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ORIGINAL ARTICLE

Intracranial Rescue Stent Angioplasty After Stent-Retriever Thrombectomy

Multicenter Experience

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Abstract

Purpose Stent-retriever thrombectomy (SRT) for acute intracranial large artery occlusion (LAO) may not result in permanent recanalization in rare cases, e.g. due to an underlying stenosis or dissection. In this specific patient group, rescue stent angioplasty (RSA) may be the only treatment option to achieve permanent vessel patency and potentially a good clinical outcome. To date, the experience with RSA is limited.

Methods In this retrospective analysis, interventional and clinical data of patients with acute intracranial LAO of the anterior and posterior circulation who underwent RSA after SRT due to an underlying lesion between 2012–2017 in four neurovascular centers were studied.

Results In this study 34 patients (mean age 67 years) were included whereby 18 patients had anterior circulation LAO and 16 patients posterior circulation LAO. The SRT maneuver count ranged between 1 and 15 (median 2). Indications for RSA were an immediate re-occlusion in 25 (74%), and a persistent high-grade stenosis in 9 patients (26%). The RSA was technically feasible in 33 patients (97%). A mTICI 2b/3 result was obtained in 26 patients (76%). Median onset-to-recanalization time was 248 min (range 80–650 min). After 3 months 10/34 patients (29%) had a good clinical outcome (modified Rankin Scale, mRS 0–2). In detail, 4/18 patients (22%) with anterior circulation LAO and 6/16 patients (38%) with posterior circulation LAO were functionally independent.

Conclusion The use of RSA can be considered for acute intracranial LAO in cases with immediate re-occlusion or high-grade stenosis after SRT alone.

Keywords Stent-retriever thrombectomy · Acute intracranial large artery occlusion · Rescue stent angioplasty · Underlying vessel lesion · Permanent revascularization

Introduction

Stent-retriever thrombectomy (SRT) is now recommended as the standard treatment for patients with acute stroke due to intracranial large artery occlusion (LAO). Since 2015, several randomized multicenter trials proved the superiority of SRT compared to best medical treatment [1–9]. These studies showed high recanalization success, with a modified Thrombolysis in Cerebral Infarction (mTICI) grade 2b or 3 [10] in up to 88% [3]. Furthermore, according to a meta-analysis of five studies, the rate of functional independence, defined as modified Rankin Scale (mRS) of 0–2, was sig-

Robert Forbrig and Hannah Lockau as well as Sascha Prothmann and Franziska Dorn contributed equally to the manuscript.
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nificantly higher in the endovascular group when compared to the controls (46% versus 26.5%, $p < 0.0001$; [1]). Results of randomized studies dealing with acute posterior circulation LAO are not yet available; however, SRT was technically and clinically effective in non-randomized trials, with a mTICI 2b/3 result in more than 70% and a good clinical outcome (mRS 0–2) in 28–50% [11–14]. Despite the initially successful recanalization, immediate re-occlusion or residual high-grade stenosis may require further endovascular treatment in some patients [14–18]. The most common pathology for an immediate re-occlusion, especially in the posterior circulation, is an underlying atherosclerotic lesion [15, 16], which is much more frequent in Asian populations [16, 19, 20]. As balloon angioplasty alone is associated with high re-occlusion rates [15, 16], rescue stent angioplasty (RSA) may be the only option in order to achieve a permanent recanalization and further functional independence; however, the literature data on this topic are scarce and particularly focused on the posterior circulation [14–18]. Behme et al. [15] published a series of seven patients with an acute basilar artery (BA) occlusion due to an underlying atherosclerotic lesion; RSA with or without prior SRT was technically effective in all patients (mTICI 2b/3: 100%) and three patients were functionally independent after 3 months (43%). To date, only one small single center survey has compared RSA ($n = 17$) and non-RSA groups ($n = 28$) after failed SRT in acute anterior circulation LAO [21].

This article presents a retrospective multicenter study and report on our experience with RSA in patients with acute intracranial anterior and posterior circulation LAO and immediate re-occlusion after initially successful SRT.

Methods

In a retrospective analysis, all patients with acute intracranial LAO of the anterior and posterior circulation, who underwent RSA between November 2012 and August 2017, were identified from the stroke databases of four tertiary stroke centers. In all centers, a total of 1617 intracranial thrombectomies were conducted in this time period.

Inclusion criteria were:

- National Institute of Health Stroke scale (NIHSS) of at least 4 on admission
- Evidence of intracranial LAO and absence of intracranial hemorrhage
- Time interval between onset of acute symptoms and groin puncture of less than 8 h in intracranial anterior circulation LAO patients and less than 12 h in intracranial posterior circulation LAO patients
- Immediate re-occlusion or remaining high-grade stenosis after SRT due to an underlying (non-embolic) vessel pathology

The anonymized patient data were prospectively entered in the databases of the participating centers. The retrospective analysis focused on interventional data, the technical efficacy of RSA, and the clinical outcome.

Baseline Characteristics

In each patient, the responsible neurologist of the respective emergency unit and/or referring hospital diagnosed acute major stroke symptoms. The first-line imaging protocol consisted of a non-enhanced cranial computed tomography (CT) and a CT angiography of the supra-aortic arteries.

