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Reconstructive endovascular treatment of basilar artery fenestration aneurysms: A multi-centre experience and literature review

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Abstract

Background: Data on outcome after endovascular treatment of basilar artery fenestration aneurysms (BAFAs) is limited. This study presents our multi-centre experience of BAFAs treated by different reconstructive techniques including coils, stent-assisted coiling (SAC), flow diversion and intra-saccular flow disruption with the Woven Endobridge (WEB).

Methods: Retrospective analysis of 38 BAFAs treated endovascularly between 2003 and 2020. The primary endpoint was complete aneurysm obliteration defined as Raymond–Roy occlusion classification (RROC) I on immediate and follow-up (FU) angiography. The secondary endpoints were procedure-related complications, rate of re-treatment, and clinical outcome.

Results: Endovascular treatment was feasible in 36/38 aneurysms (95%). The most frequent strategy was coiling (21/36, 58%), followed by SAC (7/36, 19%), WEB embolization (6/36, 17%) and flow diversion (2/36, 6%). A successful aneurysm occlusion (defined as RROC 1 and 2) on the final angiogram was achieved in 30/36 (83%) aneurysms including all patients presenting with baseline subarachnoid haemorrhage and 25/36 (69%) were occluded completely. Complete occlusion (RROC 1) was more frequently achieved in ruptured BAFAs (15/25, 60% v. 2/11, 18%; $p = 0.031$). Procedure-related complications occurred in 3/36 (8%) aneurysms. Re-treatment was executed in 12/36 (33%) aneurysms. After a median angiography FU of 38 months, 30/31 (97%) BAFAs were occluded successfully and 25/31 (81%) showed complete occlusion.

Conclusion: Reconstructive endovascular treatment of BAFAs is technically feasible with a good safety profile. Although in some cases re-treatment was necessary, a high rate of final aneurysm occlusion was achieved.

Keywords

Intracranial aneurysm, basilar artery, fenestration, endovascular treatment

Introduction

Arterial fenestrations are an anatomical variant and based on anomalies in embryonic vascular development.[1] The basilar artery (BA) is the second most common site of intracranial fenestration. The proximal part of the BA including the vertebrobasilar junction is the most common position for occurrence of BA fenestrations, but it can rarely be seen at the middle or distal segment.[2] Some authors suggest that the presence of such fenestrations predisposes for adjacent aneurysm formation due to vessel-wall weakness and haemodynamic effects.[3] Surgical treatment of basilar artery fenestration aneurysms (BAFAs) is challenging because of posterior fossa location, presence of many brainstem perforators and cranial nerves, and complex aneurysm morphology. Therefore, endovascular

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management of BAFAs has become the treatment of choice during the last two decades.[4–6] Although there are many case reports or case series presenting different endovascular approaches to treat these lesions, only a few clinical studies have analysed in a double-digit number of patients with BAFAs, which might be due to rarity of these cases.[4,7,8] In this context, there is also limited data on long-term efficacy after endovascular treatment. Therefore, we present our multi-centre experience of BAFAs treated by different reconstructive endovascular techniques including coils, stents and extra-/and intra-aneurysmal flow diversion.

Methods

Thirty-five patients harbouring 38 BAFAs were endovascularly treated at nine centres in Germany and Singapore between 2003 and 2020. Baseline characteristics, aneurysmal details, procedural aspects, complications and angiographic and clinical outcome were analysed retrospectively on an intention-to-treat basis. Inclusion criteria were presence of a BAFA and a reconstructive endovascular technique as first-line therapy. Non-ruptured and ruptured BAFAs were included. Pre-treatment led to exclusion of the current analysis. All indications were based on a case-by-case evaluation in an interdisciplinary decision-making process between neurosurgeons and interventional neuroradiologists. In patients with subarachnoid haemorrhage (SAH; Fisher > 2), Hunt and Hess grade ≥ 3 or evidence of hydrocephalus, an external ventricular drainage was performed before endovascular treatment.

Aneurysm morphology was evaluated based on a 3D angiography as described previously.[5] In brief, the relationship of the aneurysm to the fenestration and the width of the aneurysm neck were considered (type 1A, narrow neck and both loops involved; 1B, narrow neck and one loop involved; 2A wide neck/both loops; 2B wide neck/one loop). The definition of a narrow neck was a size <4 mm or a dome-to-neck ratio of >2.

The primary endpoint was a complete aneurysm obliteration defined as Raymond–Roy occlusion classification (RROC) I on immediate and follow-up (FU) angiography.[9] The secondary endpoints were procedure-related complications, rate of re-treatment and clinical outcome. Angiographic FU was performed by either computed tomography angiography (CTA), magnetic resonance angiography (MRA) or digital subtraction angiography (DSA). Clinical outcome was evaluated at discharge and during FU according to the modified Rankin Scale (mRS). An mRS ≤ 2 was defined as a favourable outcome. Each patient's angiographic and clinical status at the last FU was defined as the final outcome. Angiographic FU data included re-treatment results.

According to the guidelines of the respective local ethics committee, ethics approval was given when necessary for this anonymous retrospective study, which was conducted in accordance with the Declaration of Helsinki. The patients' consent for treatment was obtained (if possible) according to the individual, institutional guidelines. Due to the study's retrospective nature, additional informed consent was deemed unnecessary by the local ethics committees.

Statistical analysis

Categorical variables were expressed as numbers with percentages and compared using the Chi-Square and the Fisher's Exact tests, when appropriate. Continuous variables were presented as means $\pm$ standard deviation and compared using the two-sided unpaired Student's *t*-test. All calculations were performed using SPSS software (IBM SPSS Statistics for Windows, Version 25.0, Armonk, NY, USA). A p-value <0.05 was considered as statistically significant.

