Online December 2, 2020
Journal of Neuroendovascular Therapy 2021; 15: 228–232 DOI: 10.5797/jnet.oa.2020-0081

Original Article

Comparison of Treatment Results by Coil Embolization Procedures for Ruptured Cerebral Aneurysms

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Objective: In coil embolization of ruptured cerebral aneurysms, intraoperative cerebral aneurysm re-rupture and thromboembolism are of concern. A good embolic condition can be expected by adjunctive techniques, but there is an increased risk of complications. We investigated the treatment results by coil embolization procedures for ruptured cerebral aneurysms.
Methods: Between January 2016 and December 2019, 75 ruptured saccular cerebral aneurysms were treated by coil embolization at our hospital. The background factors, results of aneurysm embolization, intraoperative re-rupture, symptomatic cerebral embolism, and other factors were investigated retrospectively. We compared and examined these factors based on the procedure.
Results: The mean age was 62.8 and there were 57 female patients (76.0%). The single catheter technique (SCT) was used in 44 cases (58.7%) and the adjunctive technique was used in 31 cases (41.3%). Complete obliteration (CO) was achieved in 24 cases (32.0%), there was a neck remnant (NR) in 23 (30.7%), body filling (BF) was observed in 28 (37.3%), intraoperative re-rupture occurred in 7 (9.3%), and symptomatic cerebral embolism developed in 6 (8.0%), but no postoperative re-rupture was observed. Retreatment was required in only three cases of SCT. On comparison by procedure, the incidence of symptomatic cerebral embolism was significantly lower in SCT group than in the adjunctive technique group (2.3% vs 16.1%, $p = 0.04$).
Conclusion: Among the cases of coil embolization for ruptured cerebral aneurysms at our hospital, SCT resulted in a lower incidence of symptomatic cerebral embolism than adjunctive techniques. It is essential to select an appropriate procedure in each case by understanding the characteristics of each procedure.

Keywords ▶ subarachnoid hemorrhage, ruptured cerebral aneurysm, coil embolization, treatment result by procedure

Introduction

The primary goal of subarachnoid hemorrhage management is the prevention of the re-rupture of ruptured cerebral aneurysms. Coil embolization is frequently performed as an effective treatment in addition to surgical clipping.

However, a high frequency of complications, such as intraoperative rupture and thromboembolism, of coil embolization for ruptured cerebral aneurysms compared with that of coil embolization for unruptured cerebral aneurysms has been reported,[1)] requiring attention. Intraoperative cerebral aneurysm rupture may be fatal[2)] and flow control by a balloon is useful. However, an increase in the incidence of thromboembolism is of concern for adjunctive techniques represented by the balloon-assisted technique (BAT).

In this study, we compared the characteristics and treatment results of patients treated by coil embolization for ruptured cerebral aneurysms among different procedures.

Materials and Methods

The subjects were 75 consecutive patients with ruptured saccular cerebral aneurysms treated by intra-aneurysmal coil embolization during 4 years from January 2016 to December 2019.

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The cerebral aneurysm embolization procedure was decided by the operators based on the properties of cerebral aneurysms. The procedures were divided into SCT, double catheter technique (DCT), BAT, and stent-assisted technique (SAT), and compared considering DCT, BAT, and SAT as adjunctive techniques.

Regarding the patient background factors, the age, sex, World Federation Neurological Surgeons (WFNS) grade, location, maximum diameter, and neck diameter of the cerebral aneurysms were investigated.

Cerebral aneurysm embolization was performed under general anesthesia, as a rule, systemic heparinization was performed after sheath insertion without preoperative antithrombotic drug administration, the targeted activated coagulation time was 200–250 seconds, and ground aspirin (100–200 mg) was administered through a stomach tube after framing coil insertion. In SAT, two antiplatelet drugs (aspirin: 100–200 mg, prasugrel: 20 mg) were administered through a stomach tube before stent placement.

In addition to the embolization procedures, the presence of the use of a distal access catheter (DAC) and microcatheter tip shape (pre-shaped or manually shaped) were investigated.

