Endovascular Treatment of Brain Arteriovenous Malformations mainly fed by the Anterior Cerebral Artery

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Research

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Abstract

Background: There have been few studies on endovascular treatment (EVT) of the brain arteriovenous malformations (BAVMs) involving the anterior cerebral artery (ACA).

Methods and materials: This study continuously enrolled 60 patients with ACA-BAVMs treated with EVT. ACA-BAVMs were divided into three types: type I BAVMs were those located below and in front of the corpus callosum genu, type II BAVMs were those located in the upper area of the corpus callosum from the genu to the anterior trunk, and type III BAVMs were those located in the upper area from the anterior trunk to the splenium of the corpus callosum.

Results: The patients were aged 10 to 72 years (mean, 35.4 ± 17.0 years) and included 28 females (46.7%, 28/60). BAVMs were type I (15%, 9/60), type II (25%, 15/60), and type III (60%, 36/60). Statistical analysis showed that posterior cerebral artery (PCA) tended to be involved in type II and III BAVMs. For EVT, immediate complete or nearly complete embolization was achieved in 34 (56.7%, 34/60) cases. During EVT, there were 3 cases of intraoperative bleeding (5%, 3/60), which tended to occur in type I and II ACA-BAVMs. At discharge, 80% of patients had a GOS score of 5. During the follow-up, 89.3% of patients had mRS scores of 0 and 1.

Conclusion: This study showed that EVT carries a risk of intraoperative bleeding for type I and II BAVMs, for type II and III BAVMs, the PCA can often be involved in EVT. In general, EVT can result in a good prognosis for ACA-BAVMs.

Introduction

Brain arteriovenous malformation (BAVM) is a common intracranial vascular disease. After BAVM occurs, the feeding artery dilates and thins, as in “venolization”. The nidus undergoes dynamic remodelling, thrombosis or rupture can occur, and the draining vein can thicken and dilatate, as in “arterialization” [1, 2].

BAVMs at different sites have different characteristics [3]. BAVMs can occur in the anterior cerebral artery (ACA), which is deep in the middle of the cerebral hemispheres; its periphery is close to the medial veins of the frontal lobe, and the posterior part of the ACA is close to the deep cerebral venous system [4]. ACA-BAVMs are distributed above the corpus callosum in different sites of the A2-A5 segments of the ACA and have various characteristics [5].

Currently, there have been relatively few studies on the endovascular treatment (EVT) of ACA-BAVMs. Therefore, this study systematically collected ACA-BAVMs and classified them according to location. At the same time, the EVT of ACA-BAVMs was analysed, contributing to the meaningfulness of this study.

Material And Methods

A total of 60 patients with BAVMs supplied by the ACA system treated by EVT from January 2012 to January 2020 were collected continuously and analysed retrospectively. This study was approved by the institutional ethics committee.

Inclusion criteria

(1) The BAVM was located above the corpus callosum, at or near the midline of the ACA distribution area; (2) The ACA was the main (if not the only) source of blood supply. (3) No previous EVT, open surgery, or radiosurgery was performed before admission to our institution.

ACA-BAVM classification

BAVMs were classified according to the positional relationship with the corpus callosum and ACA. Type I BAVMs were those located on the first segment, which refers to the area below and in front of the corpus callosum genu (i.e., the A2 segment of the ACA). Type II BAVMs were those located on the second segment, which refers to the upper area of the corpus callosum from the genu to the anterior trunk (i.e., the A3 segment of the ACA). Type III BAVMs were those located on the third segment, which refers to the area from the anterior trunk to the splenium of the corpus callosum (i.e., the A4-5 segment of the ACA). These divisions and classifications of the ACA-BAVM are shown in Figs. 1.

Preoperative data collection

The patient data were collected and recorded, including the age and sex, clinical presentation, and angiographic characteristics of ACA-BAVM.

Scheme and strategy of EVT

All patients were treated under general anaesthesia via a transfemoral approach. Based on the angioarchitecture, after the three-dimensional reconstruction to show the ACA-BAVM, the main feeding artery was chosen to perform the EVT under the best degree of unfolded ACA branch. For the BAVM nidus, a Marathon or Apollo microcatheter (Medtronic, Irvine, California, USA) was used to access the nidus of the BAVM to obtain the wedge position. Then, Onyx (Medtronic, Irvine, California, USA) was cast. For flow-related aneurysms, an Echelon microcatheter (Medtronic, Irvine, California, USA) was preferred to perform coiling.

