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Endovascular treatment of intracranial arteriovenous malformations using detachable-tip microcatheters and Onyx 18[®]



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KEYWORDS

Arteriovenous malformation;
Onyx 18;
Detachabile-tip microcatheter;
Arterial embolization;
Interventional neuroradiology

Abstract

Purpose: To evaluate clinical and imaging features before embolization, data of embolization procedure and outcome in patients with ruptured or unruptured intracranial arteriovenous malformation (AVM) who were treated by endovascular embolization using detachable-tip microcatheters and Onyx 18[®].

Material and methods: Forty-three patients treated with endovascular embolization using a detachable-tip microcatheter and Onyx18[®] between January 2008 and April 2016 were evaluated. There were 27 men and 16 women with a mean age of 35.9 ± 14.1 years (range: 10–68 years). Clinical and imaging features, embolization details and post-treatment findings were analyzed. Patients were divided into ruptured AVM and unruptured AVM groups. Death, complications and total embolization rates of each group were assessed.

Results: Fifty-one embolization sessions were performed in 43 patients. Total embolization rate was 40% (17/43). There were significant relationships between AVM diameter and total embolization success and AVM diameter and complication rates. The degree of embolization was partial in all patients who had complications. Catheter retention and iatrogenic rupture were not observed in any procedure. No major neurologic deficit was seen in patients who had unruptured AVM and complications after treatment.

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Conclusions: Our results show the efficacy of endovascular embolization of AVM using detachable-tip microcatheters and Onyx 18°. A new AVM classification system based on AVM diameter for this embolization technique may be more predictive in terms of total embolization success and complication development.

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Intracranial arteriovenous malformations (AVM) are high-flow vascular anomalies seen in less than 1% of people [1]. The arterial and venous systems are connected before the capillary bed by a tangled vascular bundle called a nidus. They are the most symptomatic intracranial vascular malformations [2,3]. Symptoms according to frequency are intracranial hemorrhage, seizure, progressive neurologic deficit and systemic circulatory disorder. Intracranial hemorrhage is a symptom that occurs in 38–73% of patients with AVM and is the most frequent cause of mortality and morbidity [4,5].

Computerized tomography (CT) and magnetic resonance imaging (MRI) are helpful in patients with AVM for detecting location, relationships with parenchymal structures, evaluation of complications and post-treatment follow-up [6,7]. However, digital subtraction angiography (DSA) is the gold standard for imaging and treatment planning. Treatment options are medical treatment, endovascular embolization, surgery and radiosurgery [6]. Treatment method is determined using the Spetzler–Martin grading system [8]. Treatment of ruptured AVM is usually surgery or endovascular embolization. However, treatment of unruptured AVM has been controversial. In “A randomized trial of unruptured brain arteriovenous malformations” clinical trial, medical treatment and invasive treatment options for unruptured AVM were compared in terms of complications, and medical treatment was found to be less risky [9].

AVM can be embolized with various embolic agents. Of these, Onyx 18° has several well established indications for the endovascular treatment of AVM [10,11].

The purpose of this study was to evaluate clinical and imaging features before embolization (FBE), data of the embolization procedure (DEP) and post-treatment follow-up findings (PTFF) in patients who had ruptured or unruptured AVM and who were treated by endovascular embolization using detachable-tip microcatheters (Sonic® and Apollo®) and Onyx 18°.

