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ORIGINAL ARTICLE - VASCULAR NEUROSURGERY - ANEURYSM

Efficiency and complications of Woven EndoBridge (WEB) devices for treatment of larger, complex intracranial aneurysms—a single-center experience

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Abstract

Background Several recently published multicenter studies have reported high treatment feasibility, high safety, and good 6-month to 1-year efficiency when treating smaller intracranial aneurysms (IA) with WEB deployment. The purpose of the study was to evaluate the long-term efficiency and complications related to WEB treatment of larger, complex intracranial aneurysms in a small single-center cohort.

Methods Patients with ruptured and unruptured IA were treated with WEB devices; data were collected prospectively and analyzed retrospectively. The study evaluates complications and clinical and radiological findings at immediate and last available follow-up.

Results The study included 16 patients with 16 aneurysms and a median follow-up time of 36 months, range 13–49 months; 9/16 were females. Median age 59 with range 39–71 years. Mean aneurysm size 11.3 ± 1.7 mm, predominant location at the basilar artery bifurcation and anterior communicating artery. Three out of sixteen IAs were ruptured. Even though 75% of the IAs were immediately occluded completely, retreatment was eventually necessary in 7/15 (46.7%). Increasing neck remnants and recurrences were mainly observed past 1-year follow-up. The WEB device showed modifications over time, with six devices showing signs of compression in the long term. There was one fatality due to aneurysm rupture after 4 years.

Conclusions The long-term efficiency of WEB deployment in larger, complex aneurysms is low with about half of the cases needing at least one retreatment. A large fraction of WEB collapse past 1-year follow-up.

Keywords WEB · Endovascular treatment · Intracranial aneurysms

Abbreviations

IA	Intracranial aneurysm
WEB	Woven Endoluminal Bridge
WEB-DL	WEB dual layer device
WEB-SL	WEB single layer device
WEB-SLS	WEB single layer spherical device
A1	First segment of the anterior cerebral artery
PCoA	Posterior communicating artery
CTA	Computed tomography angiography
MRA	Magnetic resonance angiography
MRI	Magnetic resonance imaging
SD	Standard deviation
ACoA	Anterior communicating artery
MCA	Middle cerebral artery
EVT	Endovascular treatment
VA-dissection	Vertebral artery dissection

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Introduction

Treatment of intracranial aneurysms (IA), both ruptured and unruptured, aims at abolishing intra-aneurysmal flow. Regarding endovascular treatment options, this can be

achieved with an array of different methods: various types of coils, stents in conjunction with coils, therapeutic parent artery occlusion, and flow-diverting devices [14, 21]. One of the latter is the Woven Endoluminal Bridge (WEB). This is a self-expanding, braided, nitinol device, aimed for intrasaccular deployment in the IA to cause aneurysmal flow disruption and occlusion, acting as an intrasaccular flow diverter [3]. It is developed as a mono-therapeutic option and does not demand postprocedural antiplatelet therapy [11]. In some cases, standard embolization devices and techniques may not be feasible due to complex IA morphology or anatomical localization. In these cases, the WEB might be an option, in particular, when treating wide-neck bifurcation aneurysms [11–13].

The WEB is available in different models and sizes. It is classified into WEB dual layer device (WEB-DL), WEB single layer device (WEB-SL), and WEB single layer spherical device (WEB-SLS). The device has been available on the European market since 2010 and undergone several changes during the last 5 years [17, 18].

Treatment with WEB has been evaluated regarding efficacy and safety promptly after being introduced as a treatment option [18]. A recently published cumulative study recorded good treatment feasibility with few complications in smaller aneurysms [20]. Good short- and mid-term clinical and anatomical results were reported as well; however, a noticeable amount of neck remnants were recorded [20]. Long-term follow-up data are hitherto scarce. Moreover, there is very limited experience regarding treatment of larger, complex aneurysms with the WEB.

The purpose of this study is to report our clinical experience with treatment of highly selected, large, complex aneurysms treated with WEB after being deemed not suitable for low-risk treatment with other commonly available methods and devices.

Material and methods

This retrospective quality study was performed at a tertiary hospital with a catchment area of 2.7 million people. Our neurosurgical department manages up to 150 patients with ruptured IAs and approximately 100 patients with unruptured IAs yearly. Surgical and endovascular aneurysm repair is available on an around the clock basis and is performed by dedicated surgical and endovascular teams. Patients are treated in accordance with standardized guidelines [22], where aneurysms located on the middle cerebral artery are usually treated surgically and those on the posterior communicating artery predominantly allocated to surgery. In ruptured aneurysms, treatment requiring dual antiplatelet therapy is avoided. Mode of treatment is discussed and decided by the vascular team consisting of neurosurgeons and neurointerventionists.