Endovascular treatment

Endovascular treatment was performed under general anaesthesia and systemic heparinization. Dual antiplatelet medication was given 3–7 days before the intervention in cases of unruptured aneurysms. Platelet function tests were routinely performed using aspirin and P2Y12 assays (Multiplate Analyzer, Roche, Basel, Switzerland). A platelet inhibition level between 30 and 90% for clopidogrel and 350 and 550 response units for aspirin was defined as acceptable. Poor responders to clopidogrel were either counteracted by dose escalation (e.g. clopidogrel 150 mg/d) or switched to prasugrel (40 mg loading dose, 5 mg/d). In ruptured aneurysms, antiplatelets were only given intra-operatively if the use of stents were inevitable. The choice of the applied endovascular strategy was left to the operator and dependent on aneurysm morphology, vessel anatomy including the presence of both vertebral arteries (VAs) or perforating brain stem arteries with the fenestration channels and occurrence of aneurysm rupture. Narrow neck aneurysms (type 1A and 1B) were generally treated with simple coiling. Wide neck aneurysms (type 2A and 2B) were treated with coiling $\pm$ balloon remodelling, stent-assisted coiling (SAC), flow diversion and intra-saccular flow disruption. The following stents and flow-diverter types were used: laser-cut stents (Neuroform Atlas, Stryker Neurovascular, Kalamazoo, MI, USA; Enterprise, Codman, Raynham, MA, USA; Solitaire AB, ev3 Neurovascular, Irvine, CA, USA; pCONus, phenox, Bochum, Germany), braided stents (LVIS, LVIS Jr and LVIS EVO, Microvention, Tustin, CA, USA; Leo, Leo+, Balt, Montmorency, Ile-de-France, France) and extra-aneurysmal flow diverters (Derivo, Acandis, Pforzheim, Germany; Fred, Microvention; p64, phenox; Pipeline Embolization Device, Covidien, Irvine, CA, USA). The stents were either implanted within the aneurysm-involved channel (type 2B) or the dominant channel (type 2A) or in cases of re-treatment. Intra-saccular flow disruption with the

Woven EndoBridge (WEB, Microvention) was exclusively performed for type 2A BAFAs. In ruptured aneurysms, simple coiling was pursued, and stents were only applied if necessary (e.g. due to blister-like aneurysm). Basically, the preservation of the distal vertebral arteries and both fenestration channels was aimed at all cases.

Systematic literature review

Following the retrospective data collection, we reviewed the literature according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

A systematic literature search was conducted in Ovid MEDLINE, PubMed and Cochrane online scientific publication databases using medical subject headings and general search terms: ('fenestration' OR 'fenestrated' OR 'fenestrations') AND ('basilar' OR 'BA') AND ('aneurysm' OR 'aneurysms'). Studies with more than five patients were included. Study designs included case series, case-control studies and both retrospective and prospective observational studies. Publications were included if they had data reported on (a) endovascular treatment of BAFAs including choice of treatment modality, (b) angiographic results, (c) clinical outcomes including NIHSS or mRS grades, and (d) peri- or post-procedural complications (Figure 1). Two independent researchers [HS/SF] then screened abstracts and titles, and a third reader resolved discrepancies. References from the included studies were manually reviewed for additional relevant reports. Exclusion criteria were conference abstracts, animal studies, review articles, commentaries, meta-analyses and case reports. The literature search was generally confined to reports written in English. Demographic, procedural and outcome data on participants from the retrospective review were collected and are presented in Table 1.

Results

During the study period of 17 years, 38 aneurysms in 35 patients were treated endovascularly. The median age was 55 years (range, 23–79 years) and 27/35 (77%) were female. Most of the aneurysms (27/38, 71%) were located at the proximal site of the BA, and six (16%) were at the mid-basilar and five (13%) at the distal BA portion. Aneurysms with wide-neck and involvement of both loops were most common (type 2A, 18/38, 47%), followed by type 2B (12/38, 32%), type 1A (5/38, 13%) and type 1B (3/38, 8%) aneurysms. The mean aneurysm size was 7.0 ± 4.9 mm with a mean dome–neck ratio of 1.3 ± 0.7. Proximal aneurysms were most commonly type 2A (15/27, 56% v. 2/11, 18%; $p = 0.004$) and had a larger mean size than distal aneurysms (8.3 ± 5.2 v. 4.0 ± 2.4, $p = 0.014$). Seventeen (45%) aneurysms were ruptured and 36/38 (95%) had a saccular morphology. An individual overview of the patients' characteristics is shown in Table 2.

Endovascular treatment

Endovascular treatment was feasible in 36/38 (95%) BAFAs. In one patient (no. 15) suffering from small vis-à-vis BAFAs at the distal site, treatment was not feasible because navigation of the tiny aneurysms