Intracranial anterior circulation LAO was defined as occlusion of:

- the intracranial segment(s) of the internal carotid artery including the carotid T
- the first segment of the middle cerebral artery (M1)
- the second segment of the middle cerebral artery (M2)

Intracranial posterior circulation LAO was defined as occlusion of:

- the basilar artery (BA)
- the intracranial segment of the vertebral artery

The treating neurologist and neurointerventionist and the patient and/or the relatives decided in consensus for endovascular revascularization in each case. If available, the time intervals between onset of acute symptoms and groin puncture as well as final endovascular revascularization were documented. Patients received weight-adapted intravenous recombinant tissue plasminogen activator (rt-PA) prior to groin puncture, if the duration of acute symptoms of intracranial LAO did not exceed 4.5 h, and contraindications (e.g. prior surgery, metastatic tumor disease, and/or pre-existing anticoagulation/antiplatelet therapy) were absent.

Interventional and Clinical Data Analysis

Technical data including stent-retriever model, number of SRT maneuvers, individual indications for RSA, the presumed underlying vessel pathology, as well as the stent design (balloon or self-expanding) and the additional use of balloon angioplasty were evaluated. After SRT, a persistent vessel stenosis of at least 70% in diameter was defined as high-grade. A successful recanalization result was defined as mTICI 2b or 3 on the final angiogram [1, 10]. Complications including residual periprocedural stenosis, postinterventional stent occlusion and in-stent restenosis, and symp-

tomatic intracranial hemorrhage (sICH) according to the European Cooperative Acute Stroke Study (ECASS) III criteria [22] were documented. Stent patency was usually assessed by transcranial ultrasound after 24 h and also after 3 months. In-stent restenosis was diagnosed according to the criteria of Rasulo et al. [23]:

- Acceleration of flow velocity through the stenosis
- Deceleration of flow velocity distal from the stenosis
- Lateral difference of mean flow velocity
- Disturbances in flow

The NIHSS at admission and discharge as well as the final mRS after 90 days were assessed. A NIHSS improvement of more than three points was defined as "substantial", and a final mRS score 0–2 as "good clinical outcome".

Endovascular Revascularization

The use of a balloon guide catheter, the choice of the respective primary clot-retrieving device, and the indication for RSA were at the neurointerventionist's discretion in each participating center. The endovascular approach to the vessel occlusion usually consisted of a fluoroscopic, guidewire-assisted triaxial access in the sense of a 6 or 8 French guiding catheter, an intermediate or aspiration catheter, and a microcatheter. No intermediate catheter was applied when a balloon guide catheter was used. The SRT maneuvers were carried out in a standardized manner, as described by Dorn et al. [24]. In the case of an immediate re-occlusion or a persistent high-grade stenosis, the SRT maneuver was repeated and/or the neurointerventionist decided for RSA. Considering self-expanding stents, a microcatheter was placed at the anatomic site using a microguidewire; then the micro-guidewire was removed, and an appropriate stent was inserted and deployed while withdrawing the microcatheter. Prior to RSA, if necessary, percutaneous transluminal balloon angioplasty was performed. Regarding balloon-expanding stents, the lesion was crossed with the system and the stent was deployed by balloon inflation according to the manufacturers' instruction using a pressure gauge.

Antithrombotic Therapy

During the intervention, heparinized saline flushes were used by default. Prior to RSA, the neurointerventionist administered either:

- a glycoprotein IIb/IIIa inhibitor (tirofiban/Aggrastat®): as recommended by the manufacturer starting with a weight-adapted intravenous loading dose of 0.4 µg/kg/min for 30 min, followed by a maintenance dose of 0.1 µg/kg/min intravenous for at least 12 h. Overlapping, dual antiplatelet therapy with 100 mg acetylsalicylic acid (ASA) and 300 mg clopidogrel was started either orally or via the gastric tube 4 h prior to infusion stop.
- or 500 mg ASA intravenously, followed by clopidogrel (loading dose 300 mg) via the gastric tube
- or no additional medicinal therapy (in the case of pre-existing dual antiplatelet treatment).

If the routine control computed tomography (CT) within the following day showed major sICH, the antiplatelet therapy was stopped. Otherwise, it was continued orally with ASA 100 mg/day life long and clopidogrel 75 mg/day for at least 6 months.

Results

A total of 34 patients were included in the analysis. Mean age was 67 years and 11 patients (32%) were female. Table 1 summarizes the patients' baseline characteristics, interventional data, and clinical outcome.

Baseline Characteristics

The mean NIHSS at admission was 13 (range 4–26). The LAO was located in the anterior circulation in 18/34 (53%) and in the posterior circulation in 16/34 patients (47%). The most common occlusion sites were the BA in 12 patients (35%), and the M1 segment of the middle cerebral artery (MCA) in 11 patients (32%). The median time between onset of symptoms and final recanalization was 248 min (range 80–650 min) and the time between groin puncture and final recanalization ranged between 20 and 300 min (median 65 min). Intravenous rt-PA prior to the recanalization procedure was administered in 11/34 patients (32%).

