

Endovascular Treatment of Acute Intracerebral Artery Occlusions with the Solitaire Stent: Single-Centre Experience with 108 Recanalization Procedures

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Key Words

Stroke · Endovascular treatment · Stent retriever · Solitaire

Abstract

Background and Purpose: Stent retrievers are currently displacing 'classical' thrombectomy devices for recanalization in acute ischaemic stroke. The aim of our study was to show the procedural efficacy and safety of the Solitaire stent retriever as part of our multimodality endovascular approach in the treatment of ischaemic stroke. **Methods:** Between March 2008 and December 2009, 104 patients [53 females (51%), 51 males (49%), mean age 67.3 years (range 31–96)] with 108 territorial occlusions were treated with the Solitaire stent alone or in conjunction with other endovascular stroke devices. All patients were referred to our service after clinical evaluation by a team of stroke neurologists as part of our standard treatment algorithm with 0.9 mg/kg i.v. recombinant tissue-type plasminogen activator and endovascular continuation of treatment in CT angiography-proven main branch occlusion. The time of angiography was defined as the moment of groin puncture. Final reperfusion success was rated according to the Thrombolysis in Cerebral Infarction (TICI) scale; the first persistent Thrombolysis in Myocar-

dial Infarction (TIMI) 2/3 reperfusion was used for time-to-reperfusion measures. **Results:** Fifty-eight patients were treated in conjunction with intravenous lysis, 32/104 received intra-arterial lytics. Twenty-five territories were treated with the Solitaire alone; the remaining 83 were treated with a combination of mechanical thrombectomy devices or aspiration thrombectomy followed by or in conjunction with the Solitaire. The most frequent combination was a proximal aspiration/distal access catheter and Solitaire (62/108). In 15/108 procedures, temporary stenting without thrombectomy was performed. Eighty-three successful thrombectomy attempts were performed in the remaining 93 territories. The mean number of Solitaire passes was 2.46 (median 2, max. 12). The mean time from onset to reperfusion was 265 min (range 56–1,031), median 230 min; the mean angio-to-reperfusion time was 47 min (5–186), median 38.5 min. A subanalysis showed a significant reduction of the angio-to-reperfusion time when the Solitaire was used (48.7 vs. 68 min). The rate of final TICI 2b/3 reperfusion was 79% for the anterior and 77.9% for the posterior circulation (TIMI 2/3 for both: 92.5%). During or after the first deployment of the Solitaire, 72.8% showed TIMI 2/3 reperfusion. The mean National Institute of Health Stroke Scale score on admission was 15.3 and decreased by 7.8 points at clinical discharge. The

overall mortality at discharge was 16% in the anterior and 47.8% in the posterior circulation group. There were 2 cases of periprocedural intracranial haemorrhage, unrelated to the Solitaire, 6 patients had evidence of subarachnoid haemorrhage, 2 potentially related to the Solitaire deployment. In 4/108 territories, thrombus migration to previously unaffected territories was noted. Vasospasm was seen in 13% of the target vessels. One device was inadvertently detached during retrieval. All these complications had no clinical consequence. **Conclusions:** Our single-centre experience proves the technical feasibility and safety of the Solitaire for the treatment of acute intracranial vessel occlusion and approves previous reports with smaller patient numbers. Further multicentre studies with a randomized and prospective design will be necessary to verify the results.

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Introduction

Stroke accounts for 10% of all deaths worldwide [1]. Affecting many patients under the age of 60 years, it is the leading cause of long-term disability and also the most expensive one [2, 3].

Efficacy of intravenous thrombolysis with recombinant tissue plasminogen activator (rtPA) has been proven in many clinical trials [3–12]. However, it is largely accepted that the benefit of intravenous thrombolysis is low, particularly in patients with an occlusion of a major intracranial vessel [13, 14].

The superiority of intra-arterial application of tPA over low-dose heparin with regard to a complete or partial recanalization (66 vs. 18%) and a good clinical outcome (40 vs. 25%) has been proven in the Proact II study [15]. Several trials indicate the efficacy of mechanical thrombectomy, alone or in combination with intravenous and intra-arterial application of tPA [6, 15–19]. During the past few years, so-called stent retrievers have more and more displaced ‘classical’ thrombectomy devices [20, 21]. The Solitaire FR (ev3, Irvine, Calif., USA) is the first fully retrievable nitinol stent dedicated for acute stroke treatment. It may serve as a temporary endovascular bypass in acute stroke and can be completely removed potentially acting as a thrombectomy device when removed fully or partially deployed. We report on our experience with the Solitaire device as part of our multimodality endovascular approach in the treatment of ischaemic stroke.

