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ORIGINAL ARTICLE

Stent-Retriever Angioplasty for Recurrent Post-Subarachnoid Hemorrhagic Vasospasm – A Single Center Experience with Long-Term Follow-Up

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Abstract

Purpose We report our experience of using stent-retrievers for recurrent cerebral vasospasm (CVS) secondary to aneurysmal subarachnoid hemorrhage (aSAH).

Methods We performed a retrospective review of our prospectively maintained institutional database to identify all patients with recurrent CVS and treated with stent-retrievers between April 2011 and May 2017. All patients were initially treated with intra-arterial (IA) vasodilators and were subsequently re-treated with stent-retrievers if they developed recurrent vasospasm. Patients were categorized into two groups, those in which IA vasodilators were given again prior to the stent-retriever deployment (VD-first) and those in which the stent-retriever was deployed first and IA vasodilators were given subsequently (SR-first).

Results We identified 12 patients (7 females, mean age 54.9 years), 5 in the VD-first and 7 in the SR-first cohorts. Stent-retriever lumen dilatation was attempted in 53 segments (VD-first 14, SR-first 39). Stent-retriever deployment was technically feasible in all cases. Vasodilation occurred in 71.4% (10/14 segments) in the VD-first group and 82.1% (32/39 segments) in SR-first group. Additional treatment was required in 5 segments. There was no recurrent vasospasm in the SR-first group; however, 3 patients (60%) in the VD-first group showed recurrent vasospasm. No angiographical abnormality was found at long-term follow-up (7 patients, mean 29.1 months).

Conclusion The use of stent-retrievers to treat cerebral vasospasm is technically feasible and can cause long-term vasodilatation; however, this effect is maximized if stent-retrievers are used prior to infusion of IA vasodilators.

Keywords SAH · Angioplasty · Recurrent vasospasm · Stentriever

Abbreviations

Stentriever	Stent-retriever
TBA	Transluminal balloon angioplasty

Introduction

Cerebral vasospasm (CVS) is the most important cause of severe delayed neurological deterioration in aneurysmal subarachnoid hemorrhage (aSAH) patients and the challenge for the surgeon is its frequent recurrence [1]. The two most commonly used interventional treatment modalities for CVS today are transluminal balloon angioplasty (TBA) and chemical angioplasty using vasodilators [2–4]. Although the former has shown faster vasodilating effects and lower rates of recurrence [5, 6] than the latter [7], the risk of vessel injury, potential additional ischemic insults due to flow occlusion [8], and technical difficulty in delivering the balloon to the spastic vessel segments are no doubt greater with balloon angioplasty [9].

Although the radial force of the available stent-retrievers (stentrievers) is much lower than that of balloons, we be-

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Table 1 Clinical and radiological findings of the patients in the vasodilator-first group

Patients no.	Age (years)	Fisher grade	H-H grade	Aneurysm location	Initial angioplasty	Stentriever angioplasty	Devices used
1	40s	4	2	Left a-com	PID #6	In 1 day	Solitaire
2	50s	4	4	Left MCA	PID #8	In 2 days	Solitaire
3	50s	3	3	Right a-com	PID #6	In 3 days	Solitaire
4	40s	4	2	Left a-com	PID #10	In 1 day	Solitaire
5	50s	3	4	Right p-com	PID #10	In 2 days	Solitaire

H-H Hunt & Hess, *a-com* anterior communicating artery, *PID* post-ictus day, *Solitaire* Solitaire stentriever 4 × 20 mm, *MCA* middle cerebral artery, *p-com* posterior communicating artery

Table 2 Clinical and radiological findings of the patients in stentriever-first group

Patients no.	Age (years)	Fisher grade	H-H grade	Aneurysm location	Initial angioplasty	Stentriever angioplasty	Devices used
6	40s	3	2	Right p-com	PID #7	in 3 days	Solitaire 4 × 30
7	80s	4	4	Right p-com	PID #6	in 3 days	Solitaire 4 × 20
8	70s	4	4	Left ICA dorsal wall	PID #10	in 3 days	Solitaire 4 × 30
9	40s	3	2	Left MCA	PID #6	in 2 days	Trevo 4 × 20
10	40s	2	2	Right SCA	PID #6	in 1 day	Trevo 6 × 25
11	60s	3	2	Right a-com	PID #7	in 1 day	Trevo 6 × 25
12	60s	4	2	Left AICA	PID #12	in 3 days	Revive 4.5 × 22

H-H Hunt & Hess, *PID* post-ictus day, *p-com* posterior communicating artery, *MCA* middle cerebral artery, *SCA* superior cerebellar artery, *a-com* anterior communicating artery, *AICA* anterior inferior cerebellar artery

lieve that they may be of use in treating CVS and recently other groups have published their results of using stentrievers to treat CVS [10, 11]. Here we report our own experience with long-term results of using commercially available stentrievers to treat CVS in patients with recurrent CVS following the initial use of intra-arterial (IA) vasodilators.

Materials and Methods

Population

We retrospectively searched our prospectively maintained database to identify all patients admitted to our tertiary referral neurosurgery center with aSAH between April 2011 and May 2017. We identified 198 patients with aSAH and of these patients, 41(20.7%) showed symptomatic delayed CVS postoperatively despite medical management in line with best medical practice. Of the 41 patients that initially underwent IA vasodilator treatment for medically refractory CVS, 12 patients (29.3%) showed a recurrence of symptomatic CVS post-procedurally. Stentriever angioplasty was performed in these patients after confirmation of CVS on catheter angiography. After review of the medical records and angiographic images the patients treated with stentrievers were divided into two groups, those treated with IA vasodilators prior to deployment of the stentriever (vasodilator-first group) and those treated with the stentriever followed by infusion of IA vasodilator (stentriever-first group). Note that all of these patients had previously been treated with IA vasodilators and had developed recurrent CVS (Tables 1 and 2).

