Acta Neurochir (2013) 155:611–617
DOI 10.1007/s00701-013-1633-0

CLINICAL ARTICLE - VASCULAR

Critical appraisal of endovascular treatment of brain arteriovenous malformation using Onyx in a series of 92 consecutive patients

Ido Strauss · Vladimir Frolov · Dana Buchbut · Lior Gonen · Shimon Maimon

Received: 6 November 2012 / Accepted: 24 January 2013 / Published online: 21 February 2013

Abstract
Background The introduction of Onyx has led us to adopt a new treatment approach for brain arteriovenous malformation (AVM), using endovascular embolization with Onyx as the first line treatment with a curative intent. The aim of the present report is to evaluate our results using this strategy, with special emphasis on angiographic characteristics affecting treatment risks and success rates.
Methods From October 2006 to December 2009, 92 consecutive patients harboring brain AVM were treated with Onyx during 177 procedures.
Results Endovascular treatments were completed in 68 out of 92 patients. Median number of procedures was two. Complete obliteration using embolization exclusively was achieved in 25 patients, resulting in a 37 % cure rate in patients who concluded treatments (25/68), and 27 % in the cohort. In Spetzler-Martin grades 1 & 2 AVMs, complete obliteration was achieved in 48 % of the cases. Complete obliteration rates were significantly higher in lesions with superficial big feeding arteries. There were 15 bleeding complications during 177 embolization sessions (8.4 % per procedure); seven cases resolved in less than 3 months. Permanent disability rate was 6.5 %; mortality rate was 2.2 %. Bleeding was related to the use of the microcatheter/guidewire in six cases and to the use of the embolization material in nine, the amount of Onyx injected was significantly higher in those nine cases.
Conclusions Embolization of brain AVM using Onyx and detachable tip microcatheters results in a relatively high rate of complete obliteration. Angioarchitecture of the lesion can predict treatment success. Higher amounts of Onyx injected per session increase the bleeding risk.

Keywords Endovascular · Brain arteriovenous malformation · AVM · Onyx · Curative embolization

Introduction

The ultimate goal of treatment of brain arteriovenous malformation (AVM) is to reduce the risk of bleeding by complete obliteration of the vascular nidus. This has traditionally been achieved by surgical resection; however, the developments of new embolic materials like Onyx and improvements in stereotactic radiosurgery have introduced new treatment options for these lesions [1, 21]. The recent development of a detachable tip microcatheter—Sonic (Balt, Montmorency, France), designed for prolonged Onyx injections, has caused a conceptual change in our treatment strategy [11].

During the study period, we used the endovascular route as the first line of treatment for brain AVMs, with a curative intent. The goal of the present study was to critically evaluate our ongoing results in comparison to our group's early experience [11]. Special emphasis is placed on the complications and lessons learned concerning the approach, and the use of Onyx with the detachable tip microcatheter in this unselected group of 92 consecutive patients.

Parts of the results were presented as an oral poster in the European Congress of Neurosurgery (EANS) meeting in Rome 2011.

I. Strauss and S. Maimon contributed equally to this work.

I. Strauss · V. Frolov · D. Buchbut · L. Gonen · S. Maimon (✉)
Department of Neurosurgery, Tel Aviv Sourasky Medical Center, Tel Aviv University, 6 Weizmann Street, Tel Aviv 64239, Israel
e-mail: maimonsm@zahav.net.il

V. Frolov · S. Maimon
Unit of Interventional Neuroradiology, Department of Neurosurgery, Tel Aviv Sourasky Medical Center, Tel Aviv University, Tel Aviv, Israel

Patients and methods

Patients

We retrospectively reviewed the prospectively collected neurosurgical database for all patients treated for brain AVMs with Onyx at the Tel-Aviv Sourasky Medical Center between October 2006 and December 2009. Patient's charts were reviewed for demographic and clinical data (age at initial treatment, sex, presentation, neurological status at presentation, complications and outcome). This review was approved by the local ethics committee.

Patients were evaluated clinically before and after each treatment and periodically during the follow-up period. Imaging follow-up was performed between 6 months and 2 years after treatment, depending on the clinical condition of the patient and the radiological characteristics of the lesion at the completion of the treatment session. Clinical outcome was assessed using the Modified Rankin Score.

