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Endovascular treatment of intracranial aneurysms with the Woven EndoBridge – safety and efficacy

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Abstract

Purpose The Woven EndoBridge is a device for endovascular embolization of intracranial aneurysms. The aim of this study is to re-evaluate this treatment method regarding its safety and efficacy and to compare it with the results of alternative treatment strategies (clipping, coiling, etc.) and their outcome known from the literature.

Methods Forty-four intracranial aneurysms treated with the Woven EndoBridge were retrospectively identified in a clinic for diagnostic and interventional neuroradiology. The average aneurysm height was 7.1 mm, and the average width was 5.8 mm. Further the average neck diameter (3.6 mm) and the average dome-to-neck ratio (1.6) were determined. Both ruptured and non-ruptured aneurysms were included in this study. Occlusion was assessed using the WEB Occlusion Scale immediately after the intervention and after three, six and twelve months follow-up.

Results In 11% of cases ($n=5$), implantation of the Woven EndoBridge failed technically. In two patients, a thromboembolic event occurred during the intervention without consequential damage. During the observation period of twelve months, none of the study participants died because of the intervention. After twelve months, 95% of the treated aneurysms ($n=20$) showed adequate occlusion.

Conclusion Compared to other treatment strategies (clipping, coiling etc.) and their complication rates known from other studies, our results suggest that the Woven EndoBridge is a safe treatment option. Regarding the angiographic results, the Woven EndoBridge achieves occlusion rates which are comparable with those of intravascular flow diverters, but without the need of dual anti-platelet-aggregation therapy.

Keywords Woven EndoBridge · Intracranial aneurysm · Intrasaccular · Flow-diverter · Subarachnoid hemorrhage · Clipping

Introduction

It is assumed that unruptured intracranial aneurysms have a worldwide prevalence of two to five percent [1]. As these vascular pathologies are usually asymptomatic [2] they are often diagnosed incidentally. The rupture of an intracranial aneurysm leads to the formation of a subarachnoid hemorrhage (SAH), which is an acute life-threatening complication with a 30-day mortality rate of approximately 45%. A further 30% of survivors suffer serious secondary damage [3]. As no evidence-based statement can currently be made regarding rupture risk of an intracranial aneurysm and prognostic treatment scores such as the "Unruptured Intracranial Aneurysm Treatment Score" (UIATS) can only be used supportively to make a treatment decision [4], unruptured intracranial aneurysms are treated preventively. This is done by using either a neurosurgical or an endovascular approach. The latter include (stent-assisted) coiling and the use of so-called flow-diverters, whereby a distinction is made between intravascular and intrasaccular flow diverting devices [5]. In recent years, the new intrasaccular flow-diverters have become increasingly important. The Woven EndoBridge, (WEB; Microvention, Aliso Viejo, USA) is one of these intrasaccular flow-diverters. It is a basket-like shaped device consisting of a platinum wire mesh with a nitinol coating and self-expanding properties, which is intended to ensure optimal adaptation to the aneurysm morphology [6].

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Our study compares the complication and occlusion rates of the WEB with those of alternative treatment methods (clipping, (stent-assisted) coiling, intravascular flow-diverters, etc.) to find out to what extent the different treatment approaches differ in terms of their safety and efficacy. Furthermore, our study deals with the question of whether certain cerebral arteries seem to be particularly prone to the formation of aneurysms. In addition, it should be clarified how many of the patients treated with the WEB had at least one risk factor for intracranial aneurysm development.

Methods

A retrospective study design was chosen. All patients who were treated with the WEB between March 2014 and February 2021 in a Clinic for Diagnostic and Interventional Neuroradiology were included. Patient data was collected after approval by the responsible ethics committee.

Inclusion and exclusion criteria

Only patients who received WEB treatment for occlusion of a saccular intracranial aneurysm were included in this study. Patients who required additional procedures such as coiling or stenting in addition to the WEB treatment were considered separately within the study. In addition to broad-based aneurysms with a neck diameter of ≥4 mm, narrow-based aneurysms with a neck diameter <4 mm were also included. The study population included both ruptured and non-ruptured aneurysms. Partially thrombosed aneurysms were also involved. Mycotic and fusiform aneurysms were excluded from the study.

WEB-procedure

The procedure was performed under general anesthesia. The WEB was implanted via a transfemoral access. Appropriate VIA microcatheters were used. Both the WEB-SL and WEB-SLS implants were applied, whereby the SLS implants are characterized by their spherical shape. The size of the WEB was selected based on the +1/−1 rule. Follow-ups were performed after three, six and twelve months using digital subtraction angiography (DSA) or cranial magnetic resonance imaging (cMRI).