For thin feeding arteries with acute degrees in type I and II BAVMs, the microcatheter can be shaped into a “J” curve to pass the artery origin; in addition, having patience without violent manipulation is very important. For type II and III BAVMs with multiple feeding arteries, if the ACA path did not achieve satisfactory EVT, additional EVT was performed through other arteries, such as the middle cerebral artery (MCA) and posterior cerebral artery (PCA).

For EVT of ruptured BAVMs, flow-related aneurysms on the feeding artery or in the nidus of the BAVM should receive priority for treatment. In addition, for ruptured BAVMs, if there were no clear risk factors,

EVT was used to reduce the blood flow of BAVMs. For unruptured BAVMs, EVT targeted dangerous structures of those weak points, such as aneurysms in the feeding artery or dilated structures in the nidus. Conservative management should be suggested for those without dangerous structures [6].

Prognosis evaluation and follow up

EVT complications, the length of hospital stay and the Glasgow Outcome Scale (GOS) score at discharge were all recorded. The angiographic follow-up and modified Rankin Scale score (mRS) were also recorded.

Statistical analysis

GraphPad Software (LLC, San Diego, USA) was used for statistical analysis. Continuous variables are expressed as the mean $\pm$ standard deviation. Ordinary one-way ANOVA was used for multiple comparisons. The chi-square test was used to compare count data. A *P value* < 0.05 was considered to indicate a significant difference.

Results

General information

The 60 patients were aged 10 to 72 years (mean, 35.4 ± 17.0 years) and included 28 females (46.7%, 28/60) and 32 males (53.3%, 32/60). Among them, there were 22 cases of unruptured ACA-BAVMs (36.7%, 22/60), including 21 cases of headache and 1 case of epilepsy; there were 38 cases of haemorrhage (63.3%, 38/60), including 3 cases of subarachnoid haemorrhage (SAH), 17 cases of intracerebral haematoma (IH), 1 case of IH and subdural haematoma, 4 cases of intraventricular haemorrhage (IVH) and 13 cases of IH and IVH. Among the 38 cases of rupture and haemorrhage, 18 cases were Hunt-Hess grade I, 8 cases were grade II, and 12 cases were grade III.

Imaging characteristics

The diameter of the ACA-BAVM was 4.4 ± 2.6 cm (0.75–13.5 cm). The size was less than 3 cm in 19 cases, 3–6 cm in 28 cases, and more than 6 cm in 13 cases. Sixteen cases (26.7%, 16/60) were Spetzler-Martin (SM) grade I, 20 cases were SM grade II (26.7%, 20/60), 21 cases were SM grade III (35%, 21/60) and 3 cases were SM grade IV (5%, 3/60).

Six cases (10%, 6/60) had flow-related aneurysms on the feeding artery. Draining veins: Forty-two ACA-BAVMs were drained by superficial veins (70%, 42/60), 14 were drained by deep veins (23.3%, 14/60), and 4 were drained by both superficial and deep veins (6.7%, 4/60).

ACA-BAVM types

Type I BAVM was found in 9 cases (15%, 9/60). Among them, 5 were supplied by the ACA, and 4 were supplied by the ACA and MCA. Type II BAVM was found in 15 cases (25%, 15/60). Among them, 9 were supplied by the branches from the ACA, 4 were supplied by the ACA and MCA, and 2 were supplied by the

ACA, MCA, and PCA. Type III BAVM was found in 36 cases (60%, 36/60). Among them, 18 were supplied only by the ACA, 11 were supplied by the ACA and PCA, 5 were supplied by the ACA, MCA, and PCA, 1 was supplied by the ACA and MCA, and 1 was supplied by the ACA, MCA, PCA and external carotid artery (ECA).

EVT Results

In fifty-four ACA-BAVMs without aneurysms, 48 BAVMs (80%, 48/60) were embolized with Onyx via the ACA, 2 (3.4%, 2/60) via the ACA and MCA, 2 (3.3%, 2/60) via the ACA and PCA, and 1 (1.7%, 1/60) via the MCA and PCA. In 1 case (1.7%, 1/60), a diffuse type I BAVM was treated only by feeding artery coiling to reduce blood flow.

Of the 6 patients with BAVMs and aneurysms (10%, 6/60), 1 underwent aneurysm coiling and BAVM embolization with Onyx, 2 underwent aneurysm and BAVM embolization with Onyx, and 3 ruptured aneurysms underwent coiling only. For the BAVM nidus, immediate complete or nearly complete embolization was achieved in 34 (56.7%, 34/60) cases. Partial embolization was achieved in 22 (36.7%, 22/60) cases. No embolization was given in 4 (6.7%, 4/60) cases.

