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Treatment of Wide-Necked Cerebral Aneurysms Using the WEB Device Including Flow Alteration Assessment With Color-Coded Imaging: A Single Center Experience

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■ OBJECTIVE: **The Woven EndoBridge (WEB) device (MicroVention, Tustin, CA) has extended the treatment of cerebral aneurysms. Despite the fact that the WEB device has shown promising clinical results, little is known about the caused intra-aneurysmal flow alterations. Here we present our clinical experience with the WEB, including examining various syngo iFlow (Siemens AG, Erlangen, Germany) parameters to predict aneurysm occlusion.**

■ METHODS: **We reviewed the data from patients with unruptured cerebral aneurysms treated with a WEB device between 2016 and 2020. Aneurysm occlusion and complications were assessed. Furthermore, different quantitative criteria were evaluated using syngo iFlow after digital subtraction angiography.**

■ RESULTS: **A total of 26 patients hosting 26 cerebral aneurysms met the inclusion criteria. Follow-up was available for 21 patients, with a mean of 7.3 ± 6.3 months. A total of 71.4% (n = 15) of the aneurysms included were located in the anterior and 28.6% (n = 6) in the posterior circulation. Adequate aneurysm occlusion was achieved in 85.7% (n = 18). The iFlow parameters for reduced aneurysm outflow (ID-R) differed significantly from the parameters for reduced inflow (PI-R and PI-D) ($P < 0.001$). The parameters did not differ significantly between adequately and insufficiently occluded aneurysms. Only a trend towards a lower ID-R of insufficiently occluded aneurysms was observed ($P = 0.063$), indicating a potential predictive value for insufficient aneurysmal outflow. There was no treatment-related morbidity or mortality.**

■ CONCLUSIONS: **The applied syngo iFlow parameters confirmed that flow changes induced by the WEB device significantly affect outflow compared to inflow and have potential predictive value for adequate aneurysm occlusion.**

INTRODUCTION

The Woven EndoBridge (WEB) device (MicroVention, Tustin, CA), also known as an intrasaccular flow diverter, entered the market in 2011 and was developed for the treatment of wide-neck cerebral aneurysms.[1] The WEB device is an electrolytically detachable braided basket with 114–216 nitinol wires. There are two differently shaped single-layer devices (WEB SL and WEB SLS [spherical]) available in various sizes. The aim is to induce aneurysmal thrombosis by disrupting the endosaccular blood flow.[2] Many clinical studies have shown promising results using such devices with an acceptable risk profile and promising occlusion rates.[3,4] While in the early years treatment with the WEB was mainly reserved for large aneurysms, the introduction of WEB-17 devices with a low profile has safely and efficiently expanded the indication for treatment for small aneurysms (<5 mm).[5-7] Even in the scenario of a ruptured aneurysm,

Key words
- Cerebral aneurysm
- Syngo iFlow
- WEB

Abbreviations and Acronyms
2D: 2-dimensional
BOSS: Beaujon Occlusion Scale Score
CFD: Computational fluid dynamics
DSA: Digital subtraction angiography
ID: Intensity decrease
ID-R: Intensity decrease ratio
mRS: Modified Rankin scale
PI: Peak intensity
PI-D: Peak intensity delay
PI-R: Peak intensity ratio
ROI: Region of interest
TDC: Time density curve
TTP: Time to peak
WEB: Woven EndoBridge

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WEB devices have shown promising occlusion and acceptable complications rates.[7-10]

Data about the precise intra-aneurysmal flow alterations caused by the WEB device are still lacking. In the beginning, flow alterations were mainly assed visually by analysis of contrast stagnation on digital subtraction angiography (DSA) series.[1] Color-coded imaging using time density curves (TDCs) generated with syngo iFlow software (Siemens AG, Erlangen, Germany) have been shown beneficial in assessing various cerebrovascular diseases.[11,12] Previously described preclinical syngo iFlow parameters have shown promising results in the assessment of hemodynamic changes in the field of flow diversion.[13] To date, only 1 study is available that quantifies the hemodynamic effect of the WEB device using color-coded TDCs.[14]

The objective of our study was to share our clinical experience with the WEB device and evaluate hemodynamic changes with previously described syngo iFlow parameters[13] and their predictive value for aneurysm occlusion.

METHODS

Patient Selection

Ethics committee approval was obtained for this retrospective data analysis. Our database was screened for patients with unruptured cerebral aneurysms treated with a WEB device between January 2016 and December 2020. A minimum follow-up time of 6 months was required. Ruptured aneurysms as well as aneurysms additionally treated with coil embolization were excluded. Clinical outcome was evaluated by using the modified Rankin scale (mRS) before treatment, at discharge, and at follow-up. Procedure-related morbidity was defined as any neurologic worsening reflected by an increase on the mRS by 1 point at follow-up.