Statistical analysis

All treatment and follow-up angiograms were reviewed by the senior author (S.M.) to assess vascular characteristics of the lesions treated. Lesions were graded according to location as superficial or deep, and by vascular architecture as compact or diffuse (qualitative assessment). Arterial feeders were rated by size as normal or large if they were twice the diameter of normal vessels in that region, and by location as superficial if supplied only by superficial vessels or as deep if there were any deep arteries supplying the lesion. The feeding vessels were further classified as torturous or not and as en-passage or not (qualitative assessment). Venous drainage was graded as deep or superficial according to the Spetzler Martin Classification.

In order to find the associations between obliteration rate (complete vs. incomplete) to categorical variables (feeders size, location, torturousity, venous drainage) we used chi-square or Fisher-exact test as appropriate.

In order to find associations between obliteration rate and order variables (i.e. Spetzler Martin grade) and other not normally distributed variables (i.e. maximal diameter of the lesion) we used the Wilcoxon Two-Sample test.

Wilcoxon Two-Sample one-sided test was used to examine whether Spetzler-Martin grade in the complete closure group is lower than in the incomplete closure group.

The receiver operating characteristic (ROC) technique was used to find an optimal cutoff of the total amount of Onyx injected, that best differentiated between patients that did or did not have Onyx related complications (binary variable). This cutoff point is chosen to have the highest sensitivity and specificity rates.

Logistic regression We used multivariate analysis to construct a predictive model for treatment outcome (i.e. complete obliteration). The model predicts the probability of achieving complete obliteration as a function of the explanatory variables. Model selection methods as backward elimination and forward-selection were used in order to identify important factors from the explanatory variables.

The procedure

All the endovascular procedures were performed by the same invasive neuroradiologist (S.M.), and in the same angio suite using the same treatment protocol. Our treatment protocol is described in detail in a recent paper [11]. Briefly, all treatments were performed under general anesthesia in a monoplane Philips angio machine with no option to perform computed tomography (CT) on the table. Catheterization was performed with a transfemoral approach by using standard coaxial techniques. The tip of the microcatheter was navigated as close as possible to the nidus and an Onyx (Micro Therapeutics, Inc, Irvine, CA) plug was created around the catheter tip. Onyx was slowly and progressively injected into the nidus under continuous visual control. Due to its physical characteristics, Onyx can penetrate deep into the nidus. Onyx injection was interrupted whenever a main venous outlet was reached. We then tried to redirect the Onyx to another compartment by waiting for the occluded part to become more solid, creating a higher resistance to flow than in the non occluded compartments nearby. We occlude the proximal draining veins completely at the end of treatment.

When the Onyx doesn't advance and only its reflux is observed, we have learned that this can be overcome by flushing the microcatheter with a small amount (0.1–0.2 cc) of DMSO (dimethyl sulfoxide), to lower the viscosity of the ONYX and re-establish distal flow (personal observation in multiple injections over 2 years).

We stopped embolization sessions when the nidus became inaccessible due to unfavorable anatomy of feeders and a high risk/benefit ratio for the patient. At that point, other treatment options were taken into account. Patients with small remnants without bleeding, or in a deep or eloquent area, were referred to radiosurgery. Others underwent open surgery.

Results

Ninety-two consecutive patients were treated during 177 embolization procedures. Mean age at first treatment was 34.1 years (±16.8), there were 42 females (46 %). Distribution of lesions according to the Spetzler-Martin grade is shown in Table 1. The common initial presentations were bleeding in 42 patients (46 %) and seizures in 30 patients

Table 1 Patients' characteristics

	No. of pts	No. of pts finished treatment	No. of complete obliterations using embolization only (%)	Median no. of embolization sessions (range)	No. of SRS after embolization	No. operated		Observation	Continued embolization
						Elective	Urgent		
AVM I–II	28	25	12 (48 %)	1 (1–2)	9	2	–	2	3
AVM III	22	15	7 (46 %)	2 (1–3)	6	–	1	1	7
AVM IV–V	42	28	6 (21 %)	3 (1–5)	13	2	2+1*	5	14
Total	92	68	25 (37 %)	2 (1–5)	28	4	3+1*	8	24

AVM arteriovenous malformation, SRS stereotactic radiosurgery* In one case only the hematoma was evacuated. The AVM was completely occluded at the end of the embolization session, the patient bled 1 day post-treatment presumably due to hemodynamic changes. The patient recovered well. The AVM is completely obliterated with Onyx at 1.5 year angiographic follow-up

(34 %), other presentations included headaches (8 %), focal neurological deficits (2 %) and incidental findings (10 %). Eight of nine (88 %) patients with AVMs in the posterior fossa presented with spontaneous bleeding.

