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ABSTRACT

BACKGROUND AND PURPOSE: Despite the numerous studies evaluating the occlusion rates of aneurysms following WEB embolization, there are limited studies identifying predictors of occlusion. Our purpose was to identify predictors of aneurysm occlusion and the need for retreatment.

MATERIALS AND METHODS: This is a review of a prospectively maintained database across 30 academic institutions. We included patients with previously untreated cerebral aneurysms embolized using the WEB who had available intraprocedural data and long-term follow-up.

RESULTS: We studied 763 patients with a mean age of 59.9 (SD, 11.7) years. Complete aneurysm occlusion was observed in 212/726 (29.2%) cases, and contrast stasis was observed in 485/537 (90.3%) of nonoccluded aneurysms. At the final follow-up, complete occlusion was achieved in 497/763 (65.1%) patients, and retreatment was required for 56/763 (7.3%) patients. On multivariable analysis, history of smoking, maximal aneurysm diameter, and the presence of an aneurysm wall branch were negative predictors of complete occlusion (OR, 0.5, 0.8, and 0.4, respectively). Maximal aneurysm diameter, the presence of an aneurysm wall branch, posterior circulation location, and male sex increase the chances of retreatment (OR, 1.2, 3.8, 3.0, and 2.3 respectively). Intraprocedural occlusion resulted in a 3-fold increase in the long-term occlusion rate and a 5-fold decrease in the retreatment rate ($P < .001$), offering a specificity of 87% and a positive predictive value of 85% for long-term occlusion.

CONCLUSIONS: Intraprocedural occlusion can be used to predict the chance of long-term aneurysm occlusion and the need for retreatment after embolization with a WEB device. Smoking, aneurysm size, and the presence of an aneurysm wall branch are associated with decreased chances of successful treatment.

ABBREVIATION: ROC = receiver operating characteristic

Intrasaccular flow disruption has become a viable option for the treatment of technically challenging wide-neck bifurcation aneurysms. The Woven EndoBridge (WEB; MicroVention) device provides a stable construct that sits at and above the neck of

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the aneurysm. Several prospective and retrospective studies have demonstrated its efficacy and safety compared with other treatment modalities.[1-4] Also, studies have evaluated the long-term durability of the WEB device. Complete occlusion and adequate (with neck remnant) occlusion occurred in 53%–74% and 79%–94% of cases at initial follow-up, respectively, and 6.5%–16% of aneurysms underwent retreatment.[5-8] Additionally, long-term follow-up studies have demonstrated that complete occlusion and adequate occlusion occur in 51%–72% and 74%–100% of cases.[5-10]

Despite the numerous studies evaluating the occlusion rates of aneurysms following WEB embolization, there are limited studies identifying predictors of occlusion.[5–10] Previous studies have demonstrated that rupture status, smaller neck size, and posterior circulation are associated with incomplete occlusion on follow-up.[10] In addition to aneurysm morphology and patient demographics, it is vital to identify intraoperative indicators of aneurysm occlusion. Compared with the immediate posttreatment angiogram, 60%–90% of WEB-treated aneurysms continue to further occlude on short-term follow-up, while 3%–5% worsen.[2,4] Similar to other endovascular technologies such as coiling and intraluminal flow diversion, it is important to better identify preoperative and intraoperative predictors of aneurysm occlusion following WEB deployment to guide future case selection, intraprocedural decision-making, and postoperative management strategies.

Here, we analyze an international multicenter cohort of patients treated with the WEB device to identify predictors of aneurysm occlusion at follow-up and retreatment. We mainly identify medical history, aneurysm characteristics, and intraprocedural findings that predict outcomes.

MATERIALS AND METHODS

Study Criteria

Data were obtained from a prospectively maintained multicenter database including adult patients (18 years of age or older) with ruptured and unruptured intracranial aneurysms treated with the WEB device at 30 academic institutions in North and South America, Europe, and Australia. The institutional review board approval was obtained from the primary institution, and individualized approval was obtained from each site. We included patients with cerebral bifurcation aneurysms treated with the WEB device and available follow-up on digital DSA, MRA, or CTA, or documented retreatment. Exclusion criteria included the use of adjunctive modalities of treatment and previously treated aneurysms.

