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Neuropsychological Sequelae of Patients Treated with Microsurgical Clipping or Endovascular Embolization for Anterior Communicating Artery Aneurysm

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Key Words
Anterior communicating artery aneurysm · Cerebral aneurysm · Coil embolization · Endovascular embolization · Intracranial aneurysm · Microsurgical clipping

Abstract
Background and Purpose: While microsurgical clipping has been the choice of treatment for anterior communicating artery (ACoA) aneurysm, endovascular embolization is increasingly popular for treating intracranial aneurysms. Previous studies showed that in terms of mortality (i.e., death) and morbidity (i.e., functional outcome, independent living, rebleeding) rates, the clinical outcomes of coil embolization for intracranial aneurysms are as good as or even better than those of surgical clipping. However, little is known about the impact of these treatments on the cognitive functions of those survived after the treatment. Thus, the present study is designed to examine the cognitive deficits of patients treated with either surgical clipping or coil embolization. ***Method:*** Eighteen patients with a ruptured ACoA aneurysm were recruited. Half of them had undergone surgical clipping and the other half had endovascular embolization. Standardized neuropsychological tests were employed to assess their memory, executive function, motor ability, language and visual perceptual abilities. ***Results:*** The performance of the patients was in general poorer than that of the normal control subjects on tests of verbal memory, flexible thinking, ability to resist interference and motor control. However, in terms of severity, the patients who received surgical clipping demonstrated more severe impairment than those had endovascular embolization on these cognitive domains. In addition, while 33% of patients in the clipping group showed impairments on memory and executive function, no patient in the embolization group demonstrated these impairments. ***Conclusions:*** Patients with ACoA aneurysm demonstrated impaired verbal memory, executive function and motor abilities while their language and visual perception abilities remained relatively intact. However, when comparing the effect of treatment choice on the cognitive functions of these patients, the present results favored the coil embolization as the patients treated with coil embolization demonstrated significantly fewer severe cognitive deficits than patients who had undergone surgical clipping.

Introduction

The anterior communicating artery (ACoA), located at the ventral portion of the brain, is one of the most frequent sites for cerebral aneurysm [1–3]. Given that it

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locates at the anterior part of the circle of Willis, ruptured aneurysm will markedly reduce the blood supply to the anterior portion of the circle, resulting in cerebral infarction [4]. Although ACoA is relatively small, it has many perforating branches that are classified into three groups according to their vascular territories [5]: the subcallosal area, hypothalamic area, and chiasmatic area. They supply blood to the anterior hypothalamus, septum pellucidum, anterior parts of the cingulate gyrus, sections of the fornices and the anterior parts of the corpus callosum.

Given that the ACoA mostly affects the hemodynamic circulation of the posterior frontal, mesial temporal and subcortical areas, a unique pattern of cognitive deficits associated with this specific pathological change can be observed after rupture and/or repair of the ACoA. That is, patients with ruptured ACoA have demonstrated impairment on memory, and in some cases became severely amnesic [6–10]. Patients also manifest some frontal lobe dysfunction, such as personality change, confabulation, decreased initiation and perseveration [6, 7, 9–12]. Others have impairment on motor control [13]. This unique profile of cognitive deficits in patients with ruptured ACoA is usually referred to the 'ACoA syndromes' [6, 7, 14].

Management of the intracranial aneurysm has been changing since the introduction of endovascular embolization in the past 10 years [15, 16]. Conventionally, neurosurgical clipping has been the standard treatment for ACoA aneurysm in which the neck of the aneurysm is dissected with a clip. Endovascular embolization is a technique that occludes the aneurysms by placing some platinum coils into the neck of the ACoA. When this technique was first introduced in 1991 [17], it was used as an alternative treatment for patients who were not suitable for clipping due to size or location of the aneurysm [16–20]. With the introduction of controlled detachable coils to occlude the aneurysm, embolization has been increasingly used. Nowadays, endovascular embolization by thrombogenic coils becomes the primary treatment option in some hospitals [21, 22].