Anti-aggregation therapy

Within the study population, 50% (n = 17) of the patients, in whom the intracranial aneurysm was treated with the WEB only, did not receive post-interventional anti-aggregation therapy. A further 29% (n = 10) received acetylsalicylic acid (100 mg/d). In 21% of cases (n = 7), dual antiplatelet therapy with acetylsalicylic acid (100 mg/d) and clopidogrel (75 mg/d) was administered post intervention. Two patients received tirofiban due to thromboembolic events.

Data collection

The following patient-related data were considered: Patient age, gender, location of the treated aneurysm and location of other intracranial aneurysms (if present), aneurysm morphology (height, width, neck diameter, dome-to-neck ratio), risk factors of intracranial aneurysm development (including nicotine abuse, arterial hypertension, etc.) and the condition of the aneurysm (ruptured or unruptured). Furthermore, peri-interventional complications (thromboembolic events, intracranial hemorrhages, lesions of cerebral nerves), complications occurring after the intervention, the immediate reperfusion of the aneurysm, the immediate occlusion of the aneurysm, as well as the results of the follow-ups after three, six and twelve months (reperfusion and occlusion) were recorded. In patients with unsuccessful device implantation, the alternative treatment method and the cause of the unsuccessful treatment (if specified) were also determined. Furthermore, it was collected whether the patients treated with the WEB received anti-aggregation therapy after treatment. If so, a distinction was made between dual and single anti-aggregation therapy. If individual aneurysms were treated in combination with the WEB (e.g. WEB and coiling), the other treatment entity was also recorded in addition to the data listed above.

Angiographic evaluation

To quantify the morphology of the treated aneurysms in the DSA, height, width, neck diameter and the dome-to-neck ratio were measured in a 3D angiography in two orthogonal tiers. If 3D angiography was not available, 2D angiography was used. In both cases, a measurement tolerance of 10% was assumed. An experienced neuroradiologist assessed the reperfusion or residual perfusion of an aneurysm after treatment with the WEB using the WEB Occlusion Scale (WOS). The WEB Occlusion Scale was developed by Lubicz et al. and is based on the modified Raymond-Roy scale [7]. This scale contains four different categories: An aneurysm that does not accumulate any contrast agent including the marker recess and presents as completely occluded is categorized as WOS A. If the aneurysm is completely occluded but there is some contrast agent within the proximal marker recess it is classified as WOS B. When contrast agent accumulates in the neck area of the aneurysm beyond the limits of the proximal marker recess, it is assigned to WOS C. An aneurysm that presents with contrast agent in its fundus is

categorized as WOS D. In this case, the contrast agent can either continue into the recess of the distal marker or around the periphery of the device [7]. In our study, adequate occlusion was defined by WOS A or WOS B. WOS C and WOS D, on the other hand, were classified as inadequate occlusion. Treatment success achieved by the intervention with the WEB was defined by adequate occlusion and WEB treatment without the need of other devices.

Statistical analysis

The statistical analysis of the data collected was done by using Excel (Microsoft, version 16.81). In addition to the descriptive statistics, the t-test was performed as an univariate analysis. Statistical significance was assumed for a p-value <0.05.

Results

Patient and aneurysm characteristics

During the study, 44 patients underwent an intervention to implant the WEB. The average age of the study participants was 59.7 ± 11.8 years. 61% ($n=27$) of the patients were female. The age ranged between 26 and 82 years. The age difference of the two genders was insignificant ($p=0{,}906$).

Our study included a total of 73 saccular aneurysms. WEB implantation was performed in 44 of these. 39% ($n=17$) of the study participants had multiple intracranial aneurysms, some of these additional aneurysms were treated with alternative methods (e.g. coiling). Wide-neck aneurysms (neck diameter ≥4 mm) treated with the WEB device made up 34% ($n=15$) of the study population. The other 66% had a neck diameter <4 mm. Overall, 73% ($n=32$) of the aneurysms treated with the WEB were located in the circulation of the ICA. Accordingly, 27% ($n=12$) of the aneurysms treated with the WEB could be assigned to the vertebrobasilar circulation. Furthermore, two of the three most common localizations of the aneurysms treated were assigned to the ICA circulation as well. The MCA and Acom each accounted for a total of 30% ($n=13$) of the aneurysms. In addition to that 16% ($n=7$) of the treated aneurysms were located in the BA and thus in the vertebrobasilar circulation. Overall, 14% ($n=6$) of the aneurysms were ruptured at the time of intervention. The average height of the intracranial aneurysms treated with the WEB was 7.1 mm (min = 2.3 mm; max = 23.7 mm; SD = 4.7). The width of the aneurysms treated with the device averaged 5.8 mm (min = 2.6 mm; max = 14.5 mm; SD = 3.3). Further morphological parameters determined were the neck diameter (∅= 3.6 mm; min = 1.5 mm; max = 8.2 mm; SD = 1.2) and the dome-to-neck ratio (∅= 1.6; min = 0.8; max = 3.4; SD = 0.7). The proportion of small aneurysms (height <4 mm) amounted to 23% ($n=10$). Detailed baseline patient and aneurysm characteristics are summarized in Table 1.