Interventional Data

Concerning SRT, the most commonly utilized clot-retrieving devices were the Solitaire® FR Stent (22 of 34 patients, 65%), and the Trevo® ProVue Stent (Stryker, Kalamazoo, MI, USA; 9 patients, 26%). Of the patients four underwent SRT with two different stent-retrievers (Solitaire® FR and Trevo® ProVue, each). The SRT maneuver count ranged between 1 and 15, with a median of 2, 21/34 patients received 1 or 2 SRT maneuvers and 13/34 patients 3 or more SRT maneuvers. The indications for RSA were an immediate re-occlusion after SRT at the anatomic site in 25 patients (74%), and a persistent high-grade stenosis in 9 patients (26%). Based on the angiographic morphology, the most common underlying vessel pathology was a presumed atherosclerotic lesion (28 patients, 82%), followed by presumed vessel dissection in 4 patients (12%),

Table 1 Baseline characteristics, interventional data and clinical outcome of 34 patients with SRT and RSA

Patient #	Age (years)/ sex	Occlusion site	Time symptom onset/groin puncture to revascularization (minutes)	I. v. lysis	Stent-retriever/ maneuvers (*n*)	Indication for RSA	Presumed underlying lesion	Balloon angioplasty	Stent/mTICI	Antiplatelet therapy	Stent patency	sICH	NIHSS admission/ discharge	mRS 90 days
1	80 f	Distal ICA	245/65	Yes	Solitaire FR/2	Re-occlusion	Dissection	No	Enterprise/2a	Tirofiban	Patent at 3 months No restenosis	Yes	23/23	5
2	26 f	M1	–/40	No	Trevo ProVue/7	Re-occlusion	Vasculitis	No	Enterprise/2b	Tirofiban	Early post-interventional occlusion (at 24 h)	No	2/14	4
3	36 m	Distal ICA	–/300	No	Solitaire FR/1	Re-occlusion	Dissection	No	Enterprise + Solitaire AB/1	Tirofiban	Patent at 3 months No restenosis	No	7/27	3
4	46 f	Distal ICA	445/300	Yes	Solitaire FR/14	Re-occlusion	Dissection	No	Enterprise/1	ASA + clopidogrel	Early post-interventional occlusion (at 24 h)	Yes	13/–	6
5	49 m	M2	315/95	No	Solitaire FR + Trevo ProVue/7	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/3	ASA + clopidogrel[a]	Patent at 3 months No restenosis	No	21/19	3
6	81 f	M1	–/40	No	Solitaire FR + Trevo ProVue/2	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/2b	Tirofiban	Early post-interventional occlusion (at 24 h)	No	22/–	6
7	63 f	M1	<270/–	Yes	Solitaire FR/1	Re-occlusion	Atherosclerotic stenosis	Yes	Solitaire AB/3	ASA + clopidogrel	Patent at 3 months No restenosis	No	–/0	0
8	89 f	M1	165/30	Yes	Solitaire FR/1	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/2b	Tirofiban	Patent at 3 months No restenosis	No	17/3	4
9	64 m	Distal ICA	407/147	No	Solitaire FR + Trevo ProVue/15	High-grade stenosis	Atherosclerotic stenosis	Yes	Wingspan/3	Tirofiban	Patent at 3 months No restenosis	Yes	21/–	6
10	44 m	M1	296/142	Yes	Solitaire FR/6	Re-occlusion	Atherosclerotic stenosis	Yes	Wingspan/3	ASA + clopidogrel	Postprocedural restenosis <50%	No	17/12	3

Table 1 (Continued)

11	65 m	M1	<270/–	Yes	Solitaire FR/2	High-grade stenosis	Atherosclerotic stenosis	Yes	Wingspan/2b	ASA + clopidogrel	Early post-interventional occlusion (at 24 h)	No	8/7	3
12	83 f	M1	<270/–	Yes	Solitaire FR/5	Re-occlusion	Atherosclerotic stenosis	Yes	Wingspan/1	Tirofiban	Patent at 3 months No restenosis	No	21/19	5
13	56 f	M1	118/23	Yes	Preset/1	Re-occlusion	Atherosclerotic stenosis	Yes	Wingspan/3	Tirofiban	Patent at 3 months No restenosis	No	14/0	0
14	78 f	M1	300/75	No	Solitaire FR/1	Re-occlusion	Atherosclerotic stenosis	Yes	Solitaire AB/3	Tirofiban	Patent at 3 months No restenosis	No	8/2	3
15	28 f	M1	130/20	Yes	Preset/3	Re-occlusion	Vasculitis	No	Solitaire AB/2a	Tirofiban	Patent at 3 months No restenosis	Yes	21/14	5
16	75 m	M2	460/50	No	Preset/2	Re-occlusion	Atherosclerotic stenosis	Yes	Acclino/3	Tirofiban	Restenosis > 50% after 3 months[b]	No	14/1	0
17	61 m	BA	650/180	No	Solitaire FR + Trevo ProVue/5	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/3	Tirofiban	Patent at 3 months No restenosis	No	25/22	5
18	66 m	BA	–/50	No	Solitaire FR/2	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/3	Tirofiban	Patent at 3 months No restenosis	No	20/5	2
19	66 m	BA	–/55	No	Trevo ProVue/3	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/2a	ASA + clopidogrel	Early post-interventional occlusion (at 24 h)	No	4/–	6
20	79 m	BA	110/110	No	Solitaire FR/2	Re-occlusion	Atherosclerotic stenosis	Yes	Solitaire AB/3	ASA + clopidogrel	Early post-interventional occlusion (at 24 h)	No	9/14	6
21	78 m	BA	–/99	No	Solitaire FR/2	Re-occlusion	Atherosclerotic stenosis	Yes	Enterprise/2b	ASA + clopidogrel	Patent at 3 months No restenosis	No	–/25	5
22	58 m	BA	216/83	Yes	Preset/3	Re-occlusion	Dissection	No	Enterprise + Leo/2b	Tirofiban	Patent at 3 months No restenosis	No	18/16	5
23	74 m	V4	–/81	No	Solitaire FR/2	High-grade stenosis	Atherosclerotic stenosis	Yes	Enterprise + Solitaire AB/3	ASA + clopidogrel	Patent at 3 months No restenosis	No	4/4	6

