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Original Article

The Relationships between Anatomical Factors and Treatment Procedures for the Endovascular Treatment of Anterior Communicating Artery Aneurysms

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Objective: Endovascular treatment of anterior communicating artery aneurysms is difficult due to their complex anatomical structure. We retrospectively analyzed the relationships among the anatomical features, initial microcatheter positions, and initial occlusion outcomes.

Methods: In all, 66 cases were treated at our hospital. We investigated the relationships among the anatomical features of the aneurysm and A1 segment of the anterior cerebral artery (ACA), treatment procedures, and initial occlusion outcomes. We divided the initial microcatheter positions into greater and lesser curvatures based on the curvature from A1 to the aneurysm, and evaluated the outcomes.

Results: In total, 54 out of 66 patients (82%) achieved complete obliteration (CO) or had residual neck (RN) aneurysms, and 12 had residual aneurysms (RAs: 18%). Neck diameters and superior position aneurysms were correlated with initial occlusion outcomes in the multivariate analysis. The relationship between initial occlusion outcomes and initial microcatheter positions in superior position aneurysms (37 patients) was then examined. Eleven out of 26 patients (42.3%) had residual aneurysms at the greater curvature microcatheter position, whereas no residual aneurysms were detected at the lesser curvature microcatheter position. The A1 angle was not correlated with the outcomes.

Conclusion: Wide-necked aneurysms and superior position aneurysms were identified as factors leading to incomplete occlusion in the endovascular treatment of anterior communicating artery aneurysms. The microcatheter position at the greater curvature in superior position aneurysms was a factor for incomplete occlusion. This suggests that guiding the microcatheter to the lesser curvature position of A1 is important in the treatment of superior position aneurysms.

Keywords▶ anterior communicating artery aneurysm, endovascular treatment, morphology

Introduction

When performing endovascular treatment for anterior communicating artery aneurysms, large and upward aneurysms are factors for incomplete obliteration.[1,2] However, the anterior communicating artery and peripheral blood vessels have complex structures, and this may influence the difficulty of treatment. In this study, we retrospectively examined factors associated with the results of treatment, focusing on the positional relationship between the A1 anterior cerebral artery (ACA) and aneurysm, as well as the position of microcatheter insertion, during coil embolization of anterior communicating artery aneurysms.

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Materials and Methods

The subjects were 66 consecutive patients who underwent endovascular treatment of anterior communicating artery aneurysms in our hospital between April 2012 and December 2018. Prior to this study, its protocol was approved by the ethics review board of our hospital (2019-019). In all patients, treatment was performed under general anesthesia. For treatment, heparin was intravenously injected after sheath insertion to maintain the activated coagulation time (ACT) at ≥250 during surgery. In general, a simple technique was adopted and combined with adjunctive techniques, such as balloon-/stent-assisted and double catheter techniques, on an individual-patient basis. Pre- or steam-shaped microcatheters were used based on surgeons' evaluation, considering the shape of each aneurysm. Concerning ruptured cerebral aneurysms, treatment was performed within 72 hours after onset in all patients; no antiplatelet drug was administered before surgery, and the oral administration of cilostazol at 200 mg was started after confirming the absence of hemorrhagic complications the day after surgery, and continued until 14 days after surgery. Concerning unruptured cerebral aneurysms, the oral administration of aspirin at 100 mg and clopidogrel at 75 mg was started 4 days before treatment. Therapy with the two drugs was continued for 1 year for patients in whom the stent-assisted technique was used, whereas it was completed after 3 months for the other patients.

The results of embolization were evaluated using Raymond's criteria on final angiography.[3] Patients in whom no aneurysm was visualized were regarded as achieving "complete obliteration (CO)." Those in whom only the aneurysmal neck was visualized, but not the dome, were regarded as having "residual neck (RN)." Those with intra-aneurysmal visualization of contrast medium were regarded as having "residual aneurysm (RA)." From the viewpoint of rupture prevention, we considered the absence of aneurysmal-dome visualization important and divided the initial results of embolization into two groups, CO/RN and RA, to examine morphological factors affecting the results. Magnetic resonance imaging (MRI) was performed within 1 week after surgery to evaluate the presence of procedure-related diffusion-weighted imaging (DWI)-positive findings.