Methods

Patients

We retrospectively evaluated all consecutive 104 patients (108 territorial occlusions) who underwent endovascular recanalization of intracranial vessel occlusion with the Solitaire stent alone or in conjunction with other endovascular stroke devices between March 2008 and December 2009 at our stroke centre (Klinikum rechts der Isar, Technical University of Munich, Germany). All patients were referred to our service after clinical evaluation by a team of stroke neurologists as part of our standard treatment algorithm with 0.9 mg/kg i.v. rtPA (within 3 h initially, 4.5 h after the results of ECASS III [18]) and endovascular continuation of treatment in a main branch occlusion [internal carotid artery (ICA), middle cerebral artery (MCA), distal vertebral artery (segment V4), anterior cerebral artery (ACA) and basilar artery]. The final reperfusion success was rated by three independent physicians (T.L., S.S., H.L.) based on the Thrombolysis in Myocardial Infarction (TIMI) [22] and the TICI (Thrombolysis in Cerebral Infarction) scales [23]. The beginning of angiography was defined as the moment of the femoral artery puncture, and the first persistent TIMI 2/3 reperfusion result was used for time-to-reperfusion measures. Control CT scans after 18 h or more were rated for the presence of infarct and signs of haemorrhage. A symptomatic haemorrhage was defined as an increase of ≥ 4 points on the NIHSS (National Institute of Health Stroke Scale). Postprocedural outcome was rated as NIHSS score at hospital discharge.

Procedure

Treatments were not randomly assigned. All procedures were performed under general anaesthesia. Patients with an occlusion of a major intracranial artery [terminal ICA, MCA (M1 or M2 portion), basilar artery and/or the intracranial portion of the vertebral artery, ACA] as proven by CT angiography and without signs of beginning infarct demarcation on unenhanced CT scan were systematically allocated to the intra-arterial procedure.

All patients within a time window of 3 h until May 2009 and 4.5 h thereafter (ECASS III [6]) who had no contra-indications for systemic lysis (e.g. anticoagulative medication, history of intracranial haemorrhage, history of recent surgery) were treated with intravenous rtPA. Intravenous thrombolysis was stopped with the femoral puncture. The maximum dose of intravenous rtPA was 0.9 mg/kg.

All procedures were performed on a biplane angiography machine (Philips, Best, The Netherlands). No heparin was applied during the procedures. For patients with an occlusion in the anterior circulation, an 8-Fr sheath (Vista Brite tip, Cordis, Bridgewater, N.J., USA) was brought into the proximal ICA coaxially over a long 5-Fr Sidewinder SIM-2 catheter, which was removed afterwards. In cases of a vertebrobasilar occlusion, a 6-Fr guiding catheter (Envoy, Codman, Raynham, Mass., USA) was placed into the vertebral artery assisted by a 0.035-inch guide wire. An aspiration catheter – either a distal access catheter (Concentric, Mountain View, Calif., USA) or a Penumbra Aspiration catheter (Penumbra Inc., Alameda, Calif., USA) was placed distally in the ICA or vertebral artery. A non-heparinized saline solution was continuously flushed through the catheters during the procedure. The target vessel was navigated with a 0.014-inch Synchro microwire (ev3 Inc.) and either a 0.027-inch Rebar (ev3 Inc.) or a

0.021-inch Prowler select microcatheter (Codman). After passage of the clot and placement of the microcatheter distal to it, as verified by intra-arterial contrast medium injection, the initial thrombectomy device was advanced through the microcatheter, which in 83/104 patients was not the Solitaire but one of the devices labelled for use in ischaemic stroke under the CE mark at the time (Phenox clot retriever, MERCI, Penumbra). With regard to the Solitaire stent, the microcatheter was pulled back to unfold the Solitaire device completely and increase the volume of the distal access catheter for aspiration. The device was normally placed with the proximal third within the thrombus. A control angiogram was performed after successful unfolding of the stent device to evaluate re-establishment of flow. Afterward, the device was pulled back in its unfolded state under continuous aspiration with a 50-ml syringe into the distal access catheter sheath. After removal of the device, another 50 ml was aspirated from the guiding sheath to prevent re-embolization of a possibly migrating clot. This procedure was repeated until a final TICI score of 2b or 3 was reached but no more than 5 passages (with exception of 12 passes in a basilar artery occlusion) were used in a single vessel, the average number of passes being 2.46.

If the patient had a tandem occlusion of the proximal ICA, then angioplasty and stenting were performed in order to obtain access prior to distal mechanical thrombectomy.

Results

Patient Data

All 104 patients presented with acute stroke symptoms and had an occlusion of a major intracranial vessel, proved by CT angiography (fig. 1). In 4 patients, 2 vessels (MCA and ACA) were affected. Among the 108 evaluated recanalizing procedures, there were 18 (16.7%) occlusions of the distal ICA, 54 (50%) of the M1 portion and 6 (5.6%) of the M2 portion of the MCA, 24 (22.2%) of the basilar artery and/or the intracranial portion of the vertebral artery (V4 segment) and 6 (5.6%) of the ACA (table 1). Altogether, 81 patients (43 females, 38 males, mean age 65.8 years, min. 31, max. 96) had an occlusion pattern of the anterior circulation and 23 patients (10 females, 13 males, mean age 72.8 years, min. 49, max. 90) a vessel occlusion in the posterior circulation.

