Impact of Anatomic Features in the Endovascular Embolization of 181 Anterior Communicating Artery Aneurysms

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Background and Purpose—We analyzed the impact of detailed anatomic characteristics on the results of endovascular coil embolization for anterior communicating artery (AcoA) aneurysms and developed a predictive model estimating the probability of successful endovascular treatment.

Methods—One hundred eighty-one AcoA aneurysms were treated with endovascular coil embolization between August 1991 and November 2005. Morphological characteristics that were analyzed included direction of the dome, location of the neck, association with hypoplasia or aplasia of AcoA complex vessels, sac, and neck size. Immediate clinical and anatomic results, long-term morbidity/mortality, recanalization rate, and delayed aneurysm thrombosis were analyzed. ORs were calculated for each anatomic and clinical result and logistic regression was used in formulating a predictive model.

Results—There were 115 females and 66 males. Age range was 9 to 86 years (mean 57). Factors significantly associated with complete embolization included small aneurysms (<10 mm), small neck (<4 mm), and anterior dome orientation. Factors significantly associated with aneurysm recanalization after long-term follow-up included aneurysm domes >10 mm, neck location on the AcoA, posterior dome orientation, and incomplete original embolization. Globally, the majority of patients remained neurologically intact or unchanged after the procedure (92.8%). Mortality was significantly influenced by the preoperative condition of the patient. The predictive model successfully represented the likely outcomes based on morphological features.

Conclusions—AcoA aneurysm coil embolization can be safely performed with acceptable rates of morbidity. Dome and neck orientation, sack and neck size, sac-to-neck ratio, and associated anomalies should be considered to accurately assess the probability of successful treatment for AcoA aneurysms. (Stroke. 2008;39:2776-2782.)

Key Words: aneurysms ■ anterior communicating ■ coil embolization

Intracranial aneurysms are a major source of devastating hemorrhagic stroke and delayed ischemic stroke. Up to 12% of patients with subarachnoid hemorrhage die before receiving medical attention, ~40% of hospitalized patients die within 1 month after the event, and more than one-third of those who survive have major neurological deficits.1-5

The true incidence of cerebral aneurysms is unknown, but it is estimated at 1% to 6% of the population.13 Anterior circulation aneurysms comprise up to 91% of all intracranial aneurysms, and anterior communicating artery (AcoA) aneurysms account for ~40% of subarachnoid hemorrhage.6,7

Treatment for these aneurysms include microsurgical clipping and coil embolization. Since the introduction of the Guglielmi detachable coils in 1991 for the treatment of intracranial aneurysms, a growing number of ruptured and unruptured cases have been treated with endovascular techniques.5-11 The International Subarachnoid Aneurysm Trial (ISAT) and International Study of Unruptured Intracranial Aneurysms (ISUIA) clinical trials for intracranial aneurysms have shown advantages of endovascular therapy over surgical clipping for a selected group of patients.12,13 Anterior communicating artery and anterior cerebral artery aneurysms represented 45.4% of ruptured aneurysms in ISAT and 12.3% in ISUIA.12,13 However, extrapolation of the results of these studies to the clinical practice is limited given the specific criteria used in the selection of cases. Generalizations based in our current knowledge are inappropriate and underestimate the complexity of intracranial aneurysms and their treatment.

Few publications have addressed specifically the endovascular treatment of AcoA aneurysms.7,14 Furthermore, detailed anatomic characteristics and the effects of the multiple variations of these features have scarcely been reported. The growing evidence that hemodynamic factors play a fundamental role in the adequate treatment of aneurismal coiling15,16 and the close correlation between the vessels and aneurysms anatomic architecture and the

Received September 21, 2007; final revision received February 28, 2008; accepted February 29, 2008.
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Stroke is available at http://stroke.ahajournals.org

DOI: 10.1161/STROKEAHA.107.505222

2776
patterns of flow reinforce the need for a more meticulous anatomic analysis.

The purpose of our study was to analyze the impact of comprehensive anatomic characteristics and the results of coil embolization in AcoA aneurysms. Herein, we report the largest case series specifically on AcoA aneurysms with a detailed analysis. We also developed a predictive model to estimate the efficacy of endovascular treatment of this group of aneurysms and compared it to our true outcomes.