Table 1 Patient and aneurysm characteristics

Parameter	Value ($n=44$)
Patient age (years), mean ± SD	59,7 ± 11,8
Female sex, n (%)	27 (61%)
Ruptured aneurysm status, n (%)	6 (14%)
Aneurysm localization	
Middle cerebral artery, n (%)	13 (30%)
Anterior communicating artery, n (%)	13 (30%)
Basilar artery, n (%)	7 (16%)
Internal carotid artery, n (%)	5 (11%)
Vertebral artery, n (%)	3 (7%)
Pericallosal artery, n (%)	1 (2%)
Posterior inferior cerebellar artery, n (%)	1 (2%)
Posterior cerebral artery, n (%)	1 (2%)
Aneurysm size	
Height (mm), mean ± SD	7,1 ± 4,7
Dome width (mm), mean ± SD	5,8 ± 3,3
Neck width (mm), mean ± SD	3,6 ± 1,2
Dome-to-neck-ratio, mean ± SD	1,6 ± 0,7
Wide-neck aneurysms (neck width ≥4 mm), n (%)	15 (34%)

Risk factors

Arterial hypertension, nicotine abuse, alcohol abuse, type II diabetes and hyperlipidemia were recorded as risk factors for the patients included in the study population ($n=44$). Female gender was also recorded as a further risk factor for intracranial aneurysm development. In our study, a total of 36% ($n=16$) had one risk factor, while 30% ($n=13$) had two risk factors. In addition, 18% ($n=8$) were found to have three risk factors, while a further 7% ($n=3$) presented with four risk factors at the time of the intervention. In 9% ($n=4$) of the cases, the information on the modifiable risk factors collected was missing. This means that 91% ($n=40$) showed at least one risk factor for intracranial aneurysm development. An overview of the risk factors distribution is given in Table 2.

Aneurysm treatment

In 11% ($n=5$) the implantation of the WEB failed due to technical issues. For three of the aneurysms concerned, the exact cause of the unsuccessful implantation was stated. In the two remaining cases, no reasons were given. In total, two of the five affected aneurysms were ruptured. During an intervention performed on a ruptured aneurysm of the MCA (height: 4.8 mm; width: 10.9 mm; neck diameter: 5.0 mm; dome-to-neck ratio: 2.2), a secure hold of the WEB within the aneurysmal lumen could not be achieved. Therefore,

Table 2 Risk factors of the study population

Risk factors	Value ($n = 44$)
Female sex, n (%)	27 (61%)
Arterial hypertension, n (%)	25 (57%)
Nicotine abuse, n (%)	10 (23%)
Hyperlipidemia, n (%)	9 (20%)
Alcohol abuse, n (%)	4 (9%)
Type II diabetes, n (%)	3 (7%)
Missing data, n (%)	4 (9%)

this aneurysm was finally treated by coiling (11 coils). During the treatment of a non-ruptured aneurysm of the ICA (height: 4.8 mm; width: 4.2 mm; neck diameter: 4.2 mm; dome-to-neck ratio: 1.0), the WEB could not be successfully implanted because the angle between the parent artery and the aneurysm neck turned out to be unfavorable. For this reason, the aneurysm was treated by coiling (6 coils). Furthermore, the device could not be implanted during an intervention on another ICA aneurysm (height: 4.2 mm; width: 2.8 mm; neck diameter: 2.2 mm; dome-to-neck ratio: 1.3) because the microcatheter was in contact with the aneurysm wall and could therefore not be positioned optimally for the WEB release. This aneurysm was also treated by coiling (1 coil). In the case of a further unruptured MCA aneurysm (height: 5.6 mm; width: 5.1 mm; neck diameter: 1.5 mm; dome-to-neck ratio: 3.4), the device could not be implanted either. However, no particular reason was stated. In this case, neurosurgical clipping of the aneurysm was performed as an alternative procedure. The initial attempt to treat a ruptured aneurysm of the Acom (height: 5.9 mm; width: 4.6 mm; neck diameter: 4.2 mm; dome-to-neck ratio: 1.1 mm) with the WEB also failed without any reason mentioned. However, following the unsuccessful attempt to implant the device, coiling was performed (3 coils). Overall, it can be summarized that four of the aneurysms in which WEB embolization failed were endovascularly treated by coiling. Only in one case neurosurgical clipping was executed. In addition to that these technical failures mentioned happened throughout the study, whereby three of them happened in 2019 and one case each in 2016 and 2018 after first experiences with the WEB have already been made.