The mean NIHSS score on admission was 15.3 (standard deviation 5.1, min. 2, max. 27) for the anterior and 16.1 (standard deviation 11.2, min. 3, max. 42) for the posterior circulation.

Fifty-eight of the 104 patients were treated in conjunction with intravenous thrombolysis, 32/104 received intra-arterial rtPA.

Procedural Data and Angiographic Results

Initially, all Solitaire applications were performed on a compassionate use basis after approved systems or local

Table 1. Localization of the target vessels

ICA-T	M1	M2	ACA	VA-BA
18	54	6	6	24

ICA-T = Terminus of ICA; M1 and M2 = first and second portions of the middle cerebral artery; VA = vertebral artery; BA = basilar artery.

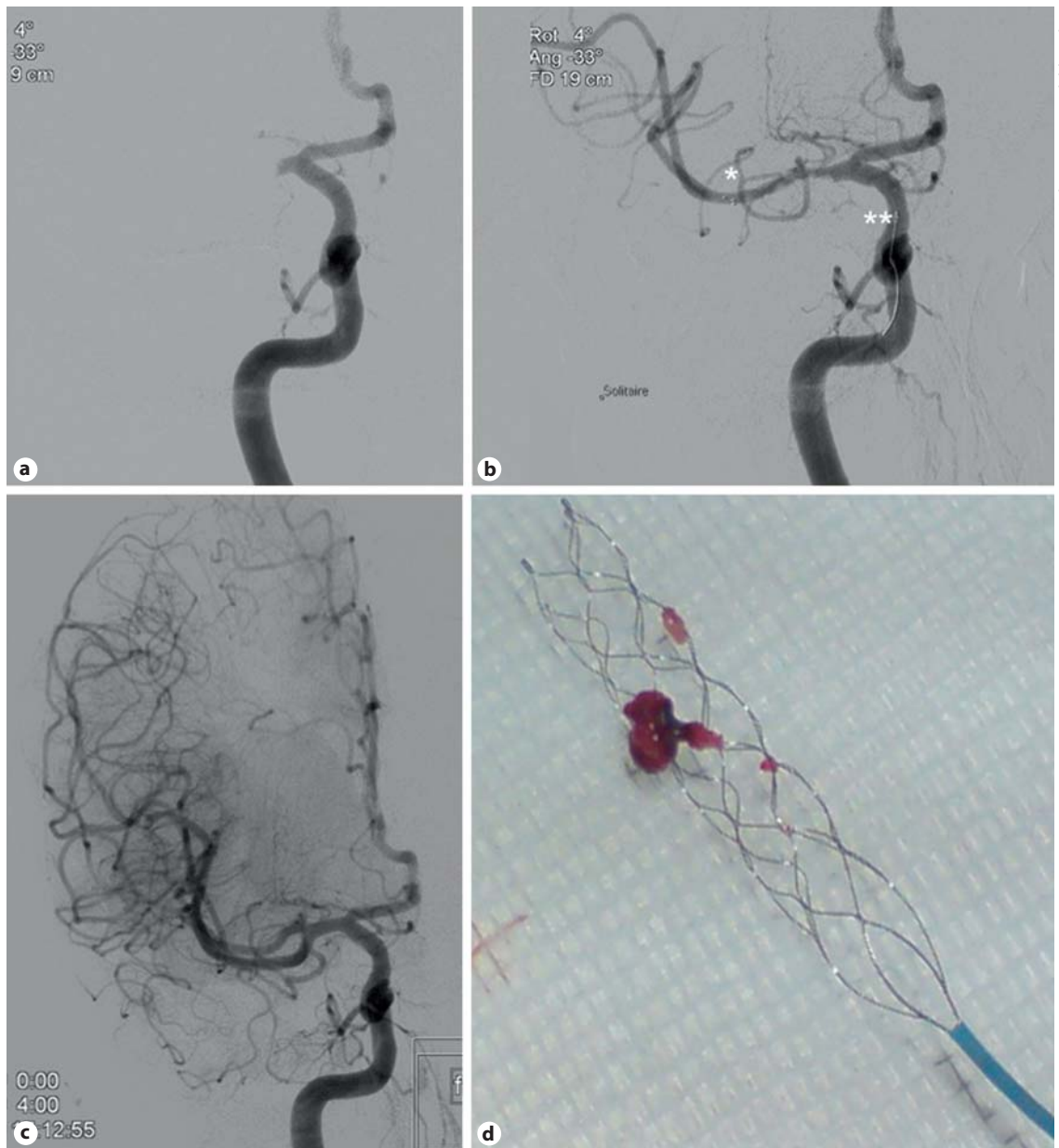
Table 2. Percentage of recanalization success according to the TICI scale

