ORIGINAL RESEARCH

Immediate Anatomic Results after the Endovascular Treatment of Unruptured Intracranial Aneurysms: Analysis of the ATENA Series

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BACKGROUND AND PURPOSE: A precise analysis of the immediate postoperative anatomic results in a large series of unruptured intracranial aneurysms treated by endovascular approach has not previously been presented. This study aimed to assess the efficacy of endovascular treatment of unruptured intracranial aneurysms in light of immediate postoperative anatomic results in a prospective, multicenter study (the Analysis of Treatment by Endovascular Approach of Nonruptured Aneurysms study; ATENA).

MATERIALS AND METHODS: Postoperative anatomic results from digital subtraction angiography (DSA) were evaluated with the Montreal scale by the treating physician and by 2 anonymous, independent, experienced neuroradiologists.

RESULTS: The analysis included 622 patients (449 women, 173 men; age range, 22–83 years; mean age, 51.2 ± 11.3 years) harboring 694 aneurysms. Evaluation of the postoperative anatomic results by the 2 independent reviewers indicated total occlusions in 437 aneurysms (63.0%), neck remnants in 156 aneurysms (22.5%), and aneurysm remnants in 101 aneurysms (14.6%). Several factors favorably affected the quality of the aneurysm occlusion with treatment, including patient age (< 65 years old; $P < .0001$), aneurysm diameter (≤ 6 mm; $P = .0049$), aneurysm dome-to-neck ratio (> 1.5; $P = .0388$), and endovascular technique (coiling or remodelling compared with stent placement; $P = .0001$).

CONCLUSIONS: The endovascular treatment of unruptured aneurysms provided satisfactory postoperative occlusion rates, with a high percentage of complete occlusion or neck remnants (85.4%). Postoperative anatomic results were significantly affected by aneurysm size and neck size, but not aneurysm location.

The Analysis of Treatment by Endovascular Approach of Nonruptured Aneurysms (ATENA) study is a prospective multicenter series that was conducted in France and Canada from June 2005 to October 2006 to evaluate clinical and anatomic results after endovascular treatment of unruptured intracranial aneurysms. The immediate clinical outcome was previously published and showed a high feasibility rate (95.7%) with low morbidity and mortality rates (1.7% and 1.4%, respectively).[1]

The results of the ATENA study indicated that endovascular treatment of unruptured aneurysms can be widely used when treatment is indicated. However, the quality of short- and long-term anatomic results and the protection afforded against bleeding remained to be precisely analyzed. This study presents a rigorous analysis of immediate postoperative anatomic results. The goal was to determine the quality of aneurysm occlusion immediately after the endovascular treatment and define factors that significantly affected the postoperative anatomic results.

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Materials and Methods

Protocol

ATENA was conducted by the French Society of Neuroradiology at 27 French and Canadian centers.[1] Inclusion criteria were patients harboring unruptured, untreated aneurysms, and aneurysms had to be less than 15 mm in diameter. Exclusion criteria were dissecting or fusiform aneurysms, aneurysms associated with brain arteriovenous malformations, aneurysms already treated with surgery or embolization, or recent subarachnoid hemorrhage related to other aneurysms. The protocol was approved by the ethics committee of Reims and informed consent was obtained from all patients.

Immediate Postoperative Imaging

Immediately after endovascular treatment, postoperative anatomic results were obtained with digital subtraction angiography (DSA). Anatomic evaluations were performed on nonsubtracted and subtracted images from frontal, lateral, and working views. 3D images were not required. Anonymous images were collected through the Web data base that was used for clinical data (Kika Medical, Nancy, France).

Image Analysis

Postoperative anatomic results were first evaluated by the treating physician; then they were anonymously and independently reviewed by 2 experienced neuroradiologists (L.P., L.S.), who were blinded to all clinical information. Discrepancies were resolved by consensus of the 2 readers. The Montreal scale was used to classify aneurysmal occlusions into 3 grades: total occlusion, neck remnant, and aneurysm remnant.[2]

Statistical Analysis

Data management was independently conducted by Kika Medical and the Clinical Research Unit of Reims University Hospital. Statistical analyses were independently performed by the Clinical Research Unit to determine patient demographics, aneurysmal characteristics, occlusion classification according to the Montreal scale, and associations between anatomic results and some of the demographic and anatomic parameters. Mean and frequency comparisons were performed with the Student *t* test and χ^2 test or the Fisher exact test, respectively. Differences were considered significant at $P < .05$. Statistical analyses were performed with SAS version 8.0 software (SAS Institute, Cary, NC).

Results

Patient Population, Aneurysmal Characteristics, and Modalities of Treatment

A total of 649 patients were initially included in the ATENA series. They harbored 739 unruptured intracranial aneurysms and were treated with an endovascular approach.