During the EVT process, there were 3 cases of intraoperative bleeding (5%, 3/60); among them, 2 occurred in type I ACA-BAVM, and 1 occurred in type II ACA-BAVM.

Prognosis and follow-up

Discharge outcome

The length of hospital stay ranged from 2 to 58 days (10.6 ± 9.2 days). At discharge, 1 patient (1.7%, 1/60) had a GOS score of 1, 8 (13.3%, 8/60) had a GOS score of 3, 3 (5%, 3/60) had a GOS score of 4, and 48 (80%, 48/60) had a GOS score of 5.

Follow-up outcome

Forty-nine patients were available at the clinical follow-up, and the follow-up ranged from 12 to 78 years (mean 31.1 ± 20.5 years). Among them, 2 patients died from non-cerebral disease; of the remaining 47 patients, 39 patients presented with an mRS score of 0, 3 with an mRS score of 1, 3 with an mRS score of 2, and 2 with an mRS score of 3. Forty-two (89.3%, 42/47) had an mRS score of 0 or 1. Of all patients, 20 patients had angiographic follow-up, of whom 18 had satisfactory EVT and 2 experienced additional EVT.

Statistical analysis

The statistical analysis is summarized in Table 1. For the ACA-BAVM diameter, ordinary one-way ANOVA showed a P value > 0.05 , indicating no significant difference among the three types. For IVH and deep vein involvement, Chi-square and Fisher's exact tests showed a P value > 0.05 , indicating no significant differences among the three types.

For intraoperative haemorrhagic complications, Chi-square and Fisher's exact tests showed a P value < 0.05, which showed that complications tended to occur on type I and II BAVMs. For PCA involvement, Chi-square and Fisher's exact tests showed a P value < 0.05, which showed that PCA tended to be involved in type II and III BAVMs.

In this study, some cases of typical EVT treatment are shown in Figs. 2–7.

Discussion

BAVM is a common congenital vascular disease that belongs to the abnormal nidus between arteries and veins and lacks an intervening capillary network; it can occur in all parts of the brain. Obviously, BAVMs in different positions have different characteristics. The architecture depends on the location, recruited arteries and draining veins, and size of the BAVM nidus [7].

The ACA lies between the cerebral hemispheres. It is located in the lower part of the cerebral falx and the upper part of the corpus callosum between the bilateral cerebral hemispheres, where it is basically isolated. Under normal conditions, the ACA system is relatively independent [8]. Unless ischaemia similar to that in moyamoya disease occurs, the ACA can be anastomosed with the posterior choroidal arteries from the PCA or with the pial branches of the PCA. This anastomosis is often characterized by a direct anastomosis between the blood supply from the PCA system and the distal trunk of the ACA [9]. Generally, the MCA only compensates for the pial branches in the distribution area of the ACA.

A comprehensive survey of BAVMs revealed that some of them occur specifically in the distribution area of the ACA, showing a variety of different vascular architectures [10]. Due to the lack of a systematic classification, this study divided the BAVMs located in the midline of the ACA according to their position, which is a scientific approach in line with the segmentation of the ACA (A2-A5 segment) (Fig. 1). So, this study classified ACA-BAVMs into types I, II and III.

In our study of ACA-BAVMs, arteries distributed along the ACA were different. For example, there is a potential collateral circulation between the posterior part of the ACA and the arterial distribution area of the PCA, and the anterior part of the ACA can only be compensated by the pia mater collateral branches of the MCA. BAVMs occurring in the posterior part of the corpus callosum and ACA are closer to the deep venous system [11].

Therefore, statistical analysis was performed on the size of BAVMs in each ACA segment to determine whether ACA-BAVMs in different segments were more likely to induce IVH and involve deep veins. However, the results showed no significant difference. This shows that in the narrow space of the ACA system, the BAVM had the same imaging and clinical characteristics. However, the statistical analysis showed that the PCA tended to involve the distal ACA.

EVT of ACA-BAVMs is the same as that in other areas and mainly aims to manage flow-related aneurysms and embolize the nidus of BAVMs to reduce the blood flow of the draining venous system [6].