TICI 0 (n = 6)	TICI 1 (n = 2)	TICI 2a (n = 15)	TICI 2b (n = 32)	TICI 3 (n = 52)
			21%	79%

intra-arterial thrombolysis had failed. With growing experience and due to the fact that interim analysis of our data had shown superior results with this technique, the stent was used as a first line or in combination with aspiration thrombectomy more often. Eighty-three procedures were performed with a combination of mechanical thrombectomy devices or aspiration thrombectomy followed by, or in conjunction with, the Solitaire. Twenty-five territories were treated with the Solitaire alone (monomodal). Fifty-two patients were treated with 2 devices (bimodal), 18 with 3 (trimodal), and in 15 patients 4 or more devices were used. The most frequent combination was the Solitaire with a proximal Penumbra aspiration catheter (42 procedures) or a distal access catheter (20 procedures). In 1 case, the lesion could not be reached with any device due to vessel tortuosity.

In the earlier 15 of 108 Solitaire procedures, temporary stenting without thrombectomy was performed. In the remaining 93 territories, 83 thrombectomy attempts were successful and 10 were unsuccessful. The mean number of Solitaire passes was 2.46 (median 2, max. 12). The mean time from onset to reperfusion was 265 min (56–1,031, median 230 min); the mean angio-to-reperfusion time was 47 min (5–186, median 38.5 min).

In the anterior circulation 64 (79%) recanalization results were rated as TICI 2b or TICI 3 (table 2). In detail, there were 6 (7.4%) TICI 0, 1 TICI 1 (1.2%), 10 TICI 2a (12.3%), 24 TICI 2b and 40 TICI 3 (49.4%) results. Seventeen recanalizations in the posterior circulation were TICI 2b/3 results (77.9%). In detail, there was no TICI 0



Color version available online

Fig. 1. **a** Angiography (ap view) demonstrates occlusion of the proximal right middle cerebral artery (MCA), **b** immediate reperfusion after deployment of a Solitaire AB 4/20 (** indicating the proximal and * the distal stent marker), **c** TIMI 3 recanalization after retrieval of the Solitaire, **d** the Solitaire device after clot removal.

result, 1 TIMI 1 (4.3%), 5 TIMI 2a (21.7%), 7 TIMI 2b (30.4%) and 10 TIMI 3 (43.5%).

Altogether, the rate of final TIMI 2/3 recanalization was 92.5%. During or after the first deployment of the Solitaire, 72.8% showed at least a TIMI 2 reperfusion.

A TIMI 2b/3 result was reached significantly more often when intravenous lysis was performed before endo-

vascular treatment (85.4 vs. 65.8%, $p = 0.02$, Fisher's exact test).

In 10 procedures, an underlying intracranial stenosis had to be treated with stent and angioplasty. Seven Solitaire stents were placed permanently and in 14 cases, self-expanding stents other than Solitaire were applied. Stent and angioplasty of the proximal ICA were necessary in 15

procedures, to access the target vessel, owing to an acute occlusion of the ICA. These patients received an additional 500 mg of intravenous acetylsalicylic acid before stent deployment and a loading dose of 300 mg clopidogrel right after the treatment to protect the ICA stent.

In 4 of 108 procedures (3.7%), thrombus migration to previously unaffected territories was noted. Vasospasm was seen in 14/108 (13%) of the target vessels. One device was inadvertently detached during retrieval. There were 3 dissections of the target vessel. All these periprocedural complications had no negative clinical influence.

Clinical Outcome

An NIHSS score was available in 71 patients of the anterior and in 19 patients of the posterior circulation group.

The mean NIHSS score in the anterior circulation was 8.3 (standard deviation 5.7, min. 0, max. 22) after the treatment (15.3 at admission) and 7.0 (standard deviation 7.0, min. 0, max. 25.0) after treatment (16.1 at admission) in the posterior circulation.

Improvement of NIHSS scores was significant for 37 patients (52.1%) in the anterior and for 5 patients (25%) in the posterior circulation group. Improvement of NIHSS scores was not significant for 34 (47.9%) in the anterior and for 14 patients (75%) in the posterior circulation group.

Overall, the mean NIHSS score decreased by 7.8 points at the time of hospital discharge.

The overall mortality at discharge was 13/ 84 (15.5%) for the anterior and 11/23 (47.8%) for the posterior circulation group.

There were 2 cases of symptomatic periprocedural intracranial haemorrhage, both due to a perforation with the separator of the Penumbra device, but unrelated to the use of the Solitaire; 6 patients had evidence of subarachnoid haemorrhage, 2 of them potentially related to the Solitaire deployment, 3 due to microwire perforation and 1 for unknown reasons. All subarachnoid haemorrhages did not lead to severe clinical symptoms.