The data for 1 patient was excluded from the analysis because the patient died before endovascular treatment because of complications with anesthesia. Thirty-two aneurysms were excluded from the analysis because the endovascular treatment failed. Twelve aneurysms were excluded from the analysis because postoperative digital subtraction angiography (DSA) was not available, or the quality was inadequate for analysis in the core laboratory. The remaining 622 patients (449 women, 173 men; age range, 22–83 years; mean age, 51.2 ± 11.3 years) harboring 694 aneurysms were evaluated postoperatively for anatomic results.

Aneurysms were located in the internal carotid artery (ICA; $n = 315$; 45.4%), the anterior cerebral and anterior communicating arteries (ACA/AcomA; $n = 200$; 28.8%), the middle cerebral artery (MCA; $n = 124$; 17.9%), and the vertebrobasilar system (VB; $n = 55$; 7.9%). Most aneurysms were less than or equal to 6 mm ($n = 401$; 57.8%), but many were greater than 6 mm ($n = 293$; 42.2%). Close to half of the dome-to-neck ratios were less than or equal to 1.5 ($n = 359$; 51.7%). The treatments included the standard coiling technique ($n = 383$; 55.2%), the remodeling technique, ($n = 258$; 37.2%), and stent placement ($n = 53$; 7.6%).

Comparison Between the Anatomic Evaluations of the Performing Physician and the Independent Reviewers

The physician who performed the treatment found that the anatomic results indicated 426 total occlusions (61.4%), 158 neck remnants (22.8%), and 110 aneurysm remnants (15.9%). The 2 independent reviewers (consensus) found that the anatomic results indicated 437 total occlusions (63.0%), 156 neck remnants (22.5%), and 101 aneurysm remnants (14.6%). When aneurysmal occlusion was quoted total by the treating physician (426 aneurysms), anatomic result was analyzed by the core laboratory as total occlusion in 335 cases (78.6%), neck remnant in 61 cases (14.3%), and aneurysm remnant in 30 cases (7.0%). When aneurysm occlusion was quoted neck remnant by the treating physician (158 aneurysms), anatomic result was analyzed by the core laboratory as total occlusion in 72 cases (45.6%), neck remnant in 61 cases (38.6%), and aneurysm remnant in 25 cases (15.8%). When aneurysm occlusion was quoted aneurysm remnant by the treating physician (110 aneurysms), anatomic result was analyzed by the core laboratory as total occlusion in 30 cases (27.3%), neck remnant in 34 cases (30.9%), and aneurysm remnant in 46 cases (41.8%). The agreement between the treating physician and core laboratory was low ($\kappa = 0.33$).

Table 1: Anatomic result evaluations in relationship to patient age[A]

	< 65 Years		≥ 65 Years	
	N	%	*N*	%
Total occlusion	396	65.2	41	47.1
Neck remnant	138	22.7	18	20.7
Aneurysm remnant	73	12.0	28	32.2
Total	607	100.0	87	100.0

[A] Number of aneurysms ($P < .0001$).

Table 2: Anatomic result evaluations in relationship to aneurysm location[A]

	ACA/AcomA		ICA		MCA		VB	
	N	%	*N*	%	*N*	%	*N*	%
Total occlusion	110	55.0	202	64.1	86	69.4	39	70.9
Neck remnant	53	26.5	68	21.6	24	19.4	11	20.0
Aneurysm remnant	37	18.5	45	14.3	14	11.3	5	9.1
Total	200	100.0	315	100.0	124	100.0	55	100.0

Note:—ACA indicates anterior cerebral artery; AcomA, anterior communicating artery; ICA, internal carotid artery; MCA, middle cerebral artery; VB, vertebrobasilar system.
[A] No significant differences were observed.

Table 3: Anatomic result evaluations in relationship to aneurysm size[A]

	≤ 6 mm		> 6 mm	
	N	%	*N*	%
Total occlusion	273	68.1	164	56.0
Neck remnant	78	19.5	78	26.6
Aneurysm remnant	50	12.5	51	17.4
Total	401	100.0	293	100.0

[A] $P = .0049$.

Table 4: Anatomic result evaluations in relationship to dome-to-neck ratio[A]

	≤ 1.5		> 1.5	
	N	%	*N*	%
Total occlusion	219	61.0	218	65.1
Neck remnant	76	21.2	80	23.9
Aneurysm remnant	64	17.8	37	11.0
Total	359	100.0	335	100.0

[A] $P = .0388$.

