@naver.com

[1] Department of Neurosurgery, Chungnam National University Hospital, Chungnam National University College of Medicine, Daejeon, Korea (Republic of)

[2] Department of Radiology, Seoul National University Hospital, Seoul National University College of Medicine, 101 Daehak-ro, 03080 Jongno-gu, Seoul, Korea (Republic of)

to prevent coil prolapse, enable dense packing of coil, and potentially divert blood flow around aneurysms, acting as a scaffold for endothelial growth and vessel healing [3–8]. Stents may also serve in promoting progressive thrombosis of coiled aneurysms [1]. Although the capacity of stents to protect against later recanalization in treated aneurysms is acknowledged, the progressive saccular occlusion afforded by stenting after coil embolization and the impact of stent type on progressive thrombosis of aneurysms have not been adequately investigated.

In this study, we evaluated outcomes of small aneurysms (<10 mm) that showed saccular filling with contrast medium immediately after stent-assisted coiling, assessing factors implicated in subsequent progressive occlusion.

Methods and Materials

Patient Population

For this retrospective review, we examined a total of 463 consecutive coil embolization procedures (involving stents) done in nearly a 4-year period (September 2012 to June 2016) at a single institution. After excluding 43 patients with non-saccular aneurysms (i.e. dissecting, fusiform, pseudoaneurysm, or blood blister-like aneurysms), 65 patients with recanalized aneurysms, and 26 patients with large aneurysms (>10 mm), 329 saccular aneurysms remained eligible for study. Another 14 patients lacking 6-month follow-up imaging were secondarily excluded, leaving 289 patients with 315 aneurysms for study enrollment (95.7% of 6-month follow-up roster). The cohort was finally reduced to 132 aneurysms, each showing saccular filling with contrast medium immediately after coil embolization (according to the Raymond classification), having further excluded 183 aneurysms with complete occlusion or residual necks. Clinical and radiologic data were analyzed to determine the fates of such aneurysms and any factors predisposing to progressive thrombosis. An algorithm of patient selection is shown in Fig. 1. This study was approved by our Institutional Review Board. The requirement to obtain written informed consent for study participation was waived.

During this period, we used three proprietary stents at our institution: Enterprise (Codman Neuro, DePuy Synthes, West Chester, PA), Neuroform (Stryker, Kalamazoo, MI), and Low-profile Visualized Intraluminal Support device (LVIS, MicroVention, Tustin, CA). Multiple patient variables, including gender, age, hypertension, diabetes, smoking, hyperlipidemia, and clinical presentation, e.g. unruptured intracranial aneurysm (UIA) vs. subarachnoid hemorrhage (SAH), were retrieved from medical records. Angiographic data were also collected, namely size of aneurysm and neck, location (anterior vs. posterior circulation), depth-to-neck ratio (D/N ratio), packing density, and use of bioactive coils (hydrogel-modified or polyglycolic acid/lactide copolymer-coated coils). Based on the length of bioactive coil engaged (relative to total length of coil inserted), aneurysms were grouped as bare (≤50%) or bioactive (>50%) coils. To reflect hemodynamic stress, all aneurysms were classified as side-wall or bifurcation type [9]. Ratios of both arterial branches involved were calculated based on maximum diameter of each (side-wall type <0.5, bifurcation type ≥0.5).

Endovascular Procedures

Most of the endovascular procedures were performed with the patient under general anesthesia. All patients underwent cerebral angiography and rotational angiography with 3D image reconstruction, using the Innova IGS 630 (General Electric, Wauwatosa, WI), Integris V and Allura Clarity (Philips Medical System, Best, The Netherlands) biplane system. Those with unruptured aneurysms received antiplatelet prophylaxis prior to coiling in a relatively consistent manner, as stipulated at our facility [10]. Dual antiplatelet agents (clopidogrel and aspirin) were administered if stent protection was anticipated during a procedure. In poor responders to clopidogrel, based on the VerifyNow P2Y12 assay (Accriva Diagnostics, San Diego, CA), cilostazol was added. A bolus of heparin (3000 IU) was administered after femoral arterial sheath placement, delivering hourly boluses (1000 IU) thereafter; and activated clotting time was monitored hourly. Dual-agent antiplatelet medication was recommended as maintenance for at least 3 months after a procedure, and then a single agent for at least 1 year.

Antiplatelet premedication was withheld in patients with ruptured aneurysms, ensuring lesions were adequately protected before initiating systemic heparinization. Loading doses of clopidogrel and aspirin were administered after procedures, and maintenance regimens were the same as those applied to unruptured aneurysms.

Angiographic Outcomes and Follow-up Monitoring

Using the three-point Raymond scale, immediate postembolization angiographic results were graded as follows: complete occlusion (no filling of aneurysms with contrast medium); residual neck (any remnant of original arterial wall defect); and residual sac (any opacification of sac) [11]. To investigate progressive occlusion, this study was restricted to aneurysms displaying persistent contrast medium-filled sacs.