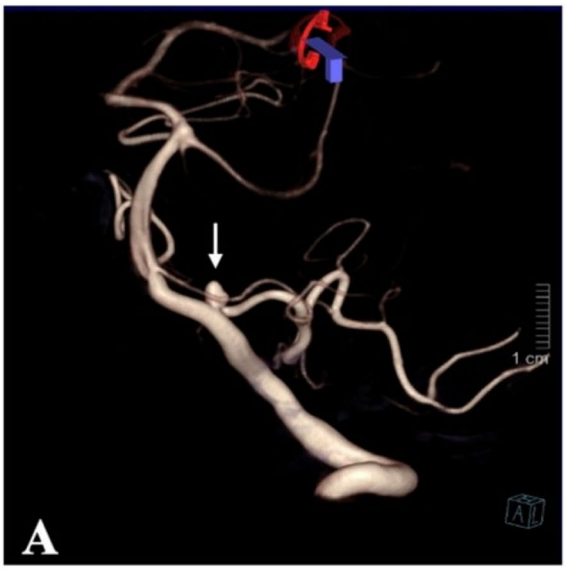
In 33 patients the WEB was implanted without the need of additional devices (e.g. coils or stents) during the index procedure or at later time points. An example of a complete WEB-treatment is given in Fig. 1. However, in our study population six aneurysms required additional endovascular treatment. Five patients received their additional treatment during the index procedure, because after the device implantation, no adequate occlusion was achieved. In all these cases additive coiling was used to occlude the aneurysm in combination with the device. Furthermore, out of these five patients, one received a stent-assisted recoiling and a further recoiling at later time point each. The

Fig. 1 **A** Before the implantation of the WEB device a 3D-angiography is performed to evaluate the aneurysm and its morphology. This image shows an aneurysm of the V4 segment at a PICA origin. **B** The WEB device is positioned in the lumen of the aneurysm. The proximal and distal radiopaque markers of the device support the interventionist during the deployment process. **C** The device is expanded. Through its self-expanding nitinol wires and a self-centering effect, maximum aneurysm occlusion should be achieved. **D** After the deployment, the correct expansion of the WEB device is checked in native digital subtraction angiogram (DSA). **E** Initially after the implantation, the control-DSA with contrast agent shows the correct positioning of the device. Although its location close to the PICA, the ladder is still perfused. **F** The 3D-reconstruction of the MRI follow-up after 12 months shows no residual aneurysm and no obstruction of the PICA (red arrow)

stent-assisted recoiling was performed after six months follow-up, because the aneurysm appeared inadequately occluded (WOS D). After twelve months follow-up the aneurysm presented as WOS D again. Therefore, a further recoiling was indicated. Another patient out of these five mentioned, underwent stent-assisted recoiling after three months follow-up, because the aneurysm presented with a reperfusion (WOS D). Only one patient of our study population underwent additional treatment at later time point, without being additionally coiled during the index procedure. In this case a stent-assisted coiling was performed after three months follow-up, because the treated aneurysm showed inadequate occlusion (WOS D). Additionally, this patient received a stent-assisted recoiling after twelve months follow-up, because the aneurysm again presented with a significant reperfusion (WOS D).