Variables registered

Data were acquired from the institutional prospective quality registry. We extracted patient demographic data and characteristics (age, sex, hypertension and other comorbidity, smoking habits, clinical presentation) along with aneurysm specific data (location, size, neck size, height, length, aspect ratio (height divided by neck diameter)), irregularities, rupture status, and anatomical status of the first segment of the anterior cerebral artery (A1) and posterior communicating arteries (PCoA). The IAs were scored in accordance with the *unruptured intracranial aneurysm treatment score* (UIATS) [4] and the PHASES [5] which predicts the 5-year cumulative rupture risk. The preoperative clinical condition of the patients with ruptured aneurysms was expressed according to the Hunt and Hess grading score [8].

We also registered the specific WEB used for each patient, reason of choice, concomitant antithrombotic treatment, follow-up, complications, grade of occlusion obtained, and retreatments.

Endovascular procedure

All patients underwent a CT angiography in advance of the treatment, a procedural conventional cerebral angiography, including rotational 3D series with reconstructions of the aneurysm. The size of WEB was chosen from the aneurysm diameter and height measurements obtained from the 3D series. Two of the WEB devices needed to be custom made (larger than the standard sizes, both 14 mm in diameter).

All procedures were performed on a biplane angiographic system with the patient under general anesthesia. Heparin was administered in the pressure bags used for flushing at a concentration of 1000 U/l. Using the transfemoral approach, a microcathether was advanced into the aneurysm. The WEB was delivered through this microcathether which was withdrawn slowly and carefully simultaneously to WEB deployment. The position of the WEB device was visualized by contrast injections at different angles, and several devices may have been tried within the aneurysm in order to find the optimal size. When deemed satisfactory, the WEB was detached. After detachment, final angiographic runs were performed.

All patients were treated with 75 mg acetylsalicylic acid daily from the day of procedure and for at least 2 weeks plus 2500–5000 IU low molecular heparin for 2 days after the procedure. Even though antiplatelet medication was not strictly mandatory due to the intrasaccular concept of the WEB, we chose to treat the patients with aspirin from the day of the procedure and for a variable number of weeks. This was considered a safety measure, due to the amount of metal of the device at the base of the aneurysm. A factor was also the

relative novelty of the device, especially in the first period of the treatments.

Follow-up imaging was routinely performed by CT angiography (CTA) within few days after the procedure and after 3 (2–4) months. For all patients except one, a MRA was also performed shortly after WEB placement. Conventional angiography was performed on selected patients only, depending on specific findings/issues on CTA/MRA.

The grade of aneurysm occlusion was categorized into three categories: (1) complete occlusion (no visible intrasaccular contrast filling), (2) neck remnant (visible contrast filling in the aneurysm neck), and (3) aneurysm remnant (visible contrast filling in the aneurysm body and/or between the WEB and the aneurysm wall). Opacification due to contrast filling at the device's concave recess was deemed total occlusion [12].

On the follow-up imaging, changes in size and shape of the device was assessed qualitatively, together with measurements of the distance between the two markers at the poles of the device in the projection providing the maximum distance. In cases of aneurysmal flow recurrences, the number of cases with device compaction as opposed to device distal displacement, as well as flow along the borders of the device, was assessed.

Statistical analysis

Continuous variables that were normally distributed are presented as the mean and standard deviation (SD). Continuous variables that were not normally distributed are presented as the median and range. Categorical variables are presented as frequencies or percentages.

The study has been approved by the institutional data protection officer as a quality study (reference number 2017/993).

Results

Patients

We identified 16 patients treated with a WEB device between June 2012 and September 2015. They accounted for 1.9% of all 833 IA treatments performed in the same period. Three hundred eighty-nine of all procedures were performed in unruptured IAs, with 141 of them being endovascular procedures. WEB treatment hence accounted for 9.2% of these. Respectively, 444 procedures were performed in conjunction with subarachnoid hemorrhage, thereof 218 surgical and 226 endovascular, with WEB accounting for 1.3% of the latter.

Indications for treatment Three aneurysms were ruptured. Of the 13 unruptured aneurysms, one had an UIATS [4] favoring conservative treatment, the PHASES [5], however, was 11, indicating a relatively high 5-year risk of rupture (Table 1). All but three patients had a PHASES of at least 10.