Image Analysis and Grading

We graded each spastic segment as mild (luminal narrowing < 50%), moderate (50% < luminal narrowing < 70%), and severe (luminal narrowing > 70%) vasospasm according to the most spastic point in each segment. After angioplasty procedures, we evaluated each segment as dilated if the diameter of the target vessel had increased to more than 80% of normal diameter. The development of moderate or severe vasospasm following initial treatment with IA vasodilators was classified as recurrent vasospasm.

Initial Treatment for Medically Refractory Cerebral Vasospasm

Our standard practice when patients develop medically refractory delayed CVS is to initially use IA vasodilators. Cerebral catheter angiography was conducted when the neurological status of patients deteriorated with no other identifiable cause. Initially, via 5 Fr right femoral access, angiography of the cerebral vessels was performed to assess the extent and severity of CVS. After confirmation of the CVS and correlation with the patients' symptoms,

the angiographic catheter was exchanged for a 5 Fr guide catheter (Envoy, Codman, Raynham, MA, USA). An Echelon 10 microcatheter (Covidien, Irvine, CA, USA) was tracked into the proximal spastic segment and 3–5 mg of nicardipine (Perdipine; Astellas, Shizuoka, Japan) was manually infused via a 1 ml syringe over a period of 15 min. Angiography was performed at the end of the procedure to confirm a satisfactory vasodilation.

Treatment for Refractory Cerebral Vasospasm Following IA Vasodilator Treatment

All procedures in both of the groups were carried out with the patient under general anesthesia and full heparinization. A bolus of heparin (3000 IU) was administered after the decision to perform angioplasty using a stentriever, delivering hourly bolus doses (1000 IU/h) thereafter, and activated clotting times were monitored.

Vasodilator-first Group

During our early experience using stentrievers we initially began the procedure by infusing 2–3 mg of IA nicardipine using the same technique as described above. Following this a microcatheter (Prowler Select plus, Codman, Raynham, MA) was tracked over a Synchro microguide wire (Stryker, Kalamazoo, MI, USA) to the spastic segment after which a Solitaire 4 × 20 mm stentriever (Medtronic, Irvine, CA, USA) was tracked in the microcatheter and unsheathed. Mostly stentriever angioplasty was attempted in a proximal segment of the spastic vasculature. We did not perform any forward loading of the stentriever. The stentriever was deployed for approximately 3 min after which the stentriever was re-sheathed. Magnified angiographic runs were performed prior to and during deployment of the stentriever and again immediately after re-sheathing in order to assess the degree of caliber change. In the case of persistent vasospasm the stentriever was re-deployed using the same method (unsheath-resheath). We did not drag the stentriever through the vasculature in a manner similar to that used when performing mechanical thrombectomy so as to minimize any potential endothelial damage and iatrogenic vasospasm.

Stentriever-first Group

Stentriever angioplasty was attempted in a distal to proximal direction within the spastic vasculature, i.e. starting in the most distal spastic segment possible and then moving proximally. The same technique of unsheathing-resheathing and 3 min deployment was used for each segment treated. This technique was used later in our experience after we noticed recurrent vasospasm in several of the stentriever treated segments after IA vasodilators were given. When the effect of the stentriever was insufficient, especially for the proximal vessel segment, TBA using a non-compliant Maverick balloon (Boston Scientific, Natick, MA, USA) with diameter of 80% of the pre-vasospasm vessel was performed. Then 2–3 mg of intra-arterial nicardipine was infused using a microcatheter for all of the patients in this group for further small vessel vasodilatation. Nicardipine was not infused in this group until all of the accessible spastic segments had been treated with the stentrievers.

Follow-up

Usually early follow-up catheter angiography was performed on the next day and delayed angiographic follow-up was performed at the operator's discretion according to the patient's neurological condition and the status of the treated aneurysm(s). Clinical assessment was performed using the National Institutes of Health Stroke Scale (NIHSS) during peri-vasospasm period and modified Rankin Scale (mRS) at discharge.

Results

Vasodilator-first Group

Vasodilator-first angioplasty was performed in 5 patients with recurrent vasospasm. A total of 14 spastic vessel segments were treated. The mean age was 48.6 years (range 42–54 years), and all of the patients except one had an endosaccular coil embolization for ruptured aneurysm. The initial treatment using IA nicardipine was performed at mean 8 days postictus (range, 6–10 days). The recurrent treatment was performed after mean 1.8 days (range, 1–3 days). Patients' demographics and clinical characteristics are summarized in Table 1. Severe (luminal narrowing > 70%) and diffuse vasospasm was observed in the majority of the patients and we performed the procedure on 2–5 vessel segments for each patient. The Solitaire 4 × 20 mm stentriever was successfully used in all cases. Infusion of 2–3 mg of nicardipine through a microcatheter in the proximal intradural internal carotid artery (ICA) was performed prior to stentriever deployment in all of these cases. Most of the vessel segments were proximal (ICA, M1, A1) and showed vasodilation after temporary deployments of stentrievers (10/14, 71.4%) with a persistent vasodilatory effect seen following resheathing of the stentriever. Early follow-up catheter angiography was performed in all of the patients and 3 (3/5, 60%) patients showed radiological and clinical evidence of significant recurrence requiring repeat angioplasty until resolution of the symptomatic CVS (Fig. 1). In this cohort 3 patients with 7