Table 1 (Continued)

24	78 m	BA	–/45	No	Trevo ProVue/1	High-grade stenosis	Atherosclerotic stenosis	Yes	Enterprise/3	Tirofiban	Patent at 3 months No restenosis	No	14/10	4
25	71 m	V4	–/142	No	Solitaire FR/1	Re-occlusion	Atherosclerotic stenosis	Yes	Wingspan/2a	Tirofiban	Patent at 3 months No restenosis	No	7/3	2
26	54 m	V4	290/50	No	Solitaire Platinum/1	High-grade stenosis	Atherosclerotic stenosis	Yes	Solitaire AB/3	Tirofiban	Patent at 3 months No restenosis	No	5/0	0
27	66 m	BA	–/30	No	Solitaire AB/3	Re-occlusion	Atherosclerotic stenosis	Yes	Solitaire AB/3	Tirofiban	Patent at 3 months No restenosis	No	6/3	3
28	74 m	Petrous ICA	80/30	No	Solitaire AB/1	High-grade stenosis	Atherosclerotic stenosis	Yes	Enterprise/3	ASA + clopidogrel	Restenosis > 50% after 3 months[b]	No	7/2	1
29	67 f	BA	240/20	No	Solitaire FR/2	Re-occlusion	Atherosclerotic stenosis	Yes	Coroflex Blue Ultra/2b	Tirofiban	Patent at 3 months No restenosis	No	6/4	1
30	72 m	BA	–/37	No	Trevo ProVue/3	High-grade stenosis	Atherosclerotic stenosis	Yes	Acclino/2b	ASA + clopidogrel	Patent at 3 months No restenosis	No	17/12	5
31	61 m	BA	202/77	No	Solitaire FR/1	High-grade stenosis	Atherosclerotic stenosis	Yes	Acclino/3	ASA + clopidogrel	Patent at 3 months No restenosis	No	5/3	3
32	58 m	V4	–/38	No	Trevo ProVue/1	High-grade stenosis	Atherosclerotic stenosis	Yes	Acclino/2b	ASA + clopidogrel	Patent at 3 months No restenosis	No	6/2	0
33	79 m	ICA + M1	–/99	No	Solitaire FR/3	Re-occlusion	Atherosclerotic stenosis	Yes	Acclino/0	ASA	No (stent placement not successful)	No	26/18	6
34	69 m	BA	250/100	Yes	Solitaire FR/2	Re-occlusion	Atherosclerotic stenosis	Yes	Acclino/3	Tirofiban	Patent at 3 months No restenosis	No	10/2	0

Stent retrievers: Solitaire® FR and Solitaire® Platinum (ev3/Medtronic, Irvine, CA, USA), Trevo® ProVue (Stryker, Kalamazoo, MI, USA), Preset® (phenox, Bochum, Germany)
Stents: Enterprise® (Codman Neuro, Raynham, MA, USA), Wingspan® (Stryker, Kalamazoo, MI, USA), Solitaire® AB (ev3/Medtronic, Irvine, CA, USA), Leo® (Balt, Montmorency, France), Acclino® (Acandis, Pforzheim, Germany), Coroflex® Blue Ultra (B. Braun, Berlin, Germany)
SRT stent-retriever thrombectomy, *RSA* rescue stent angioplasty, *I. v.* intravenous, *mTICI* modified Thrombolysis in Cerebral Infarction, *sICH* symptomatic intracranial hemorrhage, *NIHSS* National Institute of Health Stroke scale, *mRS* modified Rankin scale, *f* female, *m* male, *ICA* internal carotid artery, *M1* first segment of middle cerebral artery, *M2* second segment of middle cerebral artery, *BA* basilar artery, *V4* intracranial segment of the vertebral artery, *ASA* acetylsalicylic acid, *h* hours
[a]Prior ASA and clopidogrel therapy
[b]Balloon angioplasty in a second intervention

and presumed vasculitis in 2 patients (6%). Prior to RSA, balloon angioplasty was carried out in 28/34 patients. In 33 out of 34 patients (97%) a self-expanding permanent stent was implanted, and in 1 patient a balloon-expanding stent. The Enterprise® Stent (Codman Neuro, Raynham, MA, USA) was used in 15/34 (44%), the Solitaire® AB Stent (ev3/Medtronic, Irvine, CA, USA) in 7/34 (21%), the Wingspan® Stent (Stryker) in 6/34 (18%), the Acclino® Stent (Acandis, Pforzheim, Germany) in 6/34 (18%), the Leo® Stent (Balt, Montmorency, France) in 1/34 (3%), and the Coroflex® Blue Ultra Stent (B. Braun, Berlin, Germany) in 1/34 patients (3%). Of the patients three were treated with two permanent stents (Enterprise® + Solitaire®AB, $n = 2$; Enterprise® + Leo®, $n = 1$). Delivery and placement of the stent across the target lesion was technically successful in 33/34 patients (97%). It was technically not feasible to advance the permanent stent towards the vessel occlusion in one patient, hence balloon angioplasty alone was performed; however, this maneuver did not result in permanent vessel patency (patient 33). The final DSA run confirmed successful revascularization (mTICI 2b/3) in 26 out of 34 patients (76%). In detail, a good revascularization result was obtained in 67% of anterior and 88% of posterior circulation patients. The first-line antiplatelet therapy consisted of a glycoprotein IIb/IIIa inhibitor in 20 patients (59%), and a combination of ASA and clopidogrel in 13 patients (38%).