There were 9 females and 7 males, with a median age of 59 years (range 39–71). Twelve out of sixteen (75%) patients had arterial hypertension (Table 1). Smoking status included the following: current smokers 9/16 (56.3%), former smokers 7/16 (43.8%), and no non-smokers.

At the time of intervention, most IAs 13/16 (81.3%) were unruptured (of which 6 were symptomatic, 7 were incidental), and 3/16 (18.8%) had ruptured (Table 1). Nine aneurysms were localized at the basilar artery bifurcation (56.3%), six on the anterior communicating artery (ACoA, 37.5%), and one on the middle cerebral artery (MCA, 6.3%) (Table 1). Most of the aneurysms were ≥ 10 mm (81.3%), and the smallest aneurysm was 8.1 mm. The majority (93.8%) were wide-necked with a neck diameter ≥ 4 mm, and 11 IAs had an aspect ratio lower than 1.6. Five of the aneurysms had an aspect ratio less than 1.2.

Four out of six aneurysms located on the ACoA had a hypoplastic/aplastic A1 segment. All aneurysms located at the basilar artery bifurcation had either unilateral or bilateral aplastic/hypoplastic PCoA, and 3/9 cases had a fetal PCoA.

Further, IA and patient characteristics are detailed in Table 1.

Endovascular procedure and complications

A single WEB device was implanted in all procedures, including WEB-DL ($n = 3$) WEB-SL ($n = 11$), and WEB-SLS ($n = 2$). One aneurysm had previously been treated with coils.

Deployment of WEB device was successful in all aneurysms. In cases 4 and 6, the decision to use a WEB was taken during the EVT procedure, which initially was planned as stent and coil, but proved not feasible. In cases 2 and 16, the WEB needed supplemental coiling due to persistent circulation between the WEB and the aneurysm wall (blebs).

There were periprocedural (technical) complications in 2/16 (12.5%) patients: one VA-dissection (case 5) and one WEB device that led to bulking into the A2, but without consecutive thrombo-embolic events or compromised flow (case 14).

After primary WEB treatment, 3 (18.8%) patients had complications within 30 days: one intracerebral parenchymal hematoma in an area remote to the device and not related to the procedure occurred after 2 days (managed conservatively, case 9); one first-time seizure and small occipital infarction (case 13); and one hematoma along an external ventricular drain that also was managed conservatively (case 15).

Efficacy of WEB treatment

Figure 1 illustrates the temporal evolvement of occlusion grade and the need of retreatment in the cases of unsatisfactory

Table 1 Intracranial aneurysm and patient characteristics

No	Age/sex	Presentation	Reason of WEB treatment	Comorbility	Localization	Anatomy A1/PCoA	Size	Neck	Length	Width	Height	AR (H/neck)	UIATS	PHASES
1	58/F	Incidental	Requires 2 stents, both P1 arise from IA	Anxiety, HT	ACoA	Left A1 hypoplastic	12	4.6	10.1	10.8	7.5	1.63	Repair	11
2	59/F	Incidental	Requires 2 stents, both P1 arise from IA	Anxiety, hypothyroidism	Basilar tip	1 fetal 1 hypoplastic	13.9	5.6	13.9	10.3	13.9	2.48	Repair	10
3	62/F	Incidental	Neck includes P1 and SCA	HT	Basilar tip	Both PCoA hypoplastic	11.6	5.4	9.8	11.5	8.3	1.53	Inconclusive	11
4	48/M	SAH: Hunt and Hess 4.	High ICP, P1 arises from IA, EVT without platelet inhibitor desirable due to SAH	None	Basilar tip	1 fetal 1 aplastic	11.3	7.1	9.5	11.3	11.2	NA	NA	NA
5	67/F	Incidental	Surgical: tilts behind clivus, not suitable for stent/coll. Both P1 arises from IA	Ulcerative colitis, TIA, cardiac disease, HT	Basilar tip	Both hypoplastic 1 hypoplastic	14.1	8.6	14.1	13.7	11.9	1.38	Inconclusive	11
6	56/F	Incidental	P1 arises from IA, stent planned but proved infeasible, no surgery due to spondylodiscitis	Spondylodiscitis, HT	Basilar tip	1 hypoplastic 1 aplastic	9.4	6.1	6.8	8.2	7.1	1.16	Repair	10
7	70/F	Incidental	P1 arises from IA, stent/coil deemed higher risk	Intracranial hemorrhage 2009, HT	Basilar tip	1 hypoplastic 1 fetal	13.9	6.8	11	13.4	10.2	1.5	Inconclusive	12
8	61/M	Incidental	Large size, P1 arises from IA, higher risk with stent	COLD, lung transplanted, HT	Basilar tip	2 hypoplastic	11.9	8.1	10.6	11.9	7.7	0.95	Conservative	11
9	59/F	Incidental	Stent unfavorable, patient requests EVT	DM2, COLD, anxiety, fibromyalgia, hypothyroidism, HT	ACoA	Right A1 hypoplastic	10	3.8	87	10	10	2.63	Repair	11
10	66/F	Previous SAH	P1 arises from IA, IA previously coiled-compaction	Previous SAH arteriosclerosis, cancer, HT	Basilar tip	Both PCoA aplastic	9.2	8	7.7	9.2	6.8	0.85	Repair	9
11	54/M	Incidental	A2 arises from IA. Stent/coil planned but not feasible	Bipolar, migraine, angiodysplasia (colon), HT	ACoA	A1 normal bilateral	10.9	4.3	9.2	10.6	9.5	2.2	Inconclusive	10
12	55/M	Incidental	Stent higher risk than WEB	Alcoholism, intestinal tuberculosis	ACoA	Right A1 aplastic	11	5.8	11	7.2	7.1	1.22	Inconclusive	10
13	44/F	Incidental	Patient refuses surgery, anticoagulation, WEB deemed best EVT option	Coarctation aortae, conduit with mechanical valves, HT	Right MCA	NA	10.4	5	10.4	9.4	5.7	1.14	Inconclusive	6
14	59/M	Incidental	Large size. WEB treatment most desirable EVT	Lumbar disc herniation, HT	ACoA	Both A1 normal	8.1	6.2	6.3	8.1	5.9	0.95	Inconclusive	8
15	71/F	SAH; Hunt and Hess 3.	Platelet inhibitor unfavorable due to SAH, both P1 arise from IA	None	Basilar tip	Both PCoA hypoplastic	12.1	7.6	11.4	12.1	11.4	1.5	Repair	11
16	39/F	SAH; Hunt and Hess 2.	Coil not feasible, A2 arises from sac, vasospasm at arrival	HT	ACoA	Right A1 aplastic	11	5.8	11	10	9.2	1.59	Repair	11