Time-of-flight magnetic resonance angiography (TOF-MRA), with 3D reconstruction from source images, was

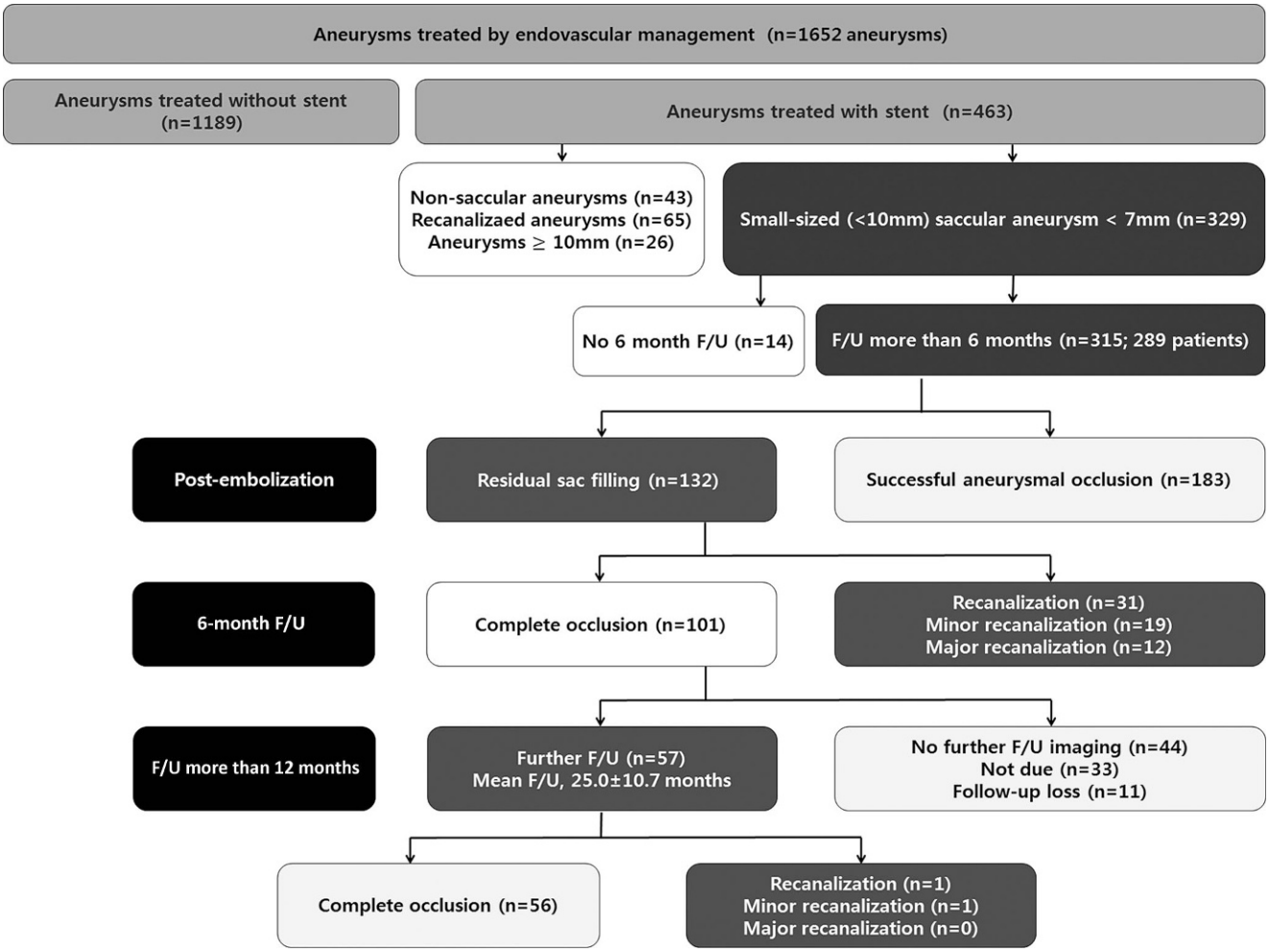

Fig. 1 Algorithm of patient population selected for study (*F/U* follow-up)

routinely recommended, to be done 6 months after coil embolization. Conventional angiography was advised if post-treatment MRA was not feasible or if recanalization was suspected by noninvasive diagnostics (i.e. MRA), enabling further intervention as warranted. Anatomic follow-up results were also rated by the Raymond scale as complete occlusion or recanalization. Progressive thrombosis was defined as complete occlusion of a sac (previously filled with contrast medium) within 6 months post-embolization. Likewise, TOF-MRA and/or conventional angiography were recommended 12, 24, and 36 months after coil embolization, again applying the Raymond scale to stratify follow-up anatomic outcomes as follows: complete occlusion, minor recanalization, or major recanalization. Major recanalization, marked by residual sac flow, was grounds for repeat embolization. Immediate angiographic results and follow-up diagnostics were interpreted by two experienced neurointerventionists (YDC 10 years and HSK 15 years experience). In event of disagreement, a consensus was established by a third interventional neuroradiologist (MHH).

