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Mechanical thrombectomy in tandem occlusion: procedural considerations and clinical results

H. Lockau · T. Liebig · T. Henning · V. Neuschmelting · H. Stetefeld · C. Kabbasch · F. Dorn

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Abstract
Introduction Acute tandem occlusions of the cervical and distal internal carotid artery (ICA) or middle cerebral artery (MCA) are associated with major stroke with intravenous (i.v.) thrombolysis alone in approximately 90 % of patients. The data on endovascular management of tandem occlusions is still limited. The purpose of this study was to review technical aspects and the current state of the literature on acute ICA stenting in combination with stent retriever-based intracranial thrombectomy.
Methods We retrospectively reviewed the data of 37 consecutive patients with tandem occlusions including clinical parameters, angiographic results, procedural aspects, complications, and hemorrhages.
Results Median National Institutes of Health Stroke Scale (NIHSS) on admission was 17 (3–30). Intracranial thrombectomy was performed prior to ICA stenting in 25/37 (67.6 %) and after stenting in 12/37 (32.4 %) patients. ICA stenting was successful in all cases, and a thrombolysis in cerebral infarction (TICI) scale 2b/3 result was achieved in 27/37 (73 %) cases. The mean angiography time was significantly shorter in the "thrombectomy first" group (43.1 ±30.8 vs. 110.8±43.0 min, $p<0.001$), and more patients had favorable outcomes after 3 months (13/25=52.0 vs. 4/12=33.3 %, $p=0.319$). In this group, intermediate catheters were used and successfully prevented embolism to unaffected territories in all cases.
Conclusion Acute stenting of the cervical ICA in combination with intracranial thrombectomy was technically feasible and safe in our series. Thrombectomy prior to proximal stenting was associated with shorter reperfusion times and a tendency towards better clinical outcome leading to a good outcome in about 50 % of the patients. Therefore, we recommend this approach in tandem occlusion requiring stent angioplasty.

Keywords Tandem occlusions · Stent retriever · Endovascular · Stroke · Stent

H Lockau and T Liebig contributed equally to the manuscript and share joint first authorship.

H. Lockau · T. Liebig · T. Henning · C. Kabbasch · F. Dorn (✉)
Department of Radiology, University Hospital of Cologne, Kerpenerstr. 62, 50937 Cologne, Germany
e-mail: franziska.dorn@uk-koeln.de

V. Neuschmelting
Department of Neurosurgery, University Hospital of Cologne, Cologne, Germany

H. Stetefeld
Department of Neurology, University Hospital of Cologne, Cologne, Germany

Introduction

Acute ischemic stroke due to tandem occlusions of the extracranial internal carotid artery (ICA) and the distal ICA (carotid T) and/or middle cerebral artery (MCA) is often associated with major stroke and an unfavorable clinical outcome [1, 2]. Tandem occlusions poorly respond to intravenous (i.v.) thrombolysis [3, 4] most likely due to the significant clot burden and the limited interaction with recombinant tissue plasminogen activator (rt-PA) at the distal occlusion [5]. Recanalization success in patients with distal ICA occlusion was limited to 5.9 % after i.v. therapy alone in one study [6].

Endovascular treatment does improve recanalization success that may result in improved clinical outcome in patients with major intracranial vessel occlusions. Stent-based thrombectomy devices ("stent retrievers") have been introduced in 2008 [7] and are the standard of care in most stroke centers today.

However, recanalization of tandem occlusions is technically challenging, and the evidence regarding the treatment of tandem occlusions is limited to case series and single-center experiences [8–15]. Different endovascular approaches have been described. Most centers seem to perform stent or balloon angioplasty of the proximal ICA lesion before intracranial recanalization, but to date, there is no standardized recommendation.

The aim of this study was to evaluate the effectiveness of endovascular treatment with stent retrievers in patients with extra-/intracranial tandem occlusions with special consideration of the technical approach.

Materials and methods

Patient selection

We retrospectively evaluated all stroke patients who underwent endovascular therapy between September 2010 and April 2013 at our stroke center and identified all cases that underwent simultaneous carotid stenting and endovascular recanalization.

Decision for treatment for all patients in our stroke database was based on the clinical presentation and the imaging findings. A team of stroke neurologists examined all patients on admission and the National Institutes of Health Stroke Scale (NIHSS) scores were noted. The patients included in this series had an NIHSS score of at least 10 or fluctuating symptoms. All patients underwent computed tomography (CT) or magnetic resonance imaging (MRI) prior to treatment. If possible, multiparametric imaging was applied using computed tomography/computed tomography angiography (CT/CTA) and CT perfusion imaging or magnetic resonance imaging/magnetic resonance angiography (MR/MRA) including the acquisition of FLAIR-weighted images and diffusion-weighted images, a T2* sequence. Imaging criteria for exclusion from endovascular therapy were the following: visible infarction in more than one third of the vessel territory, no relevant mismatch on CT perfusion imaging, and evidence of hemorrhage on CT or MRI imaging.