WEB, Woven EndoBridge Device; *EVT*, endovascular treatment; *MCA*, middle cerebral artery; *ACoA*, anterior communicating artery; *PCoA*, posterior communicating artery; *A1*, *A2*, first and second segments of the arterior cerebral artery; *P1*, first segment of the posterior cerebral artery; *SCA*, superior cerebellar artery; *AR*, aspect ratio; *UIATS*, unruptured intracranial aneurysm treatment score; *PHASES*, population, hypertension, age, size, earlier subarachnoid hemorrhage; *HT*, hypertension; *ICP*, intracranial pressure; *DM2*, diabetes mellitus 2; *COLD*, chronic obstructive lung disease; *SAH*, subarachnoid hemorrhage

WEB results. The immediate result was total occlusion in 12/16 (75%), whereas there were 3/16 immediate neck remnants and 1/16 immediate aneurysm remnant as deemed by CTA few days after the procedure.

Follow-up was unavailable in one patient (case 16). In the remaining 15 patients, the follow-up span was a median of 36 months, range 13–49 months, see Fig. 1. WEB was the single treatment during follow-up in eight (53.3%) patients, and their status at end of follow-up was total occlusion, $n = 4$; neck remnant, $n = 3$; aneurysm remnant, $n = 1$.

Retreatment

Seven patients (46.7%) needed additional surgery, endovascular treatment, or both. Two of them were retreated twice (Fig. 1). All retreatments were due to increasing circulation inside the aneurysm sac; in six cases at the aneurysm neck, basal to the implanted WEB device, two cases with circulation along the WEB (between the device and the aneurysm wall), and one case with circulation mainly along the device. In three of the retreated aneurysms, there were signs of shortening/retraction of the WEB over time; one of which also had compaction of coils (from the first retreatment, simple coiling). In two aneurysms, there were signs of distal dislocation of the WEB without shortening, thereby expanding the basal circulation.

In the aneurysms not retreated, there were signs of shortening in three WEB devices.

Of the seven patients retreated, two underwent craniotomy and clipping of the aneurysm (cases 9 and 11); whereas one patient had coiled a circulated bleb between the WEB and the aneurysm wall and underwent surgical clipping later (case 1). Three patients were retreated with stent and coils (cases 2, 4, and 7); in two of these treatments, two stents were used in a "Y"-configuration; case 5 merely underwent additional coiling. Figure 2 illustrates case 7 from initially complete occlusion to a considerably growing neck remnant after 3 years.