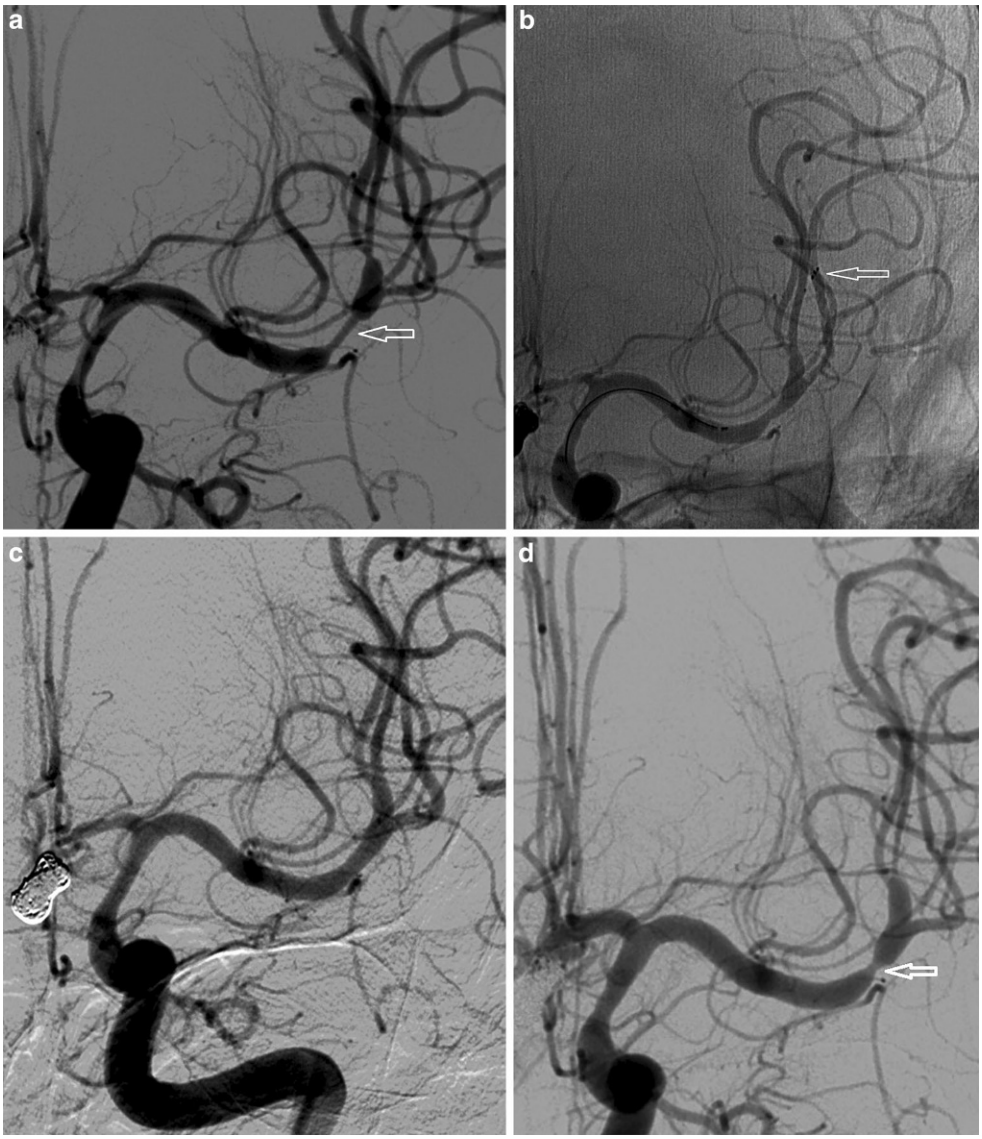

Fig. 1 Patient no. 1. **a** Initial angiogram on postictus day 7. Focal vasospasms (*arrow*) in left distal M1 and multiple proximal M2s are noted. **b** After intra-arterial infusion of 3 mg nicardipine at proximal middle cerebral artery (MCA), a Solitaire (4 × 20 mm) stentriever is temporarily deployed in M12 (*arrow*) showing moderate vasodilatation. *Arrow* distal marker of Solitaire. **c** Angiogram after finishing vasodilator and stentriever angioplasty. **d** Follow-up angiogram on the next day showing some recurrence of vasospasm on previous spastic segment of M1 (*arrow*) and proximal M2s

(50%) segments treated with stentriever underwent delayed follow-up catheter angiography at mean 44.3 months (range, 13–72 months) with no evidence of vascular injury or abnormality (Table 3).

Stentriever-first Group

Stentriever-first angioplasty was performed in 7 patients with recurrent vasospasm involving 39 spastic vessel segments. The mean age was 59.4 years (range, 42–85 years) and all the patients had endosaccular coil embolization for the ruptured aneurysm. Initial IA vasodilator was infused at mean 7.7 days postictus (range, 6–12 days). The stentriever angioplasty was performed after mean 2.6 days (range, 1–3 days). Patients' demographics and clinical characteristics are summarized in Table 2. Severe and diffuse vasospasm was observed in most of the patients and we performed the procedures on 2–12 vessel segments for each patient. The three available stentrievers (Solitaire, Trevo, Stryker and Revive, Codman) were used and we succeeded in delivering the device at the spastic segments in all of the cases without prior IA vasodilator infusion. The operator, as well as the location of the vasospastic segment, determined the choice of stent-retriever. The majority of the vessel segments showed satisfactory vasodilation after temporary deployment of stentrievers (32/39, 82.1%) with persistent vasodilatation after the retrieval of the device. The spastic segments that did not show a response to stentriever angioplasty were predominantly located proximally (ICA and M1 segments, 6/10, 60%). Transluminal balloon angioplasty was performed in the non-responsive vessel segments when available. Additional infusion of nicardipine was performed at the end of the procedure with further mild vasodilation seen in most segments (37/39, 94.9%). There

Table 3 Procedural details, clinical and radiological results and recurrence of the patients in vasodilator-first group

Patients no.	Total segments	Dilated segments	Non-dilated segments	Nicardipine dose	Symptom relief	Immediate f/u	Recur	Complication	mRS score at discharge	TFCA f/u
1	3	Rt M1(S) Lt M1-2(M) Lt A1(M)	–	Rt 2 mg Lt 3 mg	Partial	TFCA	Yes	No	1	13 months
2	2	Rt M1-2 × 2 (S,M)	–	Rt 3 mg	No	TFCA	No	Thrombosis – Tirofiban	2	3 days
3	2	Rt M1(S) Rt A1(M)	–	Rt 3 mg	Complete	TFCA	No	No	0	72 months
4	2	–	Rt M1(M) Lt M1(S)	Rt 3 mg Lt 3 mg	No	TFCA	Yes	No	5	48 months
5	5	Lt M1(S) Rt A1(M) Lt A1(M)	Lt ICA(M) Rt M1(S)	Rt 3 mg Lt 3 mg	Partial	TFCA	Yes	No	4	5 days

