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ABSTRACT

BACKGROUND AND PURPOSE: Stent bulging technique has been introduced as a technique that improves the outcome of aneurysm coiling. Our aim was to evaluate the utility of this technique, which involves the intentional herniation of stents into the bifurcation aneurysms during coiling.

MATERIALS AND METHODS: Unruptured bifurcation aneurysms treated by stent-assisted coiling using a single type of low-profile braided (LEO Baby) stent between November 2012 and October 2018 were retrospectively evaluated. The clinical (age and sex) and morphologic characteristics (aneurysm size, neck size, proximal/distal diameters of the stented artery, incorporation of the origins of the side branches to the aneurysm neck, and bifurcation angle) and response to antiplatelet therapy were evaluated.

RESULTS: Sixty-one patients (29 men, 47.5%; mean age, 55.95 [SD, 12.33] years) with 66 aneurysms were included. There were 36 aneurysms in group A (treated with the stent bulging technique) and 30 aneurysms in group B (treated by classic stent-assisted coiling). There was no significant difference in the patient and aneurysm characteristics in the groups except for the larger size and wider neck of the aneurysms in group A ($P = .02$ and $P = .04$, respectively). At the mean follow-up of 27.30 (SD, 17.45) months, there was no significant difference in the complication rate, the occlusion status, and the early and long-term occlusion rates between the groups. The stent bulging technique did not predict total occlusion (Raymond-Roy I) at the final imaging follow-up.

CONCLUSIONS: The stent bulging technique enables the coiling of larger, wide-neck aneurysms; however, we did not observe an added flow-diversion effect with the stent bulging technique compared with conventional stent-assisted coiling. We, therefore, suggest that bifurcation aneurysms should be coiled as densely and as safely as possible using this technique.

ABBREVIATIONS: ACA = anterior cerebral artery; RDPD = regional diameter percentage difference; RR = Raymond-Roy score; SAC = stent-assisted coiling; SBT = stent bulging technique; SCA = superior cerebellar artery

Stent-assisted coiling (SAC) is a safe and effective option in the treatment of wide-neck intracranial aneurysms. The stent provides a scaffold for the neointima formation and prevents coil protrusion into the parent artery. In addition, intracranial stents may result in the development of hemodynamic changes inside the aneurysm, which may lead to further aneurysm occlusion. These hemodynamic changes relate to the type (braided versus laser-cut stents), the number of stents, and the technique of stent deployment.[1,2] In some patients, SAC with a single stent may not provide sufficient neck coverage, and in these cases, dual stent placement in an X or Y configuration may be necessary. Dual stent placement is technically more challenging than basic SAC and is known to be associated with an increased rate of thromboembolic complications.[3-6] The stent bulging technique (SBT, also known as the shelf technique) has been proposed as an alternative to dual stent placement to overcome its drawbacks.[7,8] The compression technique is based on the compaction of a stent at the neck of an aneurysm, which creates a bulge and allegedly results in a higher "flow diversion effect" compared with a "uniform stent" due to the higher metallic ratio at the aneurysm neck in sidewall aneurysms.[1] Some authors have further suggested that the added flow diversion secondary to compaction is also observed in bifurcation aneurysms.[9-12] The aim of this study was to evaluate the utility of the SBT in bifurcation aneurysms by comparing the clinical and imaging outcomes of bifurcation aneurysms that are treated using a single type of stent, the classic SAC versus the SAC with SBT.