Interventional Procedure

All patients in this study received a dual antiplatelet medication of 100 mg acetylsalicylic acid and clopidogrel 75 mg daily at least 3 days prior to the intervention. Endovascular aneurysm treatment was performed under general anesthesia using a standard triaxial system. Placement of the WEB was performed using a VIA 17-33 microcatheter (Microvention) depending on the size of the WEB device. Periprocedural a dose of 3000 IU intravenous heparin was administered. A single platelet aggregation inhibition of 100 mg acetylsalicylic acid daily was continued for 3 months, unless it existed as a lifelong premedication.

Imaging Protocol

DSA was performed with a biplane flat panel detector angiographic system (Artis Q; Siemens AG) in posterior-anterior and lateral projection (2-dimensional [2D] DSA series) at a rate of 2−4 frames/second. Manual contrast medium injection (Ultravist 370; Bayer Vital, Leverkusen, Germany) was performed using a variety of standard diagnostic catheters (4−5F) and peri-interventional distal access catheters (5−6F). DSA images of all the patients were collected and postprocessed on an appropriate workstation (Leonardo Workstation; Siemens AG) using a dynamic flow evaluating software (syngo iFlow).

The software visualizes a complete 2D DSA run in a single-colored image that shows the time-dependent intensity of the contrast medium within the aneurysm and the parent vessel, and quantifies the time between the injection of the contrast medium and the maximum opacification. First, a projection plane was selected in which the aneurysm did not overlap with the parent vessel. iFlow measurements were performed before and after implantation of the WEB device as well as at follow-up DSA as follows: Regions of interest (ROI) were placed centrally within the aneurysm and at a corresponding position in the parent vessel so that the generated TDCs showed comparable flow patterns (**Figures 1C** and **2C**). The surface area of the ROIs measured between 1.60 and 3.90 mm^2 and was dependent on the vessel size. After implantation of the WEB device, the ROIs were placed in a comparable location and TDCs were created (**Figures 1D** and **2D**). At follow-up, the ROIs were placed in a comparable location, unless the aneurysm changed its morphology, in which case the intra-aneurysmal ROI was adjusted accordingly. From the TDC different values (peak intensity [PI], time to peak [TTP], intensity decrease [ID]) have been determined. Based on these values different flow parameters have been defined representing aneurysm inflow (peak intensity delay [PI-D], peak intensity ratio [PI-R]) and outflow (intensity decrease ratio [ID-R]), as previously described.[13]The prerequisite for the iFlow evaluation was a DSA run of at least 5 seconds so that the selected parameters could be applied. These applied parameters were correlated with the aneurysm occlusion rate observed during the follow-up DSA.

Aneurysm occlusion was assessed using the Beaujon Occlusion Scale Score (BOSS) previously described in the literature[15] as follows: grade 0, no residual flow inside the aneurysm or WEB; grade ó, opacification of the proximal recess of the WEB; grade 1, residual flow inside the WEB; grade 2, neck remnant; grade 3, aneurysm remnant; grade 1+3, contrast agent is depicted inside and around the device. Aneurysms showing grade 0 and ó were classified as adequately occluded. Two experienced neuroradiologists evaluated and compared the DSA series and the iFlow images.

Statistical Analysis

Continuous variables are expressed as the mean ± standard deviation. Categorical variables are presented as absolute and relative frequencies, unless otherwise stated. Fisher's exact tests were conducted to compare categorical variables between groups. Continuous variables were tested for normal distribution. The differences between the groups were compared using Student's *t* tests. Statistical significance was accepted with a 2-sided *P*-value of <0.05. All data analyses were performed with SPSS Statistics version 25 (IBM Inc., Armonk, NY).