Complications and clinical outcome

Two patients suffered a thromboembolic event during the intervention. In one case a patient presented with dysarthria when awakened. After that a disturbed perfusion of the superior M2-branch was detected. Therefore, the patient received a bolus of diluted tirofiban (27 ml with 25 µg/kg). After the bolus the patient received tirofiban with a perfusor (10 ml/h) for the next 18 h. Moreover, the patient got ASA 100 mg/d prescribed for lifetime, because the WEB device showed a slightly protrusion into the parent artery. After the tirofiban treatment the dysarthria was fully recovered, and the thrombus did resolve completely. In the second case a thrombus was detected in the A2-branch of the left ACA during the intervention. This patient received a bolus of diluted tirofiban as well (27 ml with 25 µg/kg). After that a perfusor with tirofiban was started for the next 4 h (10 ml/h). This patient received ASA 100 mg/d for lifetime and Clopidogrel 75 mg/d for three months, because the WEB device showed a light protrusion into the parent vessel as well. In this case no clinical symptoms were detected at any time. After tirofiban treatment, the thrombus did resolve completely. In none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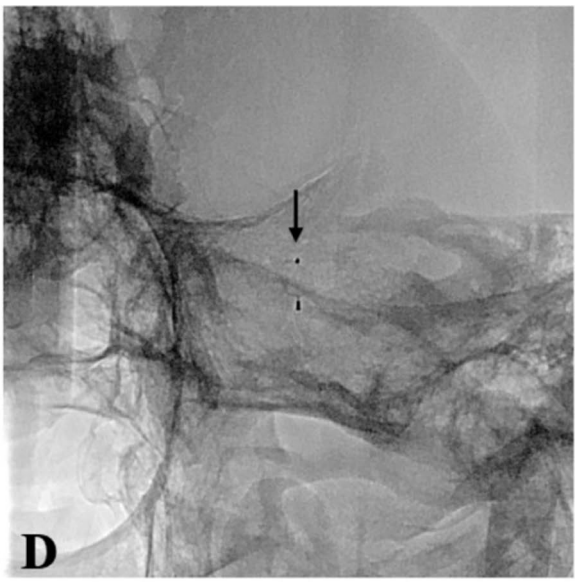
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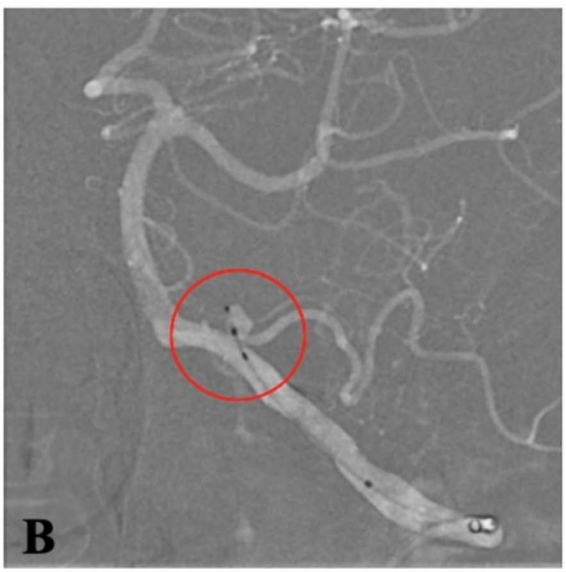
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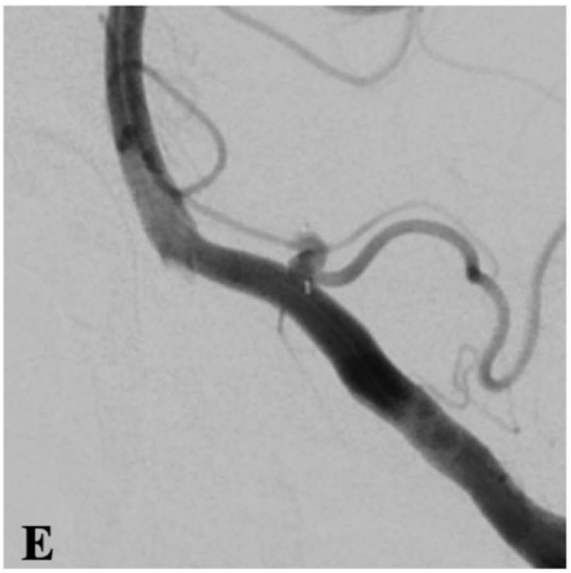
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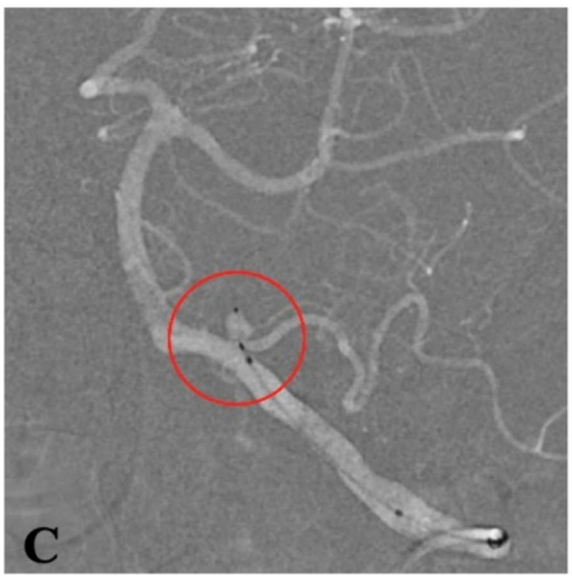
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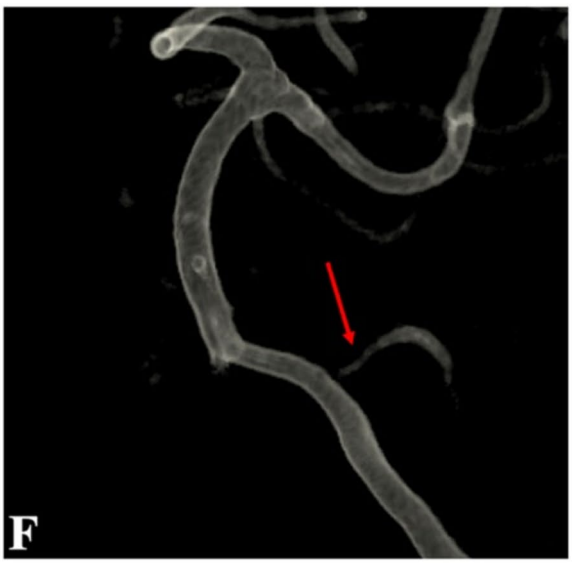
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of the endovascular treatments performed, an intracranial bleeding or cranial nerve lesion caused by the intervention was detected. During the observation period of twelve months, none of the study participants died because of the intervention. Overall, the complication rate was 5% ($n = 2$).