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MATERIALS AND METHODS

After ethics approval was obtained from the institutional review board, of Hacettepe University, we retrospectively evaluated patients with unruptured intracranial bifurcation aneurysms who underwent SAC that used a single type of low-profile braided stent (LEO Baby stent; Balt Extrusion) between November 2012 and October 2018. Patients with dual stent placement, T-stent placement, half T-stent placement, temporary stent placement, stent placement after balloon remodeling, and telescoping stent placement were excluded from the study. Additionally, patients without follow-up imaging studies were excluded from the angiographic analysis; however, their clinical findings were included in the clinical follow-up data. If the patients had multiple eligible aneurysms that were treated by the same type of stent, all their eligible aneurysms were included in the study. Patients with recurrent or residual aneurysms after a previous SAC or a flow diversion were also excluded from the study. The patient characteristics, including age and sex, and the aneurysm characteristics (aneurysm size, neck size, proximal and distal diameters of the stented artery, incorporation of the origins of the side branches into the aneurysm neck, and bifurcation angle) and the level of on-treatment platelet reactivity (measured by VerifyNow; Accumetrics) were noted. The bifurcation angle was calculated as described in the literature.[13] The aneurysm occlusion status that was based on the Raymond-Roy score (RR) immediately after the procedure and during follow-up, and clinical complications were analyzed. The mRS was used to determine the neurologic status of the patients before the procedure and during the postoperative and follow-up period.

"Recanalization" was defined as the deterioration of the RR during follow-up, whereas "progressive occlusion" was defined as an improvement of the RR during the follow-up. Incorporation of the origins of the side branches into the aneurysm neck and stent compaction were independently assessed by each of the authors, and a consensus was required if discrepancies existed regarding the arterial branch involvement or compaction. For the quantification of the compaction, the regional diameter percentage difference (RDPD) was calculated—that is, the stent diameter was measured at the parent artery (dPA) on the working projection. Then the largest diameter of the deployed stent (dMax) was measured at the aneurysm neck on the same projection. RDPD was calculated as dMax/dPA $\times 100$. A receiver operating characteristic curve was calculated, and we noted that when the cutoff value of the RDPD was set at 110% (in other words, if the dMax was, at most, 10% over the diameter of the parent artery we classified the procedure as a "basic SAC" technique), we achieved the best sensitivity and specificity values (97.2% and 96.7%, respectively) for the prediction of compaction as assessed by the operators. Hence stent bulging (compaction) was defined as compression of the braided stent beyond 110% of the diameter of the parent artery. The ranges of the RDPD were from 111.06% to 154.81% for the SBT group and from 87.21% to 109.68% for the basic SAC group.

The aneurysms were divided into groups A and B on the basis of the type of SAC procedure. Group A consisted of aneurysms that were treated with SBT. Group B consisted of aneurysms that were treated with the basic SAC technique. For each group, the imaging data at $\leq$4 months, between 5 and 12 months, and during the long term were evaluated.

General Description of the Interventional Procedure

A written informed consent form was signed by all patients before the procedure. The patients were administered antiplatelet medications (300 mg of aspirin and a thienopyridine, that is, 75 mg of clopidogrel or 10 mg of prasugrel) starting at least 5 days before the procedure. Patients were only treated if they had an adequate response to antiplatelet therapy (P2Y12 reaction units of $\geq$60 and/or percentage inhibition of $>$40%). All procedures were performed by a single surgeon. With the patient under general anesthesia, femoral access was achieved and a 6F guiding sheath was navigated to the target, which was the carotid or vertebral artery. After we inserted the guiding sheath, anticoagulation was started with a bolus injection of 70–100 IU/kg of heparin, followed by a heparin infusion to keep the activated clotting time 2–3 times higher than its baseline value. Then, using a triaxial system, we catheterized the aneurysm sac with a microcatheter for the coil embolization, and a second microcatheter was advanced across the neck of the aneurysm for the stent deployment. Before the detachment of the first coil, a LEO Baby stent was released at approximately 50%–80% of its length across the neck of the aneurysm. The coiling procedure was continued with bare platinum coils. If a coil protrusion into the parent artery was noted, stent bulging was performed by pushing the microcatheter gently forward, while an antegrade push was maintained on the stent delivery wire. The force on the microcatheter was gently withdrawn as the stent was deployed in a bulging fashion during further deployment of the stent (Online Supplemental Data). After we achieved a stable coil mass by placing more coils, the stent was detached from its deployment wire. Following the procedure, the patient's anticoagulation therapy was reversed, and dual antiplatelet therapy was continued for at least 6 months. Thienopyridines were generally discontinued after 6 months, and the patients were asked to stay on 300 mg of aspirin indefinitely.