The embolic condition of the cerebral aneurysms after embolization and the presence of intraoperative re-rupture of the cerebral aneurysms, symptomatic cerebral embolism at the time of surgery, symptomatic cerebral vasospasm, hydrocephalus, and retreatment were investigated as treatment results. Symptomatic was defined as the appearance of new neurological deficits consistent with CT and MRI examination images. The presence of symptomatic cerebral vasospasm, hydrocephalus, and use of a DAC in retreatment was investigated, excluding patients who died within 30 days after treatment.

Statistical analysis was performed using IBM SPSS Statistics version 23 (IBM, Armonk, NY, USA). Continuous variables were analyzed using the Mann–Whitney U test, and nominal variables were analyzed using the chi-square test, setting the significance level at 5%.

Results

The mean age of all 75 patients was 62.8 ± 14.5 years old, and 57 patients (76.0%) were females. The WFNS grade of subarachnoid hemorrhage was I in 22 patients (29.3%), II in 28 (37.3%), III in 2 (2.7%), IV in 18 (24.0%), and V in 5 (6.7%). Regarding the location of cerebral aneurysms, anterior communicating artery aneurysms (Acom.AN.) were the most frequent, being observed in 32 patients (42.7%), followed by internal carotid artery-posterior communicating artery aneurysms (IC-PC AN.), being observed in 14 (18.7%). The mean maximum diameter and neck diameter of cerebral aneurysms were 5.62 ± 2.58 and 3.21 ± 1.32 mm, respectively.

The embolization procedure employed was SCT in 44 patients (58.7%). Adjunctive techniques were used in 31 (41.3%); DCT in 10 (13.3%), BAT in 18 (24.0%), and SAT in 3 (4.0%). DAC was used in 14 patients (18.7%), and for the microcatheter tip shape, only pre-shaped microcatheters were used in 40 patients (53.3%).

The postoperative embolic condition was CO in 24 patients (32.0%), NR in 23 (30.7%), and BF in 28 (37.3%). Regarding complications, intraoperative cerebral aneurysm re-rupture occurred in seven patients (9.3%), and symptomatic cerebral embolism developed in six patients (8.0%). The median duration of follow-up in all patients was 467 days (interquartile range: 127–749), and no postoperative re-bleeding was noted. Five patients died within 30 days after treatment, and the cause was intraoperative re-rupture in two, heart failure in one, and unclear in two patients. Of the 70 patients excluding these 5, 11 (15.7%) developed symptomatic cerebral vasospasm, 13 (18.6%) developed hydrocephalus requiring surgery, and 3 (4.3%) required retreatment (additional coil embolization in all).

On comparing the patient background factors by the embolization procedure, the mean age of patients treated by SCT was significantly lower than that of patients treated by adjunctive techniques (60.0 vs. 66.9, $p = 0.047$). In patients treated by SCT, cerebral aneurysms were frequently Acom. AN. (61.4% vs. 29.0%, $p = 0.006$) and less frequently IC-PC AN. (6.8% vs 35.5%, $p = 0.002$) the maximum cerebral aneurysm diameter was small (4.84 mm vs. 6.73 mm, $p = 0.009$), and the neck diameter was also significantly smaller (2.54 mm vs. 4.16 mm, $p < 0.001$) (**Table 1a**).

The maximum cerebral aneurysm diameter in the DAC-used patients was smaller than that in the non-DAC-used patients (4.41 mm vs. 5.90 mm, $p = 0.031$) and the neck diameter was also significantly smaller (2.57 mm vs. 3.36 mm, $p = 0.029$). A pre-shaped microcatheter tip was used significantly less frequently for IC-PC AN. (10.0% vs. 28.6%, $p = 0.039$) (**Table 1b**).