RESULTS

Demographics, WEB Devices, and Aneurysm Location

We identified 26 patients who were treated with a WEB device and met the requirements for an iFlow evaluation. In these patients a total of 26 unruptured cerebral aneurysms have been treated. Five patients (19.2%) were excluded because of missing follow-up date, leading to a total collective of 21 patients (14 female,d 7 male) with 21 treated aneurysms. In this study only the single-layer WEB devices (SL WEB) were used. Of the aneurysms available for

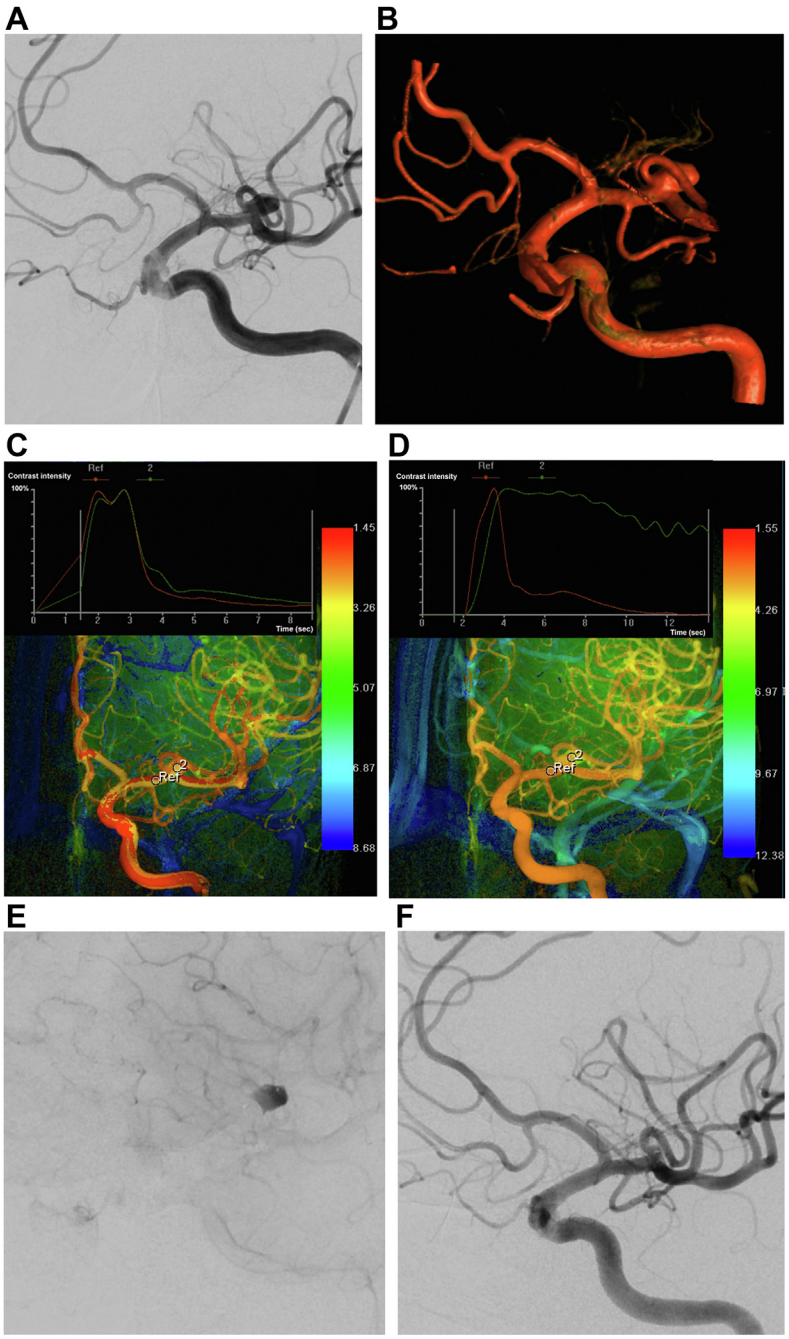

Figure 1. (**A, B**) Digital subtraction angiography (DSA) and 3-dimensional DYNA-CT reconstruction of a saccular bifurcation aneurysm (5.4 x 5.9 x 4.6 mm) of the left middle cerebral artery with a dome-to-neck ratio of 1.1. (**C**) iFlow image prior WEB implantation including the ROI of the aneurysm (*2*) and parent vessel (*REF*) as well as the TDC showing comparable flow patterns. (**D**) iFlow image and TDC after WEB implantation with a PI-D of 0.7, a PI-R of 0.84, and ID-R of 10.6 representing a curve plateau with an appropriate reduction of aneurysmal outflow. (**E**) DSA revealed a distinct stasis of contrast medium within the implanted WEB device and aneurysm. (**F**) DSA after 6 months showed an adequate occlusion of the aneurysm (BOSS ó).