Anatomical parameters

Anatomical parameters were measured using digital subtraction angiography (DSA) images. As anatomical examination items regarding aneurysms, the maximum

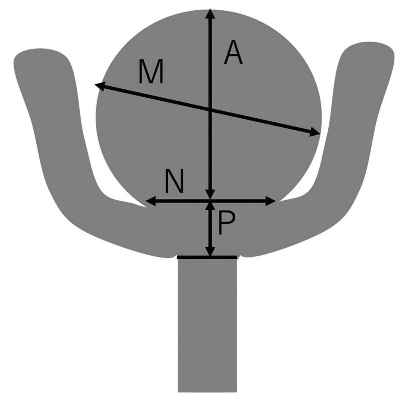

Fig. 1 Measurement of aneurysms. A: aneurysm height; A/N: ASPECT ratio; M: maximum diameter; M/N: dome to neck (D/N) ratio; N: neck; P: parent artery space; P/N: parent artery space to neck (P/N) ratio

aneurysmal diameter, neck diameter, aspect ratio, and dome/neck ratio were measured. For the neck and parent blood vessel, the height from the proximal area of a branch to the neck (parent artery space) was measured (**Fig. 1**). The relationship between the aneurysm and A1 was evaluated based on the slope at the aneurysmal end to an elongated line of the A1 ACA; an upward slope was defined as superior and a downward slope was defined as inferior (**Fig. 2A** and **2B**). Similarly, a forward slope was defined as anterior and a backward slope was defined as posterior. Furthermore, the angle of A1 branching from the internal carotid artery (ICA) was evaluated by classifying the upward and downward courses of the horizontal A1 area on a frontal view of cephalic DSA as superior and inferior, respectively (**Fig. 2C** and **2D**). In addition, the degree of contralateral A1 development was assessed. The Matas test was conducted, and patients in whom the middle cerebral artery (MCA) was not visualized through the contralateral A1 segment were regarded as having hypoplastic A1.

Regarding treatment procedures, a simple technique was compared with an adjunctive technique. In particular, we investigated the position of a microcatheter inserted into the aneurysm to examine the influence of the first position of a microcatheter on the initial results of embolization (**Fig. 3**). Focusing on flexion from A1 to the aneurysm, the side on which a microcatheter is placed, the greater or lesser curvature sides, was investigated. When the A1 direction was inverse from the aneurysmal slope, forming an S-shape, a microcatheter placed in the position presented in **Fig. 3A** was regarded as existing on the greater curvature side, and that in **Fig. 3B** as existing on the lesser curvature side. When the A1 direction was consistent with the aneurysmal slope, forming an arc shape, a microcatheter