In all the patients included in this case series, the thromboembolic occlusion was located in the anterior circulation (ACA = anterior cerebral artery, MCA = middle cerebral artery, or distal ICA = internal carotid artery) and associated with a hemodynamic stenosis, a pseudo-occlusion (defined as absent functional flow in distal internal carotid artery due to a filiform stenosis), or a complete occlusion of the ipsilateral ICA.

In our stroke center, age and time window are no absolute criteria for exclusion from endovascular stroke treatment, but the patients' clinical condition prior to the stroke event as well as the imaging findings are taken into account.

Treatment regime and procedural data

Patients within 4.5 h from symptom onset and no contraindications received i.v. thrombolysis with rt-PA at a maximum dose of 0.9 mg/kg and were referred to our service. Intravenous thrombolysis was stopped as soon as the femoral artery was punctured for placement of the sheath.

Final reperfusion success was rated based on the thrombolysis in cerebral infarction (TICI) scale; successful reperfusion was defined as TICI scores 2b and 3 [16]. The beginning of angiography was defined as the time of the femoral artery puncture, and the first persistent reperfusion result was used for time-to-reperfusion measures.

Endovascular procedure

All procedures were performed on a monoplane angiography machine (Philips, Best, The Netherlands) under general anesthesia. In most cases, intracranial thrombectomy was performed prior to stent angioplasty of the ICA ("thrombectomy first"). For this technique, an 8-F guiding catheter (VISTA BRITE TIP, Cordis, Bridgewater, NJ, USA) was positioned in the common carotid artery (CCA). The proximal lesion was passed with a microwire followed by a microcatheter and an intermediate catheter (distal access catheter (DAC); Concentric Medical, Mountain View, CA, USA), which was placed as close to the thrombus as possible. All catheters were continuously flushed with a non-heparinized saline solution. The target vessel for thrombectomy was navigated with a 0.014-in. Synchro microwire (Covidien/ ev3 Inc., Irvine, CA, USA) and either a 0.018-in. Trevo (Concentric Medical, Mountain View, CA, USA) or a Prowler select plus microcatheter (Codman, Raynham, MA, USA). After passage of the clot, an intra-arterial contrast medium (Accupaque, GE Healthcare AG, Little Chalfont, Buckinghamshire, UK) was injected to verify the microcatheter position distally to the clot. The stent retriever (Solitaire FR (Covidien/ ev3 Inc., Irvine, CA, USA); Trevo/Trevo ProVue (Concentric Medical, Mountain View, CA, USA), BonNET (Phenox, Bochum, Germany)) was deployed by withdrawal of the microcatheter, which was then completely removed to increase the lumen of the DAC for aspiration. The device was usually positioned with the proximal third overlapping the thrombus. Contrast injection was performed to evaluate the flow after placement of the stent. Within 2–5 min thereafter, the open stent retriever was withdrawn back into the DAC under continuous aspiration using a 20-mL syringe. After removal of the device, the DAC was aspirated to prevent reinjection of aspirated clot. In cases of proven intracranial stenosis, balloon angioplasty (Ryuijin, Terumo, Somerset, NJ, USA) and stenting were performed.

As soon as a TICI 2b/3 reperfusion result was achieved, a 300-cm microwire (Synchro) was introduced over the DAC and the DAC was removed. A carotid stent (Carotid WALLSTENT (Boston Scientific, Marlborough, MA, USA); Adapt (Boston Scientific, Marlborough, MA, USA); Sinus-Carotid-RX (Optimed, Ettlingen, Germany); Cristallo (Medtronic, Fridley, MN, USA)) was placed, and balloon dilatation was performed with a 4 to 5×20-mm balloon (Ryujin/Hiryu, Terumo, Somerset, NJ, USA).

In cases where the stent angioplasty was performed before thrombectomy ("stent first"), the proximal lesion was crossed with a 300-cm microwire; the stent was then placed and dilated if needed to pass the lesion with a DAC. Subsequently, intracranial thrombectomy was performed as described above. If necessary, postdilatation of the ICA stent was performed afterwards. Angio-Seal™ (St. Jude Medical, Inc., Saint Paul, MN, USA) was applied for occlusion of the femoral artery after intervention in all cases.

Antiplatelet medication

All patients that were not on prior antiplatelet medication received a weight-adapted bolus of tirofiban followed by a continuous infusion for 24 h to prevent in-stent thrombosis. After exclusion of cerebral hemorrhage on follow-up imaging, 500 mg of acetylsalicylacid (ASA) and 300 mg of clopidogrel was applied orally or over a nasogastric tube. Further medication consisted of both, ASA 100 mg and clopidogrel 75 mg daily for the next 3 months followed by a permanent monotherapy with one of the two agents.

Follow-up imaging

All patients underwent CT and/or MRI scanning at 18±6 h after the intervention. Images were rated for hemorrhagic transformation or cerebral hemorrhage and extent of infarction. Symptomatic hemorrhage was defined as an increase of >4 points on the National Institutes of Health Stroke Scale (NIHSS).

Clinical outcome

An early neurological improvement was defined as a decrease of at least 4 points compared to the initial NIHSS or an NIHSS of 0 or 1 after 24 to 48 h. Good clinical outcome after 3 months was defined by a modified Rankin Scale (mRS) score of 0 to 2.