Complications and Clinical Outcome

In the acute post-interventional phase, 4 out of 34 patients (12%) experienced sICH of which 3 had initially received

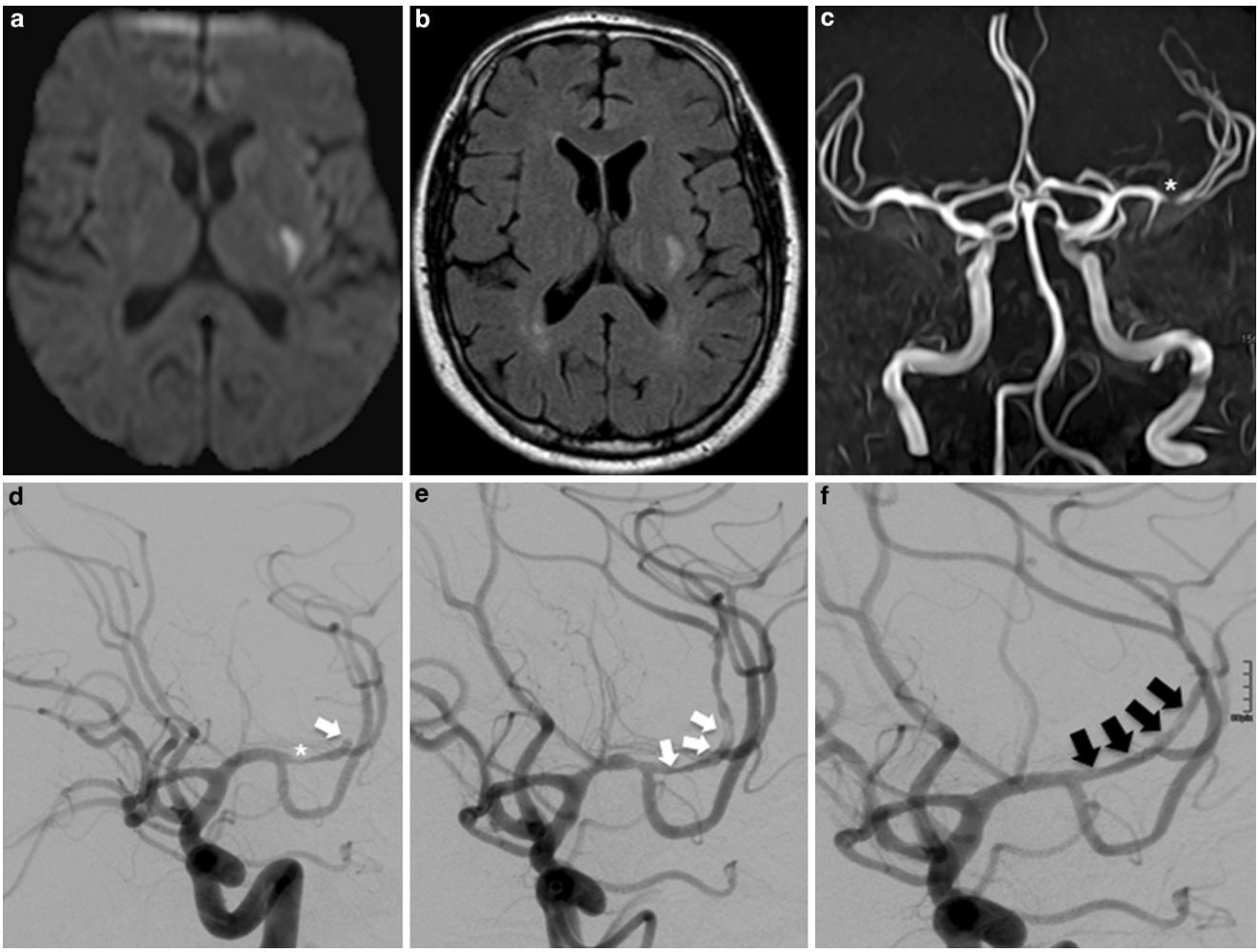

Fig. 1 A 49-year-old male with mild right-sided hemiparesis. **a** Diffusion-weighted imaging, transverse section and **b** fluid attenuated inversion recovery, transverse section showing circumscribed subacute ischemia in the internal capsule/putamen on the left. **c**, **d** 3D reformatted arterial time-of-flight angiography showing high-grade atherosclerotic stenosis of the ipsilateral M1-segment (*). **d** After treatment digital subtraction angiography now depicted a complete postbifurcation middle cerebal artery occlusion (*arrow*) in posterior-anterior projection distal from the preexisting high-grade M1 stenosis. **e** After revascularization both the high-grade stenosis and thrombotic material in the M1 and M2 segment persisted (*arrows*). **f** Rescue stent angioplasty was performed resulting in a complete revascularization with a normalized vessel diameter