Since embolization with coils has been increasingly utilized in medical institutions, many studies have been conducted to evaluate its effectiveness. Approximately 100 studies have been conducted to evaluate the complication and outcomes on embolization of intracranial aneurysms since 1990. A meta-analysis of these studies showed that 3.7% of these patients had medical complications with permanent deficits, and 54% of the cases have complete occlusion of the aneurysm [23]. Based upon these results, the authors concluded that embolization was a reasonably safe treatment for both ruptured and unruptured aneurysms. A cohort study [24], aimed at comparing the clinical outcomes of surgical clipping and embolization at 60 university hospitals in the USA, found that patients who received coil embolization (10.6%) had fewer adverse outcomes (i.e., death or move to a nursing home or rehabilitation institution at discharge) than those treated with surgery (18.5%). Although obliteration of aneurysms by embolization has been shown to achieve comparable mortality and morbidity in the management of aneurysmal subarachnoid hemorrhage, aneurysm recurrence after embolization is significantly high [25, 26].

However, it should be stressed that previous studies have only focused on examining the mortality (i.e., death) and morbidity (i.e., functional outcome, independent living, rebleeding) rates. No study, to our knowledge, has been conducted to examine the cognitive domains. Since it was reported that cognitive deficits are common sequelae of ACoA aneurysm, even for those patients who did not demonstrate any neurological impairments [27, 28], it is important to evaluate the differences on cognitive outcomes following these two treatments. The purpose of the present study, therefore, is to compare the cognitive profile of patients treated with coil embolization with that of patients who received surgical clipping.

Method

Eighteen patients with their ruptured aneurysm of ACoA proved by CT scan and angiography were recruited on a voluntary basis from the Prince of Wales Hospital (PWH) in Hong Kong. Half of them had their aneurysm repaired by microsurgical clipping and the other half were treated with endovascular embolization. The subjects were recruited based on the following four criteria: (1) All patients received the treatment between 1990 and 1999. (2) All subjects were clinically stable and in grade II or II based on the criteria of Hunt and Hess [29] before the treatment. (3) They were classified as having good or moderate neurological recovery according to the Glasgow Outcome Scale [30] in the neurological examination within 3 months of the cognitive assessment. (4) All patients had no psychiatric history.

It should be noted that the surgical clipping was the standard approach to treat ACoA aneurysm at the PWH before 1997, and embolization with coils has become the initial treatment choice since 1997 given its less invasive nature. It should be understood that a random trial study would be a preferable experimental design to study the effect of treatment. However, bounded by an ethical consideration of the patients' care, it is difficult for us to carry out a random trial study. Thus, much effort had been made to match the two groups of patients from different cohorts. First, all patients were tested at least 1 year after the treatments. Since most of the cognitive recovery occurred within the first year of the acquired brain damage, their performance should then represent their stable cognitive status

Table 1. Demographic information of the normal control subjects (NC), patients treated with coil embolization (CE) and surgical clipping (SC)

	Mean (SD) score			F value	p value[1]
	NC (n = 19)	CE (n = 9)	SC (n = 9)		
Age, years	51.63±8.47	52.13±11.47	57.00±6.68	2.46	0.10
Education, years	7.47±3.12	8.33±4.18	5.22±3.90	1.87	0.17
MMSE	27.89±2.00	26.44±5.75	25.44±4.98	1.26	0.30
Hunt and Hess grading	n/a	2.33±0.50	2.00±0.00	2.00	0.08
Aneurysm size, mm	n/a	4.63±2.56	4.75±1.26	0.11	0.09

[1] p value: after post-hoc Student-Newman-Keuls corrections.

(i.e., permanent cognitive complication). Second, the two groups of patients were matched in terms of the Hunt and Hess grading as shown in table 1. Third, the mean size of the aneurysm for the patients with coil embolization (4.63 mm) and that for the patients with surgical clipping (4.75 mm) were not significantly different.

Nineteen normal individuals without any history of neurological or psychiatric disorder were recruited from patients' family members and from service groups of the PWH. As shown in table 1, the normal control subjects and two groups of patients were matched in terms of age, level of education and performance of a Chinese version of the Mini-Mental Status Examination (CMMSE) [31].

Procedure and Stimuli

The patients were tested individually in a quiet examination room at the PWH. A comprehensive neuropsychological battery was administered to determine their cognitive functions, and the battery was delivered in the same format and order to all patients. All tests were conducted according to the standard published protocols or established procedures, and subjects were allowed to take a break or even terminate the session at any time of evaluation. The examiner was blind to the patients' medical history.

The following neuropsychological tests were chosen because they had relatively good sensitivity and specificity in differentiating patients with cognitive deficits:

(1) The measure of verbal memory was the Hong Kong List Learning Test (HKLLT) [32]. This test consisted of a randomly presented word list (i.e., random condition), and a semantically clustered one (i.e., blocked condition). It consisted of three immediate recall trials, two delayed recall trials (10- and 30-min) and one recognition task. In addition, a story-learning task was developed to assess subjects' capacity in recalling lengthy passages. In this task, two stories were read to the subject, and he/she was requested to recall the stories immediately and after 30 min, respectively.