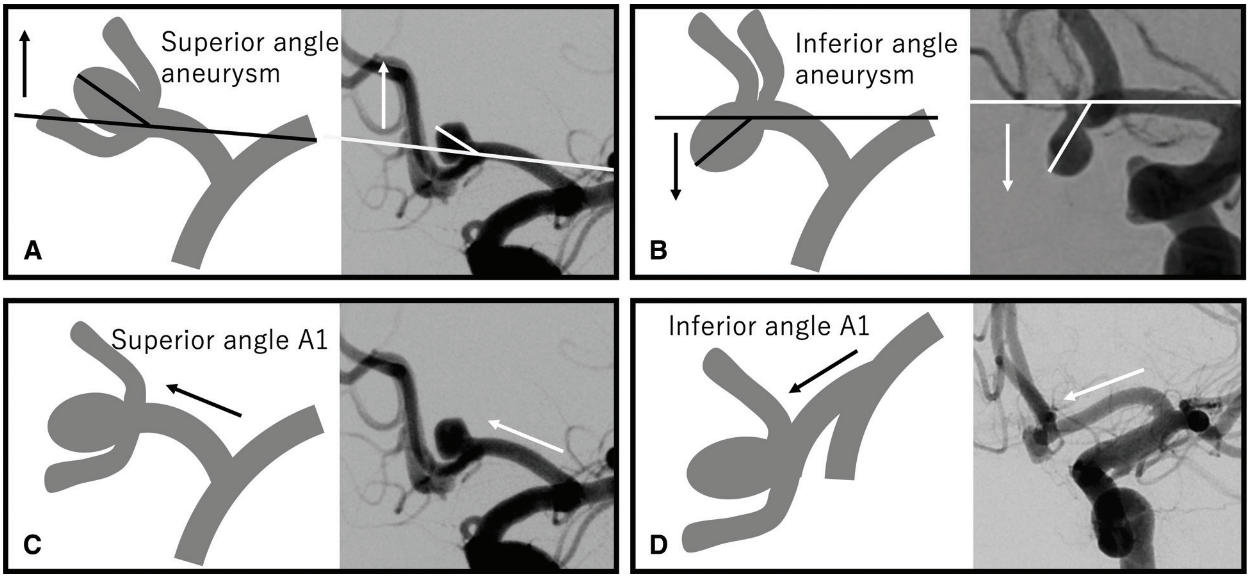

Fig. 2 Positional relationships among the A1 ACA, aneurysm, and ICA. (**A**) Superior angle. The aneurysm leaned upward from the A1 direction. (**B**) Inferior angle. The aneurysm leaned downward from the A1 direction. (**C**) Superior angle. A1 branched upward from the internal carotid artery. (**D**) Inferior angle. A1 branched downward from the internal carotid artery. ACA: anterior cerebral artery; ICA: internal carotid artery

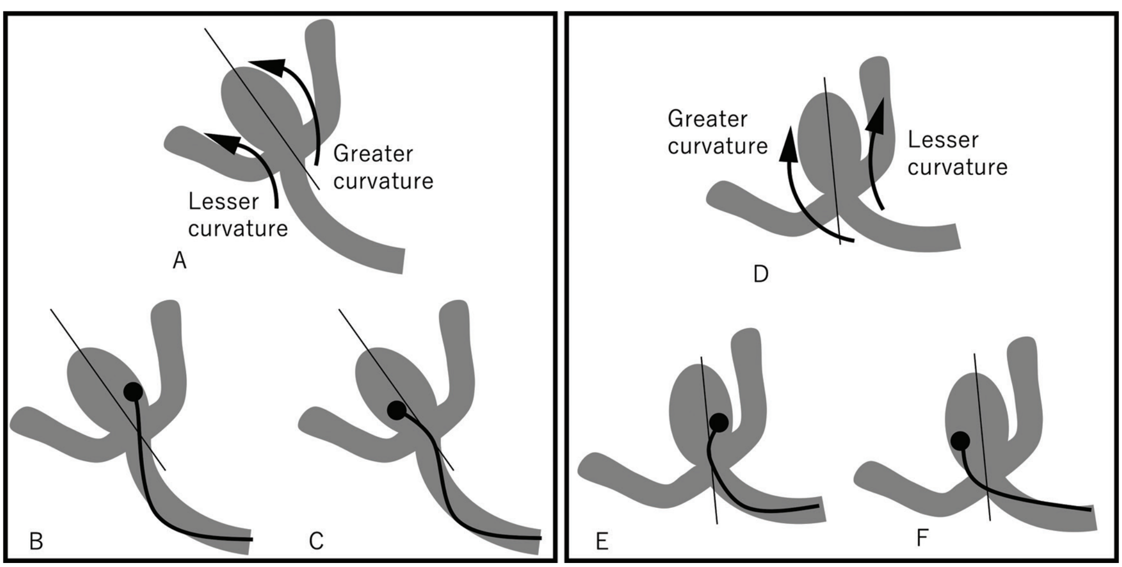

Fig. 3 Scheme of the direction of blood flow to aneurysms. (**A**) When an aneurysm branching in the opposite direction of the A1 curve formed an S shape, the greater and lesser curvature sides were defined, as indicated by the arrows. (**B**) A microcatheter was placed on the greater curvature side. (**C**) A microcatheter was placed on the lesser curvature side. (**D**) When an aneurysm branching in the same direction as the A1 curve formed an arc shape, the greater and lesser curvature sides were defined, as indicated by the arrows. (**E**) A microcatheter was placed on the lesser curvature side. (**F**) A microcatheter was placed on the greater curvature side.

placed in the position presented in **Fig. 3C** was regarded as existing on the greater curvature side, and that in **Fig. 3D** as existing on the lesser curvature side.