Subjects and Methods

Study Design, Inclusion, and Exclusion Criteria

We performed a retrospective review of 1234 medical records of patients from 1991 to 2005 who underwent coil embolization for cerebral aneurysms at UCLA Medical Center after Institutional Review Board Approval. We included all patients with AcoA aneurysms. Cases that required stenting were excluded and extremely rare.

We separated patients into 2 clinical groups according to their pre-embolization condition of good or poor. Good was defined as having an unruptured aneurysm or a ruptured aneurysm that was Hunt and Hess grade 1, 2, or 3. Poor was defined as having a ruptured aneurysm with a grade 4 or 5.

Final decisions regarding the treatment of patients with cerebral aneurysms were discussed among the faculty members of the vascular neurosurgery and interventional neuroradiology departments. The indications for coil embolization included surgical difficulty determined by the referring neurosurgeon or the UCLA Medical Center’s neurosurgical team, unsuccessful surgical attempt, refusal of surgery, direct embolization referral, elderly patients, and poor medical condition.

Anatomic Analysis

We analyzed the aneurysm morphology on digital subtraction angiography at the time of embolization. Several anatomic characteristics were collected blindly with respect to the result of the embolization. These characteristics included anterior/posterior orientation of the aneurysm dome with respect to the axis of the pericallosal arteries,14 location of the aneurysm neck with respect to the A1-A2 segment of the anterior cerebral arteries or the AcoA, dome and neck size, sac-to-neck ratios, and the presence of hypoplasia/aplasia of ipsilateral or contralateral arterial segments in the AcoA complex. Only when the anatomic characteristics could be clearly established in the available films were the cases included for analysis.

A small aneurysm was defined as the dome being <10 mm. Large aneurysms were those whose dome was 10 mm to 25 mm. Giant aneurysms were those >25 mm. A small neck was defined as <4 mm and a large neck as ≥4 mm. Sac-to-neck ratios were categorized into those >2 and those whose ratio was ≤2.

Embolization Outcome

The angiographic results were evaluated in the immediate postembolization angiography in multiple projections. An embolization was considered complete if there was no contrast filling of the dome, the body, and the neck. Residual fillings were defined as neck remnant if there was residual filling of part of the neck of the aneurysm was present, or incomplete if there was some contrast filling of the dome or sac. Attempted occlusion was defined as endovascular intervention that was attempted but embolization was not performed. A perfect result was defined as complete embolization, clinically intact or unchanged postprocedure and at the term of the follow-up, and no recanalization in the angiographic follow-up.

Statistical Methods

Descriptive statistics and cross tables for each specific anatomic feature were attained. SPSS 11.0.4 (SPSS Inc.) was used for all statistical calculations. ORs were calculated for each anatomic and clinical result for both the immediate postprocedure and follow-up terms. Mantel-Haenszel common ORs were used to evaluate the significance of the estimated risks.

Nominal logistic regression was used to predict the dependent variables complete embolization and perfect result. Logistic regression classification tables were used to assess the performance of the model by cross tabulating the observed response categories with the predicted response categories.

Results

Patient Population

One hundred eighty-one patients with 181 AcoA aneurysms were treated with coil embolization. This number reflects a referral pattern with fewer cases than expected in the general population. One-hundred fifteen were females (63.5%) and 66 were males (36.5%). Patient mean age was 57 years, with a range between 9 and 86 years (SD±15.6).

There were 144 patients (79.6%) with good preprocedural conditions. Fifty-eight were unruptured (32%), 32 were grade 1 (17.7%), 22 were grade 2 (12.2%), and 32 were grade 3 (17.7%). There were 37 (20.4%) with poor preprocedural conditions. Twenty-seven (14.9%) were grade IV and 10 (5.5%) were grade V.

Aneurysm Morphology

One hundred fifty-four aneurysms (85.1%; 154/181) were small, 20 aneurysms (11%; 20/181) were large, and 7 aneurysms (3.9%; 7/181) were giant. One hundred seven aneurysms (59.1%; 109/181) had small necks and 74 aneurysms (40.9%; 57/135) had wide necks.

One hundred forty-four aneurysms had images regarding dome orientation. Eighty-six aneurysms had the dome oriented anteriorly (59.7%; 86/144), and 58 were oriented posteriorly (40.3%; 58/144). The neck location could be well-defined in 161 aneurysms: 31 (19.2%); 31/161) were located directly on the anterior communicating artery, whereas 130 (80.8%; 130/161) had the neck located at the A1–A2 junction.