Sixty-eight patients have completed their endovascular treatments. Median number of treatments per patient was two (range, 1–5). Complete obliteration using only embolization was achieved in 25 patients, resulting in a complete occlusion rate of 37 % of the patients who completed endovascular treatment (25/68) and 27 % of the whole cohort so far (25/92). A summary of the data showing obliteration rates displayed by Spetzler-Martin grade is presented in Table 1.

In 32 patients, we achieved near complete obliteration using embolization, which enabled further adjuvant treatment using stereotactic radiosurgery (SRS, n=28, Table 1) or elective surgery (n=4, Table 1). Of note is the relatively high number of Spetzler-Martin grades IV–V that we were able to treat using this combined approach (n=42, 45.6 % of the cohort). Complete obliteration was achieved in all four electively operated patients without surgical morbidity. Results of SRS treatments are currently being evaluated and will be reported in the near future.

The mean amount on Onyx injected each treatment session was 3.9±4.2 cc. The median number of microcatheters used in each treatment (i.e. number of arterial feeders) was two (range, 1–4), with an average of 1.8 cc±1.7 cc of Onyx injected per catheter. We used the Marathon microcatheter (ev-3, Irvine, California) in 43 arterial feeders. After an initial learning period we switched to the Sonic microcatheter as our main micro catheter (233 arterial feeders). The amount of Onyx injected changed during the study period after analysis of our short-term results at the end of 2007 [11]. During the initial 2 years, we injected higher amounts of Onyx through the Sonic microcatheter (2.5±2.2 ml versus 1.5±1.3 ml, before and after December 2007, respectively; $p<0.01$, t-test).

Predictive factors In an attempt to identify factors related to successful endovascular embolization, we retrospectively analyzed all treated lesions for vascular anatomy characteristics (see Patients and methods). Lesions were classified according to location as superficial (n=57) or deep (n=35) and according to vascular architecture as compact (n=74) or diffuse (n=18). The main arterial feeders were rated as normal (n=32) or large (n=60) if they were twice the diameter of normal vessels in that region, and were further classified as superficial (n=59) or deep perforators (n=33), and as *en-passage* (n=26) or not (n=66). Venous drainage was graded as deep (n=51) or superficial (n=41), according to the Spetzler Martin criteria. Statistical analysis tested the relationship between these variables and complete obliteration of the nidus using endovascular embolization only.

Success rates of endovascular embolization were found to be significantly higher in lesions with big and/or superficial feeders. Big feeder size increased the chance for closure by 4.6 (odds ratio) compared and adjusted to small feeder size (p value 0.04, logistic-regression). Deep feeders decreased the chance of closure by 95 % adjusted to superficial feeders (p=0.007, logistic regression). Out of all completely obliterated lesions (n=25), 88 % were superficially located, 96 % had superficial feeders, and in 88 % of the cases, the feeders were large. Negative predicative factors were *en passage* feeders and eloquent location, according to the Spetzler-Martin classification.

The maximal diameter of the lesions as defined by the Spetzler-Martin grading system was inversely correlated with the chance of complete endovascular obliteration. In the complete closure group, the maximal diameter of the AVM was significantly lower than in the incomplete closure group (3.5±1.3 cm vs. 4.5±1.7 cm; p=0.04, Wilcoxon one-sided Two-Sample test).

Complications

During 177 procedures we encountered 15 symptomatic postoperative bleedings (Table 2; 8.4 % per procedure, in 16.3 % of the patients). Distribution of the complications by

Spetzler-Martin grade of the lesions and etiology of the bleedings is presented in Table 2.