Follow-up

Immediate postprocedural angiograms were obtained on anterior-posterior, lateral, and working projections to evaluate the occlusion status. Early follow-up MRAs were performed at 1–4 months postoperatively. At 5–12 months postoperatively, the second follow-up with a DSA was performed. After that, long-term follow-up imaging examinations were performed. These follow-up angiograms were reviewed for stent patency, in-stent stenosis, and aneurysm occlusion status.

Data Analysis

The SPSS 20.0 (IBM) program was used for the statistical analysis. Continuous data are presented as the mean (SD), and categoric data are presented as percentages. Between the groups, categoric variables were compared using the χ^2 test or Fisher exact test on the basis of the number of variables, and continuous variables were compared using the independent samples t test or Mann-Whitney U test on the basis of the distribution of variables. Statistical significance was set at $P < .05$.

RESULTS

Sixty-one patients with 66 aneurysms were included in our analysis. Two patients did not have imaging follow-up. Both of these patients had uneventful endovascular treatments without clinical

Table 1: Aneurysm locations

Location	Group A (%)	Group B (%)	Total No. (%)
AcomA	9 (25)	11 (36.7)	20 (30.3)
Basilar tip	1 (2.8)		1 (1.5)
Distal ACA	1 (2.8)	1 (3.3)	2 (3)
MCA bifurcation	25 (69.4)	14 (46.7)	39 (59.1)
SCA		2 (6.7)	2 (3)
Terminal ICA		2 (6.7)	2 (3)
	36 (100)	30 (100)	66 (100)

Note:—AcomA indicates anterior communicating artery.

complications and were excluded from the analysis. Twenty-nine (47.5%) patients were men, and 32 (52.5%) were women. The mean age of the patients was 55.95 (SD, 12.33) years. The locations of the aneurysms are listed in Table 1. There were 36 and 30 aneurysms in groups A and B, respectively. The results of the univariate analysis of the patient and aneurysm characteristics between the groups are listed in Table 2. The aneurysms in group A were larger. The mean aneurysm sizes were 7.95 (SD, 2.88) cm and 6.29 (SD, 2.90) cm ($P = .02$) for groups A and B, respectively. The aneurysm necks in group A were also wider, with a mean neck size of 4.68 (SD, 1.67) cm compared with 3.91 (SD, 1.39) cm ($P = .04$) in Group B. The mean age of the patients was older in group A than group B, 58.89 (SD, 10.95) years and 52.43 (SD, 13.14) years, respectively ($P = .03$). There was no statistically significant difference between the groups in terms of sex, proximal and distal diameters of the stented artery, bifurcation angle, response to antiplatelet therapy, follow-up duration, rate of complications, or rate of incorporation of the origins of the side branches to the aneurysm neck (Table 2). The overall mean follow-up duration was 27.30 (SD, 17.45) months. There was only 1 case (1,5%) with recanalization in this cohort, and this patient was in group A. In this patient, the postoperative RR score was I, and it increased to II at the 6-month follow-up and then remained stable until the final follow-up at 36 months.

There were 13 (19.7%) patients with progressive occlusions. Progressive occlusion was noted in 8 (22.2%) of the patients in group A and in 5 (16.7%) in group B. There was no difference between the groups regarding the progressive occlusion rate ($P = .57$). The overall angiographic occlusion rates at the final follow-up (mean follow-up, 27.30 [SD, 17.45] months) included an RR of I in 59 (89.4%) patients, an RR of II in 6 (9.1%) patients, and an RR of III in 1 (1.5%) patient. The patient with an RR score of III in group B was re-treated 3 months after the initial treatment without any complications. The occlusion statuses of the aneurysms immediately after the procedure and during the follow-up based on the patient's group are listed in Table 3. There was no statistically significant difference between the groups regarding the occlusion status. Additionally, there was no statistically significant difference between the groups in the imaging technique used for the follow-up, including in the early- ($\leq$4 months), medium-term (5–12 months), and longer-term ($>$12 months) evaluations (P values = 1, .24, and .71, respectively). The type of follow-up modalities that were used for each of these time periods is listed in the Online Supplemental Data.