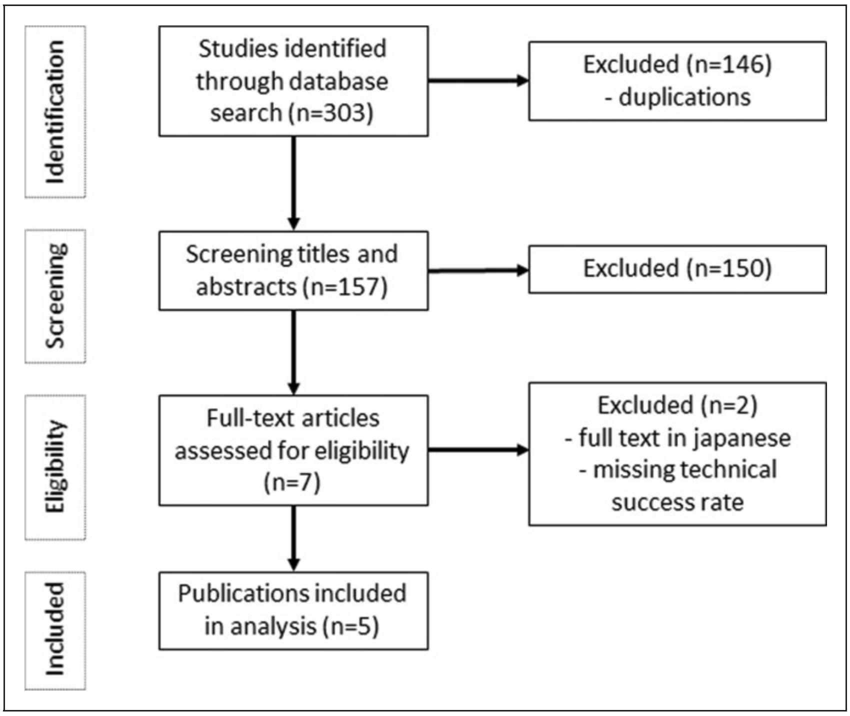

Figure 1. Preferred reporting items for systematic search strategy for the systematic review.

Table 1. Comparison between clinical studies dealing with endovascularly treated basilar artery fenestration aneurysms.

	Islak et al. 2002[4]	Peluso et al. 2007[6]	Trivelato et al. 2016[5]	Zhu et al. 2016[7]	Korkmaz et al. 2020[8]	Current study
Time period	11/1994–02/2000	01/1995–01/2007	06/2010–09/2012	01/2007–12/2014	2000–2019	2003–2020
Baseline						
No of patients/aneurysms	10/11	7/7	8/9	10/12	24/26	35/38
Ruptured aneurysms (*n* (%))	7/11 (63)	7/7 (100)	4/8 (50)	5/10 (50)	16/24 (75)	17/38 (45)
Mean age (years)	40	58	57	56	56	54
Female (*n* (%))	7/10 (70)	5/7 (71)	7/8 (88)	6/10 (60)	18/24 (75)	27/35 (77)
Mean aneurysm size (mm)	N/A	13	N/A	4	8	7
Narrow necked (*n* (%))	6/11 (55)	N/A	4/9 (44)	2/12 (17)	10/26 (38)	8/38 (21)
Proximal fBA location (*n* (%))	9/11 (82)	7/7 (100)	6/9 (67)	12/12 (100)	26/26 (100)	27/38(71)
Technique						
Coiling (*n* (%))	10/11 (91)	7/7 (100)	4/9 (45)	6/12 (50)	9/26 (35)	21/36[f] (58)
with use of balloon (*n* (%))	5/11 (45)		1/9 (11)		2/26 (8)	5/36 (14)
Parent artery occlusion (*n* (%))	1/11 (9)					
Stent-assisted coiling (*n* (%))			5/9 (55)	4/12 (33)	8/26 (31)	7/36 (19)
Stent only (*n* (%))				2/12 (17)	4/26 (15)	
Extra-aneurysmal FD (*n* (%))					5/26 (19)	2/36 (6)
Intra-aneurysmal FD (*n* (%))						6/36 (17)
Angiographic results						
Immediate occlusion result	CAO: 10/11 (91) NR: 1/11 (9)	CAO: 5/7 (71) NCAO: 2/7 (29)	CAO: 6/9 (66) NR: 3/9 (33)	CAO: 8/12 (67) NR: 1/12 (8) RA: 3/12 (24)	Successful occlusion: 26/26 (100)	CAO: 25/36 (69) NR: 5/36 (14) RA: 6/36 (17)
Procedure-related Complications (*n* (%))	0/11 (0)	0/7 (0)	1/9 (11)[c]	0/12 (0)	2/26[e] (8)	3/36 (8)[g]
Aneurysm Recurrence (%)	1/11 (9)	0/7 (0)	1/9 (11)	0/10 (0)	0/26 (0)	10/36 (28)
Retreatment (*n* (%))	2/11 (18)[a]	0/7 (0)	1/9 (11)[d]	0/10 (0)	0/26 (0)	12/36 (33)
New neurologic deficit (*n* (%))	0/11 (0)	N/A	0/9 (0)	0/10 (0)	0/26 (0)	0/36 (0)
In-hospital mortality (*n* (%))	0/11 (0)	2/7 (29)	3/8 (38)	0/10 (0)	1/24 (4)	2/35 (6)
Follow-up (FU)						
Median clinical FU (months)	31 (mean)	N/A	16.2	69.5	62 (mean)	44
mRS ≤ 2	11/11 (100)	N/A	5/8 (63)	10/10 (100)	24/26 (92)	29/29 (100)
Median angiographic FU	N/A[b]	17.5 (mean)	N/A	15	N/A	38
Angiographic FU occlusion result	N/A	CAO: 2/4 (50) NCAO: 2/4 (50)	N/A	CAO:9/10	N/A	CAO: 25/31 (81) NR: 5/31 (16) RA: 1/31 (3)

CAO, complete aneurysm occlusion; FD, flow diversion; FU, follow-up; mRS, modified Rankin Scale; NCAO, near complete aneurysm occlusion; NR, neck remnant; RA, residual aneurysm; artery aneurysms.
[a]Balloon-assisted coiling; [b]five patients with 1-year FU and two patients with 5-year FU; [c]aneurysm rupture; [d]technique of retreatment remains unclear; [e]one patient with perforating artery occlusion and one with iatrogenic vertebral artery dissection; [f]two aneurysms could not be treated successfully; [g]one patient with aneurysm rupture, one with thromboembolic occlusion of PICA and one with iatrogenic vertebral artery dissection.

Table 2. Individual overview of patients with basilar artery fenestration aneurysms.