Retreatment procedures lead to complications in two patients: Case 9 presented with a subdural hematoma after craniotomy that could be managed conservatively (the same patient had a spontaneous intraparenchymal hematoma 2 days after WEB deployment). Patient 11 had developed an increasing neck remnant in addition to a pathological inflammatory response around the WEB that also involved the ACoA (Fig. 3). The first signs of this inflammatory reaction was visible on MRI 10 months after the procedure as a perianeurysmal edema on T2-weighted images which progressed further on MRI 6 months later. When clipping this aneurysm, its ostium and parts of the ACoA were found visibly inflamed and with pathological consistency, so the ACoA had to be trapped, resulting in a right-sided infarction of the A2 territory.

Patient 5 died during follow-up from rupture of the hitherto unruptured aneurysm, 2 weeks after the last MRI at the local hospital, 3 years and 10 months after the original WEB treatment. In retrospect, we could see progressive aneurysm growth with increasing slow circulation between the WEB and the aneurysm wall. This patient had the largest aneurysm of the series, originating from the basilar tip, in which the largest WEB device was used (14 × 11 mm, custom-made).

Of the seven retreated patients, occlusion status at the end of follow-up was total occlusion $n = 5$ and aneurysm remnant $n = 1$. In case 7, only immediate status of retreatment is available (complete occlusion).

WEB size evolvement

In the aneurysm that ruptured 3 years and 10 months after initial treatment, the WEB had increased by 25%.

Four (26.6%) of the WEB collapsed over time and had decreased their size by an average of 44.5% (range 35.9–59.1%). All of them had developed significant new circulation and needed retreatment. Figure 2 illustrates this WEB modification.

In the nine aneurysms that finally became completely occluded, there was a successive slight decrease in WEB size with an average of 13.2% (0–22.9%) at latest follow-up.

We have not noticed differences between the different variants of the device (DL, SL, SLS) regarding the tendency to change in size over time.

Discussion

The present study confirmed the high technical success rate of WEB deployment. However, the long-time efficiency of WEB deployment as a stand-alone treatment option was low, with 46.7% needing at least one retreatment.

Endovascular procedure and complications

In corroboration with the recently published cumulative study by Pierot et al. [20], the technical treatment success rate in our small series was high (100%). The WEB devices were successfully deployed in all cases, despite the fact that our aneurysm population included a higher proportion of ACoA-aneurysms, which may be associated with difficulties during endovascular treatment [7].

In our study, no procedural or postprocedural thromboembolic events were observed, despite one WEB bulging onto the A2. The newly published cumulative study by Pierot et al. [20] encountered 14.4% thromboembolic events. Our regimen of use of one antiplatelet agent for at least 2 weeks concurs with 54.5% of reported cases, whereas 22.2% and 23.4% of cases were treated with 0 and 2 platelet inhibitors respectively at 1-month follow-up [20]. The routines for use of antiplatelet