Regarding the treatment results of embolization based on the procedure, no significant difference was noted in the embolic condition between SCT and adjunctive techniques. Regarding complications, intraoperative cerebral aneurysm re-rupture occurred in five patients (11.4%) treated by SCT and in two (6.5%) treated by adjunctive techniques, demonstrating no significant difference. Symptomatic cerebral

Table 1 Comparison of background factors by embolization procedure (a), with or without distal access catheter and shaping of microcatheter (b)

(a)		SCT	Adjunctive technique				p value
		n = 44	n = 31	DCT (10)	BAT (18)	SAT (3)	
Age (yo)		60.0 ± 14.6	66.9 ± 13.4	64.0 ± 14.2	68.1 ± 13.0	70.0 ± 10.2	0.047
Sex	female	33 (75.0%)	24 (77.4%)	8 (80.0%)	13 (72.2%)	3 (100%)	0.809
WFNS grade I, II		30 (68.2%)	20 (64.5%)	6 (60.0%)	12 (66.7%)	2 (66.7%)	0.740
AN site	Acom/ACA	27 (61.4%)	9 (29.0%)	4 (40.0%)	5 (27.8%)	0	0.006
	IC-PC	3 (6.8%)	11 (35.5%)	4 (40.0%)	6 (33.3%)	1 (33.3%)	0.002
	ICA	5 (11.4%)	3 (9.7%)	0	3 (16.7%)	0	0.565
	MCA	1 (2.3%)	2 (6.5%)	0	2 (11.1%)	0	0.370
	VA/BA	6 (13.6%)	5 (16.1%)	1 (10.0%)	2 (11.1%)	2 (66.7%)	0.507
	Other	2 (4.5%)	1 (3.2%)	1 (10.0%)	0	0	–
AN maximum diameter (mm)		4.84 ± 1.61	6.73 ± 3.21	7.79 ± 3.12	6.42 ± 3.12	5.09 ± 2.94	0.009
AN neck diameter (mm)		2.54 ± 0.79	4.16 ± 1.34	3.96 ± 1.16	4.17 ± 1.41	4.73 ± 1.30	<0.001

(b)		Distal access catheter			Shaping of microcatheter		
		+ (14)	+ (61)	p value	Pre-shape (40)	Manual (35)	p value
Age (yo)		69.4 ± 14.8	61.3 ± 14.0	0.060	61.6 ± 15.2	64.3 ± 13.5	0.398
Sex	female	12 (85.7%)	45 (73.8%)	0.285	30 (75.0%)	27 (77.1%)	0.828
WFNS grade I, II		9 (64.3%)	41 (67.2%)	0.533	28 (70.0%)	22 (62.9%)	0.513
AN site	Acom/ACA	8 (57.1%)	28 (45.9%)	0.448	22 (55.0%)	14 (40.0%)	0.195
	IC-PC	1 (7.1%)	13 (21.3%)	0.204	4 (10.0%)	10 (28.6%)	0.039
	ICA	1 (7.1%)	7 (11.5%)	0.537	5 (12.5%)	3 (8.6%)	0.434
	MCA	0	3 (4.9%)	0.533	1 (2.5%)	2 (5.7%)	0.449
	VA/BA	2 (14.3%)	9 (14.8%)	0.665	5 (12.5%)	6 (17.1%)	0.571
	other	2 (14.3%)	1 (1.6%)	–	3 (7.5%)	0	–
AN maximum diameter (mm)		4.41 ± 1.83	5.90 ± 2.64	0.031	6.03 ± 3.01	5.16 ± 1.86	0.300
AN neck diameter (mm)		2.57 ± 0.93	3.36 ± 1.35	0.029	3.01 ± 1.12	3.44 ± 1.49	0.358

ACA: anterior carotid artery; Acom: anterior communicating; AN: aneurysm; BA: basilar artery; BAT: balloon-assisted technique; DCT: double catheter technique; IC-PC: internal carotid-posterior communicating; ICA: internal carotid artery; MCA: middle cerebral artery; SAT: stent-assisted technique; SCT: single catheter technique; VA: vertebral artery; WFNS: World Federation Neurological Surgeons

embolism developed in one patient (2.3%) treated by SCT, being significantly lower than the incidence rate (16.1%, five patients) in patients treated by adjunctive techniques (p=0.04). Regarding the adjunctive techniques, symptomatic cerebral embolism developed in four patients (22.2%) treated by BAT, demonstrating a high frequency. No significant difference was noted in the frequency of symptomatic cerebral vasospasm or hydrocephalus. Only three SCT-treated patients (7.5%) required retreatment, and the difference was not significant (**Table 2a**).