intravenous rt-PA (patients 1, 4 and 15), in combination with a glycoprotein IIb/IIIa inhibitor in 2 patients (patients 1 and 15) and 6 of the 34 patients (18%) had a post-interventional stent occlusion within 24 h. Asymptomatic in-stent restenosis occurred in another 3 patients during the 3-month follow-up period (9%) and 2 of these patients showed a restenosis of more than 50% after 3 months and therefore received balloon angioplasty in a second intervention (patients 16 and 28). Overall, six out of nine patients with stent occlusion and restenosis had initially received ASA and clopidogrel (67%), and information on antiplatelet function testing was not available. The mean NIHSS at discharge was 10 (range, 0–27). Compared to the neurological status at admission, the NIHSS improved substantially in 16 out of 34 patients (47%). After 3 months, 10 of the 34 patients (29%) had a good clinical outcome (mRS 0–2). In detail, the functional independence rate was 22% in anterior circulation LAO (4/18 patients), and 38% in posterior circulation LAO (6/16 patients). In six patients, the neurological deficits had completely resolved (18%; patients 7, 13, 16, 26, 32 and 34). The mortality was 21% (7 out of 34 patients).

Illustrative Case 1

A 49-year-old male presented with a mild right-sided hemiparesis (patient 5, Fig. 1). Initial magnetic resonance imaging (MRI) showed circumscribed subacute ischemia in the internal capsule/putamen on the left (Fig. 1a: diffusion-weighted imaging (DWI), transversal; Fig. 1b: fluid attenuated inversion recovery (FLAIR), transversal), and a high-grade atherosclerotic stenosis of the ipsilateral M1-segment (* in Fig. 1c and d; Fig. 1c: 3D reformatted arterial time-of-flight (TOF) angiography). Dual antiplatelet therapy (ASA and clopidogrel) was initiated and 5 days later, the patient experienced acute neurological deterioration (NIHSS 21). Digital subtraction angiography (DSA) now depicted a complete postbifurcation MCA occlusion (arrow in Fig. 1d: posterior-anterior (PA) projection) distal from the pre-existing high-grade M1 stenosis. After a total of seven SRT maneuvers revascularization was achieved, but both the high-grade stenosis and thrombotic material in the M1- and M2-segment persisted (arrows in Fig. 1e: PA). Hence, RSA was performed (Enterprise®) after prior balloon dilatation, resulting in a complete revascularization with a normalized vessel diameter (Fig. 1f: PA). The neurological symptoms did not resolve substantially (NIHSS 19 at discharge, mRS 3 after 90 days).

Illustrative Case 2

A 54-year-old male with dizziness lasting for days and now an acute onset of impaired consciousness, central oculomotor dysfunction, dysarthria and gait disturbance 1.5 h prior to admission (patient 26, Fig. 2). Initial CT revealed signs of subacute cerebellar infarctions on the left (Fig. 2a: transversal), thus IV administration of t-PA was contraindicated. CT angiography was suggestive for chronic occlusion of the right vertebral artery and an acute occlusion of the intracranial vertebral segment on the left with extension to the BA (not shown), which was verified by DSA (Fig. 2b: PA; Fig. 2c: lateral view). After one SRT maneuver both the left vertebral artery and BA were revascularized, but an underlying atherosclerotic stenosis with progressive thrombus apposition (white arrows in Fig. 2d–f; Fig. 2d: PA, Fig. 2e and f: lateral view) was seen despite IV administration of tirofiban. Thus, balloon angioplasty and RSA (Solitaire® AB; ev3/Medtronic) was performed. Final DSA run showed full recanalization with slight residual irregularities of the vessel wall, but no relevant stenosis (black arrows in Fig. 2g: lateral view). The post-interventional MRI on day 8 revealed only small embolic ischemia in the left cerebellar hemisphere (Fig. 2h: DWI, transversal) and the neurological deficits resolved completely (mRS after 90 days = 0).

Discussion

Endovascular recanalization of acute intracranial LAO was demonstrated to be effective with a high level of evidence in recent years; however, in some patients SRT alone does not result in permanent revascularization, e.g. due to an underlying lesion such as an atherosclerotic stenosis, dissection or vasculitis. In general, intracranial atherosclerotic stenosis is far more frequently located in the posterior circulation [14, 25–27]. Currently, data on RSA following SRT are scarce, in particular in anterior circulation LAO.

The majority of the patients in our study showed an immediate re-occlusion after primarily successful SRT (74%). It has been suggested that in patients with underlying vessel pathology, the SRT maneuver itself may actually aggravate a pre-existing local endothelial vulnerability, in the sense of further plaque instability and rupture, local thrombosis, and finally result in re-occlusion [16]; however, similar to others [14, 16, 26], we did not encounter major SRT-related complications such as arterial perforation or tearing of perforators during the SRT maneuver across the underlying lesion. The use of SRT and/or balloon angioplasty is normally not sufficient in patients with an underlying stenosis, because these procedures do not heal, but deteriorate the underlying pathology [28]. So far, RSA may therefore be the only available technique that potentially prevents re-occlusion; here, the stent covers the vulnerable vessel segment and stops the pathological cascade as described above [15, 16].

