Unruptured intracranial aneurysms and the assessment of rupture risk based on anatomical and morphological factors: sifting through the sands of data

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Aneurysmal subarachnoid hemorrhage continues to have high rates of morbidity and mortality for patients despite optimal medical and surgical management. Due to the fact that aneurysmal rupture can be such a catastrophic event, preventive treatment is desirable for high-risk lesions. Given the variability of the literature evaluating unruptured aneurysms regarding basic patient population, clinical practice, and aneurysm characteristics studied, such as size, location, aspect ratio, relationship to the surrounding vasculature, and the aneurysm hemodynamics, a meta-analysis is nearly impossible to perform. This review will instead focus on the various anatomical and morphological characteristics of aneurysms reported in the literature with an attempt to draw broad inferences and serve to highlight pressing questions for the future in our continued effort to improve clinical management of unruptured intracranial aneurysms. (DOI: 10.3171/2009.2.FOCUS0921)

KEY WORDS • unruptured intracranial aneurysm • vascular location • rupture risk • ISUIA • aspect ratio

ANEURYSMAL SAH continues to have high rates of morbidity and mortality for patients despite optimal medical and surgical management.¹⁸ Controversy exists regarding the prevalence of unruptured intracranial aneurysms with some studies reporting rates as high as 6.5% in the general population harboring these lesions.²⁷ However, the vast experience of the neurovascular community would declare these estimates likely too high.^{30,31,43} Regardless, with the increasing use of noninvasive intracranial imaging, an increasing number of unruptured intracranial aneurysms are being incidentally discovered. The optimal procedural management of these lesions is still being debated, which can carry significant risk, with morbidity and mortality rates up to 10 and 2.5%, respectively.^{21,29}

However, due to the fact that aneurysm rupture can be such a catastrophic event, preventive treatment is desirable for high-risk lesions. Many groups have sought to find conclusive data on the natural history of unruptured aneurysms. The ISUIA trial was designed and conducted

to provide such information. The ISUIA concluded that aneurysms < 7 mm in size in the anterior circulation have an annual rupture risk of 0-0.1% per year.⁴² This was markedly lower than previous estimates, and the trial drew heavy criticism.^{9,20,25,39}

The main obstacle in evaluating cumulative risk of rupture over time is that ethically, patients with the highest risk aneurysms cannot be left untreated. Thus, these estimates will likely underestimate the true aneurysm rupture risk. In response to this, most recent literature has focused on comparing anatomical and morphological characteristics of ruptured aneurysms to unruptured aneurysms with the goal of elucidating factors associated with a high risk of rupture. These studies have had many different designs, areas of focus, and varied conclusions.

Given the variability of the literature evaluating unruptured aneurysms regarding basic patient population, clinical practice, and even aneurysm characteristics studied, a meta-analysis is nearly impossible to perform. This review will instead focus on the various anatomical and morphological characteristics of aneurysms reported in the literature with an attempt to draw broad inferences and serve to highlight pressing questions for the future in our continued effort to improve clinical management of unruptured intracranial aneurysms.

Abbreviations used in this paper: ACoA = anterior communicating artery; CFD = computational flow dynamics; ISUIA = International Study of Unruptured Intracranial Aneurysms; SAH = subarachnoid hemorrhage; WSS = wall shear stress.

TABLE 1: Comparison studies of the sizes of ruptured versus unruptured intracranial aneurysms*

Authors & Year	No. of Patients	No. of Aneurysms	Mean Size (mm)		p Value
			Unruptured	Ruptured	
Baumann et al., 2008	99	265	4	7	<0.0001
Beck et al., 2003	118	155	5.7	6.7	0.7
Nader-Sepahi et al., 2004	75	182	4.9	7.7	<0.001
Juvela et al., 2008	142	181	4.9	5.6	nc
Hoh et al., 2007	30	67	4.3	6.2	0.004
Weir et al., 2003	945	507	7.8	10.8	< 0.001
Weir et al., 2002	532	774	7	8	nc
Sadatomo et al., 2008	41	44	5.6	7.2	0.11

* Patients had single, multiple, or mixed aneurysms. Abbreviation: nc = not calculated.