In this study, 6 cases were complicated with flow-related aneurysms, with an incidence of 10%, which was lower than the reported incidence (20%) of whole-brain AVMs with aneurysms [12]. This type of aneurysm must be treated and is an absolute risk factor in BAVM cases (Figs. 2, 3, 4, 6, and 7).

EVT of ACA-BAVMs is able to produce satisfactory results, with a low complication rate of only 5%. Our study shows that 85% of cases had a GOS score of 4 or 5 at charge, and 89.3% of cases had an mRS score of 0 and 1 during the follow-up. Complete or nearly complete embolization was achieved in 56.7% of cases. The EVT degree depended on many factors, such as the nidus size, compact or diffuse types, feeding artery diameter and tortuosity. Moreover, the EVT degree was not the goal to be pursued but the resolution of the risky weak point.

After ACA-BAVM classification, EVT becomes strategic. Type I and II BAVMs are supplied by the branches of the proximal ACA, and these feeding arteries are commonly slim and multiple. Microcatheter navigation close to the BAVM nidus was difficult, which increased the EVT risk. In this study, intraoperative bleeding tended to occur in type I and II BAVMs. As type II and III BAVMs are supplied by the end of the ACA trunk, EVT is relatively easy. However, when they are supplied by the blood supply of multiple regional arteries, especially from the PCA region, EVT may be complex, and sometimes PCA has to be used to perform EVT because PCA tends to be involved in type II and III BAVMs.

Conclusion

ACA-BAVMs can be classified into types I-III according to the position of the BAVMs on the ACA. The classification was helpful. For type I and II BAVMs supplied by slim and multiple branches of the proximal ACA, EVT was difficult, and intraoperative bleeding complications were common. For type II and III BAVMs, because PCA tends to be involved in type II and III BAVMs, EVT may be complex, and sometimes PCA has to be used to perform EVT.

Limitations

This study was limited by the medical restrictions of Chinese patients, the low rate of re-examination by postoperative angiography, and the lack of long-term results.

Abbreviations

ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; L: left.

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of The First Hospital of Jilin University, and the participants gave their informed consent before inclusion in the study.

Consent for publication

Written informed consent was obtained from the patient for publication of this manuscript and any accompanying images. A copy of the written consent is available for review by the editor of this journal.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' Contributions

Conception and design: JY. Acquisition of data: KH. Analysis and interpretation of data: JY. Drafting of the article: KH. Critical revision of the article: JY. All the authors have read and approved the final manuscript.

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Tables

Table 1. Statistics of ACA BAVMs in partial imaging characteristics

	Type I BAVM (n=9)	Type II BAVM (n=15)	Type III BAVM (n=36)	<i>P</i> value
BAVM diameter	4.89 ± 2.60 cm	4.67 ± 2.04 cm	4.18 ± 2.85 cm	0.3830
IVH presentation	1/5*	4/9*	12/24*	0.4708
Deep vein involvement	2/9	5/15	11/36	0.8420
PCA involvement	0/9	2/15	17/36	0.0468
Haemorrhagic complication of EVT	2/9	1/9	0/36	0.0223

Explanation for *: For the IVH presentation line, 1/5 refers to 5 cases of haemorrhage and 1 case of ventricular involvement; 4/9 and 12/24 are the same.

Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; EVT: endovascular treatment; IVH: intraventricular haemorrhage; PCA, posterior cerebral artery.

Figures

Figure 1

BAVM classification according to the ACA and corpus callosum anatomy A: Head MRI showing the CC and the ACA around it. The red frame shows a type I BAVM located in the first segment, that is, the anteroinferior part of the CC genu. The yellow frame shows a type II BAVM located in the second segment, that is, from the CC genu to the anterior trunk. The green frame shows a type III BAVM located in the third segment, that is, from the anterior trunk to the splenium of the CC. B: Lateral head CTA showing

the ACA system and deep venous system. BAVMs can be partitioned according to the ACA, as shown in half frames and logo. Type I BAVMs were those located in the area of the A2 segment of the ACA. Type II BAVMs were located in the area of the A3 segment of the ACA. Type III BAVMs were located in the area of the A4-5 segment of the ACA. Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CC, corpus callosum; CTA, computed tomography angiography; GV: Galen vein; ICS, the internal cerebral vein; ISS: inferior sagittal sinus; MRI, magnetic resonance imaging; PCA: posterior cerebral artery; SS: straight sinus.