The sack-to-neck ratio was measured in 162 aneurysms. Sixty-two (38.3%; 62/162) had a sac-to-neck ratio >2, and 100 (61.7%; 100/162) had a sac-to-neck ratio ≤2. Last, hypoplasia or aplasia was seen in only 45 cases. The most common anomaly associated with AcoA aneurysms were hypoplasia/aplasia of 1 of the A1 segments (42 cases; 23.2%; 42/181), followed by AcoA hypoplasia/aplasia (2 cases; 1.1%; 2/181) and A2 hypoplasia in 1 case (0.5%; 1/181).

Endovascular Treatment

All procedures were performed under general anesthesia and patients received systemic heparinization through the procedure. Reversal of heparinization with the injection of protamine sulfate (10 mg/1000 U heparin) was performed in all cases unless protrusion of coils into the parent arterial lumen was present.

One-hundred forty aneurysms (77.4%; 140/181) were treated exclusively with Guglielmi detachable coils (Boston Scientific), 20 (11%; 20/181) were treated with a combination of Guglielmi detachable coils and Matrix coils (Boston Scientific), 20 (11%; 20/181) were treated exclusively with Matrix coils, and 1 (0.6%; 1/181) was treated with a combi-
nation of hydrocoils and cordis coils. In 7 (3.9%; 7/181) cases the technique of aneurysm neck remodeling using a balloon, as described by Moret,17 was performed.

**Angiographic Results**

Complete embolization was observed in 96 cases (53%; 96/181). Neck remnants were observed in 71 cases (39.2%; 71/181). Incomplete aneurysmal embolization was observed in 8 (4.5%; 8/181) cases. There were 6 unsuccessful attempts of coil embolization (3.3%; 6/181).

**Clinical Results**

In the group of patients who presented with good clinical condition, 92.4% (133/144) were neurologically intact or unchanged after the endovascular embolization. Ten patients (6.9%; 10/144) presented new neurological deficits or deterioration immediately after treatment. One-hundred twenty-nine patients completed clinical follow-up. Five patients of this group (3.8%; 5/129) had permanent neurological deficits. In this group, there was 1 death in a 59-year-old woman with a subarachnoid hemorrhage Hunt and Hess grade 2 who presented 2 weeks after bleeding in severe vasospasm. After a partial embolization of her aneurysm, bilateral middle cerebral artery strokes occurred. Intra-arterial recombinant tissue plasminogen activator injection was performed in an effort to recanalize the stroke territories, but she presented a large hemorrhagic transformation of the infarcted tissue. No deaths occurred in any of the 58 patients with unruptured intracranial aneurysms, and only 1 patient had a permanent deficit (1.7%; 1/58).

Among the 37 patients with poor preprocedural conditions, 2 had new neurological deficits or deterioration (5.4%; 2/37) immediately after the procedure. In addition, there were 4 deaths in this group. One death was a 45-year-old man with a subarachnoid hemorrhage Hunt and Hess grade 4 who had a dissection of the internal carotid artery and a large ipsilateral middle cerebral artery territory stroke. Two patients were elderly individuals who remained comatose after initial treatment with subsequent withdrawal of care. One patient had subarachnoid hemorrhage associated with a very severe traumatic head injury, multiple associated hematomas, and uncontrollably elevated intracranial pressures.

**Clinical and Angiographic Follow-Up**

We obtained clinical follow-up for 129 patients. These patients were examined by 1 of the members of the interventional neuroradiology or neurosurgery services between 1 month and 116 months after the embolization (mean, 9.7 months). Angiographic follow-up was obtained in 79 cases. Angiograms were performed between 1 month and 60 months from the original embolization (mean, 6.7 months).

In the angiographic follow-up, 44 cases were unchanged (55.7%; 44/79), 23 had further thrombosis of residual necks or aneurismal body (29.1%; 23/79), and 12 cases presented aneurismal recanalization (15.2%; 12/79). Of these recanalization cases, 9 were considered to require a second embolization, and the other 3 cases have been followed-up conservatively.

**Analysis of Data**

Immediate results and long-term results according to anatomic features show that anterior dome projection, A1-A2 neck projection, small neck size, and sac-to-neck ratio >=2 have a higher incidence of complete embolization. However, large aneurysms (OR, 0.3; CI, 0.1 to 0.9), wide neck (OR, 0.3; CI, 0.1 to 0.5), sac-to-neck ratio <2 (OR, 0.4; CI, 0.2 to 0.7), and posterior dome direction (OR, 0.5; CI, 0.3 to 0.9) reduced the probability of complete occlusion (Figure 1).