Statistical Analyses

Continuous data were expressed as mean±SD. The χ^2-test or Fisher's exact test and Student's t-test were used to assess categorical and continuous variables. All variables with *p*-values <0.1 from univariable logistic regression were then compiled for stepwise multivariable regression analysis, to identify factors significantly associated with progressive thrombosis. Results of the logistic regression model were presented as odds ratio (OR), with corresponding 95% confidence interval (95% CI) and *p*-value. Statistical significance was set at $p < 0.05$. All calculations relied on standard software (SPSS v19; SPSS, Chicago, IL).

Results

Study Population

Of 315 small (<10 mm) saccular aneurysms treated with the aid of stents, postembolization filling of the sac with contrast medium was observed in 132 (41.9%) (Table 1). Binary logistic regression analysis identified side-wall type aneurysm (p = 0.020) and packing density (≤30%) (p = 0.016) as factors significantly associated with saccular persistence immediately after stent-assisted coiling. The impact of bioactive coil (≤50%) was marginal (p = 0.067) and other factors, such as location or size of aneurysms, neck size, and stent type, did not differ significantly by group.

Progressive Thrombosis of Aneurysms with Contrast Medium Sac Filling After Stent-Assisted Coil Embolization

Of the 132 aneurysms with contrast medium-filled sacs after stent-assisted coil embolization, 101 (76.5%) displayed complete occlusion (via progressive thrombosis) in 6-month follow-up images (Fig. 2). Table 2 summarizes variables associated with progressive thrombosis. In univariable analysis, hypertension, size of aneurysm, aneurysm neck diameter, and stent type emerged as statistically significant parameters. Binary logistic regression analysis indicated that smaller neck diameter (OR = 1.533; p = 0.003), hyperlipidemia (OR = 3.329; p = 0.036), and stent type (p = 0.031) independently correlated with progressive thrombo-

Table 1 Baseline characteristics of coiled aneurysms with stent

Variables	Successful occlusion (n = 183)	Contrast sac filling (n = 132)	Univariate analysis	Multivariate analysis	Odds ratio (95% CI)
Location	–	–	0.273	–	–
Ant. circulation	164	123	–	–	–
Post. circulation	19	9	–	–	–
Presentation	–	–	0.762	–	–
Unruptured	181	131	–	–	–
Ruptured	2	1	–	–	–
Aneurysm size	–	–	0.190	–	–
≤5 mm	82	69	–	–	–
>5 mm	101	63	–	–	–
Mean (mm)	5.5 ± 1.8	5.1 ± 1.7	–	–	–
Aneurysm neck	–	–	0.563	–	–
≤4 mm	91	70	–	–	–
>4 mm	92	62	–	–	–
Mean (mm)	4.3 ± 1.4	4.3 ± 1.6	–	–	–
Aneurysm type	–	–	0.003	0.020	–
Side-wall	70	73	–	–	1.745 (1.090–2.793)
Bifurcation	113	59	–	–	–
Depth to neck ratio	–	–	0.152	–	–
≤1	36	35	–	–	–
>1	147	97	–	–	–
Mean	1.3 ± 0.4	1.2 ± 0.3	–	–	–
Bioactive coils	–	–	0.030	0.067	–
>50%	25	8	–	–	0.468 (0.207–1.056)
≤50%	158	124			
Packing density	–	–	0.003	0.016	–
>30%	136	77	–	–	0.542 (0.330–0.891)
≤30%	47	55			
Mean	35.4 ± 8.9	32.4 ± 7.8	–	–	–
Stent type	–	–	0.739	–	–
Enterprise	113	82	–	–	–
LVIS	56	37	–	–	–
Neuroform	14	13	–	–	–