(2) The measures of visuospatial memory were the Visual Reproduction subtest of the Wechsler Memory Scale – Revised (WMS-R) [33], and the Brief Visual Memory Test – Revised (BVMT-R) [34].

(3) The measures of executive functions were multifaceted. Cognitive flexibility was tested by the Verbal Fluency [35], Five-Point [36], Alternative Drawing [37] and Color Trail Making [38] Tests. The interference effect was measured by the errors on the recall trials of the HKLLT, Verbal Fluency Test, and the false-alarm errors on the recognition task of the HKLLT. The conceptual thinking was tested by the Similarities and Comprehension subtests of the Wechsler Adult Intelligent Scale – Revised (WAIS-R) [39], and the Semantic Knowledge Test that consisted of 32 true and false questions on the concrete and abstract attributes of some living and nonliving things (e.g., horses run faster than donkeys, strawberries are blue in color). Perseveration was evaluated by errors on the HKLLT, Verbal Fluency Test and Five-Point Test.

(4) The test chosen to measure the motor ability and psychomotor speed (e.g., complex volitional movement and sensorimotor integration) were the Grooved Pegboard Test [40] and the Digit Symbol subtest of the WAIS-R [39].

(5) Language function involved several aspects. Expressive language ability was assessed by the Boston Naming Test (BNT) which was used to evaluate the accuracy and ease of verbal production [41]. The aspect of verbal comprehension was tested by the Information and Comprehension subtests of the WAIS-R.

(6) The visual-perceptual functions involved aspects of visual constructional ability and visual recognition. The former was measured by copying the figures of the Visual Reproduction subtest of the WMS-R, and by constructing the designs in the Block Design subtest of the WAIS-R; whereas the latter was assessed by a short form of the Facial Recognition Test [42].

Results

The present sample size (n = 37) was relatively small to the number of variables. To avoid committing familywise statistical errors and biases on the parameter estimates, six summary scores for the cognitive domains of verbal memory, visual memory, executive function, motor speed, language, and visual perception were calculated. The summary scores were calculated by averaging the z-scores of the relevant and sensitive tests of each domain as stated in the Method section. The z-score of each test was calculated by taking the mean score of the normal control subjects as a reference point, and then compared each patient's performance to the average performance of the normal control subjects with an adjustment for the standard deviation of the latter group. One-way ANOVAs and then post-hoc Student-Newman-Keuls multiple t-tests were used to compare the means among groups.

Table 2. Summary z-scores of five cognitive domains of the normal control subjects (NC), patients treated with coil embolization (CE) and surgical clipping (SC)

Summary scores	Mean (SD) score			F value	p value
	NC (n = 19)	CE (n = 9)	SC (n = 9)		
Verbal memory	–0.1 ± 0.64	–0.33 ± 0.55	–1.00 ± 1.01	4.80	0.02*
Visual memory	0.01 ± 0.80	–0.18 ± 1.04	–0.86 ± 1.63	1.59	0.22
Executive function	–0.09 ± 0.65	–1.11 ± 0.62	–1.68 ± 2.00	5.02	0.02*
Motor ability	0.00 ± 0.85	–2.88 ± 4.74	–3.04 ± 2.34	6.13	0.01*
Language	–0.4 ± 0.88	–0.41 ± 1.18	–0.70 ± 1.16	1.11	0.34
Visual perception	0.00 ± 0.62	0.05 ± 0.79	–0.11 ± 1.40	0.07	0.94

* $p < 0.05$ after post-hoc Student-Newman-Keuls corrections.

Table 3. Performance of the normal control subjects (NC), patients treated with coil embolization (CE) and surgical clipping (SC) on the tests of executive function