Data Collection

Patient charts were reviewed to determine patient characteristics, including age, sex, smoking status, preprocedural antithrombotic use, and aneurysm rupture status. Procedural duration time to last follow-up and imaging technique at last follow-up were also determined by chart review. Interpretation of imaging was completed by the treatment team, who reported anatomic location, dimensions, the presence of a daughter sac and a vessel branch arising from aneurysm wall, the degree of occlusion (interprocedurally and at last follow-up), intraprocedural contrast stasis, and complete occlusion at last follow-up. The need for retreatment was determined by the treatment team, and retreatment was documented.

The intraoperative degree of occlusion was divided into complete occlusion (100%), near-complete occlusion (>90%), and aneurysm residual (<90%). This was calculated on the basis of the optimal aneurysm projection and the area of contrast opacification pre- and post-device deployment. Occlusion at final follow-up was evaluated on the basis of the WEB Intra saccular Therapy (WEB-IT) trial angiographic scale, including complete occlusion, near-complete occlusion with a residual neck, and residual aneurysm. Adequate occlusion was defined as complete or near-complete occlusion with a residual neck.[2] At final follow-up, the treatment team also reported the presence of complete occlusion. If patients had additional treatment, final follow-up occlusion rates were based on the patient's reported imaging follow-up available before retreatment. Stasis was assessed on

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the basis of contrast persistence within the aneurysm at the capillary phase and was only assessed in patients with noncomplete intraoperative occlusion.

Statistical Analysis

Data are presented as mean (SD) for numeric variables and as a frequency and percentage for categoric variables. Univariate logistic regression analysis was used to test covariates predictive of complete aneurysm occlusion at the most recent follow-up. Interaction and confounding were assessed through stratification and linear regression analysis. Factors predictive in univariate analysis ($P < .15$) were entered into a multivariate logistic regression analysis. However, because different measures of aneurysm size are highly correlated both physiologically and statistically, only the aneurysm maximum diameter was entered into the multivariate analysis. Logistic regression results are represented as ORs and 95% confidence intervals with the associated P value. A similar analysis was used to test covariates predictive of the need for retreatment. Categoric variables were compared using the χ^2 test with a Bonferroni correction for multiple-comparison adjustment. Intraoperative complete occlusion was evaluated as a predictor of complete occlusion and the need for retreatment using the receiver operating characteristic (ROC) curve. P values $\leq .05$ were considered statistically significant except for application of the Bonferroni correction for multiple-comparison adjustment as indicated. Statistical analysis was performed with SPSS Software 29.0.0.0 (IBM) and GraphPad Prism (GraphPad Software).

RESULTS

Baseline Characteristics

The study cohort comprised 763 patients who were predominantly women ($n = 510$, 66.8%), with a mean age of 59.9 (SD, 11.7) years. Of them, 210 (31.2%) patients were current smokers, 193 (28.7%) were former smokers, and 270 (40.1%) were nonsmokers. On admission, 327 (46.6%) patients were not being treated with antithrombotic agents, 91 (12.1%) were on a single agent, and 283 (40.4%) were on 2 agents. With respect to aneurysm characteristics, 230 (30.1%) were ruptured on admission, 639 (83.7%) were bifurcation aneurysms, 215 (30.1%) were accompanied by a daughter sac, and 78 (10.4%) had a vessel arising from the aneurysm wall. The mean aneurysm neck was 4.0 (SD, 1.4) mm, the mean maximal diameter was 6.9 (SD, 2.4) mm, the mean aneurysm height was 6.1 (SD, 2.3) mm, and the mean aneurysm width was 5.8 (SD, 2.1) mm. Patient demographics and aneurysm characteristics are summarized in Table 1.