In seven cases, the bleedings were mild, without significant mass effect and were treated conservatively. In those seven cases, the patients developed mild peri-procedural neurological deficits with good recovery and excellent functional outcome (Modified Rankin Score—mRS ≤1) at the 3-month follow-up in all cases. More severe bleedings with significant periprocedural neurological deficits were encountered in the other eight cases (4.5 % per procedure, 8.7 % of patients). Surgical evacuation of hematomas due to mass effect was required in four cases, while four patients were treated conservatively. Four patients were left with mild permanent disability (mRS 2, 4.3 % of patients), two patients were left with moderate–severe disability (mRS 3–5, 2.2 % of patients), and two patients died in the postoperative period (2.2 % of the patients). Both mortality cases were in patients harboring Spetzler-Martin grade V AVMs, situated in the posterior fossa that developed severe venous congestion with edema and posterior fossa bleedings postoperatively. At the end of follow-up, permanent disability rate was 6.5 % (6/92), mortality rate was 2.2 % (2/92).

In an attempt to define potential hazards and pitfalls in the treatment, an analysis was carried out of all the bleeding cases for their presumed etiology: Three of the symptomatic bleedings occurred during navigation, due to puncture of the feeding artery by the guidewire. In two cases, the bleeding was identified and treated during the procedure. One patient developed a small thalamic hematoma and postoperatively suffered from mild hypoesthesia that later improved, the other patient suffered from mild postoperative hemiparesis that completely resolved after 3 months. In the third case, a massive hematoma was discovered only postoperatively after the patient failed to recover from the anesthesia. The patient failed to improve and remained in a poor neurological state (mRS 5).

Three bleedings were related to the retrieval of the microcatheter from the Onyx Cast (see Patients and methods). In the first case, we used the non-detachable tip microcatheter. In the second case, the Onyx passed the third marker on the tip of the Sonic microcatheter, rendering it practically as a non-detachable tip microcatheter [11]. A third patient bled 1 day after the procedure. A known flow related aneurysm on the proximal part of the feeding artery was the presumable source, according to the location of the subarachnoid hemorrhage (SAH) on the CT performed after the new onset of headache the day following the procedure. We presume that the rupture was due to manipulation of the artery during the procedure.

Nine bleeding cases were complications related to the use of the embolization material, due to venous outflow disturbance. Six cases were immediate bleedings and three cases were late bleedings that developed more than 24 h postoperatively. All nine Onyx related bleedings occurred in big (> 3 cm), grades III–V AVMs (Table 2). Multivariate statistical analysis showed that the amount of onyx injected per session was significantly higher in the complication group (5.7±3.1 cc vs. 2.8±2.4 cc, $P<0.05$). Using the ROC procedure, it was found that 4 cc of injected Onyx was the optimal cutoff, differentiating between the two groups. Most of these complications occurred in the initial period (Fig. 1), which coincides with the limiting of the maximum amount of Onyx injected and other measures that were instituted during the study period (see Discussion).

Asymptomatic bleedings In addition, we discovered five asymptomatic small SAHs on postoperative imaging. In all those cases, contrast extravasation due to artery perforation was identified immediately during the procedure, and was treated by Onyx injection and occlusion of the artery. All five patients were neurologically intact after the procedure.

Technical complications related to guidewires or microcatheters were encountered in four cases and included one microcatheter breakage, one microcatheter disconnection in an external carotid artery branch, one microcatheter puncture during reinsertion of the guidewire through a curved segment and one retained microcatheter. All these technical complications were without clinical consequences and occurred during the initial 4 months period after the introduction of Sonic to our practice.