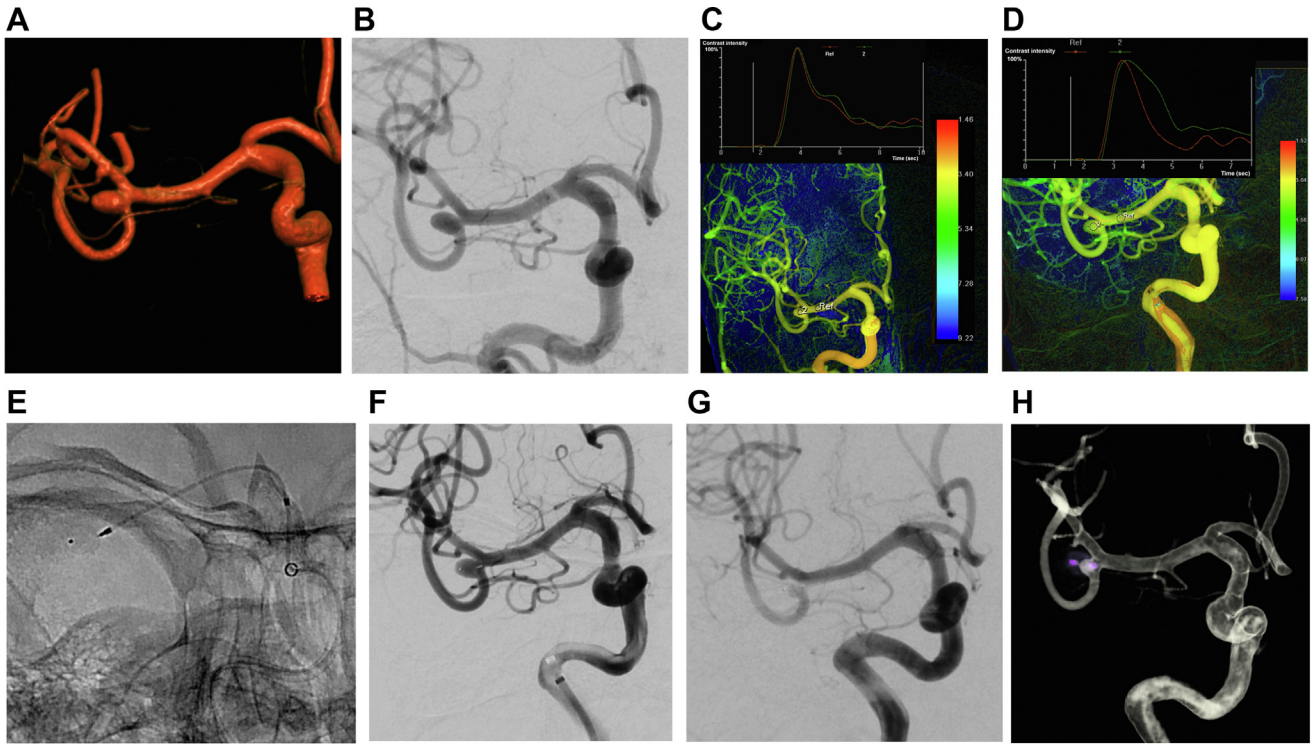

Figure 2. (**A, B**) Digital subtraction angiography (DSA) and 3-dimensional DYNA-CT reconstruction of a saccular bifurcation aneurysm (3.4 x 4.6 x 4.5 mm) of the right middle cerebral artery with a dome-to-neck ratio of 1.1. (**C**) iFlow image prior WEB implantation including the ROI of the aneurysm (*2*) and parent vessel (*REF*) as well as the TDC showing comparable flow patterns. (**D**) iFlow image and TDC after WEB implantation with a PI-D of 0. 2, a PI-R of 0.94, and ID-R of 1.29 representing inappropriate reduction of aneurysmal outflow recognizable by a rapidly decreasing cure and the lack of a plateau. (**E**) Fluoroscopy of the deployed and undetached WEB device. (**F**) DSA after detachment of the WEB device. (**G, H**) DSA and 3-dimensional DYNA-CT reconstruction after 6 months showing an insufficient occlusion of the aneurysm (BOSS 1).

follow-up, 15 of 21 (71.4%) were located in the anterior circulation and 6 of 21 (28.6%) were located in the posterior circulation. Demographic data and aneurysm location are demonstrated in detail in Table 1.

Angiographic Data and Follow-up

The aneurysms treated in this study measured a dome-to-neck ration of 1.23 ± 0.23 mm (median 1.26). The 3-dimensional morphology of the treated aneurysms and the correlating aneurysm volumes were assessed before and immediately after implantation of the WEB device (Table 2). Final DSA was performed after a median of 8 minutes with a mean of 7.6 ± 2.5 minutes. Incipient aneurysm occlusion at final DSA was seen in 8 cases (38.1%); in 4 cases (19.0%) this led to a complete occlusion after a time of 5.1 ± 1.5 minutes (median 5.0). Thus, the aneurysm size immediately after implantation of the WEB device showed a tendency to decrease compared with the initial aneurysm size. However, the decrease in aneurysm size did not differ significantly; P values are shown in Table 2. Final DSA after the interventional procedure revealed the following occlusion rates (BOSS): 0, in 4 cases (19.0%); 1, in 4 cases (19.0%); 1+3, in 13 cases (62.0%).