Aneurysm Size and Location

Two of the most basic features of intracranial aneurysms are their size and location. Consistently, investigators have reported that size is an unquestionable factor with regard to rupture risk. Furthermore, posterior circulation aneurysms have been noted to rupture more frequently than similar aneurysms in the anterior circulation. However, despite decades of observation, few studies have examined unruptured intracranial aneurysms in a prospective trial involving international centers and a heterogeneous population. The ISUIA was an attempt to elucidate the natural history of these lesions across an international population. The ISUIA published their first study in the *New England Journal of Medicine* in December 1998.² The study was divided into 2 cohorts, which consisted of a retrospective cohort of observed unruptured aneurysms, designed to evaluate risk of rupture over time, and a prospective cohort, designed to evaluate surgical risk. The retrospective cohort had 1449 patients with 1937 aneurysms, nearly evenly divided into 2 groups. Group 1 had no history of prior SAH and Group 2 comprised patients with prior SAH from another treated aneurysmal lesion and had to be functioning independently. Risk of rupture for Group 1 patients for aneurysms < 10 mm in size in the anterior circulation was 0.05% per year, compared with 0.5% annually for Group 2. Aneurysms > 10 mm in size had a risk of rupture close to 1% annually in both groups. The prospective cohort enrolled 1172 patients undergoing treatment of their aneurysms. Surgical morbidity and mortality published in this study were notably higher than previously accepted rates. This study was widely quoted and used at the time by primary care physicians, but it was considered controversial by the neurosurgical community. The main criticism was in regard to patient selection. For the retrospective cohort, all patients receiving treatment within 30 days of diagnosis were excluded, and the number of these patients was not revealed. These aneurysms almost certainly comprised the highest risk group. Aneurysms in low-risk locations, such as the cavernous segment of the carotid artery, were over-represented. Furthermore, numerous patients subsequently died of intracranial hemorrhage of unknown origin, a suspicious diagnosis for patients with known

aneurysms. Nevertheless, this study demonstrated that aneurysm size is an important risk factor for rupture.

The ISUIA published a follow-up paper in *The Lancet* in July 2003.⁴² This report more closely evaluated rupture risk based on location and size, and specifically assessed surgical and endovascular treatment risks. The 5-year cumulative rupture rates for patients without prior SAH, with anterior circulation aneurysms (not including cavernous carotid or posterior communicating artery aneurysms) were 0, 2.6, and 14.5% for aneurysms < 7, 7–12, and 13–24 mm, respectively, compared with rates of 2.5, 14.5, and 18.4%, respectively, for the same size aneurysm in the posterior circulation (including posterior communicating artery aneurysms). Patients with a history of previous SAH with aneurysms < 7 mm in size had a 0.1% yearly rupture rate. This study had many of the same limitations and criticisms as the first ISUIA study.^{21,40} Despite reporting results that were not consistent with numerous studies in the literature regarding rupture risk of unruptured intracranial aneurysms, the ISUIA data provided the first large, international, prospective data set that practitioners could use in their discussions with patients and their families.

However, many other studies, although not involving as many patients as those of the ISUIA reports, have been published regarding aneurysmal rupture risk, whose results have been marketed as challenging the ISUIA results. More specifically, Juvela et al.¹⁹ published their account of the cumulative aneurysm rupture risk in Finnish patients with long-term follow-up in which 142 patients with 182 aneurysms were evaluated and were found to have a rupture rate of 1.3% per year. A significant observation in this study was that the majority of ruptured aneurysms were < 7 mm, in contrast to the findings of the ISUIA.⁴² They also noted that larger aneurysms had a linearly increasing relative risk compared with smaller aneurysms. With respect to aneurysm location, ACoA aneurysms were found to have a higher ratio of ruptured to unruptured aneurysms than other locations. The rupture rates quoted by Juvela and colleagues were closer to those published in previous large studies of the natural history of unruptured intracranial aneurysms during the 1980s.^{15,43} The reported rate was also more equivalent with 2 previous Japanese reports noting annual rupture rates of 1.5