The presence of neck remnants was associated with wide neck size (OR, 2.9; CI, 1.5 to 5.4), sac-to-neck ratio <2 (OR, 2.3; CI, 1.2 to 4.3), AcoA neck located directly at the AcoA (OR, 2.2; CI, 1.0 to 4.7), and a posterior dome direction (OR, 1.9; CI, 1.0 to 3.6) (Figure 2). Recanalization was associated with large aneurysms (OR, 6.4; CI, 1.8 to 22), neck location

![Figure 1. OR for complete occlusion and 95% CI for significant predictors. Small dome size, small neck size, sac-to-neck ratio >=2, and anterior dome orientation are positive predictors for complete occlusion. Wide neck, sac-to-neck ratio <2, and posterior orientation are negative predictors for complete occlusion. Of note, giant aneurysms, neck orientation, and those with associated anomalies were not statistically significant.](http://stroke.ahajournals.org/)

Figure 1. OR for complete occlusion and 95% CI for significant predictors. Small dome size, small neck size, sac-to-neck ratio >=2, and anterior dome orientation are positive predictors for complete occlusion. Wide neck, sac-to-neck ratio <2, and posterior orientation are negative predictors for complete occlusion. Of note, giant aneurysms, neck orientation, and those with associated anomalies were not statistically significant.
at the AcoA (OR, 3.4; CI, 1.1 to 11.3), posterior dome direction (OR, 3.7; CI, 1.2 to 12.1), and with initial incomplete embolization (OR, 9.8; CI, 2 to 46.9). In addition, risk factors for mortality were large aneurysms (OR, 5.5; CI, 1.2 to 25.1) and poor preprocedural clinical condition (OR, 13.7; CI, 2.6 to 71.3; Figure 3).

Nominal logistic regression was used to predict the dependent variables complete occlusion and perfect result. The percentage correct for the predicted variable complete occlusion in the classification tables was 77.1% and for the predicted variable perfect result was 77.9%. Based on the results of the OR analysis, the following favorable factors were selected: small aneurysm size, small neck size, sac-to-neck ratio $>2$, A1–A2 junction location of the neck, anterior orientation of the dome, and absence of associated anomalies. The predicted probability of complete occlusion and perfect result for the possible combination of the independent variables when $\geq 1$ of the favorable factors were absent was calculated. Clear stepwise predictability is seen on the scatter plots. Each of the 6 factors represent key independent variables that can predict outcome. When the 6 characteristics were present, the predicted probability of complete occlusion was 82.5%, the predicted probability for different combinations of 5 factors with small neck was between 68% and 78%, the predicted probability for combinations of 5 factors with wide neck was 61% to 65%, the predicted probability for combinations of 4 factors with small neck was between 47% and 68%, the predicted probability for 4 factors with wide neck was 49%, the predicted probability for combination of any 3 factors including small or wide necks was between 27% and 48%, and the predicted probability for $\leq 2$ combined factors with small or wide necks was between 16.8% and 26.2% (Figure 4).

When the 6 favorable factors were present, the predicted probability of perfect result was 77.2%, predicted probability for small aneurysms with any other combination of 4 factors was between 59.4% and 72.3%, predicted probability for small aneurysms with any other combination of 3 factors was between 45% and 58%, and predicted probability for small
aneurysms with any combination of 2 other factors or any large or giant aneurysm was distributed in a broad spectrum from 2.7% and 45% (Figure 5).

Discussion

As the treatment of intracranial aneurysms using endovascular techniques becomes more common, multiple studies have tried to establish the value, indications, and limitations of these techniques.\textsuperscript{18–25} Several clinical trials compare the use of endovascular coil embolization vs microsurgical clipping have produced results that have been the object of numerous discussions and interpretations.\textsuperscript{12,13}

Aneurysm neck size has been recognized as the main limiting factor for the endovascular treatment of intracranial aneurysms since very early in the development of these techniques.\textsuperscript{10} Multiple strategies of treating wide neck aneurysms include avoidance of endovascular treatment, remodeling neck techniques using balloons, the simultaneous deployment of 2 coils at the beginning of the framing of the aneurysm, or by the use of stents.\textsuperscript{17,26–33} Stenting is particularly difficult and of limited use for AcoA aneurysms.