Associations Between Anatomic Results and Demographic, Technical, and Anatomic Factors

The anatomic result evaluations are shown in relationship to patient age (Table 1), aneurysm location (Table 2), aneurysm size (Table 3), dome-to neck ratio (Table 4), and endovascular treatment technique (Table 5). A significantly higher quality of aneurysmal occlusion was found in patients younger than 65 years ($P < .0001$), in aneurysms with diameters less than or equal to 6 mm ($P = .0049$), in aneurysms with dome-to-neck

Table 5: Anatomic result evaluations in relationship to the treatment technique[A]

	Coiling		Remodeling		Stenting	
	N	%	*N*	%	*N*	%
Total occlusion	244	63.7	170	65.9	23	43.4
Neck remnant	85	22.2	60	23.3	11	20.8
Aneurysm remnant	54	14.1	28	10.9	19	35.8
Total	383	100.0	258	100.0	*53*	100.0

[A] $P = .0001$.

ratios greater than 1.5 ($P = .0388$), and in aneurysms treated by coiling or remodeling compared with stent placement ($P = .0001$).

Discussion

The ATENA study showed that endovascular treatment of unruptured intracranial aneurysms is feasible in a high percentage of patients with low morbidity and mortality rates.[1] However, a crucial issue for endovascular techniques is the uncertainty of whether coils provide long-term durability of aneurysm occlusion and protection from aneurysm rupture.[3]

The question of the efficacy of endovascular treatment of unruptured aneurysms is fundamental but until now was not analyzed in a large series of patients with a precise methodology. The efficacy can be evaluated from both anatomic and clinical points of view. We know from the literature regarding the endovascular treatment of ruptured aneurysms that there is a clear relationship between the quality of aneurysm occlusion and the risk of rebleeding. In the CARAT (Cerebral Aneurysm Rerupture After Treatment) study conducted in a cohort of 1010 patients treated for ruptured aneurysms with coil embolization or surgical clipping, the risk for rerupture was strongly associated with the degree of aneurysmal occlusion (cumulative risk: 1.1% for complete occlusion, 2.9% for 91%–99% occlusion, 5.9% for 70%–90% occlusion, and 17.6% for $< 70\%$ occlusion).[4] Despite some methodologic limitations of CARAT (anatomic results abstracted from procedural reports leading to the heterogeneous evaluation method singularly in the clipping group and absence of independent core laboratory analysis), it seems that the protection afforded against rebleeding is related to the quality of the aneurysmal occlusion. Is the risk for rupture of unruptured aneurysms treated by the endovascular approach similarly associated with the quality of the aneurysmal occlusion? To answer this question, it is first necessary to know the precise quality of the aneurysmal occlusion immediately after the treatment and to analyze which factors affect the immediate anatomic results. These points are evaluated in the present analysis. On the contrary, the relationship between the quality of occlusion and the risk of bleeding is not analyzed in our study because long-term follow-up is not available at the present time.

In assessments of the immediate postoperative anatomic results from a large series of patients with endovascular treatment of intracranial aneurysms, 2 major points must be recognized:

1. Several scales can be used to evaluate anatomic results after endovascular treatment of ruptured or unruptured aneurysms. The 3-grade Montreal scale is the most frequently used.[2] In this scale, grade I is complete closure of the aneurysm, including the neck. A residual neck (grade II) is defined as the persistence of any portion of the original defect of the arterial wall observed on any single projection but without opacification of the aneurysmal sac. Any opacification of the sac is classified as a residual aneurysm (grade III). Consistent with observations by Raymond et al,[2] we found that sometimes a precise analysis of the immediate postoperative anatomic results was difficult when a minimal opacification was visible inside the coil mesh. Under those conditions, it is relatively difficult to assign classifications according to the scale, and some heterogeneity may be introduced from one series to another (see below).

2. To overcome this limitation, the analysis of anatomic results by an independent core laboratory is certainly useful but is rarely performed for the assessment of the anatomic results of endovascular treatment of ruptured and/or unruptured aneurysms.[3-9] Reports on recent series have shown that the evaluation conducted by the treating physician is often different from the evaluation performed by an independent core laboratory; the analysis by the treating physician tended toward better anatomic results.[10] In the ATENA study, the anatomic results were evaluated rigorously by an independent core laboratory that included 2 experienced neuroradiologists (L.P. and L.S.) who had performed endovascular treatments for more than 10 years.