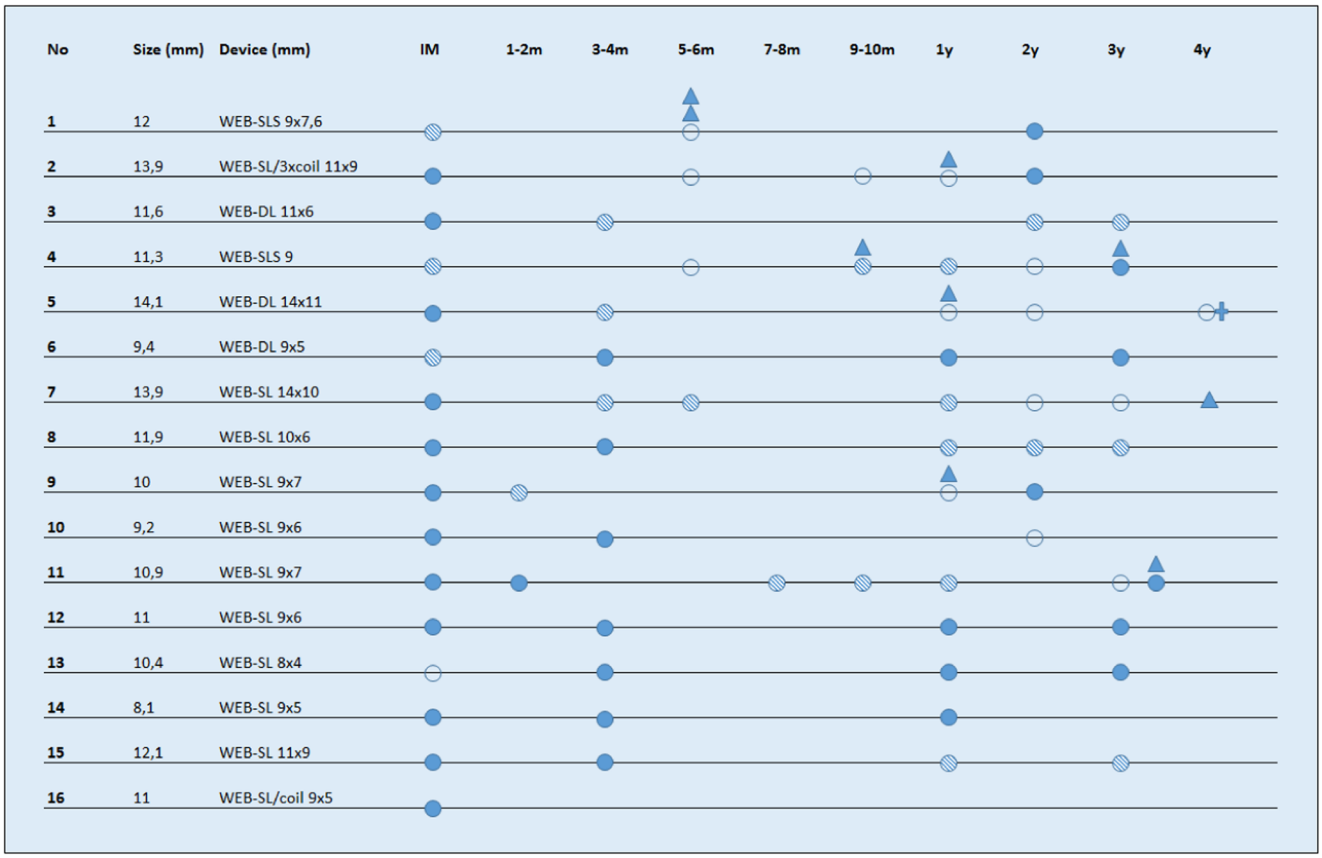

Fig. 1 Summary of devices deployed and their temporal evolvement regarding grade of occlusion throughout follow-up. Retreatment is also indicated. ( ): aneurysm remnant. ( ): neck remnant. ( ): complete occlusion. ( ): retreatment. ( ): dead. IA, intracranial aneurysm; IM, immediate occlusion grade; m, month; y, year; WEB-DL, Woven EndoBridge dual layer device; WEB-SL, Woven EndoBridge single layer device; WEB-SLS, Woven EndoBridge single layer spherical device

agents varies, however, vastly [6, 20] and the interpretation of WEB efficiency may be biased by the wide range of antiplatelet use. One of the reasons to use WEB is the need for less platelet inhibitors as compared to procedures involving stents, giving WEB an advantage in the treatment of ruptured aneurysms. However, the relation of platelet inhibitor use and thromboembolic complications with the WEB remains to be established.

One of our patients developed an inflammatory response around the WEB that also involved the parent artery. Inflammation caused by endovascular devices is a rare complication [9, 10] and probably represents a foreign body reaction [2]. To the best of our knowledge, inflammation around a WEB device has hitherto not been reported. The inflammation we observed was seen on MRI as perianeurysmal edema from 10 months after the procedure and constantly increased thereafter. The lack of reports on that phenomenon may also be attributable to shorter follow-up in other studies [16, 17, 19].

The complication rate in our series could be expected to be influenced by the high fraction of hypoplastic/missing A1 segment (of the anterior cerebral artery) and PCoAs. There are no comparable data on these anatomical features in other reports.

Efficacy of treatment and retreatment

Presently, complete occlusion as the immediate result was obtained in 75% of the aneurysms, but we used adjunctive devices more often than reported in the cumulative study (12.5% versus 7.4% [20]). Our high use of additional devices could be due to our early learning curve, or the fact that our aneurysm population included a high amount of IAs with circulated blebs or irregular configurations (62.5%), which make it more difficult to obtain complete occlusion.