Materials and methods

Patients

Patients went to intracranial AVM embolization procedure between January 2008 and April 2016 were investigated retrospectively from the hospital information management system (Avicenna®, Datasel). Forty-six patients were initially collected. Inclusion criteria were usage of detachable-tip

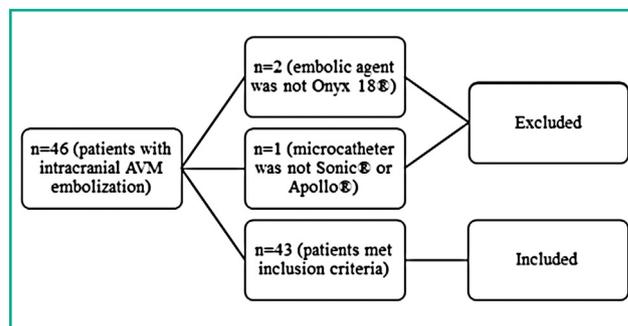


Figure 1. Flow chart diagram of patient selection.

microcatheters including Sonic® (Balt), and/or Apollo® (EV3), usage of Onyx 18° (EV3) as embolic agent in the procedures. Two patients were excluded because embolization was not performed using Onyx 18° and one patient because embolization was not performed using a Sonic® or Apollo® microcatheter. Finally, a total of 43 patients with intracranial AVM who underwent endovascular embolization were included in this study (Fig. 1). There were 27 men and 16 women with a mean age of 35.9 ± 14.1 years (range: 10–68 years). A total of 51 embolization procedures were performed in the 43 patients. The study was approved by the local clinical research ethics committee.

Data analysis

For each patient; FBE, DEP and PTFF findings were determined. For FBE: age, gender, clinical presentation, CT, MRI, perfusion MRI, diffusion tensor imaging (DTI), functional MRI, susceptibility weighted imaging (SWI), CT angiography, MR angiography and DSA findings were evaluated. Spetzler–Martin grade of lesions were determined by defining their AVM diameter point (<3 cm=1, 3–6 cm=2, >6 cm=3), deep venous drainage point (negative=0, positive=1) and eloquency of adjacent brain point (non-eloquent=0, eloquent=1). Intracranial hemorrhage presentation before endovascular treatment (EVT) was accepted as a finding of rupture and patients were grouped as ruptured and unruptured AVM [9] according to presence of intracranial hemorrhage.

Puncture route of each session (transarterial and/or transvenous), amount of Onyx 18° usage per session, type and combination of microcatheter usage per session and

Table 1 Usage counts and percentages of detachable-tip microcatheters used in endovascular embolizations.

Microcatheter	Manufacturer	Diameter	Detachabile-tip length	Usage count (<i>n</i> = 80)	Usage (%)
Sonic [®]	Balt	1.5 F	25 mm	63	79
Apollo [®]	ev3	1.5 F	30 mm	12	15
Apollo [®]	ev3	1.5 F	15 mm	5	6

Table 2 Features before endovascular treatment.

	Patient count (<i>n</i> = 43)	Percentage (%)
Gender		
Man	27	63
Woman	16	37
Clinical presentation		
Headache	14	33
Intracranial hemorrhage	12	28
Seizure	11	26
Neurologic deficit	3	7
Asymptomatic	1	2
Tremor	1	2
Headache + seizure	1	2
AVM diameter (cm)		
< 3	12	28
3–6	29	67
> 6	2	5
Deep venous drainage		
No	27	63
Yes	16	37
Eloquency of adjacent brain		
No	24	56
Yes	19	44
Spetzler–Martin grade		
Grade 1	5	12
Grade 2	15	35
Grade 3	16	37
Grade 4	7	16
Grade 5	0	0

embolization degree achieved at the end of each treatment session were evaluated in DEP category.

In PTFF, the early post-procedural period (first week after treatment) and the control follow-up period (at least three months after treatment) findings were evaluated. Applied additional treatments after embolization (surgery or radiosurgery), post-treatment control DSA findings, death and complications after treatment were evaluated. Neurologic deficit level in patients who had unruptured AVM and complications after treatment were calculated using the modified Rankin scale (mRs). Zero point was defined as normal, 1–2 points were defined as a minor neurologic deficit and 3–6 points were defined as a major neurologic deficit.

All embolization procedures were performed by an interventional neuroradiologist with 17 years of experience. A neuroradiologist with 12 years of experience in neuroradiology reviewed the imaging examinations.