In contrast to observations in other series, the evaluations of the postoperative anatomic results by the treating practitioner or by the core laboratory were not significantly different globally.[10] However, some large inconsistencies were observed with a low agreement between the treating physician and core laboratory ($\kappa = 0.33$). For example, the treating neuroradiologist judged the results from 426 aneurysms as complete occlusions, but the core laboratory judged the same group of results as 335 complete occlusions (78.6%), 61 neck remnants (14.3%), and 30 aneurysm remnants (7.0%). On the other hand, the treating neuroradiologist judged the results from110 aneurysms as aneurysm remnants, and the core laboratory judged the same group of results as 46 aneurysm remnants (41.8%), 34 neck remnants (30.9%), and 30 total occlusions (27.3%). These discrepancies are related to the difficulties in determining the rate of occlusion after endovascular treatment. As outlined before, 1 major limitation of the Montreal scale is the uncertainty regarding the classification of aneurysms in which the neck occlusion is complete, but some contrast filling is present in the coil mesh. These patterns are classified as grade A by some practitioners (as suggested by Raymond et al[2]) and grade C by others.

According to the core laboratory, the postoperative anatomic results in the ATENA series showed that a satisfactory occlusion (complete occlusion or neck remnant) was obtained in 593 aneurysms (85.4%). It is difficult to compare our series with previous reports on large series because of the methodologic heterogeneities outlined above. In the Wanke series,[6] complete or nearly complete occlusion was achieved in 34 (89.5%) of 38 aneurysms. In the Gonzalez series[8] of 233 aneurysms, angiographic results revealed complete occlusion in 138 (59.2%), neck remnants in 92 (39.5%), and incomplete occlusion in 3 (1.3%), with a high rate of satisfactory occlusion (98.7%). In the Terada series,[7] the results showed complete occlusion in 33 (45.2%) of 73 aneurysms, neck remnants in 26 (35.6%) of 73 aneurysms, and aneurysm remnants in 14

(19.2%) of 73 aneurysms, with a satisfactory occlusion in 80.8%. In the Gallas series,[11] postoperative occlusion was classified as complete in 207 aneurysms (70.0%), subtotal in 84 aneurysms (26.1%), and incomplete in 11 aneurysms (3.9%), with a satisfactory occlusion in 96.1%. In the Standhardt series complete occlusion was achieved in 57.5%, neck remnants in 34.0%, and aneurysm remnants in 8.5%, with satisfactory occlusions in 91.5%.[9] Thus, the high rate of satisfactory occlusion (between 80.8% and 98.7%) confirmed the immediate anatomic efficacy of endovascular treatment.

We found improved anatomic results in patients younger than 65 years compared with older patients (Table 1). Several factors may explain this difference including increased difficulties in the endovascular treatment and different strategy of treatment in elderly patients. As the cumulative risk for rupture is lower in older patients, the objective of having a very dense coil mesh is probably considered less important in elderly patients. The clinical analysis has shown that the morbidity rate is significantly higher in patients older than 65 years, and it can explain, in some cases, the premature interruption of treatment. The degree of postoperative aneurysm occlusion was not significantly related to aneurysm location (Table 2). This suggests that the endovascular treatment is equally effective for aneurysms in all locations. We found that 2 anatomic factors were linked to the quality of aneurysm occlusion: aneurysmal size and the dome-to-neck ratio (Tables 3 and 4). The quality of occlusion was better in aneurysms smaller than 6 mm than those larger than 6 mm in diameter. Similar results were previously reported by Terada et al,[7] Gonzalez et al,[8] and Standhardt et al.[9] The anatomic results were also better in narrow-neck aneurysms (dome-to-neck ratio > 1.5) compared with wide-neck aneurysms (dome-to-neck ratio < 1.5). This was also previously demonstrated by Gonzalez et al[8] and Standhardt et al.[9] Our evaluation of the techniques used showed that anatomic results were similar when coiling and remodeling were used but worse with stent placement (Table 5). However, the recruitment of patients in the ATENA study took place when stents were just beginning to come into use; thus, further analyses in a larger group of patients treated with stents are certainly needed to define more clearly the efficacy of stent placement.

There were several limitations to our study. First, the immediate postoperative anatomic results only represented 1 part of the anatomic efficacy of endovascular treatment. The other part of this efficacy is the prevention of the recanalization; this will be analyzed with mid- and long-term follow-ups. A second limitation was that it was not possible to analyze the relationship between the quality of postoperative anatomic results and the clinical efficacy of the endovascular treatment to prevent aneurysmal rupture because long-term clinical follow-up is actually not available. A third limitation, outlined above, was the difficulty in analyzing anatomic results with the Montreal scale. However, the definitions used in other scales are probably equally difficult; this emphasizes the importance of evaluating a large series of patients in determining whether recanalization can be more precisely predicted.

Conclusions

The immediate postoperative results in the ATENA series analyzed with a rigorous methodology showed that endovascular treatment of unruptured intracranial aneurysms was highly efficacious, with a satisfactory occlusion rate of 85.4%. Anatomic factors that affected the quality of occlusion were aneurysmal size and dome-to-neck ratio but not aneurysm location.

Appendix

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