Ant anterior, *Post* posterior

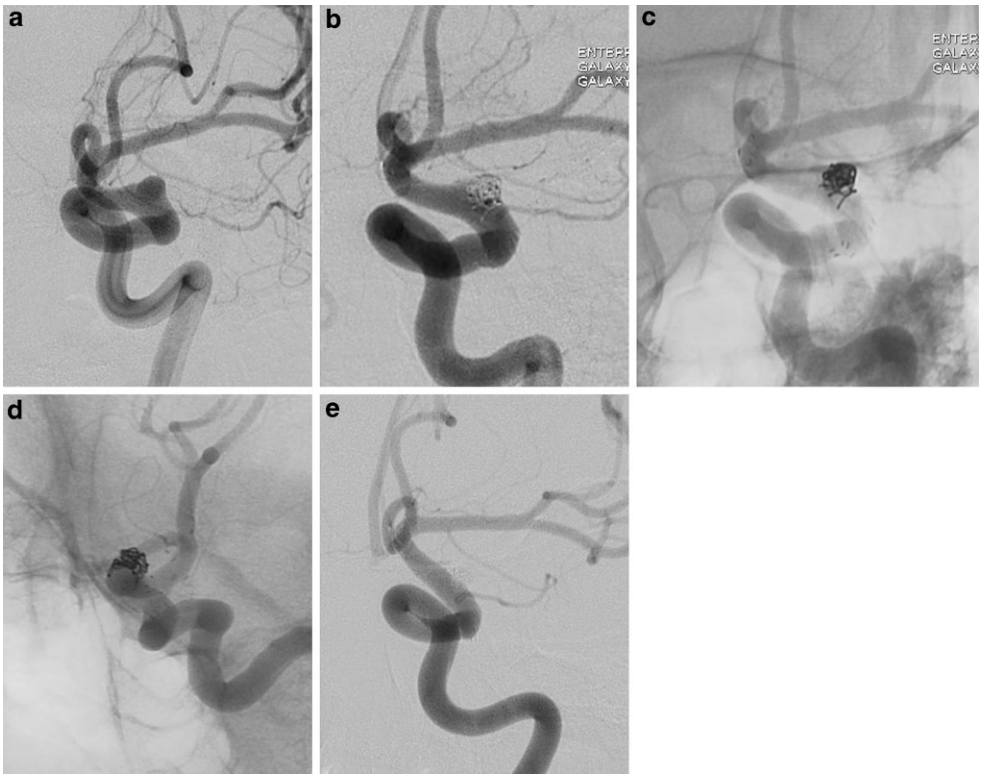

Fig. 2 Progressive thrombosis in coiled aneurysms with stent. **a** Baseline angiographic image of unruptured paraclinoid ICA aneurysm. **b**, **c** and **d** Completion angiographic image immediately after stent-assisted coil embolization showing sac filling with contrast edium. **e** Complete occlusion of the aneurysm by progressive thrombosis, 6-month follow-up angiography

Table 2 Demographic and angiographic characteristics of aneurysms showing incomplete occlusion after coil embolization ($N = 132$)

Variables	Complete occlusion ($n = 101$)	Recanalization ($n = 31$)	p-value
Clinical variables			
Female	80	27	0.326
Age, years	59.5 ± 9.7	58.2 ± 11.9	0.765
Hypertension	40	19	0.034
Diabetes	10	1	0.239
Smoking	2	2	0.204
Hyperlipidemia	36	6	0.089
Aneurysmal variables			
Ruptured	1	0	0.578
Anterior circulation	95	28	0.470
Bifurcation aneurysm	46	13	0.723
Depth to neck ratio (>1)	76	21	0.407
Maximum size (mm)	4.8 ± 1.6	5.9 ± 1.9	0.002
Neck size (mm)	4.0 ± 1.3	5.3 ± 2.1	<0.001
Procedural variables			
Stent type	–	–	0.003
LVIS	34	3	–
Enterprise	61	21	–
Neuroform	6	7	–
Bioactive coil (>50%)	5	3	0.334
Packing density	32.8 ± 7.0	30.7 ± 10.2	0.192

Table 3 Logistic regression model assessing the risk of progressive thrombosis in coiled aneurysms with stent

Variables	Odds ratio	95% CI	*p*-value
Hypertension	0.426	0.165–1.098	0.077
Hyperlipidemia	3.329	1.081–10.296	0.036
Aneurysm size	0.928	0.634–1.422	0.725
Neck diameter	0.652	0.490–0.864	0.003
Stent type	–	–	0.031
Enterprise	0.317	0.081–1.233	0.098
Neuroform	0.098	0.017–0.549	0.008
LVIS	Reference		

CI confidence interval
*$p < 0.05$ is significant

sis. LVIS was especially susceptible to progressive thrombosis, more so than Neuroform (OR = 0.098; $p = 0.008$) or Enterprise (OR = 0.317; $p = 0.098$ [significance marginal]) stents. Hypertensive status was of borderline significance (OR = 0.426; $p = 0.077$), but neither packing density nor size of aneurysm had significant impact on progressive thrombosis (Table 3).

During the follow-up period, postprocedural or delayed infarction occurred in 4 patients. Among them, only one patient was in the complete occlusion group by progressive thrombosis, whereas three were in recanalization group.

Long-Term Follow-up of Aneurysms Showing Progressive Thrombosis

Of the 101 aneurysms marked by progressive thrombosis, 57 (56.4%) were followed for ≥12 months post-embolization. The other 44 lesions lacked the required 12-month follow-up data (33 recently treated aneurysms <12 months and 11 followed for 6 months only). Mean follow-up period for this subset ($n = 57$) was 25.0 ± 10.7 months (median, 18 months). At last follow-up imaging, complete occlusion was documented in 56 aneurysms (98.2%) and residual neck (minor recanalization) in only 1 (1.8%). There were no instances of major recanalization.

Discussion

In coil embolization of intracranial aneurysms, complete occlusion is a critical goal. Despite advances achieved in endovascular techniques, incomplete occlusion is nevertheless a common feature of immediate posttreatment angiographic studies. According to other sources, 38–64% of aneurysms subjected to coil embolization show incomplete occlusion in the immediate treatment aftermath [12–16], which is an important risk factor for recanalization or rebleeding [12, 15, 17]; however, some lesions that are incompletely occluded initially may undergo progressive thrombosis during the course of monitoring, and this particular phenomenon has been well documented.