Statistical analysis

Statistical analysis was performed using SPSS 22.0.0.0 (IBM® SPSS Statistics, Armonk, NY, USA). To test categorical variables for differences, χ^2 test was performed. Mann–Whitney U tests and Student's t tests were used for comparison of continuous variables. A p value <0.05 was considered as statistically significant.

Results

Baseline characteristics and general treatment data

Overall, 245 patients with an acute intracranial artery occlusion in the anterior circulation underwent endovascular treatment between September 2010 and April 2013 at our stroke center. Thirty-seven (15.1 %) had an additional occlusion or high-grade stenosis of the proximal ICA and were treated by means of stent angioplasty. Another six patients from our stroke database with proximal high-grade stenoses of the ICA did not undergo carotid stenting, although there was an intention to treat because no stable position for the guiding catheter could be achieved or passage of the stenosis was not successful. These patients were excluded from this case series. Twenty-seven (73 %) of the 37 patients that were included in this study were male, and 10 patients (27 %) were female. The mean age was 63 years with a range from 36 to 89 years. The median NIHSS at admission was 17 (range from 3 to 30 points).

Initial angiograms revealed a complete occlusion of the ICA in 22/37 (59.5 %) patients, high-grade (>90 %) stenosis in 11/37 (29.7 %), and pseudo-occlusion in 4/37 (10.8 %) cases. We identified arteriosclerosis in 24/37 (64.9 %) and vessel dissection in 13/37 (35.1 %) cases as the etiology for the ICA occlusion or stenosis. Prior to the angiography, 20/37 (54.1 %) patients received i.v. rt-PA. Administration of rt-PA was stopped with the groin puncture.

In 3/37 (8.1 %) patients, additional intracranial stent angioplasty was required. In one patient with a long segmental dissection, overlapping stents were deployed from the proximal ICA up to the M1 segment; in another patient, M1 stenting was necessary due to a periprocedural complication resulting in a dissection. In 2 patients, a high-grade stenosis of the petrous segment of the ICA was treated with stent angioplasty.

Procedural results and periprocedural complications

As mentioned before, our endovascular treatment regimes changed over time. Stent angioplasty was performed before thrombectomy in the initial 12/37 (32.4 %) patients ("stent first") and after intracranial thrombectomy in 25/37 patients (67.6 %) ("thrombectomy first"). Median NIHSS on admission was 17 points in both groups (range from 5 to 27 in the "thrombectomy first" group and from 3 to 30 in the "stent first" group); mean age was 64 years (range from 39 to 89 years) in the "stent first" group and 62 years in the "thrombectomy first" group (range from 40 to 84 years). There was a total of 20/25 (80 %) male patients in the "thrombectomy first" group and 7/12 (58 %) male patients in the "stent first" group.

In all cases, stent retrievers were used for intracranial thrombectomy in combination with distal access catheters (DAC). In 29/37 cases, a single type of stent retriever was used (Solitaire AB/FR 19/37 (51.4 %); Trevo Pro 5/37 (13.5 %); Trevo Pro Vue 5/37 (13.5 %)). In 4/37 (10.8 %) cases, a combination of Solitaire FR/AB and Trevo Pro/ Trevo Pro Vue was used, and one patient was treated with a combination of BonNET and Solitaire AB devices. Aspiration alone without thrombectomy resulted in full revascularization in merely 2/37 (5.4 %) patients. In one patient with extremely tortuous vessels, the microcatheter could not be placed distal to thrombus and placement of a thrombectomy device was therefore not possible.

Intracranial occlusion sites as documented by DSA were as follows: distal ICA in 15/37 (40.5 %), proximal M1 segment in 13/37 (35.1 %), distal postbifurcation M1 segment in 5/37 (13.5 %) cases, M2 segment in 3/37 (8.1 %), and combined proximal M1/A1 in one case (2.7 %). The distribution between the treatment groups is shown in Table 1.

Stenting of the proximal ICA was successful in all 37 cases. In most cases, a Carotid WALLSTENT was used (24/37=64.9 %), and additional stents were used in three cases (Cristallo, Sinus-Carotid-RX, and Adapt, 1/37=2.7 % each). Adapt was used as the sole stent in 7 cases (7/37=18.9 %), and Sinus-Carotid-RX was used in another 3 cases (3/37=8.1 %). Three (8.1 %) acute stent occlusions occurred during the procedure, two in the "stent first", and one in the "thrombectomy first" group. In one case in the "stent first" group, the occlusion could be recanalized by aspiration and balloon angioplasty; in the two other cases, recanalization attempts remained unsuccessful, but sufficient cross-flow from the contralateral site was present. Other complications included one case of peripheral embolism in the "stent first" group. One case of vasospasm during treatment and one vessel dissection occurred in the "thrombectomy first" group; however, both were without further clinical relevance. One patient in the "thrombectomy first" group experienced a traumatic carotid–cavernous fistula with concomitant subarachnoid hemorrhage (SAH) due to a microwire perforation, and the patient experienced further clinical deterioration with visual impairment. During the retrieval maneuver, one Solitaire device got caught in the meshes of the ICA stent (Cristallo) that had been deployed as the first step ("stent first") and could not be passaged with DAC or the guiding catheter, but only