There were 3 (8.3%, based on the aneurysm count) adverse events in group A. One patient had a minor stroke after we changed the patient's antiplatelet regimen from prasugrel and acetylsalicylic acid to only acetylsalicylic acid at 6 months. There was a decline in that patient's baseline mRS from 0 to 2. The final status of the patient is an mRS score of 1. Two patients had stent stenosis without clinical sequelae. Both of these patients had a peculiar stenosis of the parent artery, which was at the transition zone immediately proximal to the bulged segment (Online Supplemental Data). There were 4 (13.3%, based on the aneurysm count) adverse events in group B. Of these 4 complications, 2 patients had minor strokes during the follow-up without deterioration in their final mRS score. One patient had stent stenosis without clinical sequelae. One patient with an MCA bifurcation aneurysm had stenosis of the origin of

Table 2: Univariate analysis of the patient and aneurysm characteristics between the 2 groups

	Group A	Group B	*P* Value
Total No. (%)	36 (100)	30 (100)	
Female sex (No.) (%)	20 (55.6)	15 (50)	.65
Age (mean) (years)	58.89 (SD, 10.95)	52.43 (SD, 13.14)	.03
Aneurysm size (mean) (mm)	7.95 (SD, 2.88)	6.29 (SD, 2.90)	.02
Neck width (mean) (mm)	4.68 (SD, 1.67)	3.91 (SD, 1.39)	.04
Proximal diameter of the stented artery (mean) (mm)	2.64 (SD, 0.37)	2.50 (SD, 0.37)	.13
Distal diameter of the stented artery (mean) (mm)	2.04 (SD, 0.50)	1.89 (SD, 0.40)	.18
Follow-up duration (mean) (mo)	28.28 (SD, 17.47)	26.13 (SD, 17.65)	.62
Bifurcation angle (mean) (IQR)	92.50° (SD, 25.23°) (43.38°)	92.75° (SD, 34.84°) (65.40°)	.97
Platelet inhibition (%) (mean)[a]	79.03 (SD, 17.65)	81.39 (SD, 16.27)	.58
Complications (in-stent restenosis or stroke) (No.) (%)	3 (8.3)	4 (13.3)	.69
Incorporation of the origins of at least 1 of the side branches to the aneurysm neck (No.) (%)	23 (63.9)	19 (63.3)	.96
Incorporation of the origins of both side branches to the aneurysm neck (No.) (%)	12 (33.3)	5 (16.7)	.12
Progressive occlusion (No.) (%)	8 (22.2)	5 (16.7)	.57

Note:—IQR indicates interquartile range.
[a] As measured by the VerifyNow assay.

the upper branch. Additionally, in this patient, a follow-up MR imaging showed enhancing brain lesions that are consistent with a foreign body reaction, as it is described in the literature,[14] and the patient is currently asymptomatic.

The rate of incorporation of at least 1 side branch into the aneurysm neck was similar ($P = .96$, Table 2). However, when both of the side branch origins were incorporated into the aneurysm neck, 12 (group A, 12 of 36, 33.3%) aneurysms were treated with SBT, and although not statistically significant, this rate was higher than that of the 5 (5 of 30, 16.7%) aneurysms in group B that were treated with basic SAC ($P = .12$)—that is, of the 17 aneurysms in which both of the side branches were incorporated into the aneurysm neck, 12 (70.6%) aneurysms were treated with SBT. The results of the univariate analysis of the predictors for total occlusion (RR I) on the final imaging follow-up are shown in Table 4. No significant differences were found between the groups in any of the analyzed variables, including the bulging of the stent.