Variables	Mean (± SD) score			F value	p value
	NC (n = 19)	CE (n = 9)	SC (n = 9)		
Flexible thinking					
Five-Point Test	20.42 ± 8.04	13.89 ± 7.15	12.22 ± 8.61	4.04	0.03*
Verbal Fluency Test	26.44 ± 5.60	20.00 ± 9.33	18.56 ± 6.62	4.93	0.01*
Alternative Drawing	29.06 ± 9.35	39.11 ± 15.67	67.71 ± 54.2	5.54	0.01*
Color Trail Making test (Part II)	114.4 ± 61.56	164.0 ± 100.3	206.2 ± 110.8	3.44	0.04*
Vulnerable to interference					
HKLT – intrusion	2.6 ± 0.45	1.11 ± 1.17	0.44 ± 0.53	4.50	0.02*
HKLT – false alarm	0.32 ± 0.48	1.56 ± 2.40	2.89 ± 2.97	5.83	0.01*
Verbal Fluency Test – intrusion	0.00 ± 0.00	0.44 ± 0.53	0.11 ± 0.33	6.33	0.01*
Conceptual thinking					
WAIS-R Similarities	12.33 ± 5.58	11.00 ± 5.81	7.71 ± 8.88	1.31	0.28
WAIS-R Comprehension	15.68 ± 5.97	14.89 ± 6.92	11.67 ± 6.40	1.26	0.30
Semantic Knowledge Test	6.44 ± 2.12	4.44 ± 2.88	5.33 ± 3.78	1.75	0.19
Perseveration					
HKLLT	1.89 ± 1.20	0.78 ± 0.97	1.00 ± 1.32	1.74	0.19
Verbal Fluency Test	1.28 ± 1.49	0.11 ± 0.33	1.56 ± 2.74	1.87	0.17
Five-Point Test	2.79 ± 3.36	1.67 ± 2.40	3.56 ± 3.09	0.85	0.43

* $p < 0.05$ after post-hoc Student-Newman-Keuls corrections.

As shown in table 2, performance of the two groups of patients and normal control subjects was not significantly different on visual memory, language and visual perception. However, the performance between groups was significant on the verbal memory, executive function and motor control. In particular, the performance of the patients with surgical clipping were significantly poorer than that of the patients treated with coil embolization on verbal memory and executive function, while the performance of the latter group was not significantly different from that of the normal control subjects. In addition, the motor control of both groups of patients was significantly poorer than that of the normal subjects. These results were consistent with previous studies reporting amnesia, confabulation and impaired motor control in patients with ACoA aneurysm. However, patients receiving different treatments demonstrated various levels of impairment.

When patients' cognitive domains were classified as impaired if the scores were below 1 standard deviation from the mean scores of the normal control subjects, 67% of patients having surgical clipping and 22% of patients treating with coil embolization demonstrated executive function impairment. In addition, the percentages of patients demonstrated memory impairment in the clipping group and the embolization group were 43 and 14%, respectively. Therefore, there was a trend that a smaller percentage of patients with embolization, as compared with patients having surgical clipping, demonstrated either frontal dysfunction or memory impairment. Furthermore, 33% of the patients in the surgical group demonstrated both impairments, but none of the patients in the embolization group had similar cognitive impairments.

Given that the executive dysfunction was a prominent characteristic of patients with ACoA aneurysms, further analysis was conducted to evaluate the nature of this deficit by examining the four subdomains of the executive function, namely flexible thinking, sensitive to interference, conceptual thinking and perseveration. As shown in table 3, the two patient groups, when compared with the normal control subjects, demonstrated significant impairment in flexible thinking and sensitive to interference. In addition, patients who had undergone surgical clipping were more impaired than patients treated with embolization. Although the patients demonstrated less flexible thinking, their conceptual thinking was relatively intact when compared with the normal individuals. In addition, both groups of patients did not demonstrate a tendency of perseveration. Thus, the two groups of patients were different in the level of impairment on their executive dysfunction, although the patterns of their deficit were similar.

Although it has been well known that memory impairment is associated with ACoA aneurysm, there are still some debates regarding the nature of this deficit [43]. To further examine this issue, the performance of the patients on the HKLLT was analyzed. As shown in figure 1a, two groups of patients learned significantly fewer words in the learning trials of HKLLT than the normal control subjects did in both the random ($F = 4.45$, $p = 0.02$) and blocked ($F = 4.19$, $p = 0.03$) conditions. The normal control subjects performed significantly better in the blocked condition than in the random condition ($t = 3.04$, $p = 0.01$), suggesting that their learning was facilitated by the organizational cues. However, the patients having surgical clipping ($t = 1.06$, $p = 0.33$) and embolization ($t = 1.27$, $p = 0.24$) did not demonstrate improvement with this memory intervention.