Patients (*n*)	Aneurysm type	Location	Ruptured	Technique	Immediate result (RROC)	Re-treatment	Technique	Angiographic FU (days)/modality	FU occlusion (RROC)	FU mRS
1	2B	Mid-basilar	Y	Coil	2	Y	SAC	1558/DSA	2	0
	2B	Midbasilar	N	Coil	1	N			1	
2	2A	Proximal	N	Coil	1	Y	SAC	3874/DSA 4296/CTA	1	0
3	2A	Proximal	N	SAC	3	Y	Coil/PAO	3176/DSA	2	0
4	2A	Proximal	N	Coil	3	Y	SAC	3326/DSA	1	0
5	1B	Midbasilar	N	Coil	1	N		216/DSA 982/MRA	1	0
6	2B	Proximal	Y	SAC	1	N		191/DSA	1	1
	2B	Proximal	N	SAC	1	N		2617/MRA	1	
7	2A	Proximal	N	WEB	2	N		355/DSA 3064/CTA	2	0
8	2A	Proximal	N	Coil	1	N		188/DSA	1	0
9	2B	Proximal	Y	Coil	1	N				
10	2A	Proximal	N	FD	3	N		540/DSA 623/CTA	1	0
11	2A	Proximal	N	WEB	3	N		185/MRA	1	0
12	2A	Proximal	N	WEB	1	Y	FD	503/DSA	1	0
13	2B	Proximal	Y	Coil	1	Y	SAC	324/DSA	1	2
14	2B	Proximal	N	SAC	1	Y	WEB/FD	169/DSA	3	0
15	1B	Distal	N							
	1B	Distal	N							
16	2B	Mid-Basilar	Y	SAC	1	N		441/DSA	1	0
17	1A	Proximal	Y	Coil	1	N		1460/DSA	1	0
18	2A	Proximal	Y	Coil	1	Y	SAC	1460/DSA	1	0
19	2B	Proximal	N	Coil	2	N		730/DSA 910/CTA	1	0
20	2A	Distal	Y	Coil	1	N				
21	2B	Mid-Basilar	Y	Coil	1	N		180/DSA 1125/MRA	1	0
22	2A	Mid-Basilar	Y	WEB	1	N		[a]	[a]	6
23	2A	Proximal	Y	Coil	1	Y	SAC/FD	969/DSA 1166/MRA	1	0
24	2B	Proximal	Y	SAC	1	N		150/DSA 2737/MRA	1	0
25	2A	Proximal	N	WEB	3	N		420/DSA	2	0
26	2A	Proximal	N	WEB	3	N		pending	pending	
27	2B	Proximal	N	Coil	2	N		422/MRA	2	0
28	2A	Proximal	Y	Coil	1	N		2134/DSA	1	0
29	2A	Proximal	Y	Coil	2	Y	FD	1120/DSA	1	1
30	2A	Proximal	Y	SAC	1	N		[a]	[a]	6
31	1A	Proximal	Y	Coil	1	N		670/DSA 743/MRA	1	0
32	1A	Distal	Y	Coil	1	N		1900/DSA	1	0
33	1A	Proximal	N	Coil	1	Y	SAC	3423/DSA	1	0
34	1A	Distal	N	Coil	1	Y	FD	2353/DSA	1	0
35	2A	Proximal	N	FD/Coil	1	N		1819/DSA	1	0

CTA, computed tomography angiography; DSA, digital subtraction angiography; FD, flow diverter; FU, follow-up; MRA, magnetic resonance angiography; mRS, modified Rankin Scale; RROC, Raymond–Roy occlusion classification; PAO, parent artery occlusion; SAC, stent-assisted coiling; WEB, Woven EndoBridge.
[a]no follow-up available due to death during hospital stay.

(2×1 mm) failed due to the steep angle between the aneurysms and the parent artery. As small perforators were originating from the dominant channel, a deconstructive strategy was also waived, and the patient remained under surveillance.

The most applied strategy was coiling (21/36, 58%, Figure 2), followed by SAC (7/36, 19%, Figure 3), WEB embolization (6/36, 17%) and flow diversion (2/36, 6%, Figure 4). Coiling was also the most common technique in ruptured BAFAs (12/17, 71%). Of the 21 aneurysms treated with coiling, a balloon was used in five (24%) due to a wide neck. Stents including flow diverter were exclusively used in wide-necked BAFAs (type 2A/2B). Braided stents were used in the