Table 1 Relevant patient data listed for all patients and for each treatment approach separately ("stent first" and "thrombectomy first"). Numbers of patients and percentage displayed unless otherwise noted

	All patients	"Stent first"	"Thrombectomy first"
Number of patients	37	12	25
Mean age in years (range)	63 (36–89)	64 (36–89)	62 (40–84)
Sex (%)			
Female	10 (27.0)	5 (41.7)	5 (20.0)
Male	27 (73.0)	7 (58.3)	20 (80.0)
Median NIHSS on admission (range)	17 (3–30)	17 (3–30)	17 (5–27)
Stroke etiology (%)			
Arteriosclerosis	24 (64.9)	9 (75.0)	15 (60.0)
Dissection	13 (35.1)	3 (25.0)	10 (40.0)
Side of occlusion (%)			
Right	15 (40.5)	5 (41.7)	10 (40)
Left	22 (59.5)	7 (58.3)	15 (60)
Proximal lesion (%)			
High-grade stenosis	11 (29.7)	5 (41.7)	6 (24.0)
Pseudo-occlusion	4 (10.8)	1 (8.3)	3 (12.0)
Occlusion	22 (59.5)	6 (50.0)	16 (64.0)
Intracranial occlusion site (%)			
Distal ICA	15 (40.5)	4 (33.3)	11 (44.0)
Proximal M1	13 (35.1)	5 (41.7)	8 (32.0)
Distal M1	5 (13.5)	1 (8.3)	4 (16.0)
M2	3 (8.1)	1 (8.3)	2 (8.0)
Combined ACA/M1	1 (2.7)	1 (8.3)	–
Bridging fibrinolysis with rt-PA (%)	20 (54.1)	6 (50.0)	14 (56.0)

with the microcatheter. Incidental detachment of the Solitaire device during the attempt to retrieve it resulted in complete occlusion of the ICA, which was reopened with an additional Carotid WALLSTENT, leading to satisfactory vessel patency (Fig. 2). The distribution of the complications between the groups is displayed in Table 2.

On the final angiography series, no residual stenosis over 50 % was visible, besides in the two patients with an acute stent occlusion during angiography that could not be sufficiently recanalized. There were no complications associated with the femoral sheath in our case series.

Successful reperfusion (TICI 2b/3) was achieved in 27/37 (73.0 %) patients. A TICI 3 result was achieved in 18.9 % (7/37) and a TICI 2b result in 54.1 % (20/37). Intravenous rt-PA administration prior to endovascular treatment was not a significant factor for successful reperfusion (TICI 2b/3, 14/20=70 % with i.v. rt-PA vs. 13/17=76.5 % without i.v. rt-PA; $p=0.73$). For a detailed comparison between the "stent first" and "thrombectomy first" groups, view Table 1.

The mean time from groin puncture to first permanent reperfusion, respectively, the final reperfusion result (Fig. 1), was significantly shorter when thrombectomy was performed prior to stent angioplasty (43.1±30.8 vs. 110.8±43.0 min, $p<0.001$; 58.6±26.1 vs. 130.2±45.1 min, $p<0.01$, respectively).

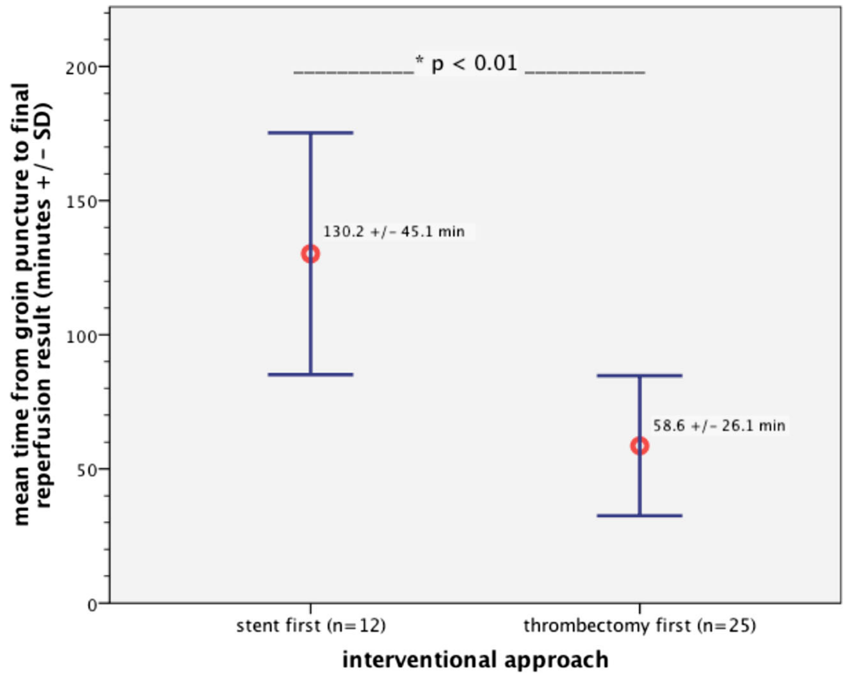
Follow-up imaging

CT scanning revealed parenchymal hemorrhage (PH) in 6/37 cases (16.2 %). Four of six patients (10.8 %) with a PH experienced clinical deterioration, and 2/6 patients (5.4 %) were asymptomatic. Four of these six patients were treated