Table 2 Distribution of complications according to Spetzler-Martin Grade, immediate severity and etiology

	No. pts	No. comp	Severity (early)		Navigation	Microcatheter retrieval	Onyx early	Onyx late
			Mild	Moderate–severe				
AVM I–II	28	2 (7.1 %)	2 (7.1 %)		–	2	–	–
AVM III	22	6 (27 %)	3(13.5 %)	3 (13.5 %)	1 (mild)	1 (1 severe)	2 (1 mild, 1 moderate)	2 (1 mild, 1 moderate)
AVM IV–V	42	7 (16.6 %)	2 (7.1 %)	5 (11.9 %)	2 (1 mild, 1 severe)	–	4 (2 mortalities, 2 severe)	1 (mild)
Total	92	15 (16.3 %)	7 (7.6 %)	8 (8.7 %)	3	3	6	3

AVM arteriovenous malformation

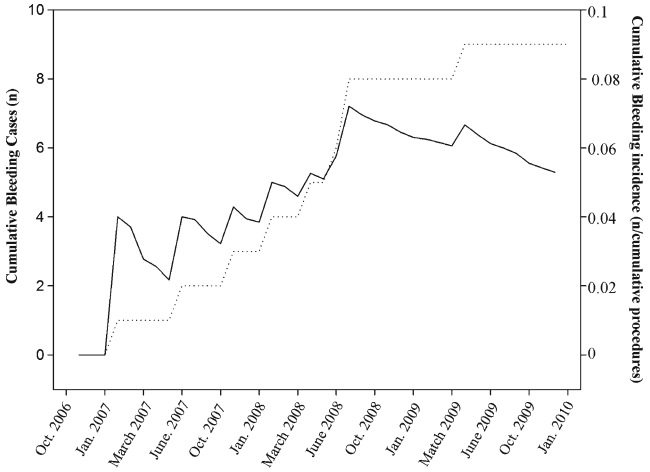

Fig. 1 Onyx related complications plotted by time. *Dotted line* represents cumulative number of bleeding cases (n). *Solid line* represents cumulative bleeding incidence (cumulative number of bleeding cases divided by cumulative number of procedures performed). Plateauing of the graph can be observed toward the second half of the study period

Discussion

Despite recent technical advancements in microsurgery, radiatiotherapy and endovascular treatments, brain AVM continue to pose a special challenge to the treating physician [1, 18, 21]. The current work critically examines our ongoing experience in the treatment of brain AVM in an unselected group of 92 consecutive patients, in an attempt to identify potential strengths and pitfalls of this technique.

During the last years since the introduction of Onyx and detachable tip microcatheters, the treatment of brain AVM has undergone a conceptual change in our practice [11]. Endovascular treatment has become our main treatment modality for these lesions, with surgery and radiosurgery reserved as adjuvant treatments when required. This change has brought about several issues concerning both the success and complication rates of treatment.

When we examine our ***success rates*** we observe three distinct patterns:

Small superficial lesions (grades I–II), in both eloquent and non eloquent areas supplied by big arterial feeders, are an ideal target for endovascular embolization using Onyx and a detachable tip microcatheter. In this group of patients, we had a high rate of complete obliteration (48 %) with no significant morbidity. This is of course also true for other treatment options, as these kinds of lesions are attractive targets also for microsurgery (especially in non eloquent locations) and radiosurgery, with a low morbidity and mortality in all treatment modalities [3, 5, 6, 12]. Treatment decisions in these cases should be based on vascular anatomy, surgeons experience and patient preference after reviewing the pros and cons of each treatment modality.

Big and complex lesions were not readily obliterated by embolization alone and also entailed their relatively high morbidity and mortality risks. However, these lesions have no optimal curative treatment option [3, 18] and often require multimodality treatments [2]. Out of 42 patients in our series harboring Spetzler-Martin grades IV–V AVMs (45.6 % f the cohort), complete obliteration was achieved in 21 % of the patients who have completed endovascular treatments (6/28). In 15 other patients significant size reduction was achieved enabling adjuvant treatment with surgery ($n=2$) or radiosurgery ($n=13$). This amounts to 21/28 patients with surgically untreatable AVMs that we were able to offer a potential cure. We are currently evaluating the long term results of the radiosurgery cohort.

Grade III AVMs deserve a special consideration. We were able to achieve a relatively high complete occlusion rate (46 %); however, there was also a significant number of treatment related complications (27 % immediate, 13.5 % permanent) in this group. This finding highlights the heterogeneity of this group of lesions, also reported in other series [7–9]. Due to the relatively small numbers, results did not reach statistical significance, however, most of the complications in this subgroup, such as early venous occlusion, were related to the use of the embolization material and occurred in medium sized lesions in eloquent locations, which were also found by Lawton et al. to carry a high surgical risk [7]. We suggest that treatment decisions should be individualized, depending mainly on the vascular anatomy, and keeping to our current practice of limiting the total amount of Onyx injected in each session, in order to avoid significant hemodynamic changes in big lesions.