Embolization procedure

All procedures were done under general anesthesia. Propofol (2 mg/kg), fentanyl (2–5 µg/kg), lidocaine (1.5 mg/kg) and vecuronium (0.1 mg/kg) were used during induction, sevofluran (MAC = 2) was used as inhalation agent and 0.01 mg/kg of vecuronium and 2 µg/kg of fentanyl were used as intravenous agents in maintenance.

The standard treatment method was applied for 46 of 51 sessions. In this method, an introducer was placed in the femoral artery under general anesthesia. Heparin (50–70 IU/kg) was injected intraarterially. The target range of activated coagulation time (ACT) was 250–300 seconds. Guiding catheters were placed in the petrosal segment of the internal carotid artery (ICA) for anterior circulation AVMs, and the V4 segment of the vertebral artery for posterior circulation AVMs. The perforating arterial branches of the AVM were reached using detachable-tip microcatheters that were compatible with dimethyl sulfoxide (DMSO). Microcatheter selection was made according to the structural features (i.e. AVM diameter, perforating artery length and course) of the AVM.

The length of the perforating artery, internal structure of the nidus and proximal drainage veins were detected with superselective angiograms. DMSO (0.25 mL) was injected for filling the dead space of the microcatheter before Onyx 18[®]. Onyx 18[®] injection was then started with 10–15 minute/mL injection speed. Injection was continued until full penetration was achieved. Protamine sulfate (1 mg) was used per 100 IU of heparin to avoid iatrogenic hemorrhage complications. Attention was paid for systolic blood pressure not to exceed 100–110 mmHg. The microcatheter was removed with slow manipulation after injection. Embolization degree at the end of procedure was evaluated with selective angiograms.

A bilateral transarterial approach was used to increase the success of the procedure in 4 procedures other than the standard treatment method. Two introducers, two guide wires, two guiding catheters and two microcatheters were used.

Transarterial and transvenous approaches were combined in one procedure besides the standard method. Each one of the introducers were placed on the right femoral artery and the left femoral vein. The right ICA and left internal jugular vein were reached using guiding catheters. A microcatheter was placed on the perforator branch of the AVM from the ICA petrosal segment. The drainage vein of the AVM that drained to the superior sagittal sinus was reached using a microcatheter in the venous side. Onyx 18[®] was injected through both of the microcatheters. Diameters, detachable-tip lengths and usage counts of microcatheters in the treatment procedures are shown in Table 1.

Statistical analysis

All statistical analyses were done using the IBM SPSS Statistics 22 program. Whether the data fitted to normal distribution was tested using Shapiro–Wilk test. When the data did not fit to normal distribution, Kruskal–Wallis test was used for comparison of three or more groups and Mann–Whitney U test was used for comparison of two groups. Data of these tests were given with average (minimum–maximum) values. Fisher’s exact test, Pearson Chi² test and Fisher–Freeman–Halton test were used for comparison of categorical variabilities. Data of these tests were given with frequency (percentage) values. Spearman correlation coefficient was used for evaluating relationships between variables. Significance level was assumed as $P < 0.05$.

Results

Frequency of FBE, DEP and PTFF

Demographic findings and FBE are shown with their frequency value in Table 2. Fifty-one embolization sessions were done in 43 patients. One embolization session was performed in 35/43 patients (81%) and two sessions in 8/43

patients (19%). The mean session count was 1.19 and the median session count was 1. Total embolization (no flow in the lesion post embolization) was performed in 17/51 sessions (33%) and 17/43 patients (40%). Partial embolization (residual flow in the lesion post embolization) was performed 34/51 in sessions (67%) and 26/43 patients (60%). No intraprocedural complications such as catheter entrapment, fracture or iatrogenic rupture occurred. The mean volume of Onyx 18[®] used per session was 5.91 ± 3.50 (SD) mL (range: 1.5–18 mL). The frequency of DEP is shown in Table 3.