Subanalysis: Angio-to-Reperfusion-Time

During the initial period of introducing the Solitaire into our stroke treatment strategy, patients were still treated with other established thrombectomy systems. After the Solitaire had been proven to be superior to those, only very few patients were treated without the Solitaire. During the transition time, which was defined as the time between the first patient treated with the Solitaire and subanalysis of two patient groups who were treated by means of mechanical thrombectomy during

the introduction period of the Solitaire (41 patients treated without and 47 patients treated with the Solitaire), we found a significant reduction concerning the mean recanalization time: the mean angio-to-reperfusion time was 68.0 min (standard deviation 49.5, median 63, min. 17, max. 307 min) and 48.7 min (standard deviation 30.8, median 44, min. 5, max. 140 min) in the 47 patients who were treated with the Solitaire (Mann-Whitney U test: $p = 0.021$). The mean angio-to-reperfusion time for all 88 patients in our subanalysis was 57.7 min (standard deviation 41.5, median 53.0, min. 5, max. 307).

Discussion

Successful reperfusion is the most important factor determining the beneficial effects of any kind of stroke treatment [24]. Over the past few years, a number of different endovascular devices have been designed and proven to be efficient for recanalization of intracranial vessel occlusion. Recently, self-expanding stents and so-called stent retrievers have been introduced as a promising alternative to 'classical' thrombectomy as they seem to offer considerable advantages over them.

The Merci trial showed a good revascularization rate (TIMI 2 and 3) of 57.3% with the Merci device itself and of 69.5% in combination with intra-arterial thrombolysis [17]. In the Penumbra pivotal trial, the rate of revascularization was reported to be 81.6%. [18]. The available data on stent retrievers is limited, but the recanalization success that can be achieved with them seems to be higher compared to classical thrombectomy: in the series of 20 patients with a vessel occlusion in the anterior circulation, Castaño et al. [25] achieved a TICI 2b or 3 recanalization in 90% (18/20) within 8 h using the Solitaire device; Roth et al. [26] reported a successful TICI 2b/3 revascularization rate of 90.2% (20/22) in 22 consecutive patients with acute cerebral artery occlusions using the Solitaire. The recanalization rates in our study are similar to these series and comparable to the results of the reported results with self-expanding stents [27–31]: a good recanalization rate was achieved in 79% when assessed with the TICI scale (TICI 2b/3) and 92.5% when assessed with the TIMI score (TIMI 2/3).

With time to reperfusion being known as the other important predictor for a good clinical outcome [32, 33] a potential drawback of conventional thrombectomy is that reperfusion is achieved only after the entire thrombus has been removed from the occluded segment and thus towards the end of the procedure. Therefore, one

major advantage of stents is that they can displace the clot and create a channel that allows for immediate reperfusion of the dependent territory, thus potentially shortening the angio-to-reperfusion time. Despite promising results with reperfusion results of up to 100% in single reports [12, 27–30, 34], permanent stenting mandates the use of long-term platelet inhibition and may thus increase the inherent risk of symptomatic intracranial haemorrhage or bleeding complications during secondary interventions such as decompression craniotomy. Also, there has to be concern about early rethrombosis because the clot is not removed, but stented to the vessel wall through the stent struts. Self-expanding stents as the Enterprise stent (Cordis) can be used as a temporary endovascular bypass when not fully deployed, as first described by Kelly et al. [33] in 2008. Initially designed for stent-assisted coil embolization of wide-necked aneurysms [35–37], the Solitaire AB was the first fully retrievable (even when completely deployed) self-expanding stent that has been used for recanalization of intracranial vessel occlusion. The Solitaire FR is the certified version for thrombectomy. Recently, technical safety and efficacy for stroke treatment have been described in animal studies and small trials for the Solitaire AB and the Solitaire FR [38–41].

In the series of Castaño et al. [25], the mean number of passes for maximal recanalization was 1.4 with a median time from groin puncture to recanalization of 50 min (3–71). Roth et al. [26] achieved an immediate flow restoration in 21 of 22 (95.4%) cases after deployment of the device. The mean time from stroke symptom onset to recanalization was 277 min, with a standard deviation of 118 min. Similar to the results of Castaño et al. and Roth et al., in our study the mean onset-to-reperfusion time was 265 min (min. 56, max. 1,031; median 230 min), and the mean angio-to-reperfusion time was 47 min (min. 5, max. 186; median 38.5 min). Immediate flow restoration was achieved after the first deployment in 72.8% in our series (table 3). A subanalysis of 88 patients in our series showed a significant reduction of the reperfusion time when the Solitaire was used.

Differently from the reports of Castaño et al. and Roth et al., we saw occlusion of previously unaffected vessels due to loss of thrombotic material during the withdrawal of the Solitaire device in only 4 of 108 procedures, but could open all of them with the Solitaire stent later on. These cases were not treated in conjunction with a distal access/aspiration catheter, and loss of thrombus to a previously unaffected vessel has never occurred after we started to use distal aspiration.