Statistical analysis

The data are expressed as the mean ± standard deviation. To compare the values between two groups, the t-test and chi-square test were used for univariate analysis, and logistic regression analysis for multivariate analysis. A p value of 0.05 was regarded as significant. For statistical analysis, we used SPSS Statistics version 26.0 software (IBM).

Results

The patients' background is shown in **Table 1**. The subjects were 66 patients, consisting of 29 (43.9%) with ruptured

Table 1 Patients' background

		Total (n = 66)	Unruptured (n = 37)	Ruptured (n = 29)
Age (years)		65.1 ± 12.7	64.8 ± 10.5	65.5 ± 15.3
Sex (M : F)		29:37	18:19	11:18
Aneurysm diameter (mm)		5.79 ± 1.8	5.91 ± 1.5	5.64 ± 2.1
Neck diameter (mm)		3.11 ± 1.4	3.60 ± 1.5	2.49 ± 0.9
Aneurysm angle	Superior	35 (53.0%)	23 (62.2%)	12 (41.4%)
	Inferior	31 (47.0%)	14 (37.8%)	17 (58.6%)
	Anterior	54 (81.8%)	31 (83.8%)	23 (79.3%)
	Posterior	12 (18.2%)	6 (16.2%)	6 (20.7%)
A1 angle	Superior	28 (42.4%)	18 (48.6%)	12 (41.4%)
	Inferior	38 (57.6%)	19 (51.4%)	17 (58.6%)
Initial outcome	CO	39 (59.1%)	20 (54.1%)	19 (65.6%)
	RN	15 (22.7%)	10 (27.0%)	5 (17.2%)
	RA	12 (18.2%)	7 (18.9%)	5 (17.2%)
Treatment method	Simple	42 (63.6%)	19 (51.4%)	23 (79.3%)
	Balloon	10 (15.4%)	6 (16.2%)	4 (13.8%)
	Double catheter	8 (12.1%)	6 (16.2%)	2 (7.0%)
	Stent	6 (9.1%)	6 (16.2%)	0 (0%)
DWI positive		29 (43.9%)	17 (45.9%)	12 (41.4%)
Symptomatic ischemia		1 (1.5%)	1 (2.7%)	0
Intraoperative bleeding		1 (1.5%)	1 (2.7%)	0
Retreatment		1 (1.5%)	0	1 (3.4%)
Recurrence		1 (1.5%)	0	1 (3.4%)

CO: complete obliteration; DWI: diffusion-weighted image; RA: residual aneurysm; RN: residual neck

Table 2 Relationship between the initial results of embolization and each factor

		RA	CO/RN	P value	
		(n = 12)	(n = 54)	Univariate	Multivariate
Age (years)		67.9 ± 9.18	64.4 ± 13.4	0.29	–
M : F		5:7	23:31	0.86	–
Unruptured		7 (58.3%)	30 (55.6%)	0.86	–
Aneurysm diameter		7.16 ± 2.04	5.49 ± 1.57	0.02	0.35
Neck diameter		4.41 ± 2.82	2.82 ± 1.06	0.016	0.001
ASPECT ratio		1.44 ± 0.63	1.88 ± 0.71	0.048	0.68
D/N ratio		1.86 ± 0.74	2.12 ± 0.75	0.3	–
P/N ratio		0.56 ± 0.31	0.69 ± 0.33	0.013	0.99
Contralateral hypoplastic A1		4 (33.3%)	8 (14.8%)	0.47	–
Aneurysm Angle	Superior	11 (91.7%)	28 (51.6%)	0.008	0.005
	Inferior	1 (8.3%)	26 (48.4%)		
	Anterior	10 (83.3%)	44 (81.5%)	0.89	–
	Posterior	2 (16.7%)	10 (18.5%)		–
A1 Angle	Superior	6 (50%)	22 (40.7%)	0.75	–
	Inferior	6 (50%)	32 (59.3%)		
Treatment method	Simple	6 (50%)	34 (63.0%)	0.51	–
	Adjunctive	6 (50%)	20 (37.0%)		
DWI (+)		7 (58.3%)	22 (40.7%)	0.71	–