A total of 80 detachable-tip microcatheters were used in 51 embolization sessions (Table 4). Microcatheter combinations used were compared with each other for total embolization success, death and complications. Also, microcatheter usage counts were compared with each other for total embolization success, death and complications. No significant difference was seen statistically (Table 5). Sessions where each microcatheter type (Sonic 1.5F/25 mm, Apollo 1.5F/30 mm, Apollo 1.5F/15 mm) were used and not used were grouped quantitatively and qualitatively. No significant difference was seen between groups in terms of total embolization success, death and complications (Table 5).

PTFF of 8 patients could not be evaluated because they quit follow-up after treatment. No death or complication

Table 3 Distribution of data of embolization and Onyx[®] 18 usage.

Puncture type	Session count ($n = 51$)		% of sessions	
Unilateral transarterial	46		90	
Bilateral transarterial	4		8	
Combined transarterial-transvenous	1		2	
Embolization degree	Session count ($n = 51$)	% of sessions	Patients ($n = 43$)	% of patients
Total	17	33	17	40
Partial	34	67	26	60

Table 4 Frequency and combinations of microcatheters used in endovascular treatment procedures.

	Session count ($n = 51$)	Session percentage (%)
Microcatheter usage count per session		
1	26	51
2	22	43
3	2	4
4	1	2
Microcatheter usage combination per session		
1 × Sonic [®] 1.5F/25 mm	21	41
2 × Sonic [®] 1.5F/25 mm	15	29
3 × Sonic [®] 1.5F/25 mm	2	4
1 × Apollo [®] 1.5F/30 mm	3	6
1 × Apollo [®] 1.5F/15 mm	2	4
1 × Apollo [®] 1.5F/15 mm + 1 × Apollo [®] 1.5F/30 mm	2	4
1 × Sonic [®] 1.5F/25 mm + 1 × Apollo [®] 1.5F/30 mm	4	8
2 × Apollo [®] 1.5F/30 mm	1	2
2 × Sonic [®] 1.5F/25 mm + 1 × Apollo [®] 1.5F/30 mm + 1 × Apollo [®] 1.5F/15 mm	1	2

occurred in the early post-procedural follow-up of these 8 patients.

Thirty-five of 43 patients had PTFF. A total of 42 embolization sessions were done for these 35 patients. Death occurred in 2/42 sessions (5%) and 2/35 patients (6%). Deceased patients had one embolization session. Death occurred in early post-procedural period in both. One of the patients who died could not be certainly evaluated for procedure-related complications. He passed away in intensive care unit after 24 hours from procedure due to hemodynamic instability. The other deceased patient experienced intracranial hemorrhage after procedure. Forty-one (41/42) control follow-up findings in sessions and thirty-four (34/35) patients could be evaluated for complications. No complication was seen in 31/41 sessions (76%). Intracranial hemorrhage after procedure was seen in 7/41 sessions (17%) and neurologic deficit after procedure in 3/41 sessions (7%).

Forty control DSA were performed for 33 patients after 3 months from the treatment. No residue or recurrence was seen in 28/40 sessions (70%). Spontaneous occlusion of the partially embolized AVM was seen in 2/40 sessions (5%). Residue was seen in 10/40 sessions (25%) (Table 6).

Relationship between FBE and DEP

A significant difference was seen between patients grouped by AVM diameter in terms of embolization degree ($P=0.008$). Total embolization of AVM was observed in 17/43 patients (40%); 9/12 AVMs (75%) that were smaller than 3 cm were embolized totally and 8/29 AVMs (28%) that were between 3–6 cm diameter were embolized totally. All AVMs (2/2; 100%) that were larger than 6 cm were embolized partially. No significant relationship was observed between other FBE and DEP categories (Table 7).

Relationship between FBE and PTFF

A significant relationship was observed between Spetzler–Martin grade and death ($P=0.035$). Both two patients who died had grade 4 AVM. None of the patients whose AVM grade was lower than 4 died. Death rate was 33% (2/6) in 6 patients who had grade 4 AVM and post-treatment follow-up.