Table 1: Patient demographics and aneurysm characteristics

	No. (%), Mean (SD)
Total No. of patients	763
Sex (female)	510 (66.8)
Mean age (yr)	59.9 (SD, 11.7)
Smoking status[a]	
Current	210 (31.2)
Former	193 (28.7)
Nonsmoker	270 (40.1)
Ruptured aneurysm	230 (30.1)
Aneurysm location	
AcomA	223 (29.2)
Basilar tip	123 (16.1)
ACA	56 (7.3)
ICA	15 (2.0)
MCA	206 (27.0)
PcomA	54 (7.1)
PICA	14 (1.8)
ICA terminus	60 (7.9)
SCA	5 (0.7)
VA	6 (0.8)
PCA	1 (0.1)
Mean aneurysm neck (mm)[b]	4.0 (SD, 1.4)
Mean maximal diameter (mm)	6.9 (SD, 2.4)
Mean aneurysm height (mm)[c]	6.1 (SD, 2.3)
Mean aneurysm width (mm)[d]	5.8 (SD, 2.1)
Bifurcation aneurysms	639 (83.7)
Daughter sac[e]	215 (30.1)
Vessel from aneurysm wall[f]	78 (10.4)
Preprocedural AP/AC[g]	
None	327 (46.6)
Single agent	91 (12.1)
Two agents	283 (40.4)

Data missing for a = 90, b = 66, c = 10, d = 4, e = 351, f = 49, g = 10, h = 62.
Note:—AcomA indicates anterior communicating artery; PcomA, posterior communicating artery; ACA, anterior cerebral artery; SCA, superior cerebellar artery; VA, vertebral artery; PCA, posterior cerebral artery; AP/AC, antiplatelets/anticoagulants.

Procedure and Follow-Up

The mean duration of the procedures was 88.0 (SD, 47.9) minutes. Immediately after WEB deployment, 212 (29.2%) patients achieved complete intraprocedural occlusion, 185 (25.5%) achieved >90% intraprocedural occlusion, and 328 (45.2%) achieved <90% intraprocedural occlusion. Contrast stasis was observed in 485 (90.3%) cases. The mean duration to final follow-up was 17.7 (SD, 20.3) months, with a minimum follow-up of 3 months and a maximum follow-up of 115 months, and the following imaging modalities were used to evaluate aneurysm obliteration: 206 (27.3%) on DSA, 376 (49.9%) on MRA, 131 (17.4%) on CTA, 9 (1.2%) on MRA/DSA, 5 (0.7%) on CTA/DSA, and 27 (3.6%) on CTA/MRA. At the final follow-up, 695 patients had the degree of aneurysm occlusion recorded and had not undergone retreatment. Of those, complete occlusion was achieved in 497 (71.5%) patients; near-complete occlusion with a neck remnant, in 139 (20%) patients; and aneurysm residual, in 59 (8.5%) patients. Of all the patients, complete aneurysm obliteration was observed in 497 (65.1%) patients on the most recent available follow-up, while 56 (7.3%) patients required retreatment. The procedural characteristics, follow-up, and outcomes are summarized in Table 2.

Predictors of Aneurysm Occlusion

Univariate and multivariate analyses were performed to identify independent predictors of complete obliteration at final follow-up (Online Supplemental Data).

On univariate analysis, factors associated with a decreased chance of complete obliteration at final follow-up were being a former smoker (OR, 0.6; 95% CI, 0.370–0.845; $P = .006$), neck diameter (OR, 0.7; 95% CI, 0.646–0.815; $P < .001$), maximal diameter (OR, 0.8; 95% CI, 0.745–0.850; $P < .001$), aneurysm width (OR, 0.8; 95% CI, 0.745–0.864; $P < .001$), aneurysm height (OR, 0.8; 95% CI, 0.742–0.854; $P < .001$), the presence of a daughter sac (OR, 0.7; 95% CI, 0.505–0.983; $P = .039$), and the presence of

a wall branch (OR, 0.4; 95% CI, 0.278–0.725; $P = .001$). In addition, intraprocedural complete occlusion at the time of treatment increased the chance of follow-up aneurysm occlusion by 3.6-fold compared with <90% occlusion (OR, 3.6; 95% CI, 2.285–5.534; $P < .001$). On multivariate analysis, independent factors negatively correlated with complete aneurysm occlusion at the last follow-up were former smoking (OR, 0.5; 95% CI, 0.311–0.82; $P = .005$) maximal aneurysm diameter (OR, 0.8; 95% CI, 0.743–0.873; $P < .001$) and the presence of an aneurysm wall branch (OR, 0.4). Intraprocedural complete occlusion increased the chance of complete occlusion at last follow-up by 3-fold (OR, 3.0; 95% CI, 1.8–4.9; $P < .001$).