Various factors have been implicated in the filling of sacs with contrast medium immediately postembolization. Gallas et al. [18] have reported that aneurysm size impacts initial occlusion of coiled aneurysms, as have Songsaeng et al. [19], who cited favorable initial treatment outcomes in small-sized aneurysms of posterior communicating artery with sac-to-neck ratios ≤2 mm. Cho et al. [1] also linked small size (≤4 mm), absence of rupture, wide necks (depth-to-neck ratio ≤1), and non-branching sites with incomplete occlusion seen immediately posttreatment by angiography. In the current study, side-wall type aneurysms and low packing density (≤30%) emerged as significant factors in sacs persisting immediately after stent-assisted coiling. Such procedures generally call for jailing and trans-cell techniques to achieve saccular coiling, both techniques being more difficult in side-wall aneurysms due to poor microcatheter control. Should packing of coil through jailing prove unsatisfactory, owing to suboptimal microcatheter position (compressed by stent), trans-cell selection may be equally problematic. These issues are particularly troublesome if paraclinoid internal carotid artery is involved. Side-wall aneurysms thus seem prone to incomplete occlusion immediately after stent-assisted coiling. Furthermore, Griessenauer et al. [20] reported higher rates of complete occlusion in aneurysms with high packing density (vs moderate or low packing density) in stent-assisted coiling. In an earlier publication by Cho et al., small neck size (≤4 mm) and high coil packing density (>30%) were identified as significant factors with respect to progressive thrombosis [1]. The current analysis also showed that smaller neck diameter (OR = 1.533; $p = 0.003$) independently correlated with progressive thrombosis. Similarly, Lee et al. [21] demonstrated that aneurysms with very small necks (2–3 mm) culminate in homogeneous intraluminal thrombosis, whereas excessive flow in wide-neck aneurysms disrupts the hemodynamics, hampering thrombosis. In our series, coil packing density was found to be significant in progressive thrombosis by univariable analysis, but not in binary logistic regression.

After stent placement in coil embolization, a dual antiplatelet maintenance regimen (clopidogrel and aspirin) is usually continued. Clopidogrel is a prodrug metabolized by hepatic cytochrome P450 enzymes, primarily the 2c19 and 3A4 isoforms, producing an active thiol metabolite that inhibits platelet aggregation. Several ex vivo studies have found that CYP3A4-dependent statins diminish the antiplatelet activity of clopidogrel by reducing its metabolic activation [22–25]. A study of 2927 patients revealed that combined use of clopidogrel and atorvastatin after coronary stenting imposed a 1.65-fold increase in relative risk for major adverse cardiovascular events, relative to clopidogrel without atorvastatin [26]. Kang et al. likewise documented that patients with hypercholesterolemia were at increased risk of thromboembolism after aneurysmal coil embolization [27]. In our study population, almost all patients with hyperlipidemia (40/42, 95.2%) took statins, whereas only 11 patients among 90 non-hyperlipidemic patients took statins due to other medical conditions ($p < 0.001$). In our binary logistic regression analysis, hyperlipidemia (OR = 3.329; $p = 0.036$) displayed significance as a factor in progressive intra-aneurysmal thrombosis of coiled aneurysms with stents. In addition, statins had marginal significance in univariate ($p = 0.075$) and multivariate analysis (0.090) (see Supplemental Table). On the other hand, no substantial adverse events were associated with co-administration of lipophilic statins and clopidogrel in several major (CREDO, CHARISMA and PROVE IT-TIMI) cardiovascular trials [28–30]. Although opinions may vary on the interaction of clopidogrel with statins, their co-administration might promote progressive saccular thrombosis in treated aneurysms.

Another issue in the setting of progressive postembolization thrombosis is stent usage. In one meta-analysis, stent-assisted coiling yielded a significantly higher rate of progressive thrombosis, compared with coiling only (29.9% vs. 17.5%) [31]. Yao et al. [32] have shown that although rates of successful occlusion immediately after coil embolization were lower with stent-assisted coiling, the rate of subsequent improvement during follow-up monitoring was significantly higher with stenting. Indeed, Jeon et al. [33] have used propensity score analysis to underscore that stent deployment may promote progressive intra-aneurysmal thrombosis in incompletely occluded lesions. The stents are thought to divert saccular flow, inducing stasis and eventual thrombosis. In addition, stents may offer a scaffold to promote endothelialization and isolate aneurysms from parent arteries. Given these factors, higher rates of progressive thrombosis may be anticipated during follow-up periods in coiling procedures with (vs. without) stent assistance.

The types of stents used in this context have also been examined. In various studies, 52–81% of coiled aneurysms with Neuroform stents deployed have later resulted in progressive thrombosis [34–37]. Lubicz et al. [38] have also determined that 53% of coiled aneurysms using Leo (14 aneurysms) and Enterprise (20 aneurysms) stents showed further thrombosis, displaying complete occlusion at 12 months. In addition, Cho et al. [39] have reported 55 aneurysms treated by LVIS-assisted coil embolization, with neck remnants ($n = 37$) and residual sacs ($n = 10$) persisting immediately thereafter. Progressive saccular obliteration was observed in 91.3% (42/46) at 6 months, although 1 patient lacked follow-up imaging; however, none of these studies properly addressed stent differences with respect to progressive thrombosis.