At last follow-up, complete aneurysm occlusion with one WEB treatment alone was observed in merely 26.7% of our cases and in 60% of those that underwent retreatment. The corresponding rate of complete occlusion was 52.9% in the cumulative study with 6.9% retreatment [20]. Many of the recurrences in our study occurred past 1 year, and the numbers of Pierot et al. [20] could be anticipated to increase with a longer follow-up period. Cognard and Januel [1] reported merely 7.2% complete occlusion at follow-up in their small series. However, the definition of complete occlusion may vary between reports and are hence somewhat difficult to

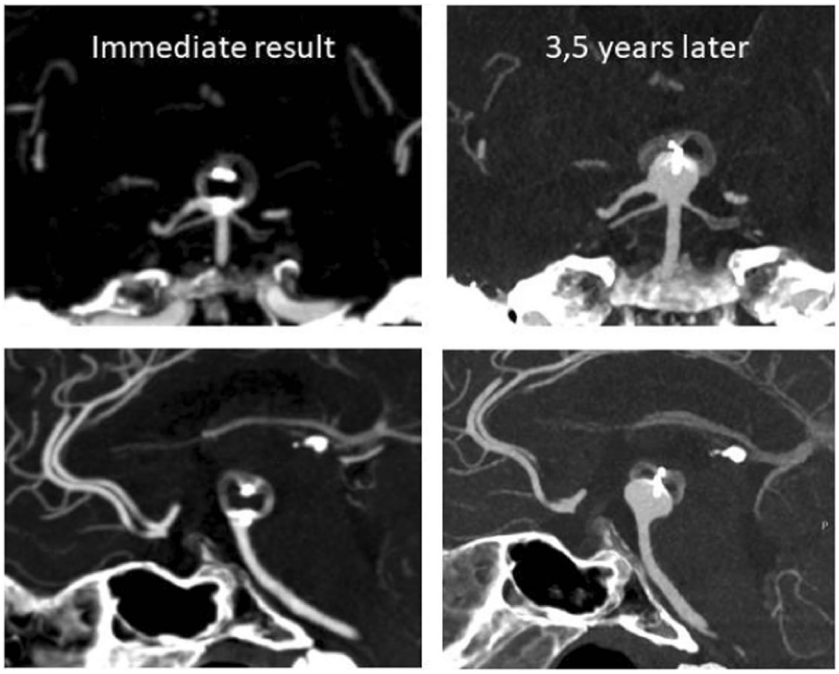

Fig. 2 Case 7 illustrating an immediate excellent result after deployment of the WEB in a basilar artery bifurcation aneurysm (left upper: coronar projection, left lower: sagittal projection). The computed tomography angiograms on the right show recurrent aneurysm and collapse of the WEB in identical projections 3.5 years later

compare. In principle, any aneurysm may still rupture unless flow is completely abolished. In light of this, total occlusion in only about half of the aneurysms is not really a satisfying result. This is particularly concerning when the WEB treatments had been carried out in (a) aneurysms that could have been clipped at a higher rate of success and at relatively low risk like MCA aneurysms and (b) in small aneurysms that may have a low risk of rupture in the first place and could be left untreated.

The present results concerning lack of total occlusion at follow-up and the need of retreatment may be explained by three factors: First, our study comprised larger aneurysms than those treated in the cumulative study [20]. The majority (81%) of our IA were classified as large (≥ 10 mm), compared to 19.6% in Webcast [16], 5.5% in Webcast 2 [19], and 3.1% in the French observatory study [17]. The WEB device is anticipated to cause flow disruption at the level of the aneurysm neck, leading to a secondary intrasaccular thrombosis [15]. However, the exact mechanism causing long-term occlusion with the WEB device after the thrombus resolves is unknown [3], and treatment may not be equally effective in small and large aneurysms considering long-term outcome. Second, the location of aneurysms: we treated only one MCA aneurysm, as IAs in this location usually are assigned to surgical treatment in our department. There was a predominance of basilar tip aneurysms in our material; a location that is more prone to recurrence and needs more often retreatment, regardless type of EVT. This is in contrast to the cumulative study where 50.9% of the IAs were located on the MCA, 21.3% on the ACoA, and only 17.8% on the BA [20].

Third, and maybe most crucial for the high rate of recurrence and need for retreatment, was our choice of WEB size