DISCUSSION

The SBT has been described using various terms in the literature, such as the "shelf technique," "barrel technique," "stent bulging," "compressed stent," "intentional stent herniation," "intentional shortening," "compaction," or "wrapped-candy" techniques.[8,11,12,15-19] Although some authors prefer to use the term "compression/compaction" for all types of aneurysms, on the basis of our review of the relevant literature, we think that the terms "compression," "compaction," "shortening," and "wrapped-candy" should be reserved for sidewall aneurysms, whereas "shelf," "herniation," or "bulging" should be used for bifurcation aneurysms. Technically, the maneuvers performed to achieve a compacted stent are similar in both scenarios; however, the intent (the ability to preserve a side branch versus the desire to achieve a better flow diversion) and the immediate angiographic results (bulged stent versus shortened stent) are different.

Supposedly, the SBT may obviate the need for Y-stent placement,[8] and it results in an increased flow diversion compared with a uniformly deployed stent.[9-11] The proponents of this technique suggest that the rate of aneurysm occlusion increases, without a risk of increased complications, due to the enhancement of the flow diversion by the increased metallic coverage (compaction) at the aneurysm neck.[12,19] To date, the studies on SBT have been limited to retrospective, small-scale, single-arm case series that have evaluated the safety and efficacy of the technique.[11] In addition, most publications about SBT relate to a single type of braided stent (LVIS family of stents; MicroVention).[8,11,15,20,21] There is only 1 study[7] and a case report[10] about stent compaction with the LEO Baby stent. With no prior comparative studies

Table 3: The aneurysm occlusion status during the follow-up[a]

		Group A (%)	Group B (%)	*P* Value
Initial	RR I	24 (66.7)	23 (76.7)	.69
	RR II	11 (30.6)	6 (20)	
	RR III	1 (2.8)	1 (3.3)[b]	
≤4 mo	RR I	18 (72)	17 (89.5)	.08
	RR II	7 (28)	1 (5.3)	
	RR III		1 (5.3)	
5–12 mo	RR I	28 (84.8)	26 (92.9)	.43
	RR II	5 (15.2)	2 (7.1)	
	RR III			
≥12 mo	RR I	26 (83.9)	23 (95.8)	.21
	RR II	5 (16.1)	1 (4.2)	
	RR III			
Final follow-up	RR I	31 (86.1)	28 (93.3)	.14
	RR II	5 (13.9)	1 (3.3)	
	RR III		1 (3.3)	

[a] Aneurysm occlusion is classified according to the Raymond Roy (RR) scale.
[b] The patient was re-treated after 3 months with complete obliteration, so the patient was not included in further angiographic analyses but was included in the final follow-up as a having a residual aneurysm case.

Table 4: Univariate analysis of the predictors for total occlusion on the final imaging follow-up

	Total Occlusion (RR I)	Non-Total Occlusion (RR II and RR III)	*P* Value
Total (No.) (%)	59 (100)	7 (100)	
Female sex (No.) (%)	30 (50.8)	5 (71.4)	.43
Age (mean) (yr)	56.76 (SD, 12.06)	49.14 (SD, 13.42)	.20
Aneurysm size (mean) (mm)	7.07 (SD, 3.02)	8.21 (SD, 2.64)	.26
Neck width (mean) (mm)	4.22 (SD, 1.56)	5.28 (SD, 1.54)	.08
Proximal diameter of the stented artery (mean) (mm)	2.55 (SD, 0.37)	2.77 (SD, 0.39)	.23
Distal diameter of the stented artery (mean) (mm)	1.94 (SD, 0.46)	2.21 (SD, 0.39)	.11
Follow-up duration (mean) (mo)	27.42 (SD, 18.14)	26.29 (SD, 10.79)	.89
Complications (in-stent restenosis or stroke) (No.) (%)	7 (11.9)	0	1
Incorporation of the origins of at least 1 of the side branches to the aneurysm neck (No.) (%)	36 (61)	6 (85.7)	.40
Incorporation of the origins of both side branches to the aneurysm neck (No.) (%)	16 (27.1)	1 (14.3)	.66
Stent bulging (No.) (%)	31 (52.5)	5 (71.4)	.44
Bifurcation angle (mean)	92.38° (SD, 30.06°)	94.54° (SD, 29.08°)	.85
Platelet inhibition (%) (mean)[a]	80.66 (SD, 17.66)	75.43 (SD, 9.14)	.36

[a] As measured by the VerifyNow assay.

between the conventional SAC and the SAC with the SBT, the increased flow diversion and comparable complication rates have remained hypothetic to date.