On comparison of the presence of the use of DAC and the shape of the catheter tip, no significant difference was noted in the embolic condition or complications (**Table 2b**).

Discussion

The outcomes of coil embolization of ruptured cerebral aneurysms are comparable with those of surgical clipping even over a prolonged period.[3,4] Adjunctive techniques may have played a major role in the expansion of the treatment indications and improvement of coil embolization outcome.

BAT was initially reported to cause intraoperative cerebral aneurysm re-rupture and increase the rate of cerebral embolism,[5,6] but complications did not increase thereafter, and a favorable embolic condition can be achieved.[1,7] In Japan, although the use of stents is not indicated for the acute-phase treatment of ruptured cerebral aneurysms, case reports of their application have increased. However, the SAT was reported to require attention because the rate of both hemorrhagic and embolic complications increases.[8,9] Therefore, there are many reports on coil embolization treatment outcomes based on the embolization procedure and no consistent viewpoint has been reached.

In this study, the frequency of symptomatic cerebral embolism was significantly lower in SCT-treated patients than in adjunctive technique-treated patients. Pierot et al.

Table 2 Comparison of treatment results by procedure (a), with or without distal access catheter and shaping of microcatheter (b).

(a)		SCT	Adjunctive technique				p value
		n = 44/40*	n = 31/30*	DCT (10)	BAT (18/17*)	SAT (3)	
Result of embolization	CO	15 (34.1%)	9 (29.0%)	3 (30.0%)	5 (27.8%)	1 (33.3%)	0.644
	NR	16 (36.4%)	7 (22.6%)	3 (30.0%)	4 (22.2%)	0	0.202
	BF	13 (29.5%)	15 (48.4%)	4 (40.0%)	9 (50.0%)	2 (66.7%)	0.097
Intraoperative re-rupture		5 (11.4%)	2 (6.5%)	0	2 (11.1%)	0	0.384
Symptomatic cerebral embolism		1 (2.3%)	5 (16.1%)	1 (10.0%)	4 (22.2%)	0	0.041
Symptomatic vasospasm*		8 (20.0%)	3 (10.0%)	2 (20.0%)	1 (5.9%)	0	0.212
Hydrocephalus*		8 (20.0%)	5 (16.7%)	1 (10.0%)	4 (23.5%)	0	0.723
Re-treatment*		3 (7.5%)	0	0	0	0	0.180

(b)		Distal access catheter			Shaping of microcatheter		
		+ (14/12*)	– (61/58*)	p value	Pre-shape (40/37*)	Manual (35/33*)	p value
Result of embolization	CO	2 (14.3%)	22 (36.1%)	0.101	11 (27.5%)	13 (37.1%)	0.372
	NR	5 (35.7%)	18 (29.5%)	0.437	12 (30.0%)	11 (31.4%)	0.894
	BF	7 (50.0%)	21 (34.4%)	0.277	17 (42.5%)	11 (31.4%)	0.323
Intraoperative re-rupture		2 (14.3%)	5 (8.2%)	0.389	6 (15.0%)	1 (2.9%)	0.077
Symptomatic cerebral embolism		2 (14.3%)	4 (6.6%)	0.311	1 (2.5%)	5 (14.3%)	0.073
Symptomatic vasospasm*		3 (25.0%)	8 (13.8%)	0.281	4 (10.8%)	7 (21.2%)	0.233
Hydrocephalus*		3 (25.0%)	10 (17.2%)	0.391	5 (13.5%)	8 (24.2%)	0.249
Re-treatment*		0	3 (5.2%)	0.564	2 (5.4%)	1 (3.0%)	0.543

*In symptomatic vasospasm, hydrocephalus and re-treatment, 70 patients were studied except for 5 patients who died within 30 days after coil embolization. BAT: balloon-assisted technique; BF: body filling; CO: complete obliteration; DCT: double catheter technique; NR: neck remnant; SAT: stent-assisted technique; SCT: single catheter technique

reported that a cerebral aneurysm diameter exceeding 10 mm and a neck diameter exceeding 4 mm are risk factors for thromboembolism induced by coil embolization for ruptured cerebral aneurysms.[10] In our study, the aneurysm diameter and neck diameter were significantly smaller in patients treated by SCT than in those treated by adjunctive techniques, suggesting that this influenced the difference in the cerebral embolism complication rate. Besides, no significant difference was noted in the postoperative embolic condition or retreatment. Therefore, in cases evaluated treatable by SCT, it was considered that unnecessary adjunctive techniques should be avoided to reduce complications.