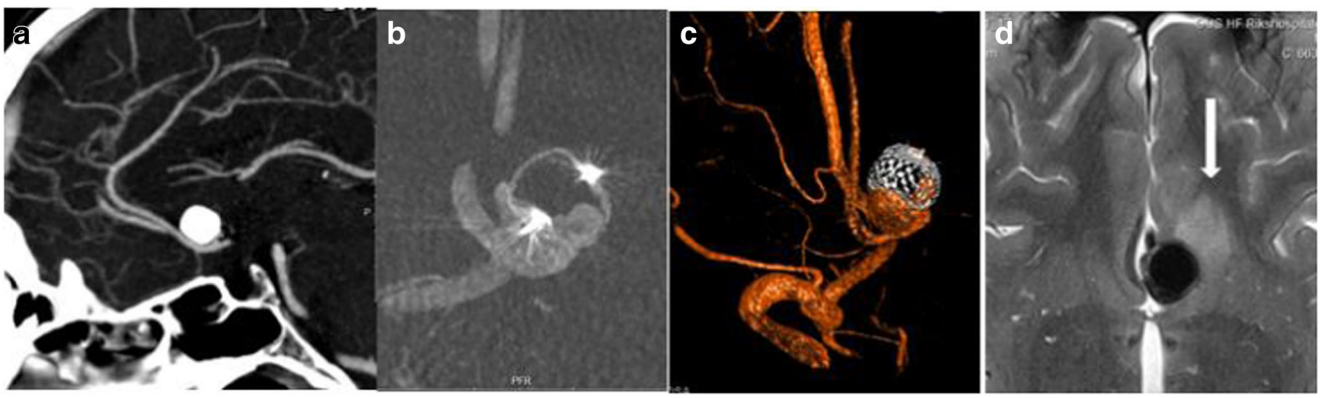

Fig. 3 Case 11 with initial complete occlusion of the aneurysm (**a**) but progressively increasing circulation at the neck after 3 years (**b**, **c**). Magnetic resonance imaging (**d**) showed slightly changed attenuation around the aneurysm (white arrow). During surgery, vast inflammation of the aneurysm and parent artery was found

which was 1 mm larger than the average aneurysm diameter, and the device height shortened by 1 mm compared to the aneurysm height. This was the sizing recommendations from the producer (Sequent Medical) at the time and has been revised after gathering more experience with the WEB into oversizing at the level of the neck (to a point that the device itself is changing in shape once released into the aneurysm, i.e., "forming" of the device). Retrospective assessment of our series was showing this "forming" of the device just in few cases, in which the final result was satisfactory. A large fraction of our failures may hence be attributed to not oversizing the WEB [6]. The risk of intraprocedural rupture when oversizing the WEB seems to be low (1.2% [20]).

WEB size evolvement

The progressively increasing (re)circulation in WEB-treated aneurysms was also pointed out by Cognard and Januel [1] and emerges very clearly in our study that has a much longer observation period. This may also be one of the reasons for our rate of retreatment being more than fivefold of that in the cumulative study [20].

Cognard and Januel [1] introduced a phenomenon called *WEB compression*, associated with poor IA occlusion in mid- and long-term follow-ups. This question was further analyzed in a prospective single-center study [6], reporting the phenomenon as quite frequent (31.6%). Herbreteau et al. [6] recorded similar occurrence of the phenomenon in both undersized and appropriate sized WEB devices. They recorded a significantly lower total occlusion (25%) in case of WEB compression, compared to cases with no WEB compression (76.9%) due to a high rate of neck remnants when WEB compression is present. Our small study provides further evidence of WEB modification over time. Our IAs that became occluded showed a small shrinkage (13.2% of original size) with preserved shapes. With complete occlusion, one expects the IA to shrink over time and possibly the WEB adapts in size in response to this intended effect. The WEB seems to have the ability to adapt to some degree to changing size of the aneurysm and remain intact, but may also collapse and lead to increasing neck remnants or aneurysm recurrence.

Limitations and strengths

Being a retrospective, single-center study, our results are prone to bias like the experience of few interventionalists, institutional treatment algorithms, and case selection. The small number of cases also limits the extent to which conclusions can be drawn. Moreover, the follow-up of patients varied and was not performed at the same intervals for all patients. The imaging modalities for the follow-ups was not consistent, using CT angiography for most of the patients and MR angiography for the others. In retrospect, some of the patients should have been followed by conventional angiography. On the other hand, it is one of few studies to look into WEB treatment of mainly larger IAs. Furthermore, our study has a longer span of follow-up than other studies. It is also an advantage that we studied WEB treatment selected in a setting where surgical treatment is readily available.

Future studies should aim at investigating WEB modification in more detail, as well as look more into the subgroup of larger, complex aneurysms. The long-term results of WEB treatment should also be studied in larger series than the present.

Conclusions

The long-term efficiency of WEB deployment in larger, complex aneurysms is low according to our series, with about half of the cases needing at least one retreatment. A large fraction of the aneurysms recanalized past 1-year follow-up, in which the choice of suitable aneurysms for WEB treatment as well as WEB sizing could be addressed. A substantial number of WEBs showed different degrees of axial compression/collapse over time.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

(The study has been approved by the institutional data protection officer as a quality study with reference number 2017/993)

Informed consent Informed consent was waived by the data protection officer for this type of study.

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