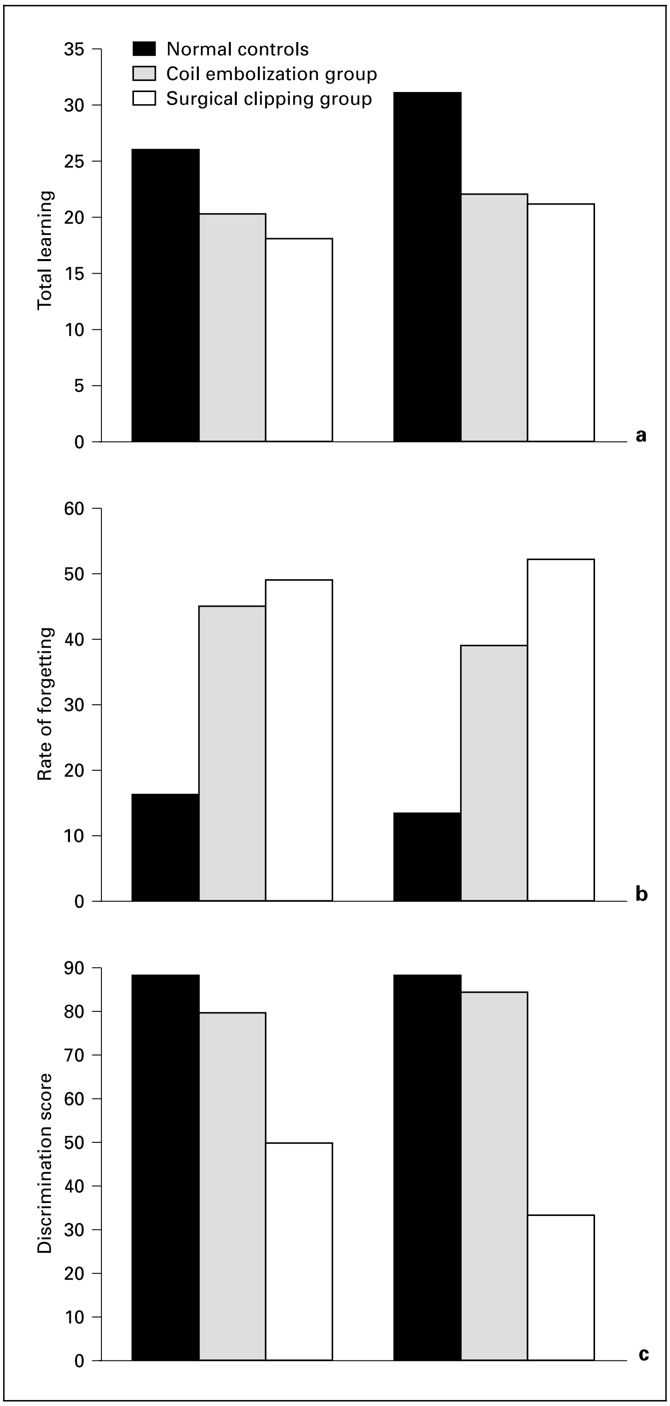

Fig. 1. Performance of the normal control subjects, patients treated with coil embolization and surgical clipping on the HKLLT: (**a**) total learning: the total words learned in the three learning trials; (**b**) the rate of forgetting: the percentage of words learned in the learning trial that was forgotten after 10 min; (**c**) the discrimination score: the percentage of all possible words recognized after 30 min with the correction of the number of false alarm errors.

Given that rapid rate of forgetting is a prominent characteristic of ACoA syndromes, comparing the rate of forgetting of the two patient groups became necessary to evaluate the effect of the two treatments on the memory deficit of the patients with ACoA. The rate of forgetting was defined as the proportion of information learned in the learning trial to that lost after 10 min in the HKLLT. As shown in figure 1b, patients treated with surgical clipping demonstrated a higher rate of forgetting than patients who had undergone coil embolization, and both groups of patients lost more information than the normal control subjects. The difference was significant in the blocked condition ($F = 4.87$, $p = 0.01$) and marginally significant in the random condition ($F = 2.78$, $p = 0.08$).

Memory impairment can to some extent be attributed to a retrieval deficit, that is, subjects have difficulty to access what they had learned. If the subjects' memory deficit is a retrieval problem, their performance on tasks that require minimal retrieval effort (i.e., recognition) tends to be less impaired or even intact [44]. The discrimination score of the HKLLT was designed to measure the subjects' ability to recognize newly learned materials, and it was calculated based upon the number of words that can be recognized by the subjects after 30 min with the correction of the number of false alarm. As shown in figure 1c, the performance of the patients treated with surgical clipping was significantly poorer than the patients who had undergone coil embolization and normal individuals in both random ($F = 6.50$, $p = 0.004$) and blocked ($F = 3.33$, $p = 0.05$) conditions. It should be stressed that the performance of patients in the embolization group was not significantly different to that of normal individuals. Therefore, the recognition paradigm seemed to facilitate the recall of patients treating with embolization but not those having surgical clipping.