Predictors of Retreatment

Univariate and multivariate analysis were performed to identify independent predictors of retreatment (Online Supplemental Data).

Factors associated with retreatment at final follow-up were younger age (OR, 0.96; 95% CI, 0.944–0.986; $P = .001$), male sex (OR, 2.1; 95% CI, 1.234–3.687; $P = .007$), ruptured status (OR, 2.0; 95% CI, 1.124–3.414; $P = .018$), posterior circulation location (OR, 1; 95% CI, 1.038–3.449; $P = .037$), neck diameter (OR, 1.2; 95% CI, 0.965–1.385, $P < .001$), maximal diameter (OR, 1.2; 95% CI, 1.120–1.357; $P < .001$), aneurysm width (OR, 1.3; 95% CI, 1.123–1.405; $P < .001$), and aneurysm height (OR, 1.3; 95% CI, 1.152–1.418; $P < .001$). Intraprocedural complete occlusion at the time of treatment decreased the chance of retreatment 5-fold compared with <90% occlusion (OR, 0.2; 95% CI, 0.058–0.476; $P < .001$). On multivariate analysis, independent predictors of retreatment were male sex (OR, 2.3; 95% CI, 1.119–4.707; $P = .023$), posterior circulation location (OR, 3.0; 95% CI, 1.367–6.476; $P = .006$), maximal aneurysm diameter (OR, 1.2; 95% CI, 1.068–1.362; $P < .001$), and the presence of a wall branch (OR, 3.8; 95% CI, 1.577–9.175; $P = .002$). Intraprocedural complete occlusion decreased the chance of retreatment 5-fold compared with <90% occlusion (OR. 0.2; 95% CI, 0.06–0.582; $P = .003$).

Table 2: Occlusion rates of treated aneurysms intraoperatively and at most recent follow-up

	No. (%), Mean (SD)
Mean duration of procedure (min)[a]	88.0 (47.9)
Immediate occlusion[b]	
100%	212 (29.2)
>90%	185 (25.5)
<90%	328 (45.2)
Contrast stasis in nonoccluded aneurysms[c]	485 (90.3)
Mean duration to last follow-up (mo)	17.7 (20.3)
Technique of last follow-up[d]	
DSA	206 (27.3)
MRA	376 (49.9)
CTA	131 (17.4)
MRA/DSA	9 (1.2)
CTA/DSA	5 (0.7)
MRA/CTA	27 (3.6)
Occlusion at last follow-up[e]	
Complete	497 (71.5)
Near-complete occlusion	139 (20)
Aneurysm residual	59 (8.5)
Complete occlusion	497 (65.1)
Retreatment	56 (7.3)

Note:—Data missing for a = 113, b = 37, c = 68, d = 9, e = 68.

Intraoperative Predictors of Outcomes

We further focused on understanding how intraoperative radiographic findings at the time of treatment predict occlusion at last follow-up and ultimate retreatment. The χ^2 with a Bonferroni correction for multiple comparison adjustment demonstrated that intraoperative complete occlusion at the time of treatment leads to an 85% rate of obliteration at last follow-up and a 98.1% rate of not requiring additional treatment. In contrast, 90%–99% occlusion and <90% occlusion lead to 51.4% and 61.3% rates of occlusion at last follow-up, respectively, as well as 90.3% and 89.6% rates of no additional treatment, respectively (Table 3).

We proceeded to evaluate the intraoperative evidence of 100% occlusion as a test for predicting occlusion at last follow-up. This evaluation provided 0.874 specificity with only 0.373 sensitivity and a positive predictive value of 0.85 (Pearson χ^2 P value and ROC curve P value <.001). Similarly, we evaluated intraoperative 100% occlusion as a predictor of no need for additional treatment. This step provided 0.929 specificity with only 0.31 sensitivity and a positive predictive value of 0.981 (Pearson χ^2 P value < .001 and ROC curve P value = .003; Table 4).