Nicardipine was infused intra-arterially before stentriever angioplasty in this group. Dilated if the diameter of target vessel is increased to more than 80% of normal diameter. Recur if decrease of diameter to less than 50% of normal diameter

f/u follow-up, *mRS* modified Rankin Scale, *TFCA* transfemoral cerebral angiography, *Rt* right, *M1* middle cerebral artery M1 segment, *Lt* left, *M1-2* middle cerebral artery M1 and M2 segments, *A1* anterior cerebral artery A1 segment, *S* preprocedural severe vasospasm (luminal narrowing > 70%), *M* preprocedural moderate vasospasm (50% < luminal narrowing < 70%)

was no radiological evidence of recurrent vasospasm seen in this cohort (Figs. 2, 3 and 4). The majority of the patients (6/7, 85.7%) improved neurologically. Immediate follow-up study was done by catheter angiography except for 1 patient and 4 patients with 25 (64.1%) vessels treated by stentriever angioplasty underwent delayed follow-up catheter cerebral angiogram after a mean of 17.8 months (range, 5–29 months) and no evidence of vascular injury or abnormality was found (Table 4).

Complications

There were three complications (25%), one in the vasodilator-first cohort and two in the stentriever-first cohort. None of the complications resulted in permanent clinical sequelae and there were no mortalities related to this treatment. In the vasodilator-first cohort a distal segment of MCA (M2) was found to be occluded in one patient but resolved with the administration of intra-arterial 1.0 mg tirofiban (patient no. 2). In the stent-retriever first cohort one distal segment of MCA (M3) was found to be occluded in one patient but resolved with the administration of intra-arterial 0.5 mg tirofiban (patient no. 7). No anti-platelet drug premedication was taken before the procedures in any of the patients. In one patient, delayed contrast leakage was seen distal to a stentriever-angioplastied MCA segment (M3). The stentriever had not been deployed at the site of the contrast leakage and we confirmed a fine cortical branch arising at the injury point, which was overlapped by another vessel on angiogram and shielded. We believe the injury was caused by the microwire tip during navigation of the microcatheter. The ruptured vessel was occluded with detachable coils without any aggravation of patient's neurological condition (patient no. 8, Fig. 5).

Discussion

Cerebral vasospasm is a well-known complication in aSAH patients that can lead to severe permanent neurologic deficits. Chemical angioplasty using a vasodilator often demonstrates only transient antispasmodic effects, and it carries the risk of systemic hypotension and intracranial hypertension, especially with the administration of large doses [12, 13]. An alternative option is TBA, which has shown more rapid and sustainable improvement. Although