One DSA follow-up was available for all patients in this study. The follow-up ranged from 6 to 21 months with a median of 7 and mean of 7.3 ± 6.3 months. We observed the following occlusion rates (BOSS): 0, in 11 cases (52.4%); ó, in 7 cases (33.3%) (Figure 1F); 1, in 2 cases (9.5%) (Figures 2G and H); and 2, in 1 case (4.8%). Respectively, leading to an adequate aneurysm occlusion (Figure 1) in 18 cases (85.7%) compared to 3 (14.3%) insufficiently occluded aneurysms (Figure 2) at follow-up. Adequately occluded aneurysms revealed a distinct stasis of contrast medium immediately after WEB device placement (Figure 1E). One of the insufficiently occluded aneurysms (BOSS 2) was due to a compression of the WEB device and was treated subsequently with stent-assisted coiling.

Further analysis of aneurysm morphology revealed greater aneurysm height (9.2 ± 3.8 mm vs. 5.3 ± 1.6 mm, P = 0.004), width (9.5 ± 3.5 mm vs. 4.9 ± 1.9 mm, P = 0.002), and volume (958.5 ± 1208.9 mm^3 vs. 146.7 ± 137.2 mm^3, P = 0.005) for insufficiently occluded versus adequately occluded aneurysms. Aneurysm height (6.7 ± 3.9 mm vs. 4.6 ± 1.5 mm, P = 0.089), neck (3.9 ± 0.7 mm vs. 3.3 ± 1.2 mm, P = 0.456), and dome-to-neck ratio (1.2 ± 0.2 vs. 1.3 ± 0.2 mm, P = 0.377) showed no significant difference. The angulation of the implanted WEB

Table 1. Demographics and Aneurysm Location

Variable	WEB
Mean age, years	60.8 ± 8.8
Median age, years	61
Age range, years	46–78
Female / male sex	14/7
Aneurysm location, n (%)	
Anterior circulation	15 (71.4)
Internal carotid artery (ICA)	3 (14.3)
Middle cerebral artery (MCA)	8 (38.1)
Anterior communicating artery (Acom)	4 (19.0)
Posterior circulation	6 (28.6)
Vertebral artery (VA)	2 (9.5)
Posteroinferior cerebellar artery (PICA)	1 (4.8)
Basilary artery (BA)	2 (10.5)
Posterior cerebral artery (PCA)	1 (4.8)

devices, which showed insufficient occlusions, was perpendicular to the course of the aneurysm dome. Comparison of aneurysm width and WEB diameter revealed a significant difference between insufficiently occluded aneurysms and adequately occluded aneurysms (−0.15 ± 0.06 mm vs. 0.36 ± 0.35 mm, $P < 0.025$).

iFlow Parameters

Prior to the WEB device implantation, the TDCs were comparable with each other in all cases demonstrating similar flow conditions within the aneurysm and the parent vessel (Figures 1C and 2C). The duration of the DSA run was comparable between adequately occluded aneurysms (BOSS 0 and ó, Figure 1) and insufficiently occluded aneurysms (BOSS 1–3, Figure 2), measuring 7.7 ± 2.1 seconds vs. 7.3 ± 3.4 seconds ($P = 0.798$). Volume of the applied contrast agent during the DSA run was also not significantly different between adequately occluded aneurysms and insufficiently occluded aneurysms measuring 7.5 ± 1.2 mL vs. 7.3 ± 0.6 mL ($P = 0.760$). None of the applied parameters (PI-D, PI-R, ID-R) revealed significant differences between adequately occluded aneurysms and insufficiently occluded aneurysms. There was a trend towards a lower ID-R of insufficiently occluded aneurysms (2.38 ± 1.62) compared with adequately occluded aneurysms (5.26 ± 3.77). The reduced ID-R was reflected in the TDCs by the fact that the intra-aneurysmal curve flattened more quickly after its peak in the case of insufficiently occluded aneurysms (Figure 2D) and the curve of adequately occluded aneurysms showed a clear plateau (Figure 1D). Comparison between incipient occluded aneurysm (BOSS 0–1) with absent occlusion (BOSS 1+3) during the interventional procedure also showed no significant difference (Figure 1). The iFlow parameters for aneurysmal inflow (PI-D and PI-R) compared with the parameter for aneurysmal outflow (ID-R) revealed significant differences. PI-D (0.63 ± 0.53) as well as PI-R (0.82 ± 0.13) were significantly less than ID-R (4.85 ± 3.66) leading to a P value of <0.001 in both cases. Subgroup analysis of the iFlow parameters between aneurysms located within the anterior and the posterior circulation and aneurysm morphology with respect to size demonstrated no significant differences. iFlow measurements in detail including P values are shown in Table 3.