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TABLE 2: Comparison studies of the aspect ratio in ruptured and unruptured aneurysms

Authors & Year	Aneurysm Population	No. of Patients	No. of Aneurysms	Mean Aspect Ratio (mm)		p Value
				Unruptured	Ruptured	
Sadatomo et al., 2008	mixed	41	44	1.56	2.24	<0.01
Beck et al., 2003	mixed	118	155	2.03	1.68	<0.001
Nader-Sepahi et al., 2004	multiple	75	182	1.8	2.7	<0.001
Hoh et al., 2007	multiple	30	67	1.63	2.39	<0.001
Weir et al., 2003	mixed	532	774	1.8	3.4	nc

and 2.3%, although these trials also had high proportions of patients with prior SAH or ICH.^{37,44} It is worth noting, however, that of 142 patients in the study by Juvela and colleagues, only 5 had asymptomatic, incidental aneurysms and 6 had symptomatic incidental aneurysms. The other 131 patients had a history of previous SAH. Thus, this population is most similar to Group 2 in the ISUIA reports, which was noted to have a 0.1% annual rupture rate for aneurysms < 7 mm. So, while the study by Juvela et al. is less burdened by the selection biases present in ISUIA, it cannot accurately estimate the rupture risk with regard to aneurysm size for patients without a previous history of SAH. Furthermore, these studies had a significantly smaller number of patients than ISUIA and were limited to patients from Finland and Japan, potentially higher risk population groups.

Many other studies have compared aneurysm size in ruptured aneurysms with that of unruptured lesions (Table 1).^{3,4,16,19,26,33,40,41} Consistently, ruptured aneurysms are larger than unruptured aneurysms. Typical results have demonstrated the mean size of unruptured aneurysms to be between 4 and 6 mm, and mean size of ruptured aneurysms is between 5 and 8 mm, which is statistically significant. Nevertheless, the majority of ruptured and unruptured aneurysms are still < 7 mm, and a substantial percentage of ruptured aneurysms are even < 5 mm.^{11,27,28} Thus, aneurysm size and location appear to be insufficient single parameters to guide treatment decisions, but they can at least serve as a guide for higher risk lesions.

Aspect Ratio

In response to the limitations of size and location as a single, dependable predictor of rupture risk, many investigators have evaluated other morphological aspects and single-/multidimensional geometric parameters of aneurysms as a predictor of rupture risk.^{3,4,13,16,17,22,26,34,38,40} More specifically, neck width, dome width, aneurysm shape, aspect ratio (height/neck width), and bottleneck factor (dome width/neck width) have been examined. Among these, aspect ratio has shown the greatest promise as a parameter to associate with rupture risk (Fig. 1).

Neck width has been examined in multiple studies, most of which place the mean width for unruptured and ruptured lesions between 2 and 3 mm, without statistically significant difference.^{14,16} However, due to the variability of aneurysm height, the aspect ratio has been found in most studies to be statistically significant between un-

ruptured and ruptured aneurysms, thus provided another valuable parameter in addition to size and location. With few exceptions,^{4,5} a higher aspect ratio has been associated with ruptured lesions (Table 2).^{5,16,26,34,40}

Hoh et al.¹⁶ published aneurysm characteristics of 30 patients with multiple aneurysms (30 ruptured and 37 unruptured); namely, 7 1D geometric indices and 5 2D indices were evaluated. Aneurysm height, diameter, aspect ratio, bottleneck factor, and aneurysm/parent artery ratio were all statistically significantly different between unruptured and ruptured aneurysms. Ujiie et al.³⁸ evaluated 207 aneurysms and found that ~ 80% of ruptured aneurysms had an aspect ratio > 1.6, whereas ~ 90% of unruptured aneurysms had an aspect ratio < 1.6. Weir et al.⁴⁰ examined 774 aneurysms and found that the mean aspect ratio of unruptured aneurysms was ~ 1.8 as opposed to 3.4 for ruptured aneurysms. The calculated odds of aneurysm rupture were 20-fold greater when the aspect ratio was > 3.47 as opposed to those < 1.38. Nader-Sepahi et al.²⁶ found the mean aspect ratio of 2.7 in ruptured aneurysms and 1.8 in unruptured aneurysms. Sadatomo et al.³³ examined 44 aneurysms and reported that the mean aspect ratio in ruptured aneurysms was 2.24, significantly greater than 1.56, which was found in unruptured aneurysms.