The possible effects of various medical conditions between the surgical clipping group and the endovascular embolization group on their cognitive functions were explored. The two groups of patients were comparable in the percentage of having a history of alcoholism ($\sim$ 10%), visual (0%) and auditory (0%) defects. Since a higher proportion of patients treated with endovascular embolization (11%) reported having brain damage when compared with patients treated with microsurgical clipping (0%), this difference should favor the surgical group. In addition, Pearson correlation between the sizes of aneurysm and executive function score ($r = -0.17$, $p = 0.62$), memory score ($r = -0.25$, $p = 0.46$) and motor score ($r = 0.33$, $p = 0.33$) were not significant.

Discussion

The primary purpose of the present study was to compare the cognitive sequelae of patients with ACoA aneurysm who had undergone surgical clipping with those who had embolization. Overall results were consistent with previous findings [6–11, 43] that patients with ACoA aneurysm in the present study demonstrated impaired verbal memory, executive function and motor abilities while their language and visual perception abilities remained relatively intact. However, when examining the effect of treatment choice on the cognitive functions of these patients, the patients treated with coil embolization demonstrated significantly fewer severe cognitive deficits than patients who had undergone surgical clipping. In particular, the performance of patients with coil embolization on tests of verbal memory and executive function was better than that of patients treated with surgical clipping, although their performance was not as good as that of the normal control subjects. In addition, while none of the patients in the embolization group demonstrated both severe memory deficit and executive dysfunction, 33% of the patients in the clipping group showed both deficits. The different performance of these two groups of patients probably cannot be attributed to baseline difference given that they were matched in age, education, Hunt and Hess grating on the time of accident, and the size of their aneurysm.

Although the two groups of patients demonstrated impaired verbal learning and a rapid rate of forgetting, the embolization group demonstrated less severe impairment than the clipping group. In addition, the learning and memory of patients in the embolization group, but not that of the clipping group, could be improved using a less effortful retrieval task (i.e., recognition). This difference may be related to the various levels of memory impairment demonstrated by the two groups of patients, but it may also suggest a possible different underlying nature of memory impairment of the two groups of patients. That is, the memory impairment of the clipping group may be attributed more to an encoding deficit, and that of the embolization group is more related to a retrieval deficit. However, further studies on this speculation are necessary before drawing a conclusion. In addition, it should be noted that recognition impairment is commonly observed on patients with frontal lobe dysfunction in which patients with more severe damage usually demonstrate more impaired recognition. Given that the patients with surgical clipping showed more frontal lobe dysfunction than the patients with coil embolization on the neuropsychological assessment in the present study, it is not surprising that their performance on the recognition test was also poorer than that of the embolization group.

Endovascular embolization associated with less cognitive deficits may be attributed to its less invasive nature. For this treatment, a soft and detachable platinum coil is delivered through a microcatheter positioned within the ACoA. Since the platinum is soft, it can adapt to the size and shape of the arteries with a minimal increase in intraluminal pressure. Thus, occlusion of the ACoA parent vessel and perforators is less likely to happen in endovascular treatment than in surgical clipping. Given that the ACoA perforating branches mediate memory [9, 45, 46], motor abilities [13] and executive functions [47], it is not surprising that preservation of the perforating branches associates with less deficits on cognitive functions.

Similar evidence for the benefit of advanced treatment to neuropsychological outcome of inpatients with ruptured ACoA aneurysms was presented by Grade [46]. He argued that persistent amnesia was more common if the surgical procedure was occlusion of one anterior cerebral artery or isolation of ACoA by clipping each end than if the neck of the aneurysm itself was clipped. It was presumed that the latter method can preserve the blood flow through the ACoA perforators. Since lack of blood supply through ACoA perforating branches to the midline portions of the basal forebrain would lead to deficits in learning and memory, preservation of the perforating branches of ACoA seems to be significant for good treatment outcomes.

Given that patients who received endovascular embolization demonstrated fewer cognitive deficits than those who had microsurgical treatment, the present results seem to favor endovascular embolization as a choice of treatment for ACoA patients. However, given the relatively small number of subjects and some variations of the age distribution among groups of subjects in the present study, further experiments with a larger sample size, better matched samples and randomized design are needed before a reliable conclusion can be drawn.

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