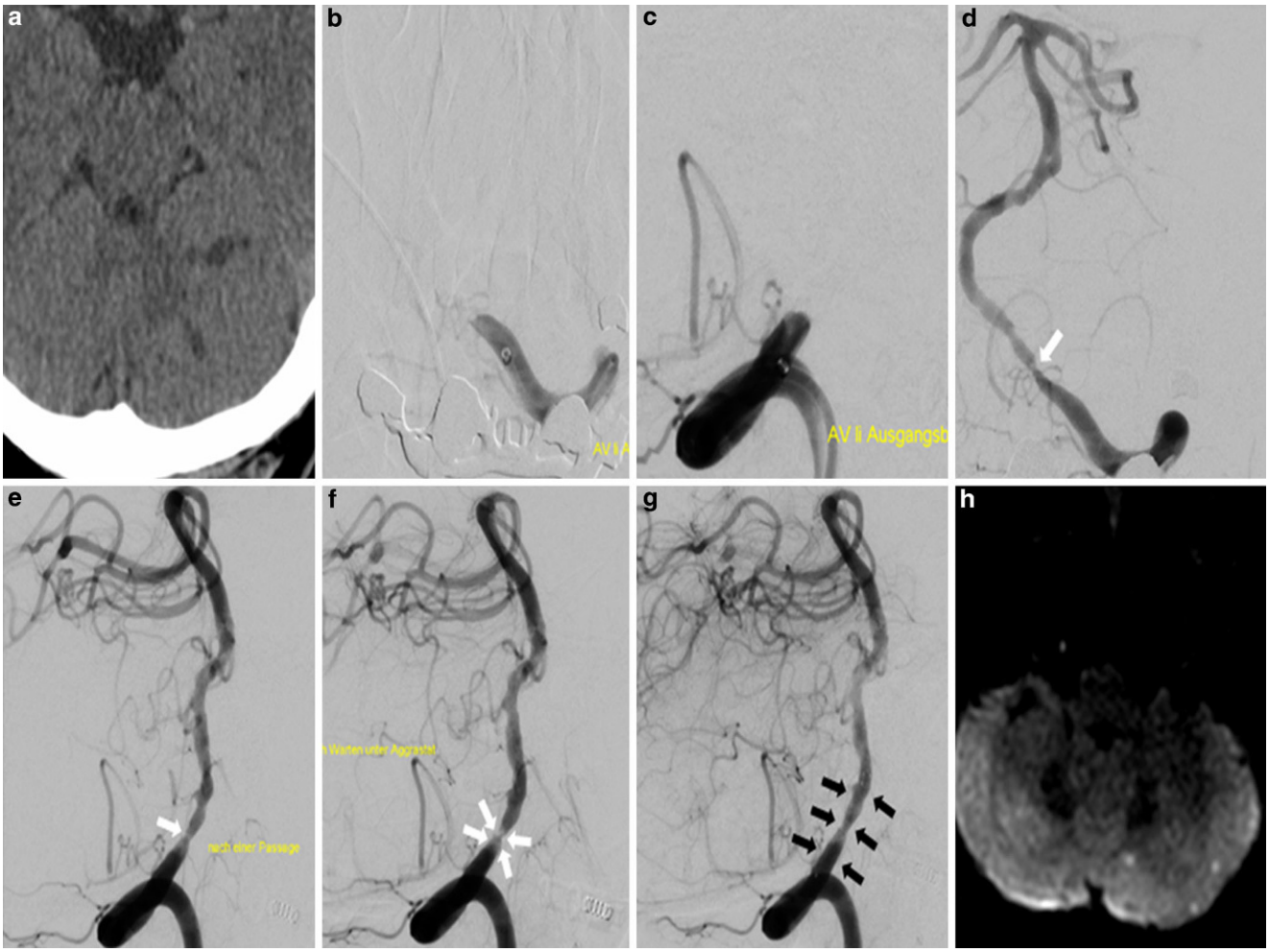

Fig. 2 A 54-year-old male with dizziness and acute onset of impaired consciousness. Initial computed tomography revealed signs of subacute cerebellar infarctions on the left (**a** transverse section). Chronic occlusion of the right vertebral artery and acute occlusion of the intracranial vertebral segment on the left was verified by digital subtraction angiography (**b** posterior-anterior projection, **c** lateral view). **d–f** After stent-retriever thrombectomy both the left vertebral artery and basilar artery were revascularized but an underlying atherosclerotic stenosis with progressive thrombus apposition persisted (*white arrows*, **d** posterior-anterior projection, **e**, **f** lateral view). Final digital subtraction angiogaphy (**g**) showed full recanalization with slight residual irregularities of the vessel wall, but no relevant stenosis (*black arrows*, lateral view). **h** Post-interventional magnetic resonance imaging on day 8 revealed only small embolic ischemia in the left cerebellar hemisphere (diffusion weighted imaging, transverse section)

Stent angioplasty of symptomatic intracranial stenosis has been debated for several years now, particularly due to the results of the Stenting vs Aggressive Medical Management for Preventing Recurrent Stroke in Intracranial Stenosis (SAMMPRIS) trial, where the 30-day risk of recurrent stroke or death was significantly higher in the stent angioplasty than in the best medical treatment group (14.7% versus 5.8%; [29]); however, the patients' clinical and vascular baseline data in the SAMMPRIS trial were different from those of the present study: whereas the SAMMPRIS patients had transient ischemic attacks or minor strokes due to an intracranial stenosis, the patients in our survey suffered from acute major stroke caused by a complete occlusion of an intracranial large artery. Although SRT initially resulted in reperfusion, it was not efficient due to immediate re-occlusion or remaining high-grade vessel stenosis; hence the prognosis was poor and RSA was considered as a brain or life-saving therapy [16, 21].