Table 2 Treatment results and outcomes listed for all patients and for each treatment approach separately ("stent first" and "thrombectomy first"). Numbers of patients and percentage displayed unless otherwise noted

	All patients	"Stent first" (*n*=12)	"Thrombectomy first" (*n*=25)
Reperfusion results (%)			
TICI 0	4 (10.8)	4 (33.3)	–
TICI 1	2 (5.4)	1 (8.3)	1 (4.0)
TICI 2a	4 (10.8)	–	4 (16.0)
TICI 2b	20 (54.1)	5 (41.7)	15 (60.0)
TICI 3	7 (18.9)	2 (16.7)	5 (20.0)
Angiography times (mean±SD) (min)			
Groin puncture to first reperfusion	55.6 (±42.0)	110.8 (±43.0)	43 (±30.7)
Groin puncture to final reperfusion	73.5 (±42.1)	130.2 (±45.1)	58.6 (±26.1)
Procedural complications (%)			
Acute stent occlusion	3 (8.1)	2 (16.6)	1 (4.0)
Peripheral embolism	1 (2.7)	–	1 (4.0)
Vasospasm	1 (2.7)	–	1 (4.0)
CCF	1 (2.7)	–	1 (4.0)
Vessel dissection	1 (2.7)	–	1 (4.0)
Detachment of thrombectomy device	1 (2.7)	1 (8.3)	–
Bedside Doppler sonography results (%)			
Not performed (occlusion preexistent)	1 (2.7)	–	1 (4.0)
No relevant residual stenosis	28 (75.7)	9 (75.0)	19 (76.0)
Stent occlusion/suspected occlusion	6 (16.2)	2 (16.7)	4 (16.0)
Relevant stenosis	2 (5.4)	1 (8.3)	1 (4.0)
Early clinical improvement (NIHSS=0/1 or improvement of >4 points) (%)	25 (67.6)	7 (58.3)	18 (72)
mRS after 3 months (%)			
mRS 0	7 (18.9)	2 (16.7)	5 (20.0)
mRS 1	5 (13.5)	1 (8.3)	4 (16.0)
mRS 2	5 (13.5)	1 (8.3)	4 (16.0)
mRS 3	6 (16.2)	2 (16.7)	4 (16.0)
mRS 4	5 (13.5)	2 (16.7)	3 (12.0)
mRS 5	2 (5.4)	1 (8.3)	1 (4.0)
mRS 6	7 (18.9)	3 (25.0)	4 (16.0)
Symptomatic parenchymal hemorrhage (%)	4 (10.8)	1 (8.3)	3 (12.0)

Fig. 1 The mean time from groin puncture to final reperfusion given in minutes (±1 standard deviation) and grouped by the interventional approach ("stent first" 130.2±45.1 min, n=12 vs. "thrombectomy first" 58.6±26.1 min, n=25; p<0.01). The reperfusion times in the "thrombectomy first" group were significantly shorter



with i.v. thrombolysis before thrombectomy. Hemorrhagic transformation of the infarcted territory without any clinical consequence was detected in another 11/37 cases (29.7 %).

Follow-up imaging detected extensive infarction of the ICA territory (>2/3) in 9/37 patients (24.3 %). In 2/37 cases (5.4 %), the infarct demarcation also involved other vessel territories: One patient showed additional infarction in the contralateral ACA and MCA territories and the other patient showed additional infarction in the ipsilateral PCA territory. Involvement of the basal ganglia was documented in 25/37 (67.6 %) of patients. In four cases (10.8 %), decompressive hemicraniectomy was deemed necessary.

During the initial hospital stay, no relevant residual stenosis or occlusion could be found in 28/37 patients (75.7 %) by bedside Doppler ultrasound. Stent occlusion was diagnosed or suspected in six patients (16.2 %), and another two patients (5.4 %) were diagnosed with relevant residual stenosis because of flow velocities of more than 400 cm/s within the stent.

Clinical outcome

Twenty-five patients (67.6 %) had improved significantly after 24 to 48 h. At discharge, 13/37 patients (35.1 %) had a mRS score from 0 to 2, and 19/37 (51.4 %) patients had a favorable to moderate outcome (mRS 0–3). Median mRS at discharge was 3.

After 3 months, the median mRS score remained 3 (0–6) with a favorable clinical outcome (mRS 0–2) in 17/37 (45.9 %) and a favorable to moderate outcome (mRS 0–3) in 23/37 patients (62.2 %). Seven patients (18.9 %) died, all of them during their initial hospital stay: six due to extensive infarction/additional ICH and one because of cardiopulmonary complications, e.g., pneumonia.