Angiographic results

Out of the 34 patients who received an aneurysm treatment only with the WEB device, 53% ($n = 18$) had the last follow-up and at least one further follow-up at an earlier time point. Immediately after the WEB implantation, 44% ($n = 15$) of the 34 aneurysms which were treated by using the WEB device only, were completely occluded ("WOS A"). A further 41% ($n = 14$) were classified as "WOS B". 9% ($n = 3$) of the aneurysms were classified as "WOS C" and 6% ($n = 2$) as "WOS D". Thus, 85% of the aneurysms ($n = 29$) were adequately occluded immediately after device implantation. 53% of the patients ($n = 18$) appeared at the first follow-up after three months. 72% ($n = 13$) of the aneurysms showed no reperfusion ("WOS A"). In 22% ($n = 4$) an enhancement of contrast agent was registered within the proximal marker recess ("WOS B"). No finding in the category "WOS C" could be identified during the first follow-up. In contrast, 6% ($n = 1$) showed a pronounced reperfusion of the aneurysm ("WOS D"). Thus, after three months, 94% of the aneurysms ($n = 17$) were adequately occluded. Only one aneurysm presented as inadequately occluded. The patient who presented with WOS D at three months follow-up received stent-assisted coiling after three months and stent-assisted recoiling after twelve months. Because of these additional retreatments, after three months, this patient was no further angiographically evaluated in the population which included patients wo had received WEB treatment only.

42% of the patients ($n = 13$) appeared for the second follow-up after six months. In 62% ($n = 8$) no reperfusion could be detected ("WOS A"). Of the remaining patients who appeared, 38% ($n = 5$) had results according to the "WOS B" category. At the second follow-up, no more pronounced reperfusion has been detected. Therefore, 100% ($n = 13$) of the aneurysms previously treated with the WEB were adequately occluded after six months. At the third follow-up after twelve months, 68% of the patients ($n = 21$) showed up. In 62% ($n = 13$) no reperfusion was detected ("WOS A"). A further 33% of the findings ($n = 7$) were assigned to the "WOS B" category. In 5% ($n = 1$) a slightly more pronounced reperfusion was classified as "WOS C". There were no results according to the "WOS D" category. Therefore, after 12 months, 95% of the treated aneurysms ($n = 20$) were adequately occluded, while only one aneurysm showed inadequate occlusion. The angiographic results of the aneurysms which were treated by WEB only, are summarized in Table 3.

Table 3 Angiographic outcome

Occlusion grade (WEB Occlusion Scale)	immediately after procedure ($n = 34$)	after 3 months ($n = 18$)	after 6 months ($n = 13$)	after 12 months ($n = 21$)
WOS A	15 (44%)	13 (72%)	8 (62%)	13 (62%)
WOS B	14 (41%)	4 (22%)	5 (38%)	7 (33%)
WOS C	3 (9%)	0	0	1 (5%)
WOS D	2 (6%)	1 (6%)	0	0

Unruptured intracranial aneurysms are associated with a worldwide prevalence of approximately 3 to 5 percent [1]. Since SAH is a serious and potentially life-threatening complication of these aneurysms, attempts have been made to establish certain criteria to predict the rupture risk for individual cerebral aneurysms. All these criteria were combined in 2015 to form a treatment score for unruptured intracranial aneurysms ("Unruptured Intracranial Aneurysm Treatment Score"; "UIATS"). This score is intended to support clinicians in their decision making (treatment or observation) regarding the approach to unruptured intracranial aneurysms. It is intended to make it possible to identify patients in whom the risk of rupture exceeds the risk of treatment [4]. By considering the currently used endovascular treatment approaches the WEB offers several advantages over the other procedures. For example, the use of the WEB usually does not require anti-aggregation therapy, which enables the treatment of acutely ruptured aneurysms [8]. In our study, two patients (5%) experienced thromboembolic complications, which subsequently regressed completely by the periinterventional administration of tirofiban. None of the patients in the study group experienced intracranial bleeding or cranial nerve lesions caused by device implantation. Furthermore, the device-associated mortality rate was 0%. The long-term results of the WEB-IT study published by Fiorella et al. in 2023 also found no intracranial bleeding or deaths caused by the intervention, which is consistent with the results of our study. However, Fiorella et al. were also unable to identify any thromboembolic complications [9].