A significant relationship was observed between AVM size and complication development ($P=0.011$). Thirty-four patients could be evaluated for complications. Ten of thirty-four patients had complications. AVM diameters were smaller than 3 cm in 11 patients (11/34) evaluated for complications, between 3–6 cm in 22 patients (22/34) and larger than 6 cm in 1 patient (1/34). All complications (100%; 10/10) of were seen in patients with 3–6 cm AVM. No complications after treatment developed in patients with AVM smaller than 3 cm (0/11). Intracranial hemorrhage or neurologic deficit was seen in 45% (10/22) of patients with 3–6 cm AVM.

No significant relationship was observed between other FBE and PTFF categories (Table 7).

Table 5 Association between microcatheter usage count, combination, type per session and embolization degree, complication and death.

	P-value
Microcatheter usage count per session	
Embolization degree	0.25
Death	0.296
Complication	0.380
Microcatheter usage combination per session	
Embolization degree	0.125
Death	0.209
Complication development	0.585
Used microcatheter type per session	
Sonic® 1.5F/25 mm usage (used or not)	
Embolization degree	0.099
Death	0.292
Complication	0.653
development	
Apollo® 1.5F/30 mm usage (used or not)	
Embolization degree	0.147
Death	0.388
Complication	0.402
development	
Apollo® 1.5F/15 mm usage (used or not)	
Embolization degree	0.318
Death	0.188
Complication	1
development	
Sonic® 1.5F/25 mm usage count	
Embolization degree	0.212
Death	0.294
Complication	0.348
development	
Apollo® 1.5F/30 mm usage count	
Embolization degree	0.093
Death	0.388
Complication	0.55
development	
Apollo® 1.5F/15 mm usage count	
Embolization degree	0.318
Death	0.188
Complication	1
development	

Relationship between DEP and PTFF

A significant relationship between embolization degree and complication development was observed ($P=0.002$). Total embolization was achieved in 14 of 34 patients evaluated for complications and 14 of 41 sessions evaluated for complications. Complications occurred in 50% (10/20) of patients with partially embolized AVM. Intracranial hemorrhage was seen in 35% (7/20) and neurologic deficit was seen in 15% (3/20) of patients. Complications were seen in 37% (10/27) of sessions where partial embolization was performed. No complication was seen in patients with totally embolized AVM (0/14) and sessions with total embolization

Table 6 Frequency of control follow-up findings in sessions.

	Control follow-up assessment count (n = 42)	% of control follow-up assessments	Patients with control follow-up findings (n = 35)	% of patients with control follow-up findings
Additional therapy				
No	25	59	18	51
Surgery	13	31	13	37
Radiosurgery	4	10	4	12
Residue recurrence				
No	28	70	28	85
Residue	10	25	3	9
Spontaneous occlusion	2	5	2	6
Unknown	2		2	
Death				
No	40	95	33	94
Yes	2	5	2	6
Complication				
No	31	76	24	71
Intracranial hemorrhage	7	17	7	21
Neurologic deficit	3	7	3	8
Unknown	1		1	

(0/14). No significant relationship was observed between other DEP and PTF categories (Table 7).

Ruptured and unruptured AVMs

In the study population, 28% (12/43) of patients had ruptured AVM and 72% (31/43) of patients had unruptured AVM (Fig. 2). Twenty-six (26/31) of patients with unruptured AVM and 9 (9/12) of patients with ruptured AVM had PTF. Death was not seen in any (0/26) of patients with unruptured AVM and death occurred in 22% (2/9) of patients with ruptured AVM. Patient that could not be assessed for complications because of he died had ruptured AVM. 12% (1/8) of ruptured patients and 35% (9/26) of unruptured patients had complications after treatment. Intracranial hemorrhage occurred after treatment in patient with ruptured AVM. Intracranial hemorrhage was seen in 23% (6/26) of patients with unruptured AVM and 11% (3/26) had neurologic deficits due to ischemia.

mRs were 2 in 56% (5/9) of patients with unruptured AVM who had complications, 1 in 33% (3/9) and 0 in 11% (1/9). According to these scores, 11% (1/9) were considered as asymptomatic (mRs=0) and 89% (8/9) were considered as patients with minor neurologic deficits (mRs=1–2) (Table 8). No major neurologic deficit (mRs ≥ 3) secondary to the treatment was seen in any of patients with unruptured AVM.