Overall, our complete obliteration rate of 37 % using endovascular embolization only, compares favorably with previous reports in the literature using either Onyx or other embolization materials [13, 15, 17, 20, 22, 23], especially when one considers the relatively high percent of high grade lesions in our unselected patient cohort. In addition, endovascular treatment was followed by elective surgery or radiosurgery in 32 other patients.

Reasons for failure to achieve complete occlusion When considering treatment options, one must take into account the chances of success and the relative risks. Subjecting a patient to multiple procedures is of course undesirable, as the patient is subjected to the risks of multiple modalities; this is especially relevant to grades I–II lesions that are readily resectable. In some small lesions (Spetzler-Martin grades I–II) in our series, we were not able to achieve complete occlusion. This was due to the unfavorable vascular anatomy with multiple small or en-passage feeders that emphasize the limitations of embolization. Injection of Onyx requires creation of an Onyx plug around the catheter tip to prevent reflux [11, 13, 24]; this cannot be achieved in

short feeders (< 15 mm). Another limitation is the need for Onyx compatible microcatheters [4], which have a relatively thick wall in order to handle the high pressure inside the lumen during the injection of Onyx. This makes them stiffer and less supple requiring a guidewire for navigation, and therefore difficult and dangerous for use in small tortuous vessels.

Another potential caveat was the use of a monoplane angio suite during the time of this study. While working with a monoplane machine, the injection has to be stopped relatively frequently to change the position of the tube, in order to monitor the Onyx progression. This intermittent cessation of activity can cause the Onyx to solidify and disrupt the process. Currently we use a biplane angio suite, and await future results concerning obliteration and complication rates.

To summarize, when evaluating an AVM for embolization with Onyx, one has to consider the aspects unique to embolization with Onyx, namely injection of relatively large amount of Onyx through a single feeder and opening of intra nidal channels between different compartments [11, 13, 22, 23]. Therefore, the key factor of the technique is the size of the feeders. If there are large readily accessible vessels feeding the nidus, that can accommodate the stiff Onyx compatible microcatheters, complete obliteration can be achieved, and sometimes through a single feeder. This is in contrast to embolization with n-butyl cyanoacrylate (nBCA), in which small amounts of glue are injected through multiple feeders, allowing the use of smaller and softer microcatheters.

Complications

Bleedings could be classified either by morphology as subarachnoidal, intra-parenchymal or by etiology. When we analyze the etiology of our bleeding complications, three distinct patterns emerge:

Firstly, perforation of a feeding artery while navigating with a guidewire in front of the microcatheter. As mentioned above, this complication arises due to the requirement of a guidewire with the stiffer catheters compatible with Onyx. It is of utmost importance to timely identify and treat these dangerous arterial bleeders [10], as they could result in severe consequences if went unnoticed, as occurred in three patients in the series. This complication is especially prone to happen in large lesions, where the complexity of the blood vessels obscures/hampers visualization. Currently, we use a "J" shaped guidewire in front of the microcatheter, to reduce the risk of vessel wall puncture.

Secondly, artery rupture during retrieval of the microcatheter from the Onyx cast. This should theoretically be eliminated with use of the new detachable tip microcatheters. The two bleedings occurred during the phase of shifting from nondetachable to detachable Sonic microcatheter. One occurred with a non-detachable tip microcatheter and the second due to mishandling of the combination of Onyx and Sonic, allowing the Onyx to pass the third marker on the tip of the microcatheter, rendering it practically into a non-detachable tip microcatheter [11]. This complication is attributed to the learning curve of a new device. After an initial learning period and using the Sonic according to the required protocol (see Patients and methods), especially making sure that Onyx does not cross the third marker, no more complications of this kind occurred. However, caution is still advised when using the relatively stiff Onyx compatible microcatheters in tortuous vessels, due to stretching of the vessel's wall.