Predictors of Intraoperative Complete Occlusion. Univariate and multivariate analyses were performed to identify independent predictors of intraoperative complete obliteration (Online Supplemental Data). On univariate analysis, factors associated with a decreased chance of complete obliteration intraoperatively were neck diameter (OR, 0.7; 95% CI, 0.629–0.844; $P < .001$), aneurysm width (OR, 0.9; 95% CI, 0.850–0.998; $P = .045$), and bifurcation aneurysm (OR, 0.5; 95% CI, 0.336–0.77; $P < .001$). On multivariate analysis, aneurysm neck diameter was negatively correlated with complete intraoperative aneurysm occlusion (OR, 0.6; 95% CI, 0.573–0.817; $P < .001$).

DISCUSSION

The WEB device has been added to our armamentarium for the treatment of wide-neck bifurcation aneurysms.[1-4] Given that an

Table 3: Intraoperative degree of occlusion and stasis as predictors of long-term outcomes

	Imaging Findings			Management		
	Obliteration	Residual/Recurrence	*P* Value	Treatment	No. Treatment	*P* Value
Intraoperative 100% occlusion	175 (85%)[a]	31 (15%)[a]	<.001[a]	4 (1.9%)[a]	207 (98.1%)[a]	<.001[a]
90%–99% occlusion	94 (51.4%)	89 (48.6%)		18 (9.7%)	167 (90.3%)	
<90% occlusion	200 (61.3%)	126 (38.7%)		34 (10.4%)	193 (89.6%)	
Contrast stasis	284 (59.2%)	196 (40.8%)	.259	48 (9.9%)	436 (90.1%)	.606
No stasis	26 (51%)	25 (49%)		4 (7.7%)	48 (92.3%)	

[a] Significant.

Table 4: Test parameters of intraoperative complete occlusion as a predictor of long-term obliteration and no additional treatment

Obliteration at Last Follow-Up	*P* Value	No Retreatment	*P* Value
Sensitivity	.373	Sensitivity	.310
Specificity	.874	Specificity	.929
Positive predictive value	.850	Positive predictive value	.981
Negative predictive value	.422	Negative predictive value	.102
Positive likelihood ratio	2.961	Positive likelihood ratio	4.345
Pearson χ^2 *P* value	<.001[a]	Pearson χ^2 *P* value	<.001[a]
ROC curve *P* value	<.001[a]	ROC curve *P* value	.003[a]

[a] Significant.

adequate occlusion rate is 80% and treatment failure occurs in 5% of cases, it is important to describe factors that are associated with treatment failure.[10] Herein, we identified that aneurysm characteristics, including anatomic location, size and wall branch vessel, and smoking status affect the probability of long-term occlusion and retreatment. We also report that intraoperative occlusion at the time of treatment predicts outcomes. These findings can inform patient selection for treatment with the WEB device and help determine postprocedural expectations and observation regimen.

We identified that immediate intraoperative occlusion predicts an 85% chance of complete occlusion at the last follow-up and a 98.1% rate of not requiring retreatment. This finding indicates a 3-fold increase in the occlusion rate compared with aneurysms with <90% intraoperative occlusion. However, intraoperative near-complete occlusion and the presence of contrast stasis were not predictive of the outcomes at last follow-up. Initial studies on the efficacy of WEB embolization indicated that most aneurysms continue to occlude compared with immediate intraoperative findings. However, 5% will worsen at short-term imaging, and 11.5% will further recanalize at long-term follow-up.[2] Goertz et al[5] reported that incomplete intraoperative occlusion was associated with incomplete occlusion at short-term follow-up (<12 months). Here, we confirm that this correlation persists at last follow-up.,[11] Near-complete occlusion with a neck remnant did not correlate with long-term occlusion or recurrence rate. This finding differs from the improved rate of occlusion observed when Raymond-Roy II is achieved during coil embolization.[12] Additionally, similar to intraluminal flow diversion, while contrast stasis is often considered a desirable intraprocedural finding, it does not appear predictive of long-term outcome.[13]