Unfortunately, the aspect ratio also has limitations as a predictor of aneurysm rupture risk. While most studies have found a statistically significant difference in aspect ratio values, there is some discrepancy as to where the threshold values lie. Aspect ratios between 1.6 and 2.2 are consistently considered borderline in risk, even with the upper limit of 2.2 not being considered significantly high risk according to some studies.^{26,40} Nonetheless, it is clear that aneurysms with aspect ratios > 3 have been shown to be at extremely high risk of rupture, whereas aneurysms with aspect ratios < 1.4 are much less likely to be at high rupture risk potential.

Fig. 1. Diagram detailing common morphological parameters used in the assessment of aneurysm rupture risk.

Aneurysm Geometry, Orientation, and Vascular Relationships

Other morphological characteristics have also received attention with regard to assessing aneurysm rupture risk. More specifically, morphological parameters such as lobulations, daughter sacs, and surface irregularity have been considered. Aneurysm wall irregularity and daughter sacs have long been associated with higher rupture risk.^{5,13,22,34}

Hademenos et al.¹³ published their account of 74 patients with aneurysms (40 ruptured and 34 unruptured) and evaluated the location and morphological factors, for example, lobulations, and reported that 16 (84%) of 19 multilobulated aneurysms had ruptured, compared with only 24 (44%) of 55 unilobular aneurysms, a statistically significant difference. Posterior circulation aneurysms were also noted to be of higher risk with multilobular posterior circulation aneurysms at the highest risk of all. Beck et al.⁵ detailed 147 aneurysms in 124 patients (94 ruptured and 53 unruptured), examining the presence of lobulations, daughter sacs, and the differences in aneurysm size. They found that multilobular aneurysms between 5 and 9 mm in dome height were more frequently ruptured than unilobular lesions (26 vs 4%). Furthermore, they could not demonstrate a significant difference based on the presence of a daughter sac, but they had < 10 such lesions in the trial. Sampei et al.³⁵ examined 25 aneurysms found to have grown on repeat angiography and found that the irregular contour and the presence of blebs correlated with faster growth and increased risk of rupture or rebleeding.

Given that intracranial aneurysms are more commonly found at either bi- or trifurcations or at regions of high impact from flowing blood, the relationship of aneurysm to the surrounding vasculature has been examined. With respect to the surrounding vasculature, Sadatomo et al.³⁴ reported on the relationship among aneurysm neck, parent artery, and daughter branches in 22 consecutive MCA bifurcation aneurysms, which were divided into a classic-type (aneurysm at midline relative to parent artery) and a deviating-type (aneurysm deviates to the side of 1 daughter artery). They found that in all cases, the deviating-type aneurysms were located on the side of the daughter artery with a narrower angle to the parent artery. Furthermore, in > 90% of the cases, the aneurysm was located on the side of the smaller artery, suggesting the dominant artery provided the hemodynamic force for aneurysm formation and likely increased rupture risk; however, this contention could not be shown statistically. In another report, Sadatomo's group³² described 18 aneurysms of the ACoA, detailing the relationships of the aneurysm to A₁, the midline, at the junction of the ACoA, and at the A₁-A₂ junction. They found that for all patients with codominant A₁ segments, the aneurysms were always of the classic type, where the aneurysm fundus arose in the midline, as opposed to patients with a dominant A₁, where the aneurysm fundus pointed to the contralateral side of the dominant A₁.