Thirdly, bleeding secondary to venous compromise was one of the leading causes of morbidity in our series. This complication can arise either acutely or within a few hours after the procedure and is usually caused by a too early advancement of Onyx into the draining veins, leading to inadequate draining of the rest of the nidus, or to venous thrombosis due to progressive slowing of blood flow. Multivariate analysis of risk factors revealed that the amount of Onyx was statistically related to the risk of bleeding secondary to venous occlusion. A similar finding was recently reported by Ovalle et al. [14]. Risk of Venous occlusion is increased, probably due to the radio-opacity of Onyx, making it harder to detect where the Onyx is advancing in large lesions (> 3 cm diameter). Overcoming this difficulty requires some experience, and we utilize several techniques to control the injection, detailed in a recent report [11]. We currently try to limit the amount of Onyx injected in a single session to 4–5 cc and divide the treatment to multiple sessions as needed [14]. One of the main lessons learned is to avoid Onyx progression into the proximal venous side too early in the course of treatment. Early proximal venous occlusion, can lead to venous flow changes causing venous congestion and bleeding [16]. Only after achieving significant size reduction of the nidus and elimination of most of the feeders, when we believe complete obliteration is achievable in the same treatment, do we go on to completely obliterate the remaining part with occlusion of the proximal venous outlet in order to cure the lesion.

When examining the incidence of complications during the study period, we can observe a decreasing trend towards the end (Fig. 1), compatible with a learning curve of a new technique. This has been achieved by implementing the principals discussed above and clinical judgment in selection of patients suitable for aggressive endovascular treatment strategy.

The two mortality cases in the series occurred in high grade AVMs in the posterior fossa. We attribute this to the high volume of Onyx injected inside the confined space of the posterior fossa, which can lead to worsening of mass effect, severe venous congestion and severe edema accompanied by bleeding [10, 16, 19] with disastrous consequences.

When considering the complication rate in this series, one has to take into account the context of the whole combined treatment [20]. Usually, when using embolization as an adjuvant treatment, one will take fewer risks during embolizations. However, when taking on a more aggressive treatment approach with a curative intent, inevitably more complications will occur during endovascular treatment, "taking over" the complications from the other treatment modality. Decision making before and during the treatment on how aggressively to proceed remains one of the most important factors.

To summarize, endovascular embolization with Onyx is a powerful treatment tool; however, it requires considerable experience and knowledge in handling the microcatheters and embolization materials. Clinical judgment in patient selection is indispensible. In many cases with favorable anatomy, curative endovascular treatment is appropriate and can achieve a high obliteration rate using embolization exclusively. In other cases, it can be used to reduce the lesion size making it suitable for surgery or radiosurgery, by reducing the risks associated.

Conflicts of interest None.