Clinical Outcome/Complications

One patient previously suffered a subarachnoid hemorrhage from an aneurysm other than that treated in this study and entered with an mRS score of 4. All WEB devices were successfully delivered with no deployment or placement problems. In 2 cases (9.5%) the implanted WEB devices showed a marginal protrusion into the parent artery. Ischemic events were observed in 1 patient (4.8%). During treatment of a right-sided MCA aneurysm a minor perfusion delay was observed during DSA in the parietal artery segment. After the intervention the patient reported a discreet left-sided upper limp hemihypesthesia. Magnetic resonance imagin revealed 2 small, punctiform cortical infarctions in the parietal lobe resulting in a postinterventional mRS score of 1. At follow-up after 6 months the patient recovered fully and the mRS score declined back to 0. In 1 case (4.8%) we experienced a compression of the WEB device, 6 months after treatment of a large right-sided MCA aneurysm leading to an insufficient aneurysm occlusion (BOSS 2). The aneurysm was retreated using a stent-assisted coil technique.

The clinical outcome, measured by the mRS scale during this study, was observed as follows: preinterventional mRS 0 = 20 (95.2%), mRS 4 = 1 (4.8%), postinterventional mRS 0 = 19 (90.5%), mRS 4 = 1 (4.8%), 1= 1 (4.8%), follow-up mRS 0 = 20 (95.2%), and mRS 4 = 1 (4.8%).

We observed neither peri-interventional bleeding, delayed aneurysm growth/rupture, nor procedural morbidity or mortality.

DISCUSSION

Treatment of wide-necked cerebral aneurysms according to the principle of intrasaccular flow disruption using the WEB device has become a safe and widely used method.[3,16,17] Despite the frequent use of these devices, quantifiable data on flow changes caused within the aneurysms are still rare. The reduction of intra-aneurysmal flow remains a central hypothesis for success after treatment with a WEB device and, to the best of our knowledge, has only been investigated once in literature using in vivo color-coded imaging (syngo iFlow).[14]

In this retrospective study we share our experience with the WEB device and evaluate hemodynamic changes with previously described syngo iFlow parameters and their predictive value for aneurysm occlusion. Cattaneo et al. described promising preclinical evaluation criteria, which are based on a comparison between intraluminal and intra-aneurysmal TDCs, aimed at the difference of maximum contrast medium intensity, delay between intensity peaks, and ratio of intensity decrease.[13] In their study, various parameters for aneurysmal inflow (PI-D and PI-R) and aneurysmal outflow (ID-R) were evaluated after intraluminal flow diversion treatment. They concluded that perfect flow conditions to promote aneurysm occlusion exist with delayed aneurysmal

Table 2. Aneurysm Morphology

	Before WEB	Immediately After WEB	*P* Value
Aneurysm width, mm	4.90 ± 2.02	3.64 ± 2.38	0.071
Aneurysm length, mm	5.82 ± 2.35	4.52 ± 3.01	0.125
Aneurysm depth, mm	5.55 ± 2.62	3.91 ± 2.70	0.052
Aneurysm volume, mm^3	262.67 ± 497.87	132.77 ± 187.08	0.269

Values are presentedas mean ± standard deviation.