In an effort to combine the morphological characteristics with the relationship of the surrounding vascu-

lature, Dhar et al.¹⁰ recently reported on 45 patients with terminal or sidewall aneurysms (25 ruptured and 20 unruptured) whose aneurysms were analyzed with respect to 8 parameters (5 old and 3 novel). The more established parameters were aspect ratio, aneurysm size, ellipticity index, nonsphericity index, and undulation index; while the novel parameters, which incorporated the parent vessel geometry, were vessel angle, aneurysm (inclination) angle, and (aneurysm-to-vessel) size ratio. Of these parameters examined, size ratio and aneurysm angle with respect to the parent artery had the strongest correlation to rupture potential, although statistically significant differences between ruptured and unruptured aneurysms were also found for aspect ratio, undulation, ellipticity, and nonsphericity index. The fact that these novel parameters involve the aneurysm's relationship to the parent vessel further supports the influence of hemodynamics from the surrounding vasculature on the behavior of the aneurysm.

Other studies have used advanced analysis of angiograms and CFD to further evaluate the relationships between the vasculature and the aneurysm in an attempt to associate specific orientations with higher risk of aneurysm rupture. Hassan et al.¹⁴ examined 68 aneurysms (45 ruptured and 23 unruptured) and classified them into 3 aneurysm groups, namely sidewall, sidewall with a branching vessel, and endwall. They found a 100% rupture rate for aneurysms with an aspect ratio > 1.6 and either a sidewall or sidewall with branching vessel-type, as opposed to 28.75% rate for endwall-type aneurysms. They also found a significantly lower rupture risk and higher flow rates in aneurysms with wide necks and wide efferent, draining arteries, thus minimizing the inflow. Another study by Castro et al.⁷ evaluated 2 ACoA aneurysms by using CFD analysis of WSS and found that an unequal amount of flow in the carotid arteries could be linked to an asymmetric, increased amount of WSS in the ACoA aneurysm, possibly rendering the aneurysm at a higher rupture risk potential. Finally, Hoi et al.¹⁷ used CFD to evaluate the influence of variable arterial curvature on lateral wall aneurysms and found that a greater degree of curvature lead to higher degrees of hemodynamic stress, thus possibly increasing rupture risk.

Aneurysm Hemodynamics

Unfortunately, each unruptured intracranial aneurysm is a unique lesion. Thus, it is probably the individual flow patterns determined by the geometric relationship with the surrounding vasculature as well as the anatomical and morphological configuration of the aneurysm that are the most important predictors of rupture risk. The most recent development in the literature of unruptured aneurysms has been the use of advanced imaging techniques and image postprocessing to visualize flow patterns and hemodynamic stress in individual aneurysms. Some early studies evaluated aneurysm simulations and models, but more recent studies look at in vivo flow dynamics. Although these imaging techniques continue to carry limitations, they are beginning to expand our understanding (or lack thereof) of aneurysm growth and its potential relationship with increased rupture risk.

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The most commonly used techniques to evaluate aneurysm hemodynamics are CFD analyses of 3D digital subtraction angiography or CT angiography images and phase-contrast MR imaging. Shojima et al.³⁶ evaluated the CFD analyses of 3D CT angiography reconstructions of 20 MCA aneurysms (3 ruptured and 17 unruptured) and found, in opposition to most previous reports, that lower WSS, compared with the parent vessel, was present in the dome of aneurysms and in the blebs and/or daughter sacs. In contrast, higher WSS values were found in ruptured aneurysms. However, Castro et al.,⁷ in their study of the effects of parent and draining arteries on CFD analyses, found that not taking into account the inflow of the parent artery as well as outflow through the efferent arteries can significantly underestimate the WSS values in the dome of the aneurysm. When corrected, they found consistently higher values of WSS in the aneurysm domes and blebs. Previous trials, such as that by Shojima et al.,³⁶ which promoted a low WSS theory for aneurysmal rupture, must be reexamined given the sensitivity of CFD analyses on the boundary conditions, namely the requirement of inflow and outflow parameters.