Table 3. Reperfusion rate (n) after first, second and third deployments of the Solitaire

	Deployment		
	1st	2nd	3rd
TICI 2a	45	34	15
TICI 2b	12	8	11
TICI 3	8	1	5

Withdrawal of the stent could be performed easily in all cases. Only 1 Solitaire stent could not be delivered to the lesion due to extraordinary tortuosity of the vasculature, and the lesion could also not be reached with any other device. In 1 case, inadvertent detachment of the Solitaire occurred.

The rate of symptomatic intracranial haemorrhage after the procedure (2/108; 1.9%) in our series is lower than the reported rate of 5–22% in previous studies on intracranial stents/stent retrievers [27, 42, 43]. In both of our cases, intracranial haemorrhage was not related to the Solitaire, but due to a perforation with the Penumbra separator. We had 6 cases with proven subarachnoid haemorrhage, 2 of them potentially related to the Solitaire deployment, 3 due to microwire perforation and 1 for unknown reasons.

The possibility of vasospasm when withdrawing an unfolded stent has been described previously [43] and occurred in 14 of our 108 cases, all without any negative consequence for the patient. We did not see any dissection of an intracranial vessel after withdrawal of the Solitaire.

Although the technical success by means of a sufficient recanalization (TICI 2b/3) was not significantly different between the anterior and the posterior circulations (75 vs. 77.9%), there was an obvious difference in the clinical outcome at discharge between the two groups: whereas more than half of the patients with an anterior-circulation infarct improved significantly, two thirds of the clinical outcome of patients with an occlusion in the posterior circulation did not. The rate of mortality at discharge was also higher for the posterior circulation (47.8 vs. 15.5%). The best explanation for these differences should be the well-known and usually devastating natural course of posterior circulation infarctions, which could not be prevented by sufficient recanalization.

Our study confirms that stent retrieval with the Solitaire is safe and technically feasible for recanalization of acute intracranial artery occlusion. Treatment of intracranial arterial occlusion with the Solitaire combines the advantages of conventional self-expanding stents – immediate flow restoration after deployment in a significantly high number of cases – with sufficient clot retrieval, and without the risk of mandatory antiplatelet medication. Our data proved the superiority of stent retrievers over other thrombectomy devices by means of a significant decrease in angio-to-reperfusion time and higher recanalization rates, making the use of stent retrievers the first choice for endovascular treatment of intracranial vessel occlusion in our stroke centre.

Our study has several limitations. First of all, we cannot provide data on long-term clinical outcome, as well as clinical information such as onset-to-recanalization time. Second, it was not a randomized, controlled trial and, therefore, it has the limitations of case series methodology.

Conclusions

Our single-centre experience proves the technical feasibility and safety of the Solitaire for the treatment of acute intracranial vessel occlusion and approves previous reports with smaller patient numbers. Further multicentre studies with a randomized and prospective design will be necessary to verify the results.

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Disclosure Statement

Prof. Liebig is a consultant to ev3.