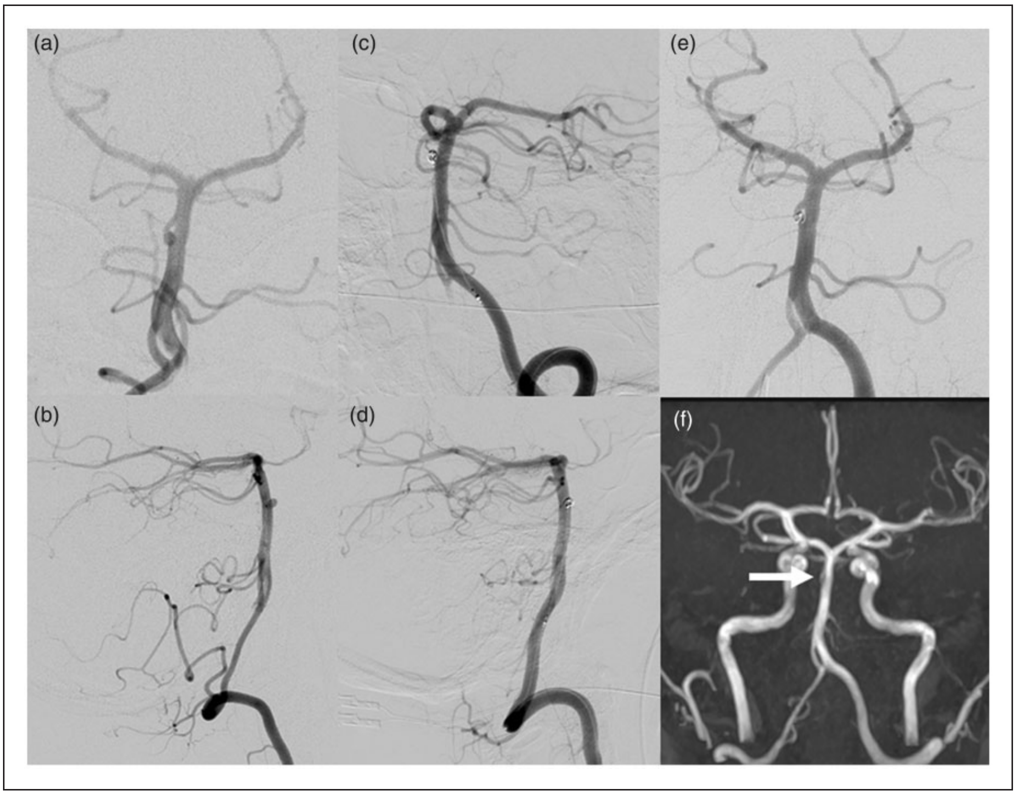

Figure 2. Patient with positive family history presented with a small, non-ruptured aneurysm at the fenestration of the mid portion of the basilar artery. (a) Digital subtraction angiography anterior posterior view; (b) lateral view, case 5. Embolization of the aneurysm with one coil was performed (c and d) resulting in complete aneurysm occlusion (e). (f) Last follow up with magnet resonance imaging and time of flight angiography after 32 months showed regular non-dominant (white arrow) and dominant branch of the basilar fenestration with unchanged result and complete occlusion (RROC 1) of the fenestrated basilar aneurysm.

majority of cases treated with SAC (4/7, 57%). In each case with SAC or flow diverter therapy, only one channel was used for stenting and the use of multiple stents was avoided. Dependent on the aneurysm type, coiling was most frequently performed in type 1A (5/21, 24% v. 0/17, 0%; $p = 0.031$), SAC in type 2B (5/7, 71% v. 7/31, 23%; $p = 0.004$), and the WEB device in type 2A (6/6, 100% v. 12/32, 38%; $p = 0.004$).

A successful aneurysm occlusion (defined as RROC 1 and 2) on the final angiogram was achieved in 30/36 (83%) aneurysms including all patients presenting with baseline SAH and 25/36 (69%) were occluded completely. Complete occlusion (RROC 1) was more frequently achieved in ruptured BAFAs (15/25, 60% v. 2/11, 18%; $p = 0.031$) and tended to be associated with smaller aneurysm size and neck width (6.4 ± 3.4 v. 9.5 ± 7.1; $p = 0.081$ and 3.5 ± 2.0 v. 5.2 ± 3.6; $p = 0.093$, respectively). Coiling and SAC were correlated with complete aneurysm occlusion at the end of the procedure (22/25, 88% v. 6/11, 55%; $p = 0.04$). Aneurysm types had no impact on aneurysm occlusion rate (AOR). In 6/36 (17%) aneurysms with wide neck (type 2A/2B), a residual flow into the aneurysm sac (RROC 3) was observed at the end of the procedure. However, three of them were treated with WEB and one with flow diverter, and none of them presented with baseline SAH.

Procedure-related complications occurred in 3/36 (8%) aneurysms. In one patient (no. 6) presenting with SAH due to wide-necked vis-à-vis BAFAs, advancing of the first coil led to aneurysm rupture. The coil was left in place and a laser-cut stent was implanted to cover the wide aneurysm neck, which enabled subsequent coil detachment with complete aneurysm occlusion. Intravenous aspirin (500 mg) was given and anticoagulation with heparin was administered to achieve a doubling of activated partial thromboplastin time. A microcatheter was then navigated through the stent struts into the adjacent aneurysm to facilitate coiling and complete occlusion. The patient was discharged with an mRS of 2. One patient with ruptured BAFA (no. 13) suffered from intra-procedural thromboembolic occlusion of the posterior inferior cerebelli artery without clinical sequela. Another patient (no. 14) suffered from iatrogenic vertebral artery dissection and received stenting after the aneurysm was occluded.

At discharge, 29/35 (83%) patients had a favourable outcome. All elective patients had an mRS of 0. Of the remaining six individuals, which all presented with ruptured BAFAs, three had an mRS of 3, one an mRS of 5 and two deceased during the hospital stay.