In terms of direct stent comparisons, despite the difference in the definition of progressive thrombosis, Durst et al. [40] recorded rates of 47% and 37% for progressive thrombosis with use of Enterprise and Neuroform stents, respectively, whereas a significantly higher rate of progressive thrombosis was achieved by Ge et al. using LVIS (33.3%) rather than Enterprise (14.3%) stents [41]. In our hands, rates of progressive thrombosis were 91.9% for LVIS, 74.4% for Enterprise, and 66.7% for Neuroform stents. Thus, LVIS stents proved highly susceptible to progressive thrombosis, more so than Neuroform (OR = 0.098; $p = 0.008$) or Enterprise (OR = 0.317; $p = 0.098$) stents. It may be that individual stent characteristics (type, cell size, degree of metal coverage, etc.) account for these differences. The LVIS stent is a braided, closed-cell stent that offers a high degree of metal coverage (~23%), much denser than that incorporated in more conventional Enterprise and Neuroform (8–11%) stents [42]. Also, the Enterprise stent is a closed-cell design, unlike the open-cell Neuroform stent.

The long-term durability of progressively occluded aneurysms treated by stent-assisted coiling seems to be excellent. In our series, only one aneurysm (1.8%) displayed minor recanalization, and no instances of major recanalization occurred. Cho et al. [1] have encountered a 6.1% rate of recanalization (minor, 3.3%; major 2.8%) during long-term follow-up (mean, 31.9 ± 7.6 months) in progressively occluded aneurysms. Such excellent durability may a consequence of stenting. Jeon et al. [43, 44] have likewise confirmed that stent deployment confers a protective effect, preventing recanalization in completely occluded or minimally recanalized aneurysms at 6-month follow-up.

Limitations of this study include its nonrandomized, retrospective, and observational design, applying TOF-MRA (per institutional protocol) to follow patients shortly after coil embolization, without baseline MRA imaging. Although some studies have shown the feasibility of TOF-MRA in evaluating occlusion of aneurysms, using digital subtraction angiography (DSA) as reference [45, 46], the degree of recanalization may be impugned by stent-induced artifact. Another limitation is the potential for bias in choice

of stent, which was weighed individually. Ultimately, only large-scale prospective studies will provide needed clarification.

Conclusion

A majority of small saccular aneurysms incompletely occluded after stent-assisted coil embolization will eventually thrombose in the course of time. Factors predisposing to progressive intra-aneurysmal thrombosis include hyperlipidemic states, smaller neck diameter, and LVIS deployment. The progressive occlusion of aneurysms that stenting confers promises excellent long-term durability.

Conflict of interest J.W. Lim, J. Lee and Y.D. Cho declare that they have no competing interests.