Discussion

In this study, we aimed to evaluate features before embolization, data of embolization, recurrence and complications after embolization in patients with AVM treated using detachable-tip microcatheters and Onyx 18[®]. Maimon et al. who used Sonic[®] microcatheters and Onyx 18[®] in 43 patients and 76 embolization sessions, reported

a total embolization rate of 37% on a patient basis and a total embolization rate of 21% on a session basis [12]. The median session number per patient was 2, and 4 sessions were needed for some of the patients [12]. In our study, 81% of patients had embolization in one session and 19% (8/43) of patients in two sessions, yielding a median session number of 1. Total embolization rate in our study (33%) was higher than that in the study of Maimon et al. We believe that this difference may be related to technical differences between treatment procedures and variable microcatheter usage in our treatment procedures.

Herial et al. used Apollo[®] microcatheters and Onyx[®] 18 in 7 embolization sessions in 3 patients with intracranial AVM and arteriovenous fistulas [13]. They reported no intraprocedural complications such as microcatheter entrapment or microcatheter retraction. Flores et al. reviewed embolizations of 61 patients with intracranial AVMs or arteriovenous fistulas using Apollo[®] microcatheters [14]. In their study, 87% of patients did not have any major neurologic deficit after embolization and no catheter entrapment occurred [14]. In our study, no intraprocedural complications such as catheter entrapment, fracture or iatrogenic rupture occurred. Except for the patient that had intracranial hemorrhage after embolization and passed away, patients with complications did not have major neurologic deficits. In our opinion, embolizations using detachable-tip microcatheters may provide a potential benefit for intraprocedural safety.

In the ARUBA trial, which was a study of unruptured AVMs, death and complication rates were less frequent in patients treated only medically compared to patients who had invasive therapy such as surgery, embolization or radiosurgery in addition to medical therapy [9]. In this trial, a death rate of 1.8% was reported in patients who received additional invasive treatment whereas a death rate of 0% was reported in patients treated only medically [9]. The hemorrhagic stroke rate was 22%, the ischemic stroke rate was 8% and the total complication rate was

Table 7 Association between each other of features before embolization (FBE), data of embolization procedure (DEP) and post-treatment follow-up findings (PTFF).

	<i>P</i> -value
Relationships between FBE and DEP	
Age – puncture type	> 0.99
Age – embolization degree	> 0.99
Sex – puncture type	> 0.99
Sex – embolization degree	> 0.99
Clinical presentation – puncture type	> 0.99
Clinical presentation – embolization degree	0.531
AVM diameter – puncture type	> 0.99
AVM diameter – embolization degree	0.008
Deep venous drainage – puncture type	> 0.99
Deep venous drainage – embolization degree	0.523
Eloquency – puncture type	1
Eloquency – embolization degree	1
Spetzler–Martin grade – puncture type	1
Spetzler–Martin grade – embolization degree	0.177
Relationships between FBE and PTFF	
Age – death	> 0.99
Age – complication development	> 0.99
Sex – death	> 0.99
Sex – complication development	> 0.99
Clinical presentation – death	0.425
Clinical presentation – complication development	0.26
AVM diameter – death	0.113
AVM diameter – complication development	0.011
Deep venous drainage – death	0.131
Deep venous drainage – complication development	0.714
Eloquency – death	1
Eloquency – complication development	1
Spetzler–Martin grade – death	0.035
Spetzler–Martin grade – complication development	0.32
Relationships between DEP and PTFF	
Puncture type – death	1
Puncture type – complication development	1
Embolization degree – death	0.547
Embolization degree – complication development	0.002

Bold indicates significant difference.