In our study, the technical success was high and a good revascularization result (mTICI 2b/3) was achieved in more than 75% of patients. These data confirm observations by other RSA study groups [14, 21, 25, 26]. Of the patients without stent occlusion 37% were functionally independent after 3 months. This is a higher rate than in the intervention group in the MR CLEAN study [4]; however, none of the patients had a favorable clinical outcome when stent occlusions occurred. These data are comparable to other studies: Baek et al. who analyzed 45 patients with acute anterior circulation LAO in whom SRT alone failed, reported a good clinical outcome for 35% in the RSA group

(17 patients) versus 7% in the non-stent angioplasty group [21]. Concerning RSA in acute posterior circulation LAO, in the study of Möhlenbruch et al. 33% of patients were functionally independent after 3 months [25]. These data support the hypothesis that patients in whom the standard therapy is expedient may clinically benefit from RSA, given permanent stent patency. Early stent occlusion was one of the major complications in our series: nearly one third of our patients had either an early occlusion of the stent or an in-stent restenosis. As stent occlusion was not correlated with a certain stent type, we believe that stent patency rather depends on adequate inhibition of platelet aggregation. Of the patients with early stent occlusion or severe restenosis two thirds had received ASA and clopidogrel periprocedurally or postprocedurally, which may be not sufficient in the acute setting. Due to general anesthesia, clopidogrel was administered via the gastric tube, possibly resulting in delayed intestinal resorption and insufficient antiplatelet effect. We cannot prove that a more potential first-line medicinal treatment with a glycoprotein IIb/IIIa inhibitor would have resulted in stent patency in these patients; however, recently published data by Woo et al. support this assumption [18]. Antithrombotic therapy in acute stroke patients is a balancing act due to the potential risk of sICH, especially if intravenous rt-PA was given prior to the procedure [30], and to date no consistent recommendations for antiplatelet medication in the acute stroke phase are available [9]. The rate of sICH was low in our study group (12%). Out of four patients with sICH, three received intravenous rt-PA, two patients additionally a glycoprotein IIb/IIIa inhibitor. These data are comparable to the RSA series of Baek et al. (sICH rate 12%), but slightly higher than those of the large randomized anterior circulation LAO thrombectomy trials, which reported sICH rates of less than 10% in patients after thrombectomy alone [1]. In the present study, the clinical outcome was better in posterior than in anterior circulation LAO patients. This is most probably the result of both a higher recanalization success and a lower rate of postinterventional stent occlusions in the former group. In addition, there was a higher rate of underlying lesions other than atherosclerotic stenosis (presumed dissection or vasculitis) in the patients with anterior circulation LAO. Vasculitis was presumed in these patients based on the angiographic pattern and the conspicuous cerebrospinal fluid findings; however, the diagnosis was not confirmed by biopsy. In four patients pre-existing dissection was suspected based on the angiographic pattern and a highly difficult catheterization of the lumen. In general, the precise angiographic classification of the underlying lesion (atherosclerosis, dissection, vasculitis) is difficult in most cases. Particularly, the differentiation between atherosclerotic stenosis and residual/resistant thrombus is not always possible, but it may substantially affect the risk of stent occlusion or restenosis.

Patients undergoing only one or two SRT maneuvers had more commonly a favorable clinical outcome when compared to those patients receiving more than two SRT maneuvers. One explanation may be the shorter recanalization time in the former group, as supported by Dorn et al., who found that an increase of the SRT maneuver count may unnecessarily prolong the intervention and lead to a deterioration of the clinical outcome [31]. Furthermore, our results indicate that patients with onset recanalization times of less than 300 min might have a better clinical outcome after 3 months than those with longer time intervals; however, these data have to be interpreted with caution due to missing statistical significance. Furthermore, it is known that selected patients with prolonged symptoms potentially benefit from mechanical revascularization, as well [1, 32, 33].

There are several study limitations: (i) due to the retrospective study design, the following data were not available: pre-hospital mRS, comorbidities, laboratory data, ASPECT score at admission and (ii) the study population is relatively small and heterogeneous; therefore, a profound statistical analysis was not possible.

Conclusion

So far, RSA is the only chance to permanently restore blood flow in patients with underlying vessel pathology and an immediate re-occlusion or high-grade stenosis after initially successful SRT. The RSA is technically feasible, provides good recanalization results, and may be the only chance for a certain patient group to potentially achieve functional independence. Our data suggest that a quick decision for RSA, instead of numerous SRT maneuvers, may save valuable time and increase the likelihood of good clinical outcome. More data focusing on the efficacy of periprocedural antiplatelet therapy is necessary.

Compliance with ethical guidelines

Conflict of interest R. Forbrig, H. Lockau, F. Flottmann, T. Boeckh-Behrens, C. Kabbasch, M. Patzig, A. Mpotsaris, J. Fiehler, T. Liebig, G. Thomalla, O.A. Onur, S. Wunderlich, K. Kreiser, M. Herzberg, F.A. Wollenweber, S. Prothmann and F. Dorn declare that they have no competing interests.

Ethical standards 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. We declare that all patients and/or their relatives gave informed consent prior to inclusion in this study.

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