Cebral et al.⁸ evaluated 62 aneurysm models, based on 3D digital subtraction angiograms from patients, using CFD. These models were divided into 4 types: 1) single inflow jet, single vortex of flow; 2) single inflow jet, multiple vortices; 3) multiple inflow jets, single vortex; and 4) multiple inflow jets, multiple vortices. Type 1 was the most frequently encountered, followed by Type 4, Type 2, and Type 3. Types 4 and 2 were the most frequently multilobulated, large in size, and had a higher aspect ratio. Type 1 aneurysms, in contrast, were more likely to be smaller, unilobular, and have a smaller aspect ratio. The rates of rupture for each type of aneurysm were 27, 45, 60, and 58%, respectively. Importantly, although the majority of small aneurysms were Type 1, a significant number were also Type 3 and Type 4. Still, the only statistically significant predictor of rupture risk in this report was the size of the flow impingement region. Aneurysms with small inflow jet streams or smaller flow impingement size were 6.3 times more likely to have ruptured; however, neither large neck nor large aneurysm size statistically correlated with a smaller flow impingement region.

In an effort to allow hemodynamic measurements in vivo, phase-contrast MR imaging has been championed given the availability of MR imaging throughout the world. Ahn et al.¹ examined anthropomorphic in vitro models of 2 intracranial aneurysms to show the feasibility of 3D phase-contrast MR imaging as an alternative to CFD models. One potential advantage of phase-contrast MR imaging is the ability to visualize both the velocity and inflow hemodynamics within and around the aneurysm in vivo. The results showed the highest WSS at the inflow zone of the aneurysms, but they did show a local area in the bleb of one aneurysm and in the dome of the other to have had constant high WSS without temporal variation. These results were consistent with most high WSS theories.

Meckel et al.²⁴ went a step further and examined cardiac-gated 3D phase-contrast MR imaging of 5 aneurysms in vivo and found that the highest aspect ratio (2.2)

had a single inflow jet with multiple vortices. Two small, smooth aneurysms with the smallest aspect ratios (1.1 and 1.3) had single inflow jets and single vortices. Despite the fact that the WSS was underestimated due to the lack of inflow (parent artery) and outflow (efferent arteries) boundary corrections, this study showed that in vivo phase-contrast MR imaging could correlate flow dynamics, aspect ratio, and fundus size in a series of aneurysms. Unfortunately, both CFD and phase-contrast MR imaging techniques currently require a significant amount of image postprocessing and computational power that neither is practical for clinical use at this time.

Limitations

Inherent limitations exist in any attempt to study factors of aneurysm rupture risk. Specifically, most of the previously discussed studies have examined morphological characteristics of ruptured aneurysms in comparison with unruptured aneurysms. Unfortunately, this methodology does not account for the possible changes in morphology that high-risk aneurysms may experience over time, potentially evolving into the gross morphology associated with ruptured aneurysms. Thus, evaluating unruptured aneurysms of any shape or size at only one point in time is foolhardy, because the future evolution of the lesion is unpredictable and likely unknown. Examining a population of unruptured aneurysms over time without treatment, regardless of size or location, monitoring hemodynamics, and the evolution of aneurysmal morphology over time would provide the ultimate natural history study. Unfortunately, such a study will never be completed due to the unacceptable ethical dilemma present with regard to patient safety and previous clinical experience.

In an effort to study ruptured and unruptured aneurysms in the same patients, Hoh,¹⁶ Baumann,³ and Nader-Sepahi²⁶ and their colleagues examined only patients with multiple aneurysms—the vast majority of patients had 1 ruptured aneurysm, and the remainder were unruptured. However, as Weir³⁹ commented in *Stroke*, the ISUIA^{2,42} results are unclear as to whether patients with multiple aneurysms represent a higher risk population. Thus, it remains to be seen if the aneurysms seen in patients with multiple aneurysms behave independently or are part of a systemically increased risk. Most of the other studies used in evaluating the risk of aneurysm rupture and the factors related to such risks use a mixture of patients with single and/or multiple aneurysms indiscriminately. Furthermore, there is a considerable variability in the ratios of patients with ruptured and unruptured lesions. However, Beck⁴ and Sadatomo³⁴ had nearly equal numbers of ruptured and unruptured aneurysms in their reports and the studies by Weir^{40,41} had a majority of ruptured aneurysms.