inflow (high PI-D) in combination with decreased aneurysmal outflow (high ID-R). The results of our study show that these parameters could be implemented easily in a clinical setting. Baseline imaging characteristics, such as contrast volume and duration of the DSA run to perform reliable iFlow analysis, were comparable in adequately and inadequately occluded aneurysms. Hemodynamic analysis in all cases of our study revealed a low PI-D (0.63 ± 0.53) and PI-R (0.82 ± 0.13) which reflects only a minor delay of aneurysmal inflow. The aneurysmal outflow, on the other hand, showed a high ID-R (4.85 ± 3.66) and therefore a significant delay ($P < 0.001$). Our results confirm that flow changes from a WEB device mainly affect aneurysmal outflow and appear to be different from the flow changes observed after endoluminal flow diversion, bearing in mind that the results of Cattaneo et al. were in vitro.[13] A recently published small clinical study using the same iFlow parameters for aneurysms after flow diverter treatment confirmed our results and showed that flow changes after flow diverter treatment significantly affect the inflow into the aneurysm.[14] Gölitz et al. also describe a significant flow-disrupting effect of the WEB device that reduces the outflow more than the inflow in their TDC analysis.[15] Despite the fact that the TDC analysis using iFlow by Gölitz et al. recorded different parameters compared with our study, we believe that the results are comparable. Another method that has been used to assess the flow alterations of intrasaccular devices is computational fluid dynamics (CFD). Mut et al. were also able to confirm in their CFD simulation that the WEB device leads to a significant reduction in the aneurysmal flow postinterventionally.[18] However, CFD simulations are not ideal to reflect the physiologic and patient-specific flow changes and seem to be time-consuming compared to in vivo TDC analysis. The literature shows that iFlow parameters can be applied in a variety of ways and clinical experience is still rare, especially when it comes to flow assessment after treatment with WEB devices. Compared with the data from Gölitz et al., we believe that the parameters used in this study are easier to apply, not only because they have already shown promising and successful in vivo[13] and clinical[14] results.

Our follow-up DSA revealed adequate occlusion in 85.5%, which is comparable to the occlusion rates reported in literature.[3,19,20] At the end of the interventional procedure, incipient aneurysm occlusion was found in a total of 38%, including 19% of complete occlusions with a median of 5 minutes after implantation of the WEB. Immediate occlusion of the aneurysm at the end of the procedure seems to be a common finding after WEB implantation and has been described in the literature in up to 28%.[21] Unfortunately, none of the iFlow parameters applied had a significant predictive value for adequate aneurysm occlusion. Neither the comparison of immediately occluded aneurysms with insufficiently occluded aneurysms during the interventional procedure nor the comparison of adequately occluded aneurysms with insufficiently occluded aneurysms during the follow-up revealed a significant difference. We only saw a trend towards a lower ID-R (2.38 ± 1.62) of insufficiently occluded aneurysms compared with adequately occluded aneurysms (5.26 ± 3.77) with a *P* value of 0.063. In addition, the morphology of the aneurysm seems to play an important role when it comes to residual aneurysmal filling after WEB device treatment. We were able to correlate insufficiently occluded aneurysms with a significantly greater aneurysm height, width, and volume compared to occluded aneurysms. This supports the data recently published by Fortunel et al.,[22] confirming that larger aneurysm diameter appears to be a risk factor for incomplete aneurysm occlusion. Another interesting aspect is the correct dimensioning of the WEB device, adapted to the aneurysm diameter. Our results and the results of Fortunel et al. show that undersized WEB devices are also associated with residual aneurysm filling after treatment and also represent a risk factor. We believe that of the iFlow parameters investigated, ID-R has the greatest potential to serve as a predictor of aneurysm occlusion. In theory, low ID-R correlates with insufficient reduction of aneurysmal outflow and could serve as a predictor of inappropriate WEB size selection. ID-R could be of great value to neurointerventionists in their decision to select the most appropriate WEB device and potentially improve long-term outcomes. Furthermore, identifying adverse flow changes could help neurointerventionists in their decision to change strategy and use alternative endovascular treatments. Given that the cohort in our study is quite small and that the number of immediately occluded aneurysms during the procedure and the number of insufficiently occluded aneurysms during follow-up are also quite small, an assessment in a larger study population will be necessary.

The durability of aneurysm occlusion after WEB implantation has been investigated in many studies and plays an important role in the field of endosaccular flow diversion since remnants are described in literature with a rate of 2%–16%.[16,19,23] Remnants are described from completely occluded aneurysms and can even occur within a period of up to 3 years after treatment.[20] They are mostly associated with a WEB shape modification in conjunction with a height reduction also referred to as "compression" of the device.[16] Unfavorable wide-neck aneurysms and WEB undersize