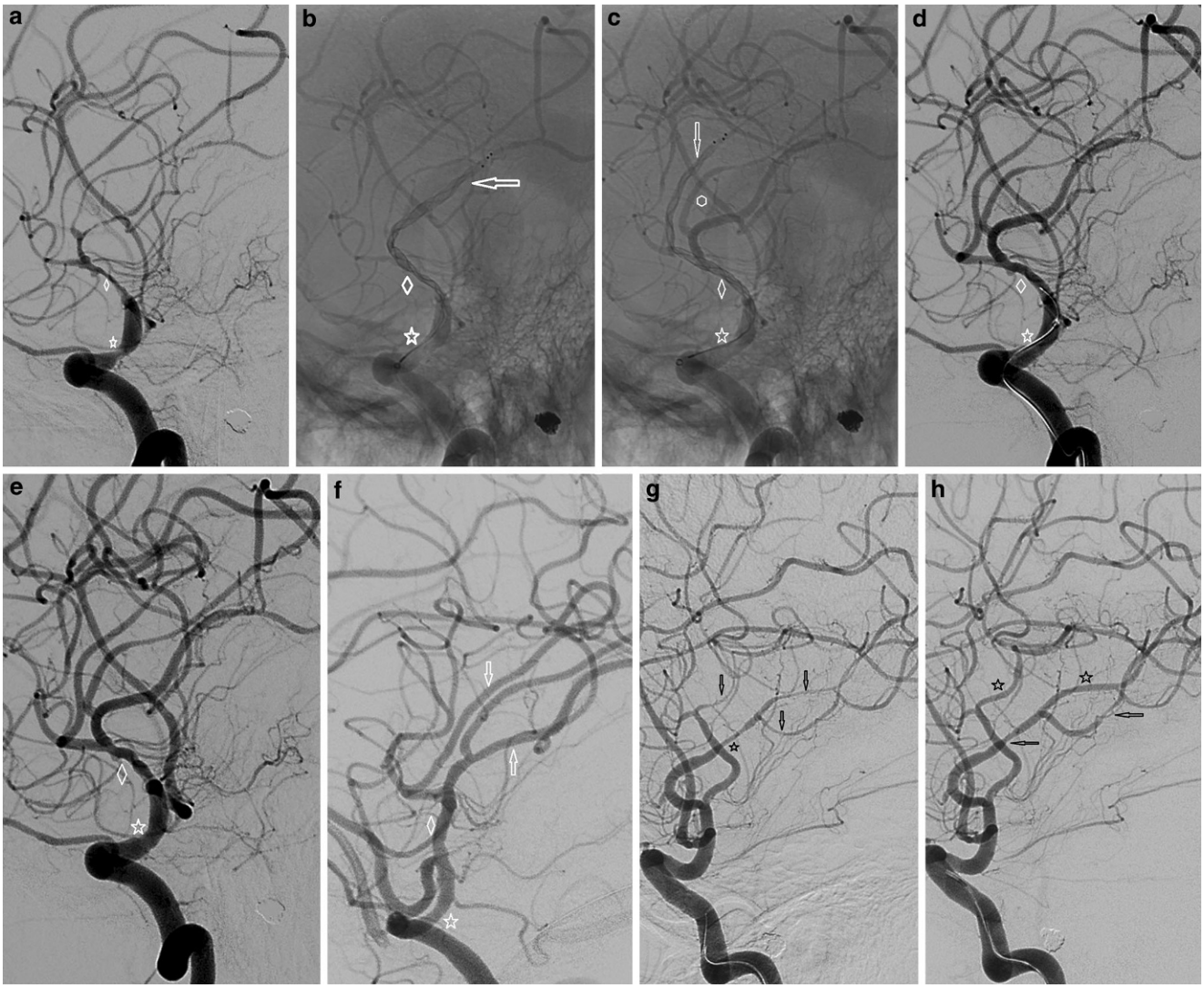

Fig. 2 Patient no 10. **a** Initial angiogram on postictus day 7. Vasospasms in right distal ICA (*star*), M1 (*diamond*), multiple proximal M2s are noted. **b** Trevo (6 × 25 mm) stentriever is temporarily deployed in inferior M2 branch (*arrow*) showing sufficient vasodilatation. **c** Similar vasodilatation is attained by the same stentriever in the superior M2 branch (*arrow*). Another M2 branch between the two M2s was already dilated in the same way (*hexagon*). **d** Angiogram after finishing mechanical angioplasty using stentriever only. **e** Angiogram after additional intra-arterial infusion of 3 mg nicardipine at distal ICA. **f** Angiogram at 14 months follow-up showing no evidence of vessel abnormality in the angioplastied distal segments (*arrows*) with Trevo stentriever. Also, note that the vasospasm of the distal ICA (*star*) and M1 (*diamond*) is resolving more and more as the procedures progress before the infusion of nicardipine (**a–d**). **g** Vasospasm in left distal M1 (*star*) and 3 M2s (*arrow*) are noted. **h** Vasodilatation of 2 M2s are attained (*stars*) while remaining vasospasms in distal M1 and M2 (*arrows*) are shown at post-stentriever angioplasty angiogram

TBA has proven therapeutically effective, the possibility of vessel injury and challenges with distal navigation are limitations to its use for most neurointerventionists.

The use of stentrievers has revolutionized the management of thromboembolic stroke and although these devices have not been designed to treat vasospasm we believed that they may be of use. At first, considering the relatively low radial force, we tried to use this device only to enhance the effects of vasodilator medications and temporarily deployed the stent-retrievers into the spastic vessel segments after IA vasodilator infusion. This approach did seem to result in more marked and rapid dilatation of the treated segments than the use of nicardipine alone even in larger vessels such as the terminal ICA. Interestingly we also noted that an improvement in the caliber of the proximal vessels had a downstream effect with reduction in the vasospasm of the distal vasculature. This caliber change occurred only after the deployment of the stentriever and so cannot be explained easily by the earlier infusion of the vasodilator. A similar effect was noted by Bhogal et al. [11] in one of their patients; however, recurrence of vasospasm was noted in 3 patients (3/5, 60%; Fig. 1; Table 3) and we thought that preceding use of vasodilator before mechanical vasodilatation might diminish the durability. It is similar with the be-

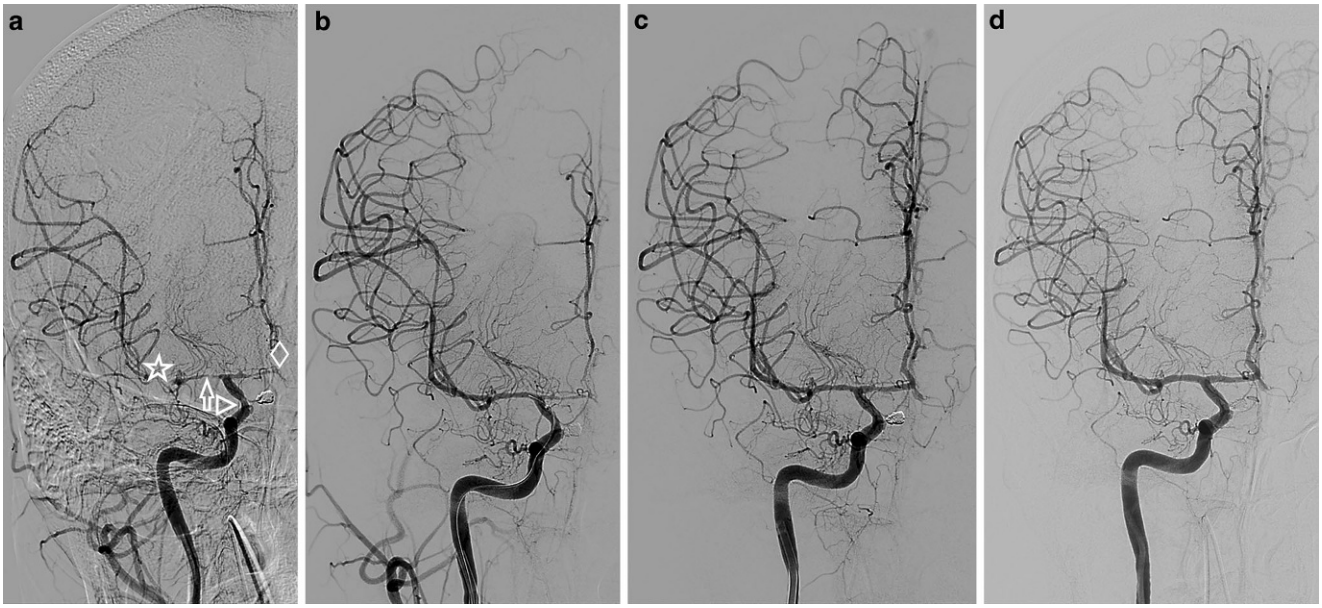

Fig. 3 Patient no. 10. **a** Initial anteroposterior angiogram with severe vasospasm extending from distal ICA (*triangle*) to M1 (*arrow*) and M2 (*star*). Same status is noted in ACA (*diamond*) also. **b** Angiogram after mechanical angioplasty using Trevo (6 × 25 mm) stentriever showing dilated M1, M2s and even distal ICA. **c** Angiogram after additional intra-arterial nicardipine 3 mg infusion, A1 has also been angioplastied with stentriever before infusion of vasodilator. **d** Follow-up angiogram on the next day shows no evidence of vasospasm on angioplastied vessels by stentriever