Reperfusion success (TICI 2b/3) was a strong predictor of favorable outcome (mRS 0–2), both at discharge (mRS 0–2 at discharge 13/27=48.1 vs. 0/10=0 % TICI 2b/3 vs. TICI 0–2a, p=0.007) and after 3 months (mRS 0–2 after 3 months 16/27=59.3 vs. 1/10=10 % TICI 2b/3 vs. TICI 0–2a, p=0.01). By tendency, early clinical improvement occurred more frequently in patients with successful reperfusion (NIHSS<4 or=0/1 in 20/27=74.1 vs. 5/10=50 % TICI 2b/3 vs. TICI 0–2a, p=0.24). In addition, there was a tendency towards better outcomes in patients who received intracranial thrombectomy prior to carotid stenting (mRS 0–2, 13/25=52.0 % in the "thrombectomy first" group compared to 4/12=33.3 % in the "carotid stent first" group, p=0.319). Intravenous thrombolysis as a bridging concept prior to angiography did not have a significant impact on the outcome (mRS 0–2, 10/20=50 % with i.v. rt-PA vs. 7/17=41.2 % without i.v. rt-PA; p=0.74).

To take the high percentage of dissections (13/37=35.1 %) as the underlying pathology in our case series into account, we decided to compare this patient group to all patients with an arteriosclerotic stroke etiology. The mean age differed significantly between these two patient groups (dissection: mean 52, range 36–7 vs. arteriosclerosis: mean 68, range 46–89; p<0.01), but we could not find any differences concerning gender (male 10/13=76.9 vs. 17/24=70.8 %; p=1.00), NIHSS on admission (median 18, range 7–27 vs. median 16, range 3–30; p=0.25), reperfusion results (TICI 2b/3, 10/13=

76.9 vs. 17/24=70.8 %; p=1.00), or mRS after 3 months (mRS 0–2, 8/13=61.5 vs. 9/24=37.5 %; p=0.19).

Discussion

There is growing evidence for a potential benefit for stroke patients with intracranial large artery occlusions, which are treated by means of mechanical thrombectomy. Randomized studies comparing endovascular stent retriever therapy with i.v. thrombolysis are still pending, but large mono- and multicentric series with more than 100 patients and one multicentric prospective single-arm study including 190 patients report high reperfusion rates of 78 to 85 % [17–19]. Furthermore, two randomized trials proofed the advantage of the Solitaire and Trevo stent retrievers compared to the older MERCI device, both respecting the reperfusion success as well as the clinical outcome [20, 21].

However, approximately one out of five patients with an intracranial vessel occlusion presents with an additional occlusion or high-grade stenosis of the extracranial ICA [22]. This occlusion pattern responds poorly to i.v. thrombolysis and is associated with a poor clinical outcome [5].

Because vascular surgery can only address the proximal lesion, tandem occlusions are usually managed by endovascular means [23]. So far, several stroke centers reported their experience with recanalization of tandem occlusions with different techniques in smaller series [8–15]. Reperfusion in these series was successful in up to 75 % [14], and rates for a good clinical outcome after 3 months varied from only 20 % [12] up to 41.6 % [14] and 50 % [13].

The data on stent retriever-based treatment of tandem occlusions is limited to a few single-center experiences [24–27]. Mpotsaris et al. described a series of 17 patients who required emergency stenting in the extracranial portion of the ICA in addition to intracranial thrombectomy with the Solitaire stent retriever. They observed a very high reperfusion success (94 %) and a good clinical outcome in more than half of their patients (54 %) after 3 months [24]. Son et al. reported on 11 patients with an extra-/intracranial tandem occlusion who were treated with the Solitaire stent retriever or a Penumbra aspiration catheter. A TICI 2b or 3 reperfusion was achieved in all of their patients [25]. Cohen et al. achieved a complete reperfusion in 6 of 7 patients with tandem occlusions and a good clinical outcome in 72 % of their patients after 1 month [26]. Stampfl et al. recently published a series of 24 patients with tandem ICA/MCA occlusions that were treated with stent retriever thrombectomy and proximal stent angioplasty. Reperfusion success (TICI 2b/3) was 62.5 %, but only 25 % of the patients improved significantly and only 29.2 % had a good clinical outcome after 3 months [27].

To the best of our knowledge, our case series comprised of 37 patients who underwent thrombectomy with stent retrievers in addition to emergency proximal ICA stenting is the largest case series published on treatment exclusively with this particular approach. Concerning endovascular treatment of tandem occlusions in general, it is only outnumbered by a recent publication of Fischer et al. who reported 76 tandem occlusions. In their series, various treatment regimes are described, comprising intra-arterial thrombolysis alone, as well as stent retriever-based thrombectomy [28]. Thus, comparability to our study is limited.

In our series, all stent angioplasties were technically successful, and complete (TICI 2b/3) reperfusion was achieved in 73.0 %, which is comparable to the results in the series of Stampfl et al. [27]. Distal aspiration with intermediate catheters was performed in all of our patients. In two cases, aspiration alone resulted in full intracranial revascularization. In all other cases, stent retrievers were used for mechanical thrombectomy. When compared to the series of Stampfl et al., the rate for a good mRS at 3 months (45.9 %) was higher in our group [27]. However, the number of patients with a good clinical outcome at 3 months was low compared to the smaller series of Cohens and Mpotsaris et al. [24, 26].

Spontaneous reperfusion of the intracranial vessel occlusion has been described in the literature as a common finding in patients with tandem ICA/MCA occlusions after stenting of the proximal ICA [14, 25]. However, similar to the data of Stampfl et al. [27], we did not find this phenomenon in any of our patients in the "stent first" group.