Regarding the clipping of intracranial, unruptured aneurysms, in 2023 Darsaut et al. found out that in 22% of the cases new neurological complications occurred after the procedure. In addition, 22% also experienced serious adverse events. The observation period for their study was one year [10]. Compared to the complication rate of our study population (5%), which was also observed over a period of one year, the complication rate of clipping is significantly higher due to the more serious procedure.

In a study by Kabbasch et al. (2019), thromboembolic events occurred in 7.5% (n = 5) by coiling of unruptured intracranial aneurysms. Furthermore, bleeding caused by the intervention occurred in 1.5% of cases (n= 1). Neurological complications were detected in 4.5% (n= 3) [11]. These results differ from the complication rate of our study (5%).

In 2023, Boisseau et al. investigated the performance of stent-assisted coiling in unruptured intracranial aneurysms. In this study, it was shown that a total of 26.6% of patients (n= 25) treated with stent-assisted coiling experienced adverse events. 22.3% (n= 21) experienced an ischemic and hemorrhagic event [12]. The significant hemorrhagic complication rate compared to our study population can probably be explained by the need for anti-aggregation therapy in the context of stent-assisted coiling, which is usually not necessary when using the WEB [13].

In a meta-analysis from 2019, Cagnazzo et al. examined the use of various intravascular flow-diverters in the treatment of non-ruptured, distally located intracranial aneurysms in the anterior circulation. Thromboembolic complications occurred in 9.9% of the interventions. Hemorrhagic complications occurred in 2.6% of cases [14].

The occlusion rates of the WEB determined in our study largely agree with those in the literature. Immediately after the intervention, 85% of all aneurysms were adequately occluded. Furthermore, 95% of the aneurysms were adequately occluded at the first follow-up after three months. At the time of the second follow-up, after six months, 100% of the aneurysms showed adequate occlusion. In addition to that, 95% of the aneurysms presented as adequately occluded at the last follow-up after twelve months. However, it should be noted that not the same number of patients attended all follow-up appointments. Ozpeynirci et al. were able to determine adequate occlusion in a total of 91.4% of the treated aneurysms in their study conducted in 2019 with a median follow-up period of nine months [15].

In 2023 Hassankhani et al. published a systematic review regarding the long-term outcomes of intracranial aneurysms treated with the WEB device. At one year follow-up they presented a complete occlusion rate of 56,85%, which is quite similar to the complete occlusion rate described in our study at the same time point (62%). In addition to that, they claimed that 87,11% of the treated aneurysms presented as adequately occluded after one year follow-up. In our study population, at this time point, 95% of the aneurysms were categorized as adequately occluded. Moreover, during these twelve months of observation, 3,45% of the aneurysms in their study required retreatment. In our study collective 3% of the aneurysms, which were initially treated with the WEB only, had to receive retreatment to reach a better occlusion result [16].

Furthermore, the five-year occlusion results of the WEB-IT study published by Fiorella et al. in 2023 underline the efficacy of the WEB device as well. However, they could not carry out a follow-up in all 96 patients after five years. Nevertheless, they demonstrated adequate occlusion in 87.8% of cases and their study also included both ruptured and non-ruptured aneurysms. Besides not only broad-based bifurcation aneurysms were included, even though these made up the majority of the aneurysms (83.2%). In our study population 34% of the treated aneurysms were defined as broad based. Despite this discrepancy the occlusion results were similar. This underlines that the WEB device seems to be an effective treatment option not for wide-neck aneurysms only. However, it must be mentioned that aneurysms with reperfusion at the neck area (WOS C) were classified as adequately occluded in the WEB-IT study, whereby in our study a WOS C reperfusion was categorized as inadequate occlusion. It should also be mentioned that their population included four different aneurysm localizations [9], whereas the present study analyzed eight different localizations.

Although the mentioned treatment results of the WEB device are promising, it is not as flexible as other treatment options (e.g. (stent-assisted) coiling) regarding its use in complex anatomic conditions. In these situations, the additional use of alternative treatment options can ensure adequate occlusion of the specific aneurysm, whereas the single use of the device would not achieve a similar result, or the aneurysm is not even accessible for WEB implantation [17]. Despite this potential weakness, studies show that the WEB device leads to adequate treatment results, especially in wide-neck bifurcation aneurysms [9, 15, 16]. However, future developments could aim to introduce technological enhancements, such as sensors or feedback systems that facilitate placement. In addition, further long-term studies on the efficacy and safety of the WEB device in more complex clinical scenarios would be desirable in order to further expand its field of application.