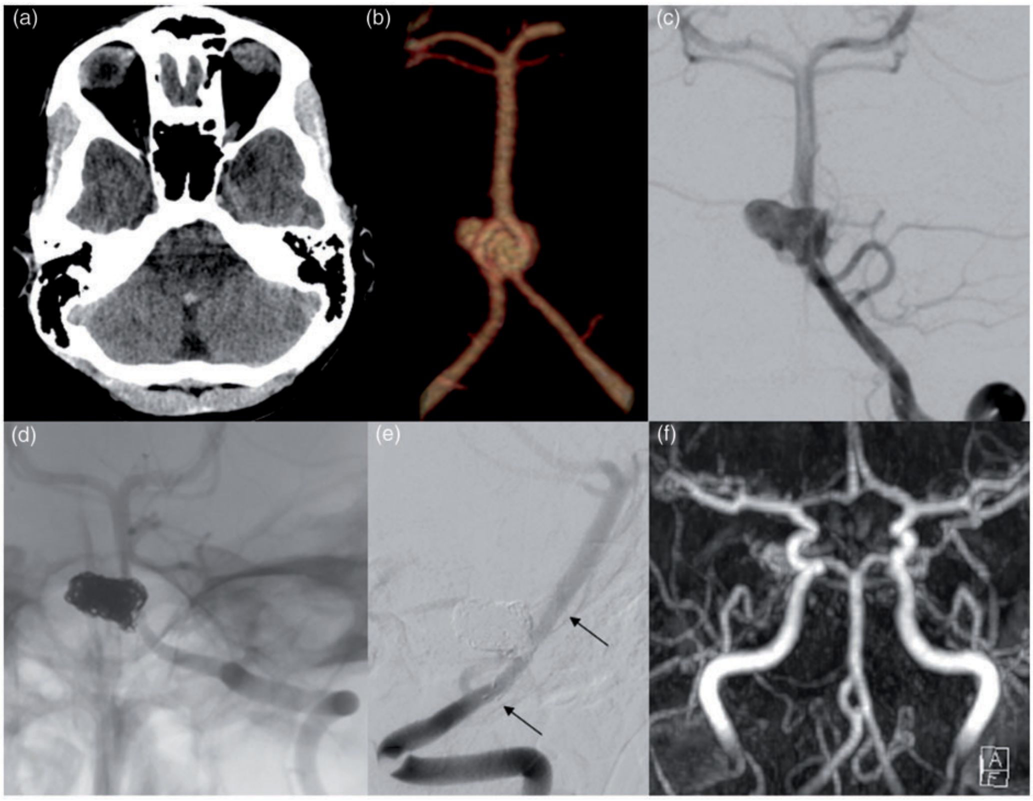

Figure 3. A patient was admitted with sudden onset of headache to the emergency department (Hunt and Hess 2, case 24). (a) Baseline computed tomography showed a thin subarachnoid and intraventricular haemorrhage. (b) 3D computed tomography angiography demonstrated a fenestrated aneurysm of the proximal basilar artery with involvement of both loops and incorporation mainly of the left trunk (type 2B). Access was obtained via both vertebral arteries. A microcatheter was jailed within the aneurysm and a braided stent (LVIS Jr., 3.5×15 mm) was deployed from the mid portion of the basilar artery to the distal v4 segment just above the ostium of the posterior inferior cerebelli artery (c). Subsequently, the aneurysm was occluded completely (RROC 1) by the use of 11 coils (d). (e) Follow-up examination showed complete closure of the aneurysm and a proper wall apposition of the stent on digital subtraction angiography after 150 days (black arrows) and on final magnetic resonance imaging after 5 years (f).

Re-treatment

Re-treatment was executed in 12/36 (33%) aneurysms in 16 procedures. One re-treatment procedure was undertaken in 9/12 (75%) aneurysms, two in 2/12 (17%) and three procedures in 1/12 (8%) aneurysm. Two out of 12 aneurysms were scheduled procedures as both wide-necked aneurysms were ruptured initially, and a residual neck was left intendedly during the emergent procedure done with coiling (nos 1 and 29). The most frequent re-treatment strategy was SAC (7/16, 44%) and flow diverter therapy (5/16, 31%). In all BAFAs except for one, the recurrent aneurysm was occluded successfully with the applied techniques. One patient (no. 14) with proximal BAFA and SAC was re-treated three months later due to aneurysm recurrence with WEB and flow diverter stent into the contralateral channel, but still showed slight blood flow into the aneurysm during FU. This patient remains under surveillance so far. In our analysis, no predictor of re-treatment was found, but aneurysm size tended to be larger (9.4 ± 6.7 v. 6.3 ± 3.5, $p = 0.081$).

Follow-up

Median clinical and angiographic FU was 44 (interquartile range, 19–92) and 38 (interquartile range, 16–50) months, respectively. Angiographic FU was available for 29 patients harbouring 31 BAFAs. Two deceased during the hospital stay, one FU was still pending at the time of submission and three were lost to FU. Of the remaining, 30/31 (97%) BAFAs were occluded successfully and 25/31 (81%) showed complete occlusion. Complete aneurysm occlusion after the initial procedure was associated with complete occlusion during FU (20/25, 80% v. 1/6, 17%, $p = 0.033$). Of the 33 survivors, all patients with available FU (29/29, 100%) showed a favourable clinical outcome.

Discussion

This multi-centre study is the most extensive series of endovascularly treated BAFAs to date. We found that BAFAs are a rare phenomenon and that endovascular treatment of such aneurysms utilizing reconstructive