Our study showed that challenging bifurcation aneurysms, in which the aneurysm neck incorporates both of the origins of the side branches, may also be treatable with conventional SAC (29.4% of such aneurysms in this cohort), yet as a technical option, SBT may provide further benefit to the surgeon but without a significant increase in the procedure-related complications. However, we did not observe a higher aneurysm obliteration rate when the stents were bulged/compacted. This is an unexpected finding given the abundance of clinical and simulation studies that have suggested that there is a possible relationship between the aneurysm obliteration rate and a decreased porosity/increased pore density at the aneurysm neck.[12,17,22-24] One reason for the lack of such an association in our study may be that bifurcation aneurysms do not respond to flow diversion as well as sidewall aneurysms. All of the aneurysms in our study were bifurcation aneurysms. In addition, bulging invariably creates transition zones at the edges of the aneurysm neck that reduce the flow diversion.[25,26] Another reason for the lack of association may be the diminished effect of the flow diversion in coiled bifurcation aneurysms—that is, the strong effect of coiling on the final angiographic result may override the moderate flow diversion that is induced by the woven stent. After all, in approximately 80% of the aneurysms that are coiled without stents, an adequate occlusion is achieved in the long term.[27] Although the flow diversion properties of braided stents have not been definitively proved clinically, the data in the literature have suggested that the recurrence or persistence of aneurysms are further lowered if braided stents are used, which diminishes the rate of an inadequate obliteration (RR III) to approximately 5%–10% of the aneurysms on follow-up.[17,28-31]

Very large cohorts of patients may be required to demonstrate an additional flow diversion by compaction/bulging beyond the diversion that is provided by the coils[32] and the braided stents themselves. In addition, the clinical implications of a significant-yet-small difference in the residual or recurrent aneurysm filling, if it exists, may not be profound. Given the risk of the inability to regain access into the aneurysms once a microcatheter is kicked out of the aneurysm, the higher risk of loss of endovascular access to the aneurysm through the compacted stent (and secondary "undercoiling") needs to be weighed against the potential advantages of flow diversion. We, thus, suggest that aneurysms should be coiled as densely and yet as safely as possible when the SBT is used, and the surgeon should not undercoil the aneurysm expecting an extra flow diversion to complete the aneurysm occlusion.

Our study adds to the literature because it is the only study that has compared the classic SAC with the SBT, and this study defined the exact role of SBT for the first time. Additionally, among similar studies, our study has the longest follow-up duration that has been reported for the SBT. On the other hand, this study has limitations. The limitations of the study are related to the retrospective methodology, the generalizability of the results to other centers, and the use of a single type of braided stent. Because the data collection was retrospective, we categorized the follow-up intervals as $\leq$4 months, 5–12 months, and $>$12 months. Furthermore, compaction was selectively used for aneurysms in which a propensity of coil encroachment onto the parent artery was suggested during the deployment of the first coil—that is, a selection bias inherently occurred by performing SBT in aneurysm cases in which regular SAC was likely to be unsuccessful.

CONCLUSIONS

The final occlusion rates in bifurcation aneurysms that were treated with classic SAC compared with those that were treated with SAC with the SBT were similar. Because SBT was used as a bailout technique for the classic SAC in this study, we infer that in comparison with the classic method, SBT had a favorable effect on the initial success of embolization but without an added influence on the long-term occlusion rate in complex bifurcation aneurysms. The lack of a clear-cut supplementary flow-diversion effect during the follow-up implies a need for dense coiling of aneurysms when the SBT is used because re-entry into a recanalized aneurysm for retreatment may be too cumbersome or impossible.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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