Because the aim of any stroke treatment must be to successfully revascularize as soon as possible [29], evaluation and definition of appropriate techniques are necessary. We describe two different approaches comprising stent angioplasty before or after intracranial thrombectomy with both techniques providing different advantages and disadvantages.

In the literature, most centers seem to address the proximal lesion (either by means of balloon angioplasty and/or stent angioplasty) prior to recanalization of the intracranial occlusion [11, 24–28]. The main advantage of this technique is that it creates a direct access to the distal occlusion. Subsequently, "blind" probing of the ICA with the microwire and catheter, which holds the risk of a vessel dissection or even vessel perforation, is not necessary.

Spiotta et al. published a series of 16 patients treated with the proximal to distal approach [30]. Stent retriever was only used in two of their patients. The authors consider this technique to be safer and more efficient for the patients and argue that distal protection is not necessary and that successful recanalization of the proximal lesion promotes thrombolysis. However, this thesis is mainly based on one case in which intracranial thrombectomy became unnecessary after recanalization of the proximal lesion and—most importantly and different from our evaluation—procedural times have not been evaluated.

Successful navigation through an occluded vessel has been reported already in the early 1990s [31, 32]. Since then, microcatheters and wires have become more flexible and easier to navigate. In our series, all proximal lesions could be passed without difficulty not only with the microwire and catheter but also with a flexible intermediate catheter (DAC) that was placed proximally and as close to the intracranial lesion as possible. Dislodgment of a thrombus and subsequent distal embolization during stent deployment is one concern about this "retrograde" technique and can largely be avoided by continuous DAC aspiration. Using this technique, we had no distal arterio-arterial embolization in any of our cases that were treated in the "thrombectomy first" order, but in one case that was treated with initial stent angioplasty.

Already in 2005, Nedeltchev et al. described the endovascular treatment of 25 patients with acute stroke due to tandem occlusions successfully using a retrograde technique [33]. Briefly, their endovascular approach included the passage of the proximal occlusion with a guidewire and secondary placement of an 8-F guiding catheter and a coaxial infusion catheter distally to the thrombus followed by thrombus aspiration using the proximal guiding catheter as a protective device. As the second step stenting of the proximal portion of the ICA was performed, and if necessary, additional i.a. urokinase was applied. Successful recanalization was achieved in 21/25 (84 %) of the patients, and additional reperfusion of the MCA territory (defined as TIMI 2/3) was achieved in 11 of their 21 patients (52 %). Significantly, more patients treated by endovascular means had a favorable long-term clinical outcome in their case series compared to a group of 31 patients from their stroke center that received medical treatment alone (mRS 0–2, 14/25=56 vs. 8/31=26 %). With respect to the rapid development of new devices in the field of endovascular stroke treatment and the meanwhile available stent retrievers for vessel recanalization, which were exclusively used for thrombectomy in our case series, successful reperfusion was less frequent in the study of Nedeltchev et al., whereas the clinical results were better. Reasons for the better outcomes in their case series might base on the stricter patient selection with no patients being treated beyond a time window of 6 h and the lower initial median NIHSS compared to our patient group (12 versus 17).

Concerning the reperfusion success, we did not find any difference between the two approaches. However, we found a distinct tendency to a better clinical outcome in patients who received intracranial thrombectomy prior to carotid stenting (52.5 % good outcomes in the "thrombectomy first" group versus 33.3 % in the "carotid stent first" group).

Although only two stent occlusions and no relevant residual stenosis were visible on final angiography series, follow-up bedside Doppler ultrasound studies revealed a relatively high rate of early stent occlusions and suspected occlusions (6/37=16.2 %) as well as two cases of relevant residual stenosis (2/37=5.4 %). We consider insufficient response to antiplatelet therapy or inadequate dosage of antiplatelet medication as the most likely reason for these findings.

Stent retrievers have not only been proven to reach higher recanalization rates but also at shorter time compared to older devices. With this technique, procedural times of less than 15 min are no exception. Admittedly, stent angioplasty with