In our cohort, occlusion at the last follow-up was achieved in 71.5% of cases, and adequate occlusion, in 91.5% of cases, with retreatment required in 7.3% of cases. These results are consistent with findings in previous literature.[5-10] Long-term occlusion rates appeared to decrease and the probability of retreatment increased as aneurysm size parameters increased. These include maximum aneurysm diameter, height, width, and neck dimension. Goertz et al[5] demonstrated that the midterm (<12 months) occlusion rate negatively correlates with aneurysm diameter and height, while they only associated aneurysm neck with long-term occlusion rates. Similarly, Fujimoto et al[9] reported that their retreatment group had significantly larger aneurysm sizes. Of note, Zhang et al[10] reported that an aneurysm neck of 4–10 mm may be optimal for WEB treatment. Aneurysm size has been correlated with a decreased chance of occlusion after treatment with other endovascular modalities as well.[14,15] Like previous studies, in our cohort, aneurysms in the posterior circulation had a lower chance of complete occlusion and were more likely to require retreatment.[10,16]

Compared with coiling, the WEB device has a predetermined shape and relies on flow disruption to achieve embolization. Aneurysm characteristics such as irregular shape and the presence of an aneurysm wall branch vessel can affect WEB placement and flow diversion, respectively, and impede aneurysm occlusion. The presence of a wall branch was identified as a risk factor for nonobliteration and retreatment. While this factor has not been identified before, the presence of an aneurysm wall branch tends to promote persistent flow through the aneurysm. This phenomenon has also been observed with intraluminal flow diverters.[17] Additionally, a daughter sac was associated with decreased rate of complete occlusion. While further studies are needed to explain this phenomenon, the presence of a daughter sac likely makes optimal WEB sizing more challenging.[9]

In accordance with previous analysis, we confirm here that ruptured and unruptured aneurysms have the same occlusion rates,[18] and we demonstrated a 2-fold increase in the retreatment rate only on univariate analysis. The literature on the occlusion rate of ruptured aneurysms is variable, with some studies suggesting a decreased occlusion rate for these aneurysms,[5,10] while others found that ruptured status does not affect the occlusion rate.[11,18] Most important, Diestro et al[18] previously reported no evidence of rerupture following WEB embolization of ruptured aneurysms, and the occlusion rate was decreased by only 20%. Ruptured aneurysm status represents a well-known risk factor for recanalization after coiling.[19]

Intraprocedural complete occlusion being a strong predictor of long-term outcomes independent of patient and aneurysm characteristics suggests that proceduralists should aim to achieve immediate occlusion. This finding also suggests that the degree of occlusion should be considered postdeployment but before detachment of the WEB device to determine whether positioning and sizing are adequate. Complete occlusion of the aneurysm post-WEB deployment can provide confidence that this aneurysm has a good chance of remaining occluded and not requiring retreatment. Most interesting, immediate occlusion in our data was only inversely correlated with aneurysm neck size and no other patient or aneurysm parameters. This result may be attributed to the WEB device apposition in the neck driving the initial flow disruption leading to immediate occlusion.

Limitations

This study is limited by its retrospective design; however, to our knowledge, this is the largest retrospective study assessing predictors of prognosis after WEB aneurysm treatment. The mean duration to last follow-up was also 17.7 months, with a range from 3 to 115 months, and longer follow-up is certainly needed to clarify outcomes of patients with residual aneurysm filling after WEB device placement. Additionally, follow-up was completed with a

variety of modalities including DSA, CTA, or MRA. On the basis of a recent analysis by El Naamani et al,[20] there is no difference in the positive predictive value among these imaging modalities when predicting recurrence rates. Rating intraprocedural occlusion and aneurysm contrast stasis can be subjective and may be inaccurate. Additionally, assessment of occlusion at angiographic follow-up was self-adjudicated. The gradual introduction of automatic segmentation and rating of occlusion will improve the accuracy of these studies.

CONCLUSIONS

This retrospective study allows analysis of factors associated with aneurysm occlusion or retreatment following intrasaccular flow disruption. Specifically, we were able to determine which intraoperative imaging factors physicians can rely on to predict the postoperative course. Additionally, we confirm the established rate of aneurysm occlusion following WEB embolization and the correlation with aneurysm size and anatomic location. We also note how aneurysm architecture (wall branch or presence of a daughter sac) can affect the flow-diverting properties of the WEB device. This analysis will provide information to improve patient selection and guide postoperative management.

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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