The literature is rather limited with regard to the evolution of aneurysmal morphology over time. Burns et al.⁶ monitored 165 patients with 191 unruptured aneurysms by using serial MR angiography over a median follow-up period of 47 months. They noted that 10% of patients had aneurysm growth over that time period, during which they documented 1 incident of aneurysm rupture. The

only statistically significant predictor of growth was previous aneurysm size. For aneurysms < 8, between 8 and 12, and ≥ 13 mm, the frequency of enlargement was 6.9, 25, and 83%, respectively. A significant limitation of this study was that a large number of patients were lost to follow-up, and growth and rupture rates remained unknown for these patients.

Matsubara et al.²³ monitored changes in aneurysm morphology in 140 patients with 166 unruptured aneurysms by using serial CT angiography for a mean follow-up of 17.7 months. They observed growth or new development of blebs/daughter sacs in 6.4% of patients (6 aneurysms grew and 4 developed blebs). Statistically significant predictors were aneurysm size and basilar apex bifurcation or internal carotid artery location. Other predictors of growth were patient or family history of SAH, presence of a preexisting bleb, hyperlipidemia, and diabetes. No aneurysm rupture was reported during the duration of the study; however, 7 aneurysms were treated.

For aneurysm growth to occur, it may be assumed that changes may occur in the aneurysm wall itself. Frosen et al.¹² reported on the histological analyses of the wall tissue in 66 clipped aneurysms (24 unruptured and 42 ruptured). They described the following 4 broad categories of aneurysm wall characteristics: 1) endothelialized wall with organized smooth muscle; 2) thickened wall with disorganized smooth muscle; 3) hypocellular wall with myointimal hyperplasia or luminal thrombus; and 4) extremely thin thrombosis-lined hypocellular wall. They observed progressively higher proportions of ruptured aneurysms for each of the categories studied as follows: 42, 55, 64, and 100% respectively. The authors discussed the possibility that these 4 categories may represent a continuum of aneurysm wall degeneration occurring over time.

These studies clearly demonstrate that aneurysms are capable of growing and evolving over time. Nevertheless, the evolution of aneurysm growth and wall characteristics has yet to be shown to be the absolute causative agent of increased rupture risk or simply an incidental alteration in any conclusive way. The observations that patients with existing blebs/daughter sacs may be more likely to develop further blebs and that aneurysm walls undergo progressive remodeling over time both are consistent with theories that lesions with unstable hemodynamic flow patterns ultimately present a higher risk of rupture. Further studies examining the relationship of these characteristics need to be pursued.

Conclusions and Future Considerations

Ultimately, every aneurysm is a unique lesion with an individualized mixture of geometry, size, location, and relationship to its surrounding vasculature. While many surrogates, such as size and location, have long been used to estimate rupture risk, our clinical experience has taught us that sometimes small aneurysms can lead to devastating morbidity and mortality, and large aneurysms can be quite stable. Advanced imaging studies have begun to help elucidate the relationship between the anatomy, morphology, and hemodynamic patterns of unruptured in-

tracranial aneurysms. However, in the absence of practical, clinical applications of advanced imaging techniques, practitioners are left to use their clinical acumen as well as the limited amount of high-quality literature to help determine which management strategy is best for the aneurysms in question.

Currently, the literature suggests that higher risks of rupture are associated with posterior circulation or posterior communicating aneurysms, size > 7 mm, high aspect ratio or bottleneck ratio, irregular surface and daughter sacs, and small parent artery and/or draining vessels.

As imaging technology advances, including fast acquisition MR imaging for hemodynamics, high-spatial resolution for aneurysm wall motion, and low signal detection for molecular imaging, the opportunities to observe the in vivo behavior of unruptured intracranial aneurysms will likely increase. It is not unreasonable to think that the risk of aneurysm rupture will be determined by a multitude of factors, including genetic, comorbidities present, precise configuration of the intracranial vasculature, and the specific anatomical and morphological factors of the lesion itself. It is clear that intracranial aneurysms are not static but dynamic structures and the morphological characteristics assessed at one point in time may not be the same ones assessed at a later time. So, to improve our understanding of how these anatomical and morphological factors relate to rupture risk, we must also examine those same properties over time. But, in the end, it will be a combination of factors beyond just morphological characteristics that determine the rupture risk potential of unruptured intracranial aneurysms.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Manuscript submitted January 15, 2009.

Accepted February 26, 2009.

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