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Radiologic assessment of rupture risk in small (<5 mm) posterior communicating artery aneurysms

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Abstract

Although previous studies have investigated the predictors of posterior communicating artery (PCoA) aneurysm rupture with clinical and radiologic parameters, the accessibility of "small PCoA aneurysms (<5 mm)" has rarely been reported. Here, we designed a study to identify the factors which are thought to be risky and prone to rupture in small PCoA aneurysms (<5 mm).

A total of 114 patients diagnosed with PCoA aneurysm under 5 mm in size on digital subtraction angiography were retrospectively enrolled and divided into ruptured (n=51) and unruptured (n=63) groups. Clinical variables were reviewed, and 10 radiologic parameters were obtained, including maximum diameter, height, width, neck width, aspect ratio, dome-to-neck ratio, bleb formation, size ratio, presence of fetal-type PCoA, and inflow angle. Statistical analyses were conducted to compare the groups (ruptured vs unruptured) and identify the risk factors for rupture.

High rupture rate of small PCoA aneurysm is noted (51/114, 44.7%). In the comparison analysis, parameters of size ratio ($P=.045$), aspect ratio ($P=.001$), and bleb formation ($P=.015$) were significantly different between the 2 groups. In the regression model, the aspect ratio ($P=.045$) and bleb formation ($P=.004$) were significantly associated with the rupture of aneurysm.

In respect of small (<5 mm) PCoA aneurysms of our cohort, morphologic parameters of "bleb formation" and "a high aspect ratio" are present more often in ruptured aneurysms as compared to unruptured aneurysms.

Abbreviations: CT = computed tomography, DSA = digital subtraction angiography, MRA = magnetic resonance angiography, PCoA = posterior communicating artery, UCAS = unruptured cerebral aneurysm study, UIA = unruptured intracranial aneurysm.

Keywords: aneurysm, posterior communicating artery, rupture, small

1. Introduction

According to the recent prospective study for identifying the rupture risk of an unruptured cerebral aneurysm (UCAS), small unruptured intracranial aneurysms (UIAs) under 3 or 4 mm in diameter have a low rupture rate (0.3%–0.45% per year), and thus can be managed with observation.[1] However, clinicians have commonly observed "rupture" of small UIAs that were not indicated for treatment by the UCAS. In literature review, posterior communicating artery (PCoA) aneurysms account for 15% to 25% of all intracranial aneurysms; of the "ruptured PCoA aneurysms," approximately 40% were less than 5 mm in diameter.[2–5] Also, according to the UCAS, as compared with aneurysms in the middle cerebral arteries, those in the posterior and anterior communicating arteries were more likely to rupture (hazard ratio, 1.90 and 2.02, respectively). In addition, with the increase of screening tests using brain magnetic resonance angiography (MRA) or computerized tomographic angiography, the detection of UIA is no longer uncommon (2%–5%).[2,6,7] Physicians can easily encounter patients with small aneurysms less than 5 mm in size in their out-patient clinics.

It is now well understood that the rupture of aneurysms depends on the size and other factors such as the location, shape, or hemodynamic characteristics.[7,8] However, in the clinical settings, the treatment of unruptured aneurysms was mostly based on the size of the aneurysm due to a lack of reliable rupture risk assessment tools in small UIAs.[8] Several efforts have been made; a report based on a scoring system for morphological and clinical findings has been applied and is regarded as effective,[9] and the development of high-resolution vessel-wall MRA has emerged as an important tool for predicting unstable aneurysms.[10,11] However, these studies generally enrolled the small to moderate size aneurysms instead specifying the small aneurysms (<5 mm), the size of which often renders the physicians

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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challenging to treat or observe. Especially, small PCoA aneurysms can be easily treated with endovascular treatment with safety and excellent outcomes;[12,13] "small size of PCoA aneurysm" is no longer a contraindication of treatment considering its dismal outcomes of rupture.[5,6,14]

Although previous studies have attempted to determine the predictors of PCoA aneurysm rupture with clinical, morphologic, and hemodynamic characteristics parameters,[6–8] the accessibility of small PCoA aneurysms (<5 mm) has rarely been reported. Here, we investigated parameters related to the aneurysmal rupture in small PCoA aneurysms (<5 mm) to help determine the treatment decisions.

2. Materials and methods

2.1. Patients

The current study was approved by the Institutional Review Board of the Human Research Center of the institution, and the requirement for informed consent was waived due to the study's retrospective design. We retrospectively reviewed 181 patients diagnosed with PCoA aneurysm on computed tomographic angiograph or MRA at our institution between January 2013 and December 2019. Of 181 patients, 67 who had not undergone conventional rotational digital subtraction angiography (DSA) or had larger aneurysm (>5 mm) were excluded. Finally, we enrolled 114 patients who had PCoA aneurysm on DSA with a maximum aneurysm diameter of less than 5 mm.

Enrolled patients were divided into ruptured (n = 51) and unruptured (n = 63) groups according to the imaging findings. Rupture of PCoA aneurysm was defined when the aneurysm was definitively diagnosed on DSA, and the diffuse subarachnoid hemorrhages were identified on brain computed tomography (CT) scans. In patients with multiple aneurysms, rupture of the PCoA aneurysm was diagnosed by the presence of hematoma around the PCoA on operation findings or the bleeding pattern on CT scans. Unruptured aneurysms of asymptomatic patients were defined by the absence of hemorrhage on CT scans and red blood cells in the cerebrospinal fluid tapping study. The flowchart of the patient enrollment is illustrated in Figure 1.

2.2. Clinical assessment

The baseline characteristics of the patients were obtained by reviewing the medical records, including age, sex, past medical histories (uncontrolled hypertension, diabetes mellitus, hyperlipidemia), familial history of subarachonoid hemorrhage, habitual histories (smoking, alcohol abuse), and medical history of antiplatelet or anticoagulants. The previous symptom of oculomotor nerve palsy and the presence of aneurysms in other locations were also investigated. Uncontrolled hypertension was based on the usual systolic blood pressure of over 140 mm Hg regardless of medication administration. These parameters were based on the previous known associated factors for aneurysmal rupture.[2,3,7,15]

2.3. Radiologic assessment

With the 3-dimensional rotation angiograms, we investigated 10 radiologic parameters currently identified as associated with rupture risk in previous reports (Fig. 2).[4,14,16–18] They are divided into size-related, morphologic and hemodynamic factors according to the characteristics of the parameters:

1. Size-related parameters: maximal diameter, width, height, and neck width,
2. Morphologic parameters: bleb formation, aspect ratio, and dome-to-neck ratio, and
3. Hemodynamic parameters: inflow angle, size ratio, and fetal-type PCoA.

Secondary calculated parameters of aspect ratio, dome-to-neck ratio, and size ratio were presented in Figure 2. Fetal-type PCoA was defined as a PCoA with a diameter similar to or larger than that of the PCoA P2 segment, related to the atrophic P1 segment.[4] The aneurysm neck plane was described as the plane of the external projection of the aneurysm from the intracerebral artery.

2.4. Statistical analysis

Continuous data are expressed as means ± standard deviations, and categorical data are reported as frequencies and percentages.