lief that TBA is most effective if it is performed before the administration of intra-arterial vasodilators [2]. Although the number of patients in this cohort is too small for statistical significance and the complication rate increases in the stentriever-first group, we do believe that stentriever angioplasty should be done before vasodilator infusion. The reason that chemical vasodilatation prior to the stent-retriever deployment appears to be less effective at causing prolonged vasodilatation is unknown; however, this effect has been seen by other groups. Fischell et al. [14] previously observed that arterial paralysis can be induced after balloon angioplasty; however, significantly less stretch was required to achieve the same degree of arterial paralysis if the vessel was in a contracted state. This suggests that arterial contraction somehow predisposes a vessel to arterial paralysis following mechanical dilatation. Other groups [15] have also shown similar results but the underlying reason for this difference is yet to be deduced. Furthermore, we noticed that the main contributor of the vasodilation effect could not be discriminated between the vasodilator and the stentriever if the infusion was performed first. We also expected that these devices would more easily dilate the distal vessels, which have a smaller diameter and thinner wall. Therefore, we changed our protocol to combine TBA for proximal larger vessel segments and start mechanical angioplasty using stentriever from the most distal vessel segments possible and proceed retrogradely. Importantly in this cohort we infused vasodilator intra-arterially only after completion of stentriever vasodilation meaning that the differential effects of the stentriever and vasodilator can be more easily determined. The results of the 7 patients in the stentriever-first cohort confirmed that stentrievers can effectively dilate the distal segment sufficiently without the help of vasodilators and the use of stentrievers first appears to reduce recurrence of cerebral vasospasm postprocedurally ($p = 0.045$, Fisher's exact test; Figs. 2, 3 and 4, Table 4).

Bhogal et al. [11] recently reported their initial experience using a similar method. Although they reported no recurrences even in their 2 cases that used vasodilator concomitantly or prior to the stentriever, based on our experience we believe that it is better to deploy the stentriever first and infuse vasodilator medication second as this appears to limit the risk of recurrence. We believe that stentriever-based lumen dilatation represents a potential alternative strategy for the treatment of delayed CVS especially in the distal vessel segments and it may offer advantages over TBA in that it does not restrict cerebral blood flow nor is the sizing of vessels as crucial as with balloons especially if the original size of the vasospastic vessel is unknown. The trackability of modern stentrievers also makes treating more distal segments easier and the experience of interventionists with stentrievers, thanks to thrombectomy, is likely to far exceed that of balloon angioplasty meaning that those with less experience may be able to more safely perform stentriever angioplasty treatment. Although the number of cases is limited, our long-term follow up results shows the safety of the procedure on the vessel wall integrity.

Based on our own experiences, it is reasonable to consider TBA for distal ICA and proximal MCA. The radial forces of the presently available stentrievers are not suf-