In 2019, Kabbasch et al. published a study that examined the coiling of non-ruptured intracranial aneurysms. At the time of the last follow-up, which took place after an average of 15 months, 60.8% of the treated aneurysms showed complete occlusion. In addition, 27.5% of the coiled aneurysms had a reperfusion at the neck area and in a further 11.8% the aneurysm sack itself contained reperfusion [11]. In our study, 62% of the aneurysms were completely occluded at the last follow-up, which took place after twelve months, although only 21 patients attended the follow-up. In addition, no aneurysm showed complete reperfusion during the last follow-up and only one case of reperfusion at the neck area was assessed.

Regarding stent-assisted coiling of unruptured broad-based bifurcation aneurysms, the meta-analysis conducted

by Papadopoulos et al. in 2020 showed that 50.2% of the aneurysms were completely occluded immediately after the intervention. In the further course, 63.83% of the aneurysms presented as completely occluded [18]. In our study, 44% were completely occluded immediately after the intervention. After one year, as already mentioned, 62% of the aneurysms treated with the WEB showed complete occlusion.

In a meta-analysis from 2015, Briganti et al. examined the treatment of intracranial aneurysms using intravascular flow-diverters. At the last follow-up, the authors were able to demonstrate complete occlusion in 81.5% of cases. However, 8% of the aneurysms received additional coiling, which should be considered when assessing the occlusion results. In terms of immediate occlusion, the average complete occlusion rate was 10.8% [19], which differs immensely from the immediate complete occlusion rate in our study (44%).

When considering the risk factors for the development of intracranial aneurysms within the study population, it is striking that 91% ($n = 40$) of the patients presented with at least one risk factor. The three most common risk factors were female gender as a non-modifiable risk factor (61%), arterial hypertension (57%) and nicotine abuse (23%) as modifiable risk factors. According to a study conducted by Karhunen et al. in 2021, arterial hypertension and nicotine abuse are the most potent risk factors for the development of intracranial aneurysms [20]. The nicotine contained in cigarette smoke and various other substances can lead to endothelial dysfunction and, in the worst case, to aneurysm rupture [21, 22].

In addition, arterial hypertension can also lead to the development of endothelial dysfunction, which is considered an essential step in the formation of intracranial aneurysms [23]. Moreover, gender also plays an important role in the development of intracranial aneurysms. A connection between estrogen deficiency and an increased risk of developing intracranial aneurysms has been proved. This explains why especially older women present with these vascular pathologies [24]. The effect is caused by reduced estrogen levels which lead to increased inflammatory reactions [25].

In our study, the MCA (30%), the Acom (30%) and the BA (16%) were frequently affected by intracranial aneurysms. In the WEBCAST-2 study the most common locations of the intracranial aneurysms treated with the WEB were the MCA (45.5% or $n = 25$), the Acom (29.1% or $n = 16$) and the BA (16.4% or $n = 9$) as well [26].

Limitations

This study has various limitations. Even though the study population is relatively large compared to many other studies regarding this topic, nevertheless its small size can lead to a distorted representation of prevalence and significance. In addition, a retrospective study design was chosen, which means that for some parameters, corresponding data was missing in a large number of patients (e.g. regarding the follow-up appearances by the patients). The quality and completeness of the required data could therefore not be influenced and depended, among other things, on the conscientiousness and detail of the documentation of various clinic employees and the willingness of the patients to cooperate. Therefore, it cannot be ruled out that significant correlations occurring in the clinical practice were not depicted. In addition to that the study was a single-center study, as only patients who were treated in the Department of Diagnostic and Interventional Neuroradiology were included. This may result in selection bias, although a direct comparison of all collected data with those of other (multicenter) studies and meta-analyses showed similar results.

Conclusion

The results of our study show that the WEB is a safe and efficient endovascular treatment approach for saccular intracranial aneurysms with a small or wide neck as well. Although the latter are well known for their instable occlusion results, our experience suggests that the WEB-treatment offers stable occlusion in this special type of aneurysm, which often is sophisticating in its treatment. A further advantage of the WEB compared to other endovascular treatment techniques like intravascular flow diverters is that no dual anti-platelet-aggregation therapy is needed, while similar occlusion results are achieved. The results of our study are in line with those from other studies on the WEB, e.g. the WEB-IT study. Compared to the other techniques (clipping, coiling etc.), and their complication rates known from different publications, our results suggest that the WEB seems to be a safer treatment option as well. These results are similar to previous studies on the WEB. Due to a limited number of patients included, our results should be validated by further studies.

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Declarations

Ethical approval Approval was obtained from the ethics committee of the Saarland Medical Association, in Saarbrücken, Germany. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed consent As all patients in our retrospective study were treated at our university hospital, the patients consent to the use of their anonymized data for research purposes as part of the medical patient information sheets. This consent is part of the medical patient informa-

tion sheets and this procedure is contractually agreed by the clinic. Regarding the consent for publication it was not necessary to obtain consent because only images as X-rays and angiographic images are contained in this publication and additionally all data were anonymized.

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

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