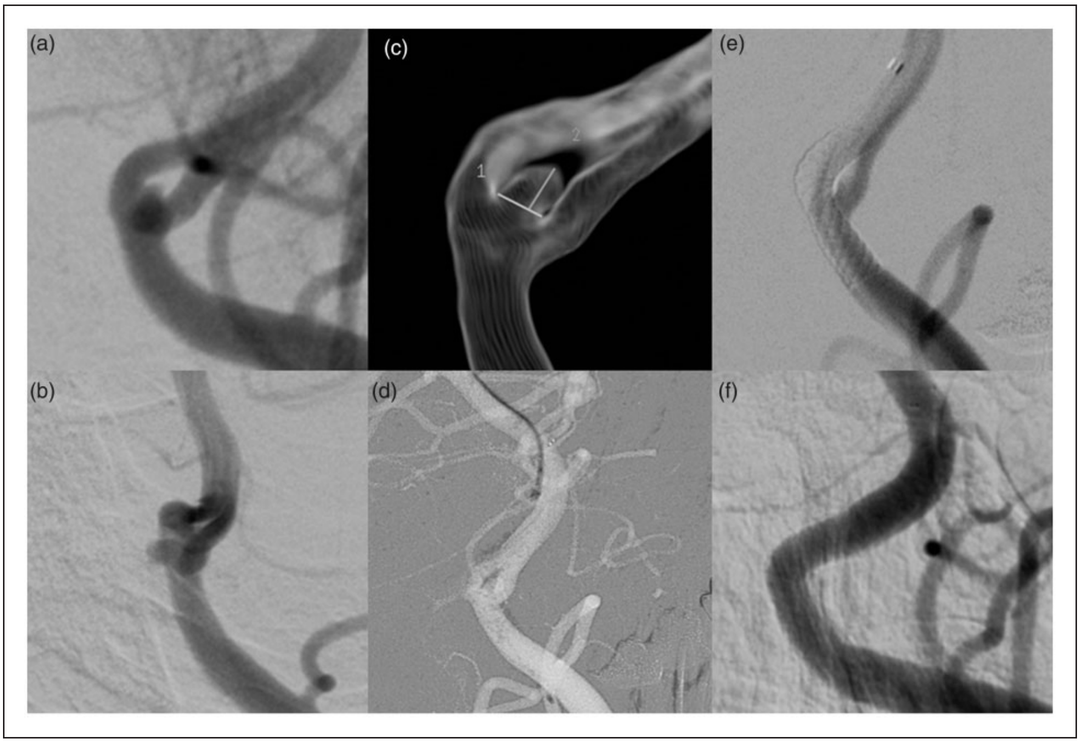

Figure 4. Digital subtraction angiography shows a small, non-ruptured aneurysm at the centre of a basilar fenestration in a patient in her sixties (case 10) involving both loops (type 2A): (a) anterior posterior view; (b) lateral view; (c) 3D reconstruction. Due to its blister-like morphology a detachment of coils was not possible. Instead, a Pipeline 3.5/14 mm was implanted from the proximal basilar artery into the dominant (right) channel of the basilar fenestration (d and e). Follow-up angiography after 540 days shows complete occlusion of the basilar artery fenestration aneurysm (RROC 1) and meanwhile an occlusion of the non-stented and non-dominant (left) channel of the basilar fenestration (f) without clinical sequela (mRS 0). The dominant branch and the distal basilar artery remained patent.

techniques is technically feasible with a good safety profile. Although in some cases re-treatment was necessary, a high rate of final aneurysm occlusion was achieved.

The development of BA fenestrations is closely related to embryogenesis and due to a failure of fusion of the two primeval basilar arteries.[7] BA fenestrations' exact frequency is unclear but assumed to differ between 0.02 and 5%.[4] Mainly, fenestrations occur at the lower part of the BA and accordingly 71% of all BAFAs in our study were located at the proximal site. The creation of aneurysms within such fenestrations might be promoted by histological features including absence of tunica media at the medial vessel wall and discontinuity of elastin at the proximal end of the fenestration.[5,8] Interestingly, proximal BAFAs were most commonly wide-necked with the involvement of both channels (56%) and more prominent in size than BAFAs at other locations. A possible explanation for this phenomenon might be hemodynamic forces in the vertebrobasilar junction, which induce wall shear stress.[10]

Our study's central point is the high AOR of 97% at long-term FU of more than three years. This is the most extended FU period compared to the five studies identified by our comprehensive literature review. However, only two studies have reported FU AOR: Peluso et al. demonstrated a successful AOR of 100% by exclusively using coils after a mean FU of 17.5 months[6] and Zhu et al. reported a complete AOR of 90% by using coils and/or stents after a median FU of 15 months.[7] No specific angiographic FU and AOR were available.[4,5,8] The immediate AOR in our study is comparable to those described in the literature with complete and successful AOR of 69% (v. 66–91%) and 83% (v. 75–100%), respectively.[4–8] However, a comparison between the studies is difficult as treatment strategies have changed over time and new equipment for endovascular therapy of intracranial aneurysms has come to the market including different types of microcatheters, stents and flow diverting devices. For example, in the study of Islak et al. even parent artery occlusion was part of the primary treatment strategy[4] and only in the study of Korkmaz et al. flow diverters were used.[8] In the present study, aneurysms also were treated with intra-saccular flow disruption (WEB), which was recently described as feasible treatment option for this type of lesion.[11]

The rate of re-treatment in literature varies between 0 and 18%. In our study, the re-treatment rate due to aneurysm recurrence was 28%, reflecting the complexity of the disease. As it is known that wide-neck configuration and size are predictors of aneurysm recurrence and re-treatment,[12] arguments for the higher re-treatment rate are that either the portion of narrow-necked BAFAs in our study was lower with

21% compared to previous studies with 38, 44 and 55%, respectively,[4,5,8] or that mean aneurysm size of 7 mm was larger, for example, in comparison with the work of Zhu et al. (4 mm).[7] One-third of patients with the residual flow into the aneurysm at the end of the initial procedure (2/6) were treated with coil and SAC and underwent re-treatment due to increasing aneurysm growth. This is an advice that occlusion of BAFAs during the primary procedure (mainly if coils are used) should be done sufficiently since the presence of a residual aneurysm after initial treatment predicts rate of re-treatment.[12] The other four patients initially received flow diverter therapy or flow disruption and did not required re-treatment during FU.

In principle, the choice of the optimal endovascular strategy is an individual decision based on aneurysm characteristics including size, neck width, involvement of fenestration loops and occurrence of perforators, and vessel anatomy of the afferent VAs and presence of SAH. Most of the anatomic information can be estimated on a 3D angiography. However, significant branches and small perforators can originate from both fenestration loops and even high-quality angiographs may not detect all of these perforators.[2] Therefore, it is desirable to waive deconstructive strategies as primary approach and preserve both channels of the fenestration segment.[13] Figure 5 demonstrates an algorithm that might facilitate treatment decisions. In our study, one patient (no. 3) initially treated with SAC received parent artery occlusion due to redundant aneurysm recurrence. Both VAs were of dominant calibre, and through unilateral occlusion of the intradural VA segment aneurysm closure was achieved without new neurologic symptoms.