Table 3. Overview of the measured iFlow parameters

Measurement Point	PI-D	PI-R	ID-R
Occlusion (n), postinterventional			
BOSS 0–1 (8)	0.55 ± 0.33	0.82 ± 0.10	5.57 ± 4.79
BOSS 1+3 (13)	0.68 ± 0.63	0.81 ± 0.15	4.40 ± 2.90
P Value	0.531	0.966	0.574
Occlusion (n), Follow-up			
BOSS 0-0` (18)	0.67 ± 0.56	0.81 ± 0.13	5.26 ± 3.77
BOSS 1-3 (3)	0.43 ± 0.32	0.86 ± 0.12	2.38 ± 1.62
P Value	0.358	0.565	0.063
Aneurysm Location (n)			
Anterior circulation (15)	0.54 ± 0.36	0.83 ± 0.11	5.08 ± 4.21
Posterior circulation (6)	0.87 ± 0.82	0.79 ± 0.17	4.23 ± 1.89
P Value	0.385	0.634	0.548
Aneurysm Size (n)			
Small (volume <100 mm^3) (9)	0.63 ± 0.43	0.81 ± 0.12	4.13 ± 2.54
Large (volume >100 mm^3) (12)	0.63 ± 0.62	0.83 ± 0.14	5.39 ± 4.36
P Value	1.0	0.746	0.419

Values are presented as mean ± standard deviation.

have been reported as a predisposing factors for a device compression, but the underlying mechanism remains unknown.[20] Despite the fact that the clinical relevance of aneurysm remnants is yet not fully understood, we believe that indication for retreatment should be considered generously since delayed rupture has been reported in a few cases up to a period of more that 5 years.[19,24] Follow-up over a period up to 21 months revealed aneurysm remnants in 14.3%. Of the seen remnants, 4.8% were associated with a compression of the WEB device into a large middle cerebral artery aneurysm. Fortunately, we did not observe aneurysm growth or delayed rupture in our study. Nevertheless, retreatment was necessary in 4.8% and performed by means of stent-assisted coiling. The retreatment rate observed in our study was comparable to the rate generally reported in the literature after implantation of WEB devices (5.6%–11%).[3,8,20]

Ischemic complications occurred in 4.8%, as 1 patient suffered a minor stroke after treatment of a right sided middle cerebral artery aneurysm leading to a postinterventional mRS of 1. At follow-up after 6 months the patient recovered fully and the mRS score declined back to 0, leading to a morbidity and mortality rate of 0% in this study. Ischemic complications found in our study were comparable with a recently published systematic review, in which a total of 963 aneurysm have been treated with a WEB device.[19]

Limitations

This study is limited due to its retrospective design, the small number of patients, and relatively short follow-up period for patients who met the criteria for the applied iFlow parameters. Hemodynamic analysis of cerebral aneurysms using iFlow remains a heterogeneous method.[13,15,25] The parameters assessed in this study are just one of the many ways to analyze such data, which makes a direct comparison of our results with similar studies difficult. Additionally, the DSA acquisition was performed by manual injection of a contrast agent instead of mechanical injection, as this is our clinical standard. Sadasivan et al. recently demonstrated that low-rate hand injection appears to be superior to mechanical injection and is best suited for TDC analysis due to the consistency of the angiogram.[26] Finally, aneurysm occlusion is multifactorial and depends on more than just hemodynamic changes after WEB implantation. Further evaluation of the TDC analysis in a larger patient cohort is needed to support our preliminary results.

CONCLUSIONS

The aneurysm occlusion rate, observed complications, and retreatment rate in our study were comparable to those reported in the current literature. In addition, our study provides insight into hemodynamic changes in cerebral aneurysms with wide neck after treatment with WEB devices using various iFlow parameters. We were able to confirm that flow alterations caused by the WEB device significantly influences the outflow compared with the inflow of the aneurysm. Unfortunately, none of the applied parameters revealed a predictive value regarding adequate aneurysm occlusion in our small cohort. Based on the trend observed in our study, we believe that the aneurysmal outflow parameter (ID-R) has the greatest predictive potential for aneurysm occlusion. Further research with larger cohorts is needed to evaluate if these iFlow parameters can be used as a monitoring tool for intraprocedural flow analysis before

detachment of the WEB device. Therefore, flow analysis could be useful for neurointerventionalists to select the most suitable WEB, identify adverse flow alterations, and thus contribute to patient safety and possibly improve long-term outcomes.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Andreas Simgen: Project development, Interventions, Angiographic evaluation, Writing — original draft. **Annabelle Weyrich:** Investigation, Writing — original draft. **Philipp Dietrich:** Investigation, Angiographic evaluation. **Safwan Roumia:** Interventions, angiographic evaluation. **Ruben Mühl-Benninghaus:** Interventions, Angiographic evaluation. **Umut Yilmaz:** Interventions, Angiographic evaluation, Formal analysis, Writing — review & editing. **Wolfgang Reith:** Project development, Interventions, Angiographic evaluation, Writing — review & editing. **Michael Kettner:** Interventions, Angiographic evaluation.

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