CO: complete obliteration; DWI: diffusion-weighted image; RA: residual aneurysm; RN: residual neck; D/N: dome to neck; P/N: parent artery to neck

Table 3 Relationship between the first position of the microcatheter and initial results of embolization

Initial outcome		Aneurysm angle							
		Superior angle				Inferior angle			
		RA (n = 11)	CO/RN (n = 26)	Total (n = 37)	P value	RA (n = 1)	CO/RN (n = 28)	Total (n = 29)	P value
Catheter position	Greater curvature	11	16	27	P = 0.016	1	17	18	P = 0.426
	Lesser curvature	0	10	10		0	11	11	

CO: complete obliteration; RA: residual aneurysm; RN: residual neck

Table 4 Relationship between the presence of DWI-positive findings and each factor

		DWI (+) (n = 28)	DWI (-) (n = 37)	P value Univariate	P value Multivariate
Age (years)		68.1 ± 13.6	63.1 ± 11.8	0.13	–
M : F		13:15	15:22	0.39	–
Aneurysm diameter		6.02 ± 2.09	5.61 ± 1.53	0.39	–
Unruptured		21 (75%)	16 (43.2%)	0.9	–
Neck diameter		3.80 ± 1.74	2.60 ± 0.74	0.002	0.21
ASPECT ratio		1.53 ± 0.58	1.98 ± 0.75	0.008	0.66
D/N ratio		1.76 ± 0.61	2.29 ± 0.77	0.003	0.27
P/N ratio		0.69 ± 0.35	0.84 ± 0.33	0.1	0.85
Contralateral hypoplastic A1		6 (21.4%)	9 (24.3%)	0.22	–
Aneurysm angle	Superior	18 (64.3%)	18 (48.6%)	0.25	–
	Inferior	10 (35.7%)	19 (51.4%)		
	Anterior	23 (82.1%)	30 (81.1%)	0.89	–
	Posterior	5 (17.9%)	7 (18.9%)		
A1 angle	Superior	13 (46.4%)	14 (37.8%)	0.33	–
	Inferior	15 (53.6%)	23 (62.2%)		
Treatment method	Simple	10 (35.7%)	29 (78.4%)	0.001	<0.001
	Adjunctive	18 (64.3%)	8 (21.6%)		
Initial outcome (CO/RN)		22 (78.6%)	31 (83.8%)	0.71	–

CO: complete obliteration; DWI: diffusion-weighted imaging; D/N: dome to neck; RN: residual neck; P/N: parent artery to neck

cerebral aneurysms and 37 (56.1%) with unruptured cerebral aneurysms. Concerning the initial results, CO was achieved in 39 patients (59.1%), RN was noted in 15 (22.9%), and RA in 12 (18.0%). The procedure was performed using a simple technique in 42 patients (63.6%), whereas adjunctive techniques were used in 24: the balloon-assisted technique in 10 (15.4%), double catheter technique in 8 (12.1%), and stent-assisted technique in 6 (9.1%). Overall, DWI-positive findings were noted in 29 patients (43.9%), and they were symptomatic in 1 (1.5%). One patient (1.5%) had intraoperative rupture. There was no postoperative hemorrhage in any patient. After surgery, image-based follow-up was possible in 57 patients, with a mean follow-up of 24.8 months. During the course, additional treatment was required for one patient (1.5%). This patient had a ruptured upward aneurysm; a microcatheter was placed on the greater curvature side for treatment and initial embolization resulted in RA. Recurrence was detected 1 month after the initial treatment and additional embolization was performed, leading to CO.