References

- 1 The world health report 2004. Annex table 2: deaths by cause, sex and mortality stratum in WHO regions, estimates for 2002. Geneva, World Health Organization, 2004.
- 2 Dewey HM, Thrift AG, Mihalopoulos C, Carter R, Macdonell RAL, McNeil JJ, Donnan GA: 'Out of pocket' costs to stroke patients during the first year after stroke – results from the north east Melbourne stroke incidence study. *J Clin Neurosci* 2004;11: 124–137.
- 3 Evers SM, Struijs JN, Ament AJ, van Genugten ML, Jager JH, van den Bos GA: International comparison of stroke cost studies. *Stroke* 2004;35:1209–1215.
- 4 The National Institute of Neurological Disorders and Stroke rt-PA Stroke Study Group: Tissue plasminogen activator for acute ischemic stroke. *N Engl J Med* 1995;333:1581–1587.
- 5 The NINDS t-PA Stroke Study Group: Intracerebral hemorrhage after intravenous t-PA therapy for ischemic stroke. *Stroke* 1997;28: 2109–2118.
- 6 Hacke W, Kaste M, Bluhmki E, Brozman M, Davalos A, Guidetti D, et al: Thrombolysis with alteplase 3 to 4.5 hours after acute ischemic stroke. *N Engl J Med* 2008;359:1317–1329.
- 7 Hacke W, Kaste M, Fieschi C, von Kummer R, Davalos A, Meier D, et al: Randomised double-blind placebo-controlled trial of thrombolytic therapy with intravenous alteplase in acute ischaemic stroke (ECASS II). *Second European-Australasian Acute Stroke Study investigators. Lancet* 1998;352:1245–1251.
- 8 Steiner T, Bluhmki E, Kaste M, Toni D, Trouillas P, von Kummer R, et al: The ECASS 3-hour cohort: secondary analysis of ECASS data by time stratification. ECASS study group. *European Cooperative Acute Stroke Study. Cerebrovasc Dis* 1998;8:198–203.
- 9 Wahlgren N, Ahmed N, Dávalos A, Ford GA, Grond M, Hacke W, et al: Stroke Monitoring Study investigators: Thrombolysis with alteplase for acute ischaemic stroke in the safe implementation of thrombolysis in stroke-monitoring study (SITS-MOST): an observational study. *Lancet* 2007;369:275–282.
- 10 Wahlgren N, Ahmed N, Davalos A, Hacke W, Millan M, Muir K, et al: Thrombolysis with alteplase 3–4.5 h after acute ischaemic stroke (SITS-ISTR): an observational study. *Lancet* 2008;372:1303–1309.
- 11 Shobha N, Buchan AM, Hill MD: Canadian Alteplase for Stroke Effectiveness Study (CASES): thrombolysis at 3–4.5 hours after acute ischemic stroke onset – evidence from the Canadian Alteplase for Stroke Effectiveness Study (CASES) registry. *Cerebrovasc Dis* 2011;31:223–228.
- 12 Gálldiks N, Zaro-Weber O, Dohmen C, Neveling M, Haupt WF, Fink GR, Sobesky J: Systemic thrombolysis with rt-PA in patients under 40 years of age: a subgroup analysis of the Cologne Stroke Experience. *Cerebrovasc Dis* 2010;30:514–518.
- 13 Schellinger PD, Kohrmann M, Hacke W: Thrombolytic therapy for acute stroke. *Handbook Clin Neurol* 2008;94:1155–1193.
- 14 Schellinger PD, Ringelb P, Hacke W: European Stroke Organisation 2008 guidelines for managing acute cerebral infarction or transient ischemic attack. Part 2. *Nervenarzt* 2008;79:1180–1184, 1186–1188, 1190–1201.
- 15 Del Zoppo GJ, Higashida RT, Furlan AJ, et al: PROACT: a phase II randomized trial of recombinant pro-urokinase by direct arterial delivery in acute middle cerebral artery stroke. PROACT Investigators. *Prolyse in Acute Cerebral Thromboembolism. Stroke* 1998;29:4–11.
- 16 Smith WS: Safety of mechanical thrombectomy and intravenous tissue plasminogen activator in acute ischemic stroke. Results of the multi Mechanical Embolus Removal in Cerebral Ischemia (MERCi) trial. Part I. *AJNR Am J Neuroradiol* 2006;27:1177–1182.
- 17 Smith WS, Sung G, Saver J, Budzik R, Duckwiler G, Liebeskind DS, et al: Mechanical thrombectomy for acute ischemic stroke: final results of the Multi MERCI trial. *Stroke* 2008;39:1205–1212.
- 18 Penumbra Pivotal Stroke Trial Investigators: The Penumbra Pivotal Stroke Trial: safety and effectiveness of a new generation of mechanical devices for clot removal in intracranial large vessel occlusive disease. *Stroke* 2009;40:2761–2768.