References

1. Cho YD, Jeon JP, Rhim JK, Park JJ, Yoo RE, Kang HS, Kim JE, Cho WS, Han MH. Progressive thrombosis of small saccular aneurysms filled with contrast immediately after coil embolization: analysis of related factors and long-term follow-up. Neuroradiology. 2015;57:615–23.
2. Park W, Song Y, Park KJ, Koo HW, Yang K, Suh DC. Hemodynamic characteristics regarding recanalization of completely coiled aneurysms: computational fluid dynamic analysis using virtual models comparison. Neurointervention. 2016;11(1):30–6.
3. Spiotta AM, Miranpuri A, Chaudry MI, Turner RD 4th, Turk AS. Combined balloon stent technique with the Scepter C balloon and low-profile visualized intraluminal stent for the treatment of intracranial aneurysms. J Neurointerv Surg. 2013;5(Suppl 3):iii82–iii79.
4. Wanke I, Forsting M. Stents for intracranial wide-necked aneurysms: more than mechanical protection. Neuroradiology. 2008;50:991–8.
5. Aenis M, Stancampiano AP, Wakhloo AK, Lieber BB. Modeling of flow in a straight stented and nonstented side wall aneurysm model. J Biomech Eng. 1997;119:206–12.
6. Phatouros CC, Sasaki TY, Higashida RT, Malek AM, Meyers PM, Dowd CF, Halbach VV. Stent-supported coil embolization: the treatment of fusiform and wide-neck aneurysms and pseudoaneurysms. Neurosurgery. 2000;47:107–13.
7. Park KY, Kim BM, Kim DJ. Comparison between balloon-assisted and stent-assisted technique for treatment of unruptured internal carotid artery aneurysms. Neurointervention. 2016;11:99–104.
8. Liu H, Choe J, Jung SC, Song Y, Yang KH, Park KJ, Goo HW, Park WH, Suh DC. Does a low-wall coverage stent have a flow diverting effect in small aneurysms? Neurointervention. 2015;10:89–93.
9. Ingebrigtsen T, Morgan MK, Faulder K, Ingebrigtsen L, Sparr T, Schirmer H. Bifurcation geometry and the presence of cerebral artery aneurysms. J Neurosurg. 2004;101:108–13.
10. Cho YD, Lee WJ, Kim KM, Kang HS, Kim JE, Han MH. Endovascular coil embolization of middle cerebral artery aneurysms of the proximal (M1) segment. Neuroradiology. 2013;55:1097–102.
11. Roy D, Milot G, Raymond J. Endovascular treatment of unruptured aneurysms. Stroke. 2001;32:1998–2004.
12. Gonzalez N, Murayama Y, Nien YL, Martin N, Frazee J, Duckwiler G, Jahan R, Gobin YP, Viñuela F. Treatment of unruptured aneurysms with GDCs: clinical experience with 247 aneurysms. AJNR Am J Neuroradiol. 2004;25:577–83.
13. Murayama Y, Nien YL, Duckwiler G, Gobin YP, Jahan R, Frazee J, Martin N, Viñuela F. Guglielmi detachable coil embolization of cerebral aneurysms: 11 years' experience. J Neurosurg. 2003;98:959–66.
14. Murayama Y, Viñuela F, Tateshima S, Song JK, Gonzalez NR, Wallace MP. Bioabsorbable polymeric material coils for embolization of intracranial aneurysms: a preliminary experimental study. J Neurosurg. 2001;94:454–63.
15. Ng P, Khangure MS, Phatouros CC, Bynevelt M, ApSimon H, McAuliffe W. Endovascular treatment of intracranial aneurysms with Guglielmi detachable coils: analysis of midterm angiographic and clinical outcomes. Stroke. 2002;33:210–7.
16. Thornton J, Debrun GM, Aletich VA, Bashir Q, Charbel FT, Ausman J. Follow-up angiography of intracranial aneurysms treated with endovascular placement of Guglielmi detachable coils. Neurosurgery. 2002;50:239–49.
17. Raymond J, Guilbert F, Weill A, Georganos SA, Juravsky L, Lambert A, Lamoureux J, Chagnon M, Roy D. Long-term angiographic recurrences after selective endovascular treatment of aneurysms with detachable coils. Stroke. 2003;34:1398–403.
18. Gallas S, Pasco A, Cottier JP, Gabrillargues J, Drouineau J, Cognard C, Herbreteau D. A multicenter study of 705 ruptured intracranial aneurysms treated with Guglielmi detachable coils. AJNR Am J Neuroradiol. 2005;26:1723–31.
19. Songsaeng D, Geibprasert S, ter Brugge KG, Willinsky R, Tymianski M, Krings T. Impact of individual intracranial arterial aneurysm morphology on initial obliteration and recurrence rates of endovascular treatments: a multivariate analysis. J Neurosurg. 2011;114:994–1002.
20. Griessenauer CJ, Adeeb N, Foreman PM, Gupta R, Patel AS, Moore J, Abud TG, Thomas AJ, Ogilvy CS, Baccin CE. Impact of coil packing density and coiling technique on occlusion rates for aneurysms treated with stent-assisted coil embolization. World Neurosurg. 2016;94:157–66.
21. Lee D, Yuki I, Murayama Y, Chiang A, Nishimura I, Vinters HV, Wang CJ, Nien YL, Ishil A, Wu BM, Viñuela F. Thrombus organization and healing in the swine experimental aneurysm model. Part I. A histological and molecular analysis. J Neurosurg. 2007;107:94–108.
22. Clarke TA, Waskell LA. The metabolism of clopidogrel is catalyzed by human cytochrome P450 3A and is inhibited by atorvastatin. Drug Metab Dispos. 2003;31:53–9.
23. Lau WC, Waskell LA, Watkins PB, Neer CJ, Horowitz K, Hopp AS, Tait AR, Carville DG, Guyer KE, Bates ER. Atorvastatin reduces the ability of clopidogrel to inhibit platelet aggregation: a new drug-drug interaction. Circulation. 2003;107:32–7.
24. Neubauer H, Gunesdogan B, Hanefeld C, Spiecker M, Mugge A. Lipophilic statins interfere with the inhibitory effects of clopidogrel on platelet function – a flow cytometry study. Eur Heart J. 2003;24:1744–9.
25. Mach F, Senouf D, Fontana P, Boehlen F, Reber G, Daali Y, de Moerloose P, Sigwart U. Not all statins interfere with clopidogrel during antiplatelet therapy. Eur J Clin Invest. 2005;35:476–81.
26. Brophy JM, Babapulle MN, Costa V, Rinfret S. A pharmacoepidemiology study of the interaction between atorvastatin and clopidogrel after percutaneous coronary intervention. Am Heart J. 2006;152:263–9.
27. Kang HS, Han MH, Kwon BJ, Jung C, Kim JE, Kwon OK, Oh CW. Is clopidogrel premedication useful to reduce thromboembolic events during coil embolization for unruptured intracranial aneurysms? Neurosurgery. 2010;67:1371–6.
28. Saw J, Steinhubl SR, Berger PB, Kereiakes DJ, Serebruany VL, Brennan D, Topol EJ; Clopidogrel for the Reduction of Events During Observation Investigators. Lack of adverse clopidogrel-atorvastatin clinical interaction from secondary analysis of a randomized, placebo-controlled clopidogrel trial. Circulation. 2003;108:921–4.