The initial results of embolization are shown in **Table 2**. Univariate analysis demonstrated that the aneurysmal diameter, neck diameter, aspect ratio, and upward aneurysms affected the results of embolization, whereas the angle of AI branching from the ICA did not. Multivariate analysis revealed the neck diameter and upward aneurysms to affect the initial results of embolization. Of these, we examined the relationship between the first position of an MC and initial results of embolization in 37 patients with upward aneurysms. Of 27 patients in whom an MC was initially placed on the in-flow side, RA was noted in 11 (40.7%). Of 10 in whom an MC was initially placed on the out-flow side, there was no RA in any patient (P = 0.016). There was no association between the first position of an MC and downward aneurysms (**Table 3**).

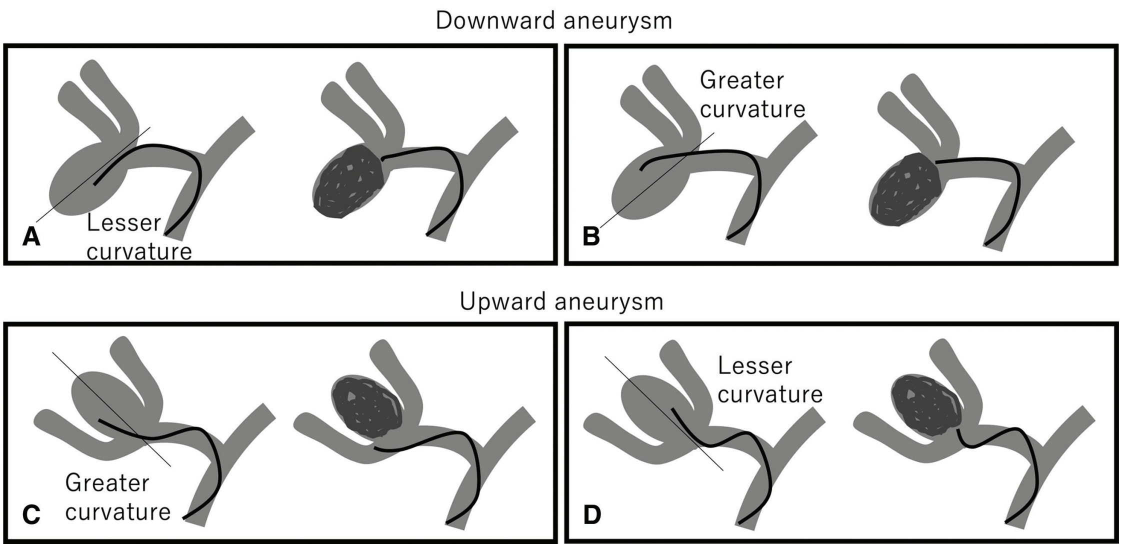

Fig. 4 Positional relationship of a microcatheter in the initial and final stages. (**A**, **B**) Schemes of downward aneurysms. A microcatheter may be relatively stable in the final stage regardless of its first position (greater or lesser curvature sides). (**C, D**) Schemes of upward aneurysms. When a microcatheter is present on the greater curvature side in the initial stage, it may come off in the contralateral A1 direction in the final stage, as shown in (**C**). On the other hand, when a microcatheter is present on the lesser curvature side in the initial stage, it may be stable in the final stage, as shown in (**D**).

There was no association between the use of adjunctive techniques and favorable initial results of embolization.

The initial results of embolization with respect to the DWI-positive rate are shown in **Table 4**. Univariate analysis demonstrated DWI-positive findings to be associated with the neck diameter, aspect ratio, D/N ratio, and use of adjunctive techniques. Based on multivariate analysis, only the use of adjunctive techniques was related to DWI-positive findings ($P < 0.001$). In 22 (78.5%) of 28 patients with ruptured aneurysms, a simple technique was adopted and DWI-positive findings were noted in 7 (25%). There was no significant difference in the DWI-positive rate between the ruptured and unruptured aneurysm patients. In the former, the DWI-positive rate was lower.