However, adjunctive techniques are necessary, depending on the case. Chung et al. reported no significant difference in the embolic condition or complications among DCT, BAT, and SAT in a series of wide-neck aneurysms, including unruptured and ruptured cerebral aneurysms, and they concluded that DCT was the best. Because DCT enables to avoid antiplatelet drug administration and intraoperative parent artery ischemia.[11] Furthermore, no significant difference was noted in the embolic condition or complications among the three adjunctive techniques: DCT, BAT, and SAT in the present series. However, in BAT group, the frequency of symptomatic cerebral embolism was 22.2%, being high, for which it is necessary to pay attention to the balloon inflation time and antithrombotic therapy. As described above, SAT is not indicated for acute-phase treatment of ruptured cerebral aneurysms because a high rate of complications has been reported, and its use is limited to patients who are difficult to treat using either DCT or BAT. Zhang et al. reported that the complete obliteration (CO) rate immediately after treatment was low among patients treated by SAT compared with that in the non-stent use group. However, the CO rate increased with time, and the recanalization rate was low,[9] suggesting that it is essential not to apply excessive embolization in acute-phase treatment. Also, the antiplatelet drug administration method is a problem in the SAT. Ryu et al. reported that the frequency of complications in the group with preoperative antiplatelet drug administration was not different from that in patients with unruptured cerebral aneurysms. However, the complication rate increased in the group with postoperative administration.[12] In this study, SAT was performed in only three patients with ruptured cerebral aneurysms. We first induced a microcatheter to securely place a stent, and administered two antiplatelet drugs (aspirin, prasugrel) through the gastric tube. After that, the patient waited for 15–30 minutes until the blood level of prasugrel increased,

and then stents were placed. No complications were observed by this method.

Regarding the presence of the use of DAC and microcatheter tip shape, no significant difference was noted in the embolic condition or complications. In the cases using pre-shaped microcatheters, there were many cases of intraoperative re-rupture, and symptomatic cerebral embolism tended to be less. Pre-shaped microcatheters are less commonly used in IC-PC AN, where adjunctive techniques are frequently used. As a result, symptomatic cerebral embolism may tend to be less frequent with pre-shaped microcatheter.

Furthermore, no significant difference was noted in intraoperative cerebral aneurysm re-rupture in this study. In the seven patients in whom intraoperative cerebral aneurysm re-rupture occurred, the cerebral aneurysm was located at a distal site in many cases, Acom.AN. in four patients, distal posterior inferior cerebellar artery aneurysm in one patient and the internal carotid aneurysm in two patients. The employed embolization procedure was SCT in five patients, BAT in two, without DAC in five, and pre-shaped microcatheter in six. The cause of re-rupture was perforation by the microcatheter due to instability of the tip in the aneurysm in two patients and perforation by the coil in four. Perforation by the coil due to the fixation of the microcatheter by BAT was suspected in one patient. The reason for microcatheter instability was considered to be an inappropriate length from the tip to the bent region. Therefore, when treating distal aneurysms, the use of DAC is essential if the microcatheter operability is poor. In addition, it is important not to always use a pre-shaped microcatheter, but to use a manual shape in consideration of the length from the point of flexion to the tip, and the proximal curve of the parent artery.

This was a single-center retrospective study involving a small number of patients. A large-scale study is needed in the future.

Conclusion

Based on the investigation of coil embolization for ruptured cerebral aneurysms in the small number of patients at our hospital, SCT caused symptomatic cerebral embolism less frequently than adjunctive techniques. It is essential to select an appropriate surgical procedure for each case after understanding the characteristics of the procedures well.

Disclosure Statement

The authors declare no conflict of interest.

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