Clearly, embolization of AcoA aneurysms involves several key factors beyond neck size or sac-to-neck ratios. These aneurysms in themselves present a heterogeneous group of features that may each improve or halt the ability to perform coil embolization. We have identified 6 key factors affecting the outcome for coil embolization of AcoA: dome direction, neck location, presence of associated anomalies, neck size, dome size, and sac-to-neck ratios. These 6 factors each play key roles in the access and stability of the catheter system, clearly influencing the success of coil deployment and embolization.

In a prospective study of 37 patients with AcoA aneurysms who underwent endovascular embolization, Proust et al\textsuperscript{14} have shown a rate of 75.8% complete occlusion in posteriorly oriented aneurysms, compared with 100% in those with the domes directed anteriorly. This tendency is in agreement with our findings. These findings point to the particular difficulties in the treatment of posteriorly oriented aneurysms, which appears challenging for both current endovascular and surgical techniques. The authors concluded that anteriorly directed aneurysms may be better candidates for clipping, whereas posteriorly directed fundi may be optimally treated with endovascular coiling. However, optimal treatment for AcoA aneurysms cannot be determined by any 1 anatomic characteristic, but rather all the morphological features and clinical scenario need to be considered. For example, a posteriorly directed aneurysm with the 5 other beneficial characteristics we have described may be a great candidate for endovascular coil embolization. Conversely, an anteriorly directed aneurysm without the other beneficial factors may be a poor candidate for coiling. Our predictive model clearly demonstrates that a comprehensive morphological evaluation is more important than isolated anatomic features.

Independently from the incomplete embolization group, which is the major predictor of recanalization, aneurysms with large neck size located at the AcoA, or domes directed posteriorly, have also a higher tendency to recanalize. In these particular groups of lesions, incomplete aneurysmal sac embolization, more than residual necks, were the initial

\begin{figure}
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\includegraphics[width=\textwidth]{figure4.png}
\caption{Predicted probability of complete occlusion. The graphic shows the range of predicted probabilities according to the number of positive predictive anatomic features present. Small aneurysm size, small neck size, sac-to-neck ratio >2, A1–A2 junction orientation of the neck, anterior orientation of the dome, and absence of associated anomalies are the 6 independent positive factors affecting the probability of embolization.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Predicted probability of perfect result. The graphic shows the range of predicted probabilities according to the number of positive predictive anatomic features present. Small aneurysm size, small neck size, sac-to-neck ratio >2, A1–A2 junction orientation of the neck, anterior orientation of the dome, and absence of associated anomalies are the 6 independent positive factors affecting the probability of embolization.}
\end{figure}
angiographic result that was strongly associated with recanalizations. In addition to coil density, the particular effect of patterns of flow in aneurysms of these morphological peculiarities may cause higher impact with pulsation over the coil mass, resulting in coil compaction over time.34 Further research in the hemodynamic factors associated with specific morphological characteristics may also improve our understanding of the long-term results of endovascular embolization.35–37

Our results did not show correlation between the anatomic characteristics of the AcoA aneurysms and the risk for new neurological deficits as a consequence of aneurismal rupture or stroke. However, large aneurysms and poor preprocedural condition were associated with higher mortality.

The use of the predictive model reinforces the idea that careful consideration to the anatomic characteristics affects the results of the endovascular embolization of intracranial aneurysms. The quantitative results of our evaluation demonstrate objectively lower rates of success in the endovascular treatment as the favorable anatomic characteristics dissipate.

Limitations of the present study include the retrospective design, as well as the limited follow-up. Also, it was impossible to measure other associated characteristics on 2-dimensional digital subtraction angiography, such as the specific angles between the A1, A2, and A-com, and the aneurysm dome or neck.

Conclusion

Endovascular coil embolization is not homogeneously successful for a particular aneurysm location. Detailed anatomic features of the aneurysms should be considered when attempting endovascular treatment. Identifying the key elements that make coil embolization more or less successful is paramount when presenting the therapeutic options to patients.

This type of detailed morphological analysis should be performed for all major locations of intracranial aneurysms to rationally guide the selection of the best modality of treatment and to provide patients with accurate estimations of the probability of complete embolization and possible need for further treatments or studies.

Acknowledgments

The authors thank Jim Sayre for his help in statistical analysis.

Disclosures

None.

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*Stroke*. 2008;39:2776-2782; originally published online July 10, 2008;
doi: 10.1161/STROKEAHA.107.505222
*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2008 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/39/10/2776

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