Discussion

Several studies reported that the initial results of endovascular treatment (embolization) for cerebral aneurysms were favorable in 79.2%–89.6% of all unruptured cerebral aneurysm patients[4,5] and in 89.2%–92.2% of all ruptured cerebral aneurysm patients.[6–8] On the other hand, concerning the results of endovascular treatment for anterior communicating artery aneurysms, the initial results were favorable in 71% according to a meta-analysis in 2018[9]; the initial results of embolization were slightly poorer than those at other sites. In particular, an aneurysmal diameter of ≥10 mm, aneurysms branching from the anterior communicating artery, and upward aneurysms were reported as factors associated with incomplete obliteration.[1,2,10,11] This study revealed that initial microcatheter insertion on the lesser curvature side led to the favorable initial results of embolization in patients with upward aneurysms. In those with downward aneurysms, the initial state of the microcatheter became relatively stable in the final phase of coil insertion regardless of its position: the greater or lesser curvature sides (**Fig. 4A** and **4B**). Concerning upward aneurysms, the above finding was possibly because the microcatheter was stable even in the final phase when it was present on the lesser curvature side in the initial phase (**Fig. 4D**), although the microcatheter end frequently came off from the neck in the contralateral A1 direction in the final phase when it was present on the greater curvature side (**Fig. 4C**). A previous study emphasized the necessity of preparing sharply angled microcatheters in accordance with aneurysmal branches in patients with upward aneurysms, and found that an unstable microcatheter led to incomplete treatment.[2] In this study, steam-shaped microcatheters were used in 30 (81.1%) of the patients with upward aneurysms, but their shapes did not reflect the course of each aneurysm or parent artery; this may have played a role in the incomplete initial results of embolization. Furthermore, concerning the angle of A1 branching from the ICA, we assumed it to be more difficult to guide a microcatheter to A1 in inferior-type lesions with a sharp angle and suspected an unstable microcatheter during embolization, leading to treatment results through migration in the MCA direction. However, this study demonstrated no such involvement, consistent with the previous study.[2)]

Furthermore, the use of adjunctive techniques did not influence the initial results of embolization, and instead increased the DWI-positive rate. According to several studies, the incidences of perioperative symptomatic ischemic complications in patients with ruptured and unruptured cerebral aneurysms range from 4.7% to 12.5% and from 3.5% to 4.6%, respectively.[5,12–14)] A large aneurysmal diameter and wide neck are considered to be associated with such complications.[15,16)] To reduce the incidence of ischemic complications, preoperative antiplatelet therapy is useful.[17,18)] Especially in patients with wide-neck aneurysms, dual-antiplatelet therapy (DAPT) is useful and safe.[12)] In this study, there was an association between the use of adjunctive techniques and the DWI-positive rate. This may have been because many aneurysms in this study had a wide neck or a large diameter. In addition, adjunctive techniques for the small-diameter ACA may have reduced the blood flow, resulting in thrombus formation. The DWI-positive rate was low in ruptured aneurysm patients although they did not receive antiplatelet drugs. This may have been because many ruptured aneurysm patients did not receive adjunctive techniques.

This study has several limitations. First, this was a retrospective study and the number of subjects was small. Second, the catheter shape depends on the surgeons' skills; this may have led to variation in the results. Furthermore, for the vascular structure assessment of aneurysms, a three-dimensional (3D) structure was simplified based on the aneurysmal direction and A1 angle; therefore, the morphological assessment was not entirely accurate.

For coil embolization of anterior communicating artery aneurysms, it is important to place a microcatheter on the lesser curvature side, especially in upward aneurysm patients. The catheter shape may be an important key to success in treatment. With the widespread use of 3D printers, recent studies reported favorable results by preparing a 3D cerebral aneurysm model and forming a catheter shape along the model.[19,20)] In particular, concerning upward anterior communicating artery aneurysms, if the use of 3D printers facilitates satisfactory reproduction of shaping procedures, which currently depend on surgeons' skills, it may lead to favorable initial results of embolization.

Conclusion

Regarding endovascular treatment of anterior communicating artery aneurysms, the results of embolization of wide neck or upward aneurysms were insufficient in many cases. In patients with upward aneurysms, the initial results of embolization were unfavorable when a microcatheter was present on the greater curvature side. In these patients, microcatheter shaping for guiding to A1 on the lesser curvature side may be important to improve the initial results of embolization.

Disclosure statement

Yuji Matsumaru received lecture fees from Medtronic and Daiichi Sankyo. The first author and the other authors have no conflicts of interest.

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