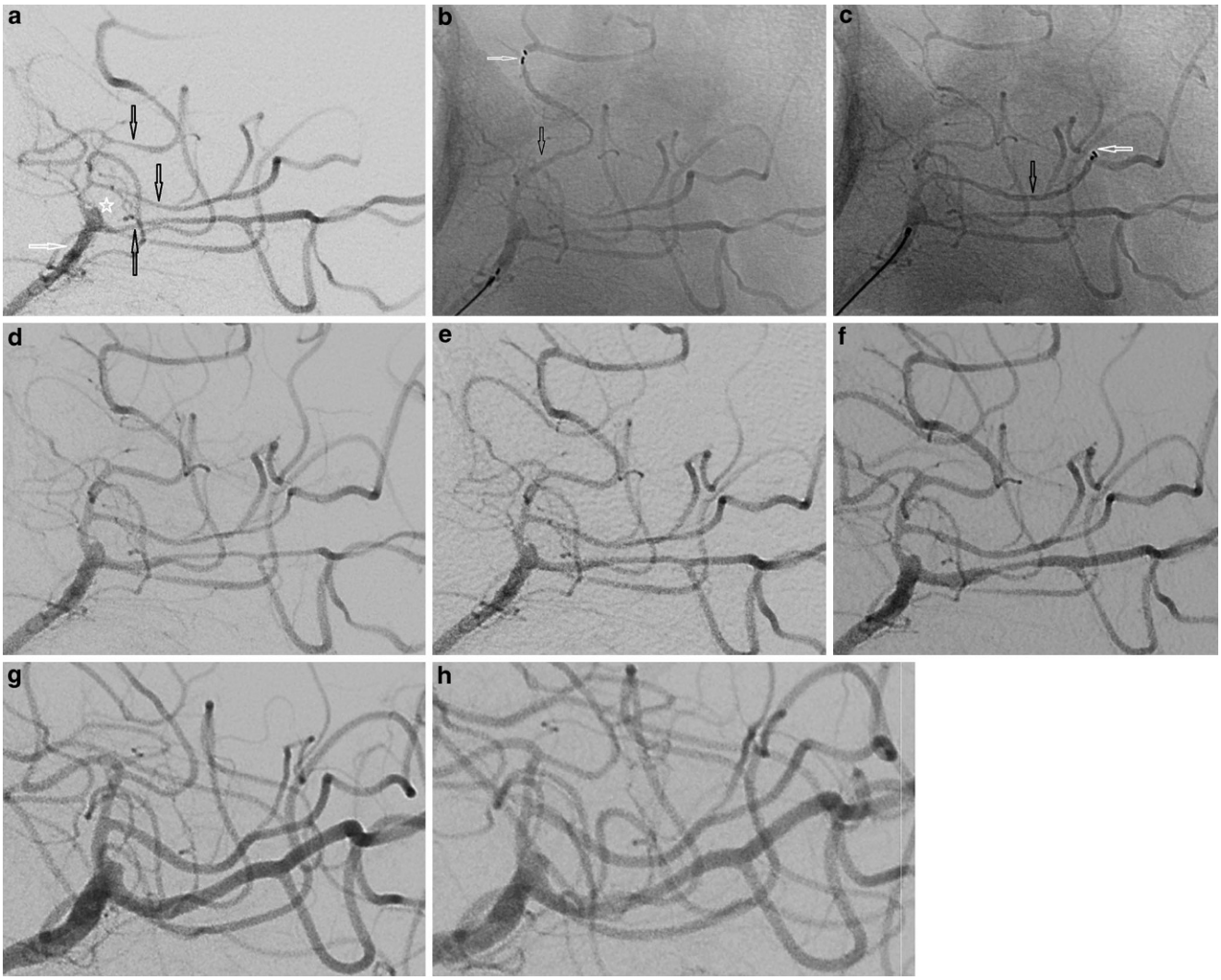

Fig. 4 Patient no. 6. **a** Initial angiogram on postictus day 10 showing multiple spastic M2s (*black arrows*) and incidental tiny aneurysm (*star*) on MCA bifurcation. *White arrow* M1. **b**, **c** Mechanical angioplasty using Solitaire (4 × 30 mm) stentriever in the spastic M2s (*black arrow*). *White arrow* distal marker of Solitaire stentriever. **d** Angiogram after finishing mechanical angioplasty using stentriever only. **e** Angiogram after additional intra-arterial infusion of 3 mg nicardipine at M1. **f** Follow-up angiogram on the next day shows no evidence of recurrence on proximal vessels. **g**, **h** Angiogram at 10 and 29 months follow-up showing no evidence of vessel abnormality in the previously angioplastied M2s. No significant interval growing of tiny MCA bifurcation aneurysm is also noted

ficient for these relatively large vessel segments although successful results have been published [10]. We found that stentrievers with 4 mm diameter were not sufficiently effective to treat the distal ICA, proximal M1 and even sometimes larger M2 branches (Table 4); however, we have also seen cases where the proximal M1 and even distal ICA can be dilated by the stentriever with a larger diameter. This may be a result of the difference in the radial force between the different stents, stents of different size, and the different designs of the various available stentrievers [16]. We also noted interesting effects on the proximal vasculature when distal vasospasm was treated and vice versa. For example, in Fig. 2 (patient no. 10) the diameters of the proximal MCA and even distal ICA increased gradually as the number of distal segments dilated by the stentrievers increased. A dedicated device with more radial force and better vessel wall opposition may increase the feasibility and efficacy even in the larger and highly angulated arteries.

The risk of thromboembolism (2 patients) and vessel injury (1 patient) during microwire and microcatheter navigation, stentriever deployment still exists. Considering that the 2 patients with intraprocedural thrombus did not show any clinical difference in age, frequency of vasospasm, severity of SAH, and severity of spasm, we suggest patients undergoing stentriever lumen dilatation should be fully heparinized and even premedication with anti-platelet agents be considered according to operator's discretion. Similarly,

Table 4 Procedural details, clinical and radiological results and recurrence of the patients in stentriever-first group

Patients no.	Total segments	Dilated Segments	Non-dilated segments	Nicardipine dose	Symptom relief	Immediate f/u	Recur	Complication	mRS score at discharge	TFCA f/u
6	7	Rt M2 × 3 (S,S,M) Rt A1-2(S) Lt A1-2(S)	Rt ICA (M)-TBA Rt M1(M)-TBA	Rt 3 mg	Complete	TFCA	No	No	0	29 months
7	2	Rt M1(S) Rt M2(S)	–	Rt 2 mg	Partial	CTA	No	Thrombosis—Tirofiban	6	5 days
8	4	Rt M2 × 3(S,M,S)	Rt M1 (S)-TBA	Rt 2 mg	No	TFCA	No	Distal vessel injury—trapping	5	1 month
9	3	Lt M1(S) Lt A1-2(S)	Lt ICA (S)-TBA	Lt 3 mg	Complete	TFCA	No	No	0	23 months
10	12	Rt M1(S) Rt M2 × 3(S,S,S) Lt M2 × 2(M,M) Rt A1-2(S) Rt P1-2(M) Lt P1-2(M) BA(M)	Lt M1(S)* Lt M2(S)*	Rt 3 mg Lt 3 mg BA 3 mg	Partial	TFCA	No	No	3	14 months
11	3	Rt M1(M) Rt A1-2(S) Lt A1-2(S)	–	Rt 2 mg Lt 2 mg	Complete	TFCA	No	No	0	5 months
12	8	Rt M2 × 3(S,S,S) Lt M2 × 2(S,S) Rt A1-2(S) Lt A1-2(S)	Lt M1(S)-TBA	Rt 2 mg Lt 2 mg	Complete	TFCA	No	No	2	1 day

Nicardipine was infused intra-arterially after stentriever angioplasty in this group. Dilated if the diameter of target vessel is increased to more than 80% of normal diameter. Recur if decrease of diameter to less than 50% of normal diameter

*Non-dilated segment at the end of procedure

f/u follow-up, *mRS* modified Rankin Scale, *TFCA* transfemoral cerebral angiography, *CTA* CT angiography, *Rt* right, *Lt* left, *M1* middle cerebral artery M1 segment, *M2* middle cerebral artery M2 segment, *A1-2* anterior cerebral artery A1 and A2 segments, *P1-2* posterior cerebral artery P1 and P2 segments, *BA* basilar artery, *TBA* transluminal balloon angioplasty using a non-compliant Maverick balloon (Boston Scientific, Natick, MA) with diameter of 80% of prevasospasm vessel, *S* preprocedural severe vasospasm (luminal narrowing > 70%), *M* preprocedural moderate vasospasm (50% < luminal narrowing < 70%)

manipulation of the guidewire and microcatheters, and deployment of the stents should be performed under high magnification and with due care and for the treatment of more distal vasospasm we would advocate treatment with the patient under general anesthesia. In addition, further research to determine the adequate duration of temporary deployment to maximize the vasodilatory effect and minimize the thromboembolism is necessary. Although prior administration of low-dose vasodilator into proximal portion of the spastic vessel before wire navigation could be performed and may aid safer catheter navigation, this may have a consequence of a higher recurrence rate as was seen in our study; however, this again may be mitigated by purposefully designed stents. Using a softer tip version microwire such as Synchro2 soft tip can also help reduce vessel injury from the microwire.