29. Saw J, Brennan DM, Steinhubl SR, Bhatt DL, Mak KH, Fox K, Topol EJ; CHARISMA Investigators. Lack of evidence of a clopidogrel-statin interaction in the CHARISMA trial. J Am Coll Cardiol. 2007;50:291–5.
30. Lotfi A, Schweiger MJ, Giugliano GR, Murphy SA, Cannon CP, Investigators T. High-dose atorvastatin does not negatively influence clinical outcomes among clopidogrel treated acute coronary syndrome patients – a pravastatin or atorvastatin evaluation and infection therapy-thrombolysis in myocardial infarction 22 (PROVE IT-TIMI 22) analysis. Am Heart J. 2008;155:954–8.
31. Phan K, Huo YR, Jia F, Phan S, Rao PJ, Mobbs RJ, Mortimer AM. Meta-analysis of stent-assisted coiling versus coiling-only for the treatment of intracranial aneurysms. J Clin Neurosci. 2016;31:15–22.
32. Yao PF, Yu Y, Yang PF, Xu Y, Hong B, Zhao WY, Liu JM, Huang QH. Safety and long-term efficacy of endovascular treatment of small posterior communicating artery aneurysms by coiling with or without stent: a single center retrospective study. Clin Neurol Neurosurg. 2013;115:2502–7.
33. Jeon JP, Cho YD, Rhim JK, Park JJ, Cho WS, Kang HS, Kim JE, Han MH. Effect of stenting on progressive occlusion of small unruptured saccular intracranial aneurysms with residual sac immediately after coil embolization: a propensity score analysis. J Neurointerv Surg. 2016;8:1025–9.
34. Gu DQ, Zhang X, Luo B, Long XA, Duan CZ. The effect of Neuroform stent-assisted coil embolization of wide-necked intracranial aneurysms and clinical factors on progressive aneurysm occlusion on angiographic follow-up. J Clin Neurosci. 2013;20:244–7.
35. Fiorella D, Albuquerque FC, Deshmukh VR, McDougall CG. Usefulness of the Neuroform stent for the treatment of cerebral aneurysms: results at initial (3–6-mo) follow-up. Neurosurgery. 2005;56:1191–201.
36. Maldonado IL, Machi P, Costalat V, Mura T, Bonafe A. Neuroform stent-assisted coiling of unruptured intracranial aneurysms: short- and midterm results from a single-center experience with 68 patients. AJNR Am J Neuroradiol. 2011;32:131–6.
37. Yahia AM, Latorre JG, Gordon V, Whapham J, Swarnkar A, Fessler RD. Progressive occlusion of aneurysms in neuroform stent-assisted treatment of intracranial aneurysms. J Neurol Neurosurg Psychiatr. 2011;82:278–82.
38. Lubicz B, Bandeira A, Bruneau M, Dewindt A, Baleriaux D, De Witte O. Stenting is improving and stabilizing anatomical results of coiled intracranial aneurysms. Neuroradiology. 2009;51:419–25.
39. Cho YD, Sohn CH, Kang HS, Kim JE, Cho WS, Hwang G, Kwon OK, Ko MS, Park NM, Han MH. Coil embolization of intracranial saccular aneurysms using the Low-profile Visualized Intraluminal Support (LVIS™) device. Neuroradiology. 2014;56:543–51.
40. Durst CR, Khan P, Gaughen J, Patrie J, Starke RM, Conant P, Liu KC, Jensen ME, Evans AJ. Direct comparison of Neuroform and Enterprise stents in the treatment of wide-necked intracranial aneurysms. Clin Radiol. 2014;69:e471–e6.
41. Ge H, Lv X, Yang X, He H, Jin H, Li Y. LVIS stent versus enterprise stent for the treatment of unruptured intracranial aneurysms. World Neurosurg. 2016;91:365–70.
42. Wang C, Tian Z, Liu J, Jing L, Paliwal N, Wang S, Zhang Y, Xiang J, Siddiqui AH, Meng H, Yang X. Flow diverter effect of LVIS stent on cerebral aneurysm hemodynamics: a comparison with enterprise stents and the pipeline device. J Transl Med. 2016;14:199.
43. Jeon JP, Cho YD, Rhim JK, Yoo DH, Kang HS, Kim JE, Cho WS, Han MH. Extended monitoring of coiled aneurysms completely occluded at 6-month follow-up: late recanalization rate and related risk factors. Eur Radiol. 2016;26(10):3319–26.
44. Jeon JP, Cho YD, Rhim JK, Yoo DH, Cho WS, Kang HS, Kim JE, Han MH. Fate of coiled aneurysms with minor recanalization at 6 months: rate of progression to further recanalization and related risk factors. AJNR Am J Neuroradiol. 2016;37:1490–5.
45. Nakiri GS, Santos AC, Abud TG, Aragon DC, Colli BO, Abud DG. A comparison between magnetic resonance angiography at 3 teslas (time-of-flight and contrast-enhanced) and flat-panel digital subtraction angiography in the assessment of embolized brain aneurysms. Clinics (Sao Paulo). 2011;66:641–8.
46. Ferré JC, Carsin-Nicol B, Morandi X, Carsin M, de Kersaint-Gilly A, Gauvrit JY, Desal HA. Time-of-flight mr angiography at 3t versus digital subtraction angiography in the imaging follow-up of 51 intracranial aneurysms treated with coils. Eur Radiol. 2009;72:365–9.