30% in invasively treated patients [9]. The hemorrhagic stroke rate was 5%, the ischemic stroke rate was 3% and the total complication rate was 8% in patients treated only medically.

In our study, 72% of patients had unruptured AVM. None of them died after EVT; 23% of them had intracranial hemorrhage and 11% had ischemic neurologic deficits. The level of neurologic deficits were determined using mRs in patients who had unruptured AVM and complications. In addition, no major deficit was seen in any of them, 11% were asymptomatic and 89% had minor neurologic deficits. Complication rates were similar to those in the ARUBA trial, however none of patients with unruptured AVM died after treatment in our study.

In the ARUBA trial, patients treated with surgery, embolization or radiosurgery were evaluated in the same category [9]. The efficacy of each of these 3 treatments has not been compared with medical treatment separately.

There were no informations about technical aspects of invasive procedures. Situations such as suspicious population selection and lack of examination of the results of treatment as a whole are present in this study. When these factors are considered together, the results of the ARUBA trial should be considered with caution [15–17].

Spetzler–Martin Grading was only found to be significantly related to death in our study. Both patients who died had grade 4 AVM. Despite that, AVM diameter, one of the components of the Spetzler–Martin classification, was significantly associated with complication development and total embolization success.

Crowley et al. reported that there were no significant differences between Spetzler–Martin grades in terms of complication rate [18]. In the study of Hartmann et al., in which n-butyl-cyanoacrylate was used, Spetzler–Martin Grading itself and its components (diameter, deep venous drainage, eloquency of adjacent brain) were not