Figure 2

Typical case of type I BAVMs with aneurysm in the ACA branch A: Head CT showing subarachnoid haemorrhage in the longitudinal fissure with hydrocephalus. B: CTA showing an aneurysm (arrow) located in a branch of the ACA. C: Two-dimensional DSA of the right internal carotid artery showing an aneurysm (arrow) in the feeding artery of the BAVM, as well as other branches of the blood supply (star). D: X-ray film showing casting Onyx (ellipse). E: Posttreatment DSA of the right internal carotid artery showing that the aneurysm in the feeding artery was embolized; the BAVM remained (ellipse), and other feeding arteries are shown (star). F: Posttreatment CT showing drainage of the lateral ventricle. Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; R: right.

Figure 3

Typical case of type II BAVMs with aneurysm in the ACA branch A: Head CT showing haemorrhage in the right frontal lobe. B: CTA showing a BAVM supplied by the branch of the ACA (ellipse). C-D: Two-dimensional (C) and three-dimensional (D) DSA of the right internal carotid artery showing BAVMs supplied by a single branch of the ACA, with a dissecting aneurysm at the beginning (arrows). E: X-ray film showing Onyx casting (ellipse). F: Posttreatment DSA of the right internal carotid artery showing that

the BAVM was not seen. Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; R: right.

Figure 4

Typical case of type II BAVMs with multiple aneurysms in the ACA trunk A: Head CT showing haemorrhage in the longitudinal fissure. B: CTA showing a BAVM (ellipse) supplied by the ACA trunk with multiple aneurysms (arrows). C: Two-dimensional DSA of the left internal carotid artery showing BAVMs supplied by the ACA trunk with two aneurysms (arrows). D: Posttreatment DSA of the left internal carotid artery showing that the aneurysms were occluded by parent artery coiling. Abbreviations: ACA, anterior

cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; L: left.

Figure 5

Typical case of type III BAVMs A: Head CT showing a haematoma located in the frontal parietal lobe. B: CTA showing a BAVM (ellipse) at the end of the ACA draining to the sagittal sinus. C: Left vertebral artery DSA showing that the posterior circulation is not involved in the blood supply of the BAVM. D: Three-

dimensional DSA reconstruction of the right internal carotid artery showing that the terminus of the ACA is involved in the blood supply of the BAVM. E: X-ray film showing Onyx casting. The arrow shows the coils in the feeding artery near the nidus, and the “pressure cooker” technique is used during treatment. F: Posttreatment DSA of the right internal carotid artery showing that the BAVMs were nearly completely embolized, while the draining veins remained (ellipse). Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; L: left; R: right.

Figure 6

Typical case of type III BAVM with multiple aneurysms in the ACA trunk A: Head CT showing subarachnoid haemorrhage in the longitudinal fissure. B: CTA showing a BAVM (ellipse) at the end of the ACA, which drains to the sagittal sinus and is supplied by the ACA, MCA and PCA. The ACA is the main feeding artery, with multiple aneurysms (arrow and triangle). C: Left vertebral artery DSA showing that the posterior circulation is involved in the blood supply of the BAVM. D: A stent was used to assist in coiling the aneurysms (arrows) in the ACA. E: MRI re-examination after 3 days showing new haemorrhage in the longitudinal fissure, which was considered to be caused by a ruptured aneurysm. F-G: PAO was performed to occlude the aneurysm and the parent artery (arrow). H: DSA in the venous phase showing that the reversed blood supply of the ACA distribution area in the frontal lobe (ellipse) originates from the BAVM to the ACA (star). Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; L: left; MCA: middle cerebral artery; MRI, magnetic resonance imaging; PAO: parent artery occlusion; PCA: posterior cerebral artery; R: right.

Figure 7

Typical case of type III BAVMs with aneurysm in the lenticular artery A: Head CT showing intraventricular haemorrhage. B: CTA showing the BAVM (ellipse) near the midline. C-E: Two-dimensional (C and E) and three-dimensional (D) DSA showing a BAVM supplied by the lenticular artery of the MCA and ACA. Stars in C-D refer to the lenticular artery, and arrowheads refer to the aneurysm. E: The pial collateral circulation of the PCA also supplies the BAVM (star). F: Coiling and Onyx casting (ellipse) were used to occlude the

aneurysm in the lenticular artery. G: Post-treatment CT showing ventricular drainage. H: DSA of the right internal artery re-examination 6 months after treatment showing no recurrence of the aneurysm. Abbreviations: ACA, anterior cerebral artery; BAVM, brain arteriovenous malformation; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; MCA: middle cerebral artery; PCA: posterior cerebral artery; R: right.