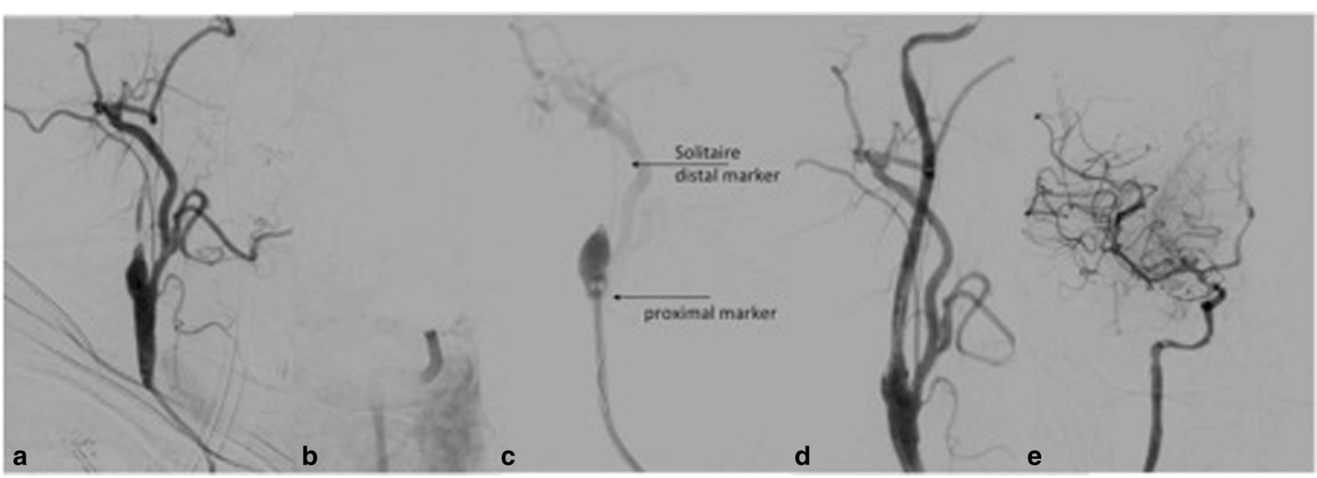


Fig. 2 Case example. Initial angiogram revealed a pseudo-occlusion of the right ICA (*a*) with additional complete occlusion of the carotid T (*b*). The proximal lesion could be passed with a microwire and placement of a carotid stent (Cristallo) was possible. The stent could easily be passed with microwire and catheter, but not with either the DAC or the guiding catheter. The distal lesion was thereafter reached with microwire and microcatheter and a Solitaire stent retriever was deployed. During withdrawal, the Solitaire got intertwined in the meshes of the previously deployed ICA stent and finally detached (*c*). The subsequent complete occlusion could be reopened after deployment of another ICA stent (Wallstent) (*d*) and the final angiogram showed complete revascularization (*e*). The patient recovered completely (NIHSS at discharge of 0)

concomitant thrombectomy is technically more challenging than a single procedure alone, thus, leading to longer reperfusion times. Stampfl et al. found a median increase of the reperfusion time of 20 min when proximal stent angioplasty was necessary [27]. In Cohen's series, mean time to therapy was 3.8 h (range 2–5.5) and mean time to reperfusion was 51 min (range 38–69) [26]. In our patients, median time from groin puncture to first and to final reperfusion was significantly shorter when thrombectomy was performed as the first step (43.1±30.8 vs. 110.8±43.0 min, $p<0.001$; and 58.6±26.1 vs. 130.2±45.1 min, $p<0.01$). As "thrombectomy first" leads to an earlier revascularization of the dependent brain territories, patients may benefit in addition from this technique.

We did not find any statistical difference in procedural complication rates between the two groups. However, in one patient treated with stent angioplasty of the proximal ICA before thrombectomy, the proximal stent could not be passed with either the DAC or the guiding catheter, but only with the microwire and catheter after deployment. The attempts to retrieve the Solitaire stent retriever into the proximally positioned guiding catheter resulted in interaction of the stent meshes and finally detachment of the Solitaire that subsequently caused occlusion of the ICA (Fig. 2). After deployment of a wallstent, full recanalization could be achieved and the patient experienced no deterioration (NIHSS=0 at discharge). In this case, an open-cell design carotid stent (Cristallo) was used, but also a closed-cell stent design could not guarantee easy navigation of the distal ICA with the guiding or DAC catheter. Interaction between different devices is always a concern in interventional neuroradiology and can be avoided when performing thrombectomy first.

Bleeding complications are a feared risk in any acute stroke treatment and have been higher in a majority of the larger thrombectomy studies compared to intravenous treatment approaches [17, 34–36]. Opening large arterial vessels into infarcted tissue bears a potential risk to increase bleeding complications. In our case series, symptomatic parenchymal hemorrhages were within the range of other studies on thrombectomy; an increased number of relevant bleedings could not be observed. Out of six documented intracranial hemorrhages (16.2 %), four (10.8 %) were clinically symptomatic and four of these cases were possibly related to prior i.v. administration of rt-PA. Thus, we did not find an increased risk for hemorrhage under the described periprocedural antiplatelet regime, which is consistent with previous reports [14, 24].

This study has several limitations, and the results have to be interpreted with care. Our retrospective single-center study is prone to selection bias. There is no control group for comparison of patients' baseline characteristics and outcomes. Also, there was no randomized selection for the two techniques, and the patient number in the groups was different. Also, the patient cohort is not homogenous for included patients suffered from acute strokes of different etiologies and with different vessel occlusion patterns.

Conclusion

Our series suggests that stent retriever-based endovascular treatment of tandem ICA/MCA occlusions is technically feasible and safe and may be associated with improved clinical outcome. Intracranial thrombectomy with distal aspiration followed by proximal stent angioplasty leads to shorter reperfusion times and earlier revascularization of the downstream territory. Furthermore, primary carotid stenting followed by stent-based mechanical thrombectomy bears potential risks due to interaction of the devices.

Ethical standards and patient consent We declare that all human and animal studies have been approved by the local Ethics Committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

Conflict of interest TL consults for Concentric, now part of Stryker.

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