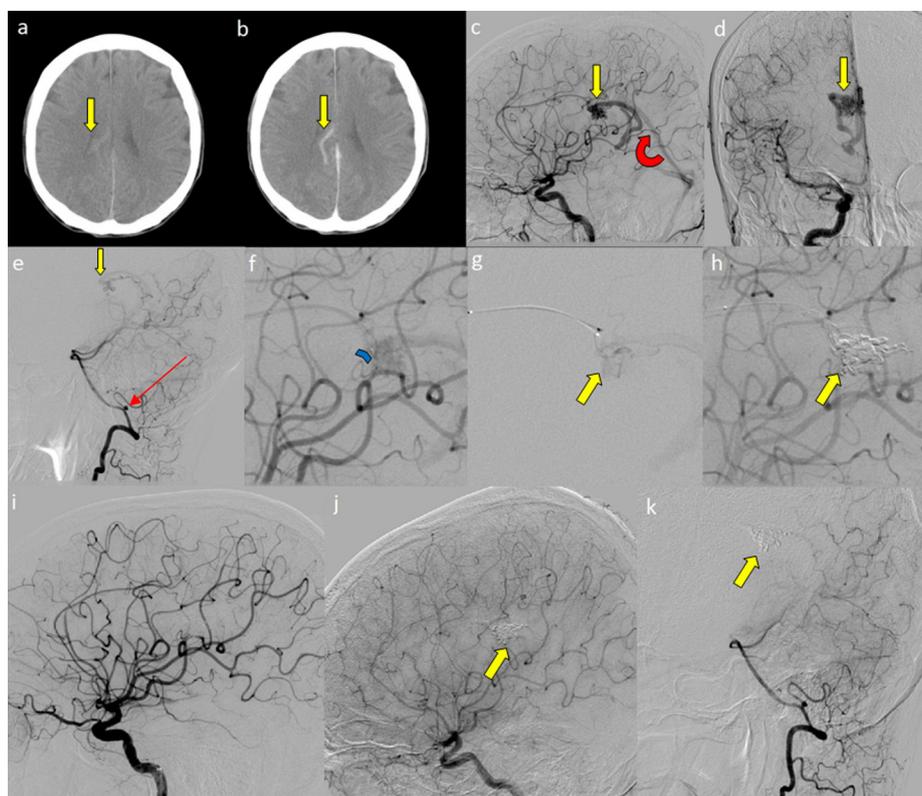


Figure 2. Preprocedural, intraprocedural and post-treatment follow-up examinations of a 61-year-old man with unruptured pericallosal arteriovenous malformation (AVM) treated with endovascular embolization: a: non-contrast CT; a tubular structure (yellow arrow) in right supracallosal level which was isodense with gray matter; b: contrast-enhanced CT; lesion showing total enhancement (yellow arrow); c, d: digital subtraction angiography (DSA) of anterior circulation; an AVM lesion (yellow arrows) in right pericallosal level which has two perforator arteries originating from anterior cerebral artery and deep venous drainage to sinus rectus (red curved arrow); e: DSA of posterior circulation; another perforator (yellow arrow) arising from posterior circulation and an aneurysm (red arrow) originating from posterior inferior cerebellar artery; f: selective DSA during embolization session; microcatheter tip (blue arrowhead) at artery–nidus junction; g: superselective DSA obtained by contrast injection from the microcatheter at artery nidus junction; intranidal structure (yellow arrow); h: selective DSA when the target penetration (yellow arrow) was just acquired by using Onyx 18[®]; i: anterior circulation DSA done at the end of session; no residue flow; j, k: anterior and posterior circulation angiograms done after three months from treatment; fully embolized lesion (yellow arrows).

Table 8 Neurologic deficit degrees determined using modified Rankin scale (mRs) in patients with unruptured AVM and post-treatment.

	Patient count (<i>n</i> = 9)	Percentage (%)
mRs point		
0	1	11
1	3	33
2	5	56
3	0	0
4	0	0
5	0	0
6	0	0
Morbidity level		
Asymptomatic	1	11
Minor deficit	8	89
Major deficit	0	0

significantly related to neurologic deficit after embolization [19]. Kim et al. stated that there is no significant association between Spetzler–Martin Grading and complication development [20].

Spetzler–Martin Grading was made for surgery of intracranial AVMs to predict mortality and morbidity risks and not especially for grading of endovascular embolization [8]. Studies have been made on intracranial AVM classification for endovascular embolization [21,22]. However, these classifications are based on technical difficulties of endovascular embolization, not for predicting mortality and morbidity. These findings give rise to the thought that grouping by AVM diameter may predict total embolization success and complication development better than Spetzler–Martin Grading. Further investigations carried out with more patients should provide clarification.

Our study has some limitations. It was a single-center and retrospective study. The number of patients was relatively small and follow-up periods were short. Having no idea about 8 patients who left follow-up after the early post-procedural period is lacking in terms of assessment of effectiveness. Further studies with more patients and longer follow-up is needed for optimal evaluation.

In conclusion, the curative function of endovascular embolization in AVM is increasing parallel to development of catheters, microcatheters and embolic agents. Total embolization success rates are adequate in treatments

done with detachable-tip microcatheters and Onyx 18[®]. We believe that higher total embolization success rates and lower death and complication rates may be achieved with development in microcatheter and embolic agent technology. A new AVM classification system primarily based on AVM diameter for this embolization technique may be more predictive than Spetzler–Martin Grading in terms of total embolization success and complication development.

CRedit author statement

Rifat Ozpar: methodology, data curation, writing – original draft.

Omer Fatih Nas: conceptualization, methodology, validation.

Kadir Hacikurt: visualization, writing – review & editing.

Mevlut Ozgür Taskapilioglu: resources, investigation.

Hasan Kocaeli: investigation, validation.

Bahattin Hakyemez: conceptualization, supervision.

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Consent for publication

Consent for publication was obtained for every individual person's data included in the study.

Disclosure of interest

The authors declare that they have no competing interest.

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