References

1. Barr JC, Ogilvy CS (2012) Selection of treatment modalities or observation of arteriovenous malformations. Neurosurg Clin N Am 23(1):63–75
2. Chang SD, Marcellus ML, Marks MP, Levy RP, Do HM, Steinberg GK (2007) Multimodality treatment of giant intracranial arteriovenous malformations. Neurosurgery 61(1 Suppl):432–442, discussion 442–444
3. Hamilton MG, Spetzler RF (1994) The prospective application of a grading system for arteriovenous malformations. Neurosurgery 34 (1):2–6, discussion 6–7
4. Jahan R, Murayama Y, Gobin YP, Duckwiler GR, Vinters HV, Viñuela F (2001) Embolization of arteriovenous malformations with Onyx: clinicopathological experience in 23 patients. Neurosurgery 48(5):984–995, discussion 995–7
5. Kano H, Lunsford LD, Flickinger JC, Yang H-C, Flannery TJ, Awan NR, Niranjan A, Novotny J, Kondziolka D (2012) Stereotactic radiosurgery for arteriovenous malformations, Part 1: management of Spetzler-Martin Grade I and II arteriovenous malformations. J Neurosurg 116(1):11–20
6. Katsaridis V, Papagiannaki C, Aimar E (2008) Curative embolization of cerebral arteriovenous malformations (AVMs) with Onyx in 101 patients. Neuroradiology 50(7):589–597
7. Lawton MT (2003) Spetzler-Martin Grade III arteriovenous malformations: surgical results and a modification of the grading scale. Neurosurgery 52(4):740–748, discussion 748–9
8. Lawton MT, Kim H, McCulloch CE, Mikhak B, Young WL (2010) A supplementary grading scale for selecting patients with brain arteriovenous malformations for surgery. Neurosurgery 66(4):702–713, discussion 713
9. Ledezma CJ, Hoh BL, Carter BS, Pryor JC, Putman CM, Ogilvy CS (2006) Complications of cerebral arteriovenous malformation embolization: multivariate analysis of predictive factors. Neurosurgery 58(4):602–611, discussion 602–11
10. Liu L, Jiang C, He H, Li Y, Wu Z (2010) Periprocedural bleeding complications of brain AVM embolization with Onyx. Interv Neuroradiol 16(1):47–57
11. Maimon S, Strauss I, Frolov V, Margalit N, Ram Z (2010) Brain arteriovenous malformation treatment using a combination of Onyx and a new detachable tip microcatheter, SONIC: short-term results. AJNR Am J Neuroradiol 31(5):947–954
12. Morgan MK, Rochford AM, Tsahtsarlis A, Little N, Faulder KC (2004) Surgical risks associated with the management of Grade I and II brain arteriovenous malformations. Neurosurgery 54(4):832–837, discussion 837–9
13. Mounayer C, Hammami N, Piotin M, Spelle L, Benndorf G, Kessler I, Moret J (2007) Nidal embolization of brain arteriovenous malformations using Onyx in 94 patients. AJNR Am J Neuroradiol 28(3):518–523
14. Ovalle F, Shay SD, Mericle RA (2011) Delayed intracerebral hemorrhage after uneventful embolization of Brain Arteriovenous Malformations (AVMs) is related to volume of embolic agent administered: multivariate analysis of 13 predictive factors. Neurosurgery. doi:10.1227/NEU.0b013e3182357df3
15. Panagiotopoulos V, Gizewski E, Asgari S, Regel J, Forsting M, Wanke I (2008) Embolization of intracranial arteriovenous malformations with ethylene-vinyl alcohol copolymer (Onyx). AJNR Am J Neuroradiol. doi:10.3174/ajnr.A1314
16. Picard L, Da Costa E, Anxionnat R, Macho J, Bracard S, Per A, Marchal JC (2001) Acute spontaneous hemorrhage after embolization of brain arteriovenous malformation with N-butyl cyanoacrylate. J Neuroradiol 28(3):147–165
17. Saatci I, Geyik S, Yavuz K, Cekirge HS (2011) Endovascular treatment of brain arteriovenous malformations with prolonged intranidal Onyx injection technique: long-term results in 350 consecutive patients with completed endovascular treatment course. J Neurosurg 115(1):78–88
18. Spetzler RF, Martin NA (1986) A proposed grading system for arteriovenous malformations. J Neurosurg 65(4):476–483
19. Spetzler RF, Wilson CB, Weinstein P, Mehdorn M, Townsend J, Telles D (1978) Normal perfusion pressure breakthrough theory. Clin Neurosurg 25:651–672
20. Valavanis A, Yaşargil MG (1998) The endovascular treatment of brain arteriovenous malformations. Adv Tech Stand Neurosurg 24:131–214
21. van Beijnum J, van der Worp HB, Buis DR, Al-Shahi Salman R, Kappelle LJ, Rinkel GJE, van der Sprenkel JWB, Vandertop WP, Algra A, Klijn CJM (2011) Treatment of brain arteriovenous malformations: a systematic review and meta-analysis. JAMA 306(18):2011–2019
22. van Rooij WJ, Sluzewski M, Beute GN (2007) Brain AVM embolization with Onyx. AJNR Am J Neuroradiol 28(1):172–177, discussion 178
23. Weber W, Kis B, Siekmann R, Jans P, Laumer R, Kühne D (2007) Preoperative embolization of intracranial arteriovenous malformations with Onyx. Neurosurgery 61(2):244–252, discussion 252–254
24. Weber W, Kis B, Siekmann R, Kuehne D (2007) Endovascular treatment of intracranial arteriovenous malformations with onyx: technical aspects. AJNR Am J Neuroradiol 28(2):371–377