Options to ensure blood flow within both loops include coiling and intra-aneurysmal flow disruption with WEB. Both techniques can also be safely applied in ruptured BAFAs. Coiling is typically performed, when the neck is small (type 1A/1B) or in combination with balloon remodelling if the BAFA is wide-necked. Therefore, the balloon should be positioned in the channel, which had greater incorporation into the aneurysm neck. However, most of the re-treated BAFAs (58%) were wide-necked and initially treated with coiling in our study. Treatment with disruption of intrasaccular flow is a reasonable option for wide-necked BAFAs if aneurysm morphology and size are suitable for the device. Especially in BAFAs involving both loops (type 2A) the WEB device's advantage is the sealing against the inflow from both channels and thereby enabling reconstruction of the parent artery/fenestration. Wide-necked BAFAs involving one loop (type 2B) were not treated with WEB in our study as correct device placement might be impeded, for example, due to an unfavourable angle between parent artery and aneurysm dependent on distal VA anatomy.

Flow diverter stents also can be used to treat posterior circulation aneurysms, but ischemic complications due to perforator occlusions or thromboembolic events should not be underestimated.[14] In this study, two patients (6%) with wide-necked BAFAs were initially treated with flow diverters, and both aneurysms were completely occluded. However, one patient (no. 10) showed an additional occlusion of the non-stented and non-dominant channel of the fenestration on FU angiography but remained asymptomatic. This emphasizes the importance of understanding the region's anatomy as sacrificing a fenestration channel might

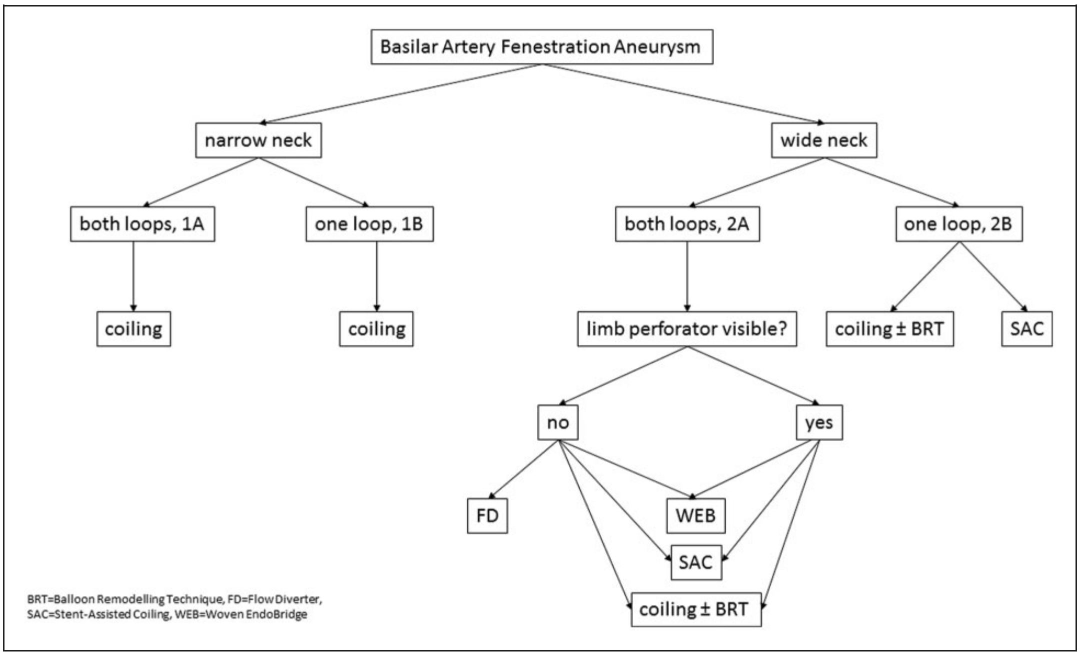

Figure 5. Treatment algorithm dependent on aneurysm type. BRT, balloon remodelling technique; FD, flow diverter; SAC, stent-assisted coiling; WEB, Woven EndoBridge.

be a consequence of flow diverter therapy. Therefore, patient selection for flow diverter stents must be made very carefully, especially if the opposite channel carries perforator arteries.

Another reasonable treatment option for wide-necked BAFAs is SAC,[5,7,8] but use in ruptured cases might carry risk of haemorrhagic complications due to intraoperative application of antiplatelet medication.[15] In our cohort, four out of seven aneurysms initially treated with SAC suffered from baseline SAH, but due to the complex morphology of aneurysm and neck coiling (alone or in combination with balloon remodelling), was not sufficient. None of them exhibited haemorrhagic complications, but one individual died due to pulmonary embolism. The stent type choice should be made individually as laser-cut stents enable coil detachment, and braided stents also have flow diverting properties, which provide a reconstruction of the aneurysm neck. For instance, in one of our patients (no. 16), a braided stent was necessary due to a blister-like BAFA as the coil could not be detached entirely within the tiny aneurysm sac. Hence, an LVIS EVO stent was placed within the leading channel to stabilize the coil's intra-aneurysmal part and fix the distal part of the coil between stent and vessel wall, respectively. However, a general statement about recommended stent types cannot be made in this study due to the low number of cases.

Despite different techniques applied throughout the study period of nearly two decades procedure-related complication rates and morbidity is low in our study. This emphasizes the meaning of endovascular treatment of such complex aneurysms with a good safety profile compared to surgical treatment with increased mortality and morbidity due to adjacent cranial nerves, presence of vital structures and deep and challenging nature of this region surgery.[13]

This study's main limitation is the retrospective design with the attendant selection bias, absence of a control group and heterogeneity of the patient group, which included patients with different aneurysm types, locations and morphology. Nevertheless, this study represents the most extensive series of patients with BAFAs treated by reconstructive techniques.

Conclusion

Reconstructive endovascular treatment of BAFAs is technically feasible with a good safety profile, and even flow diverter and flow disruption seems to be a reasonable option in carefully selected patients. Although in some cases re-treatment was necessary, a high rate of final aneurysm occlusion was achieved.

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