- 19 Yoshimura S, Egashira Y, Sakai N, Kuwayama N, Recovery by Endovascular Salvage for Cerebral Ultra-Acute Embolism-Japan retrospective survey group: Retrospective nationwide survey of acute stroke due to large vessel occlusion in Japan: a review of 1,963 patients and the impact of endovascular treatment. *Cerebrovasc Dis* 2011;32:219–226.
- 20 Rohde S, Bösel J, Hacke W, Bendszus M: Stent retriever technology: concept, application and initial results. *J Neurointerv Surg* 2011, E-pub ahead of print.
- 21 Costalat V, Marchi P, Lobotesis K, Maldonado I, Vendrell JF, Riquelme C, Mourand I, Milhaud D, Héroum C, Perrigault PF, Arquizán C, Bonafé A: Rescue, combined, and stand-alone thrombectomy in the management of large vessel occlusion stroke using the Solitaire device: a prospective 50-patient single-center study: timing, safety, and efficacy. *Stroke* 2011;42:1929–1935.
- 22 TIMI Study Group: Thrombolysis in Myocardial Infarction (TIMI) Trial: phase I findings. *N Engl J Med* 1985;312:932–936.
- 23 Higashida RT, Furlan AJ, Roberts H, et al: Trial design and reporting standards for intra-arterial cerebral thrombolysis for acute ischemic stroke. *Stroke* 2003;34:109–137.
- 24 Rha J-H, Saver JL: The impact of recanalization on ischemic stroke outcome: a meta-analysis. *Stroke* 2007;38:967–973.
- 25 Castaño C, Dorado L, Guerrero C, Millán M, Gomis M, Perez de la Ossa N, et al: Mechanical thrombectomy with the Solitaire AB device in large artery occlusions of the anterior circulation: a pilot study. *Stroke* 2010;41:1836–1840.
- 26 Roth C, Papanagiotou P, Behnke S, Walter S, Haass A, Becker C, et al: Stent-assisted mechanical recanalization for treatment of acute intracerebral artery occlusions. *Stroke* 2010;41:2559–2567.
- 27 Levy EI, Mehta R, Gupta R, Hanel RA, Chamczuk AJ, Fiorella D, et al: Self-expanding stents for recanalization of acute cerebrovascular occlusions. *AJNR Am J Neuroradiol* 2007;28:816–822.
- 28 Brekenfeld C, Schroth G, Mattle H, Do D, Remonda L, Mordasini P, Arnold M, et al: Stent placement in acute cerebral artery occlusion: use of a self-expandable intracranial stent for acute stroke treatment. *Stroke* 2009;40:847–852.
- 29 Levy EI, Siddiqui AH, Crumlish A, Snyder KV, Hauck EF, Fiorella DJ, et al: First Food and Drug Administration-approved prospective trial of primary intracranial stenting for acute stroke: SARIS (Stent-Assisted Recanalization in Acute Ischemic Stroke). *Stroke* 2009;40:3552–3556.
- 30 Mocco J, Hanel RA, Sharma J, Hauck EF, Snyder KV, Natarajan SK, et al: Use of a vascular reconstruction device to salvage acute ischemic occlusions refractory to traditional endovascular recanalization methods. *J Neurosurg* 2010;112:557–562.
- 31 Zaidat OO, Wolfe T, Hussain SI, Lynch JR, Gupta R, Delap J, et al: Interventional acute ischemic stroke therapy with intracranial self-expanding stent. *Stroke* 2008;39:2392–2395.
- 32 Humpich M, Singer OC, du Mesnil de Rochemont R, Foerch C, Lanfermann H, Neumann-Haefelin T: Effect of early and delayed recanalization on infarct pattern in proximal middle cerebral artery occlusion. *Cerebrovasc Dis* 2006;22:51–56.
- 33 Kelly ME, Furlan AJ, Fiorella D: Recanalization of an acute middle cerebral artery occlusion using a self-expanding, reconstrainable, intracranial microstent as a temporary endovascular bypass. *Stroke* 2008;39:1770–1773.
- 34 Zaidat OO, Suarez JI, Sunshine JL, Tarr RW, Alexander MJ, Smith TP, et al: Thrombolytic therapy of acute ischemic stroke: correlation of angiographic recanalization with clinical outcome. *AJNR Am J Neuroradiol* 2005;26:880–884.
- 35 Liebig T, Henkes H, Reinartz J, Miloslavski E, Kühne DA: Novel self-expanding fully retrievable intracranial stent (SOLO): experience in nine procedures of stent-assisted aneurysm coil occlusion. *Neuroradiology* 2006;48:471–478.
- 36 Klisch J, Clajus C, Sychra V, Eger C, Strasilla C, Rosahl S, et al: Coil embolization of anterior circulation aneurysms supported by the Solitaire AB neurovascular remodeling device. *Neuroradiology* 2009;52:349–359.
- 37 Klisch J, Eger C, Sychra V, Strasilla C, Basche S, Weber J: Stent-assisted coil embolization of posterior circulation aneurysms using Solitaire AB: preliminary experience. *Neurosurgery* 2009;65:258–266.
- 38 Papanagiotou P, Roth C, Walter S, Behnke S, Politi M, Fassbender K, et al: Treatment of acute cerebral artery occlusion with a fully recoverable intracranial stent: a new technique. *Circulation* 2010;121:2605–2606.
- 39 Castaño C, Serena J, Dávalos A: Use of the new Solitaire TM AB device for mechanical thrombectomy when MERCI clot retriever has failed to remove the clot: a case report. *Interv Neuroradiol* 2009;15:209–214.
- 40 Wehrschiuetz M, Wehrschiuetz E, Augustin M, Niederkorn K, Deutschmann H, Ebner F: Early single center experience with the Solitaire thrombectomy device for the treatment of acute ischemic stroke. *Interv Neuroradiol* 2011;17:235–240.
- 41 Stampfl S, Hartmann M, Ringleb PA, Haehnel S, Bendszus M, Rohde S: Stent placement for flow restoration in acute ischemic stroke: a single-center experience with the Solitaire stent system. *AJNR Am J Neuroradiol* 2011;32:1245–1248.
- 42 Levy EI, Ecker RD, Hanel RA, Sauvageau E, Wehman JC, Guterma LR, et al: Acute M2 bifurcation stenting for cerebral infarction: lessons learned from the heart: technical case report. *Neurosurgery* 2006;58:E588.
- 43 Roth C, Papanagiotou P, Behnke S, Walter S, Haass A, Becker C, et al: Stent-assisted mechanical recanalization for treatment of acute intracerebral artery occlusions. *Stroke* 2010;41:2559–2567.