The current study demonstrates encouraging long-term treatment results for recurrent post-hemorrhagic CVS; however, larger studies are mandatory to determine the safety and efficacy of this technique and these should ideally be performed with dedicated stents with higher radial force and smaller cell size to optimize vessel wall contact. Ideally, histological analysis should be performed in order to determine the mechanism of action of stent-based lumen dilatation as well as the effects on the various cellular structures of the vessel wall.

Our study has several limitations inherent to its retrospective nature. First, the small sample size and use of the stentrievers only in recurrent CVS make generalizability difficult. Similarly, a variety of different stentrievers were used making interpretation of the individual stent properties difficult. Second and most importantly, the possibility of natural improvement of vasospasm should not be excluded.

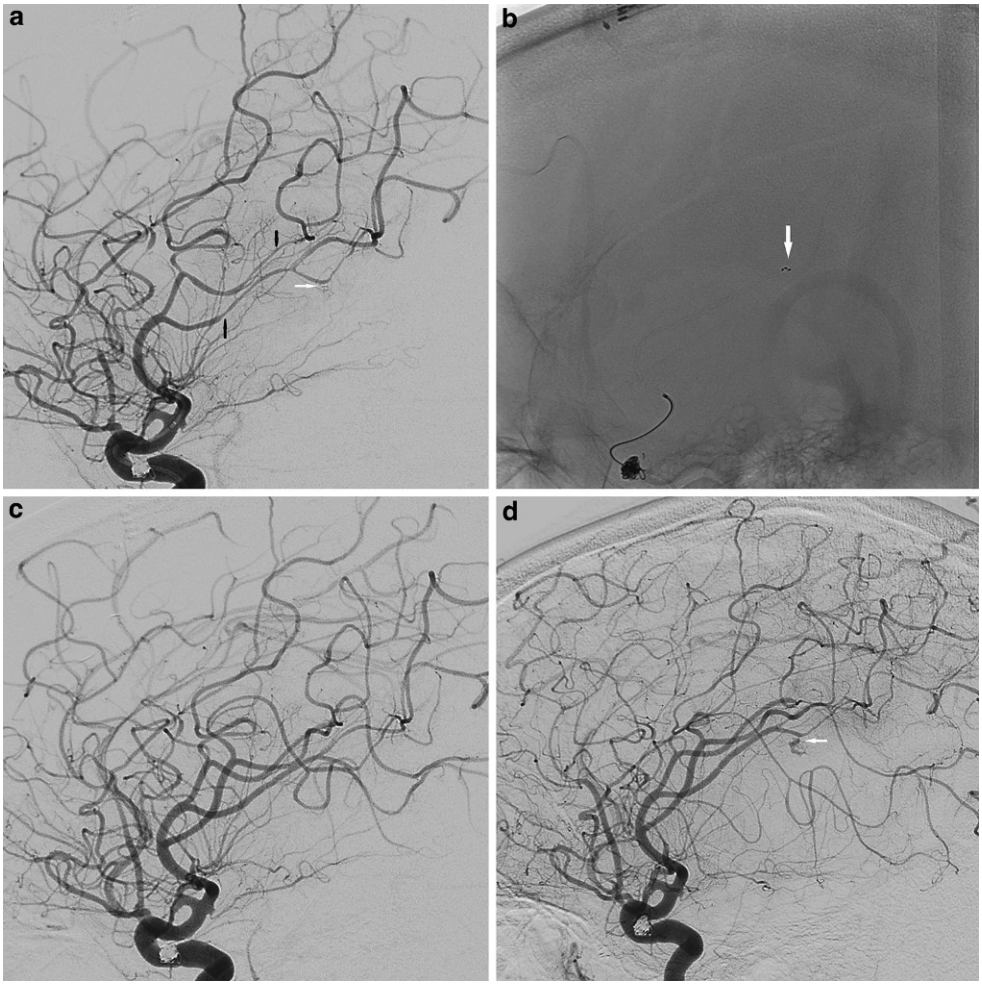

Fig. 5 Patient no. 8. **a** Initial angiogram on postictus day 13 showing multiple spastic M2 segments (*black arrows*). The *white arrow* indicates fine branch arising at the distal curved segment. **b** Deployed Solitaire (4 × 30 mm) stentriever in the spastic M2 segments is shown not covering the distal curved fine branch segment (*arrow* points to the distal marker of the stent). **c** Angiogram after stentriever plus vasodilator angioplasty shows resolved vasospasm. No evidence of abnormal contrast leakage is noted. **d** Angiogram after 2 days when de novo hematoma was noted in CT shows contrast leakage at the origin of fine branch at distal curved segment. Leakage point (*arrow*) can be found easily due to the arterial shift caused by de novo hematoma. Due to the poor initial condition of the patient, no clinical aggravation was noted before and after the trapping of the vessel using detachable coils

We found several vessel segments where mild to moderate vasospasm resolved completely using only a vasodilator in this cohort.

Conclusion

Treatment of recurrent delayed cerebral vasospasm secondary to aneurysmal SAH with stent-retrievers is technically viable. There may be an advantage to the deployment of the stent-retrievers prior to the infusion of vasodilators. The development of stents optimized to treat vasospasm should be encouraged.

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Compliance with ethical guidelines

Conflict of interest H.-J. Kwon, J.-W. Lim, H.-S. Koh, B. Park, S.-W. Choi, S.-H. Kim, J.-Y. Youm and S.-H. Song declare that they have no competing interests.

Ethical standards Approval by the institutional review board at our institute and acquisition of informed consent from the patient and/or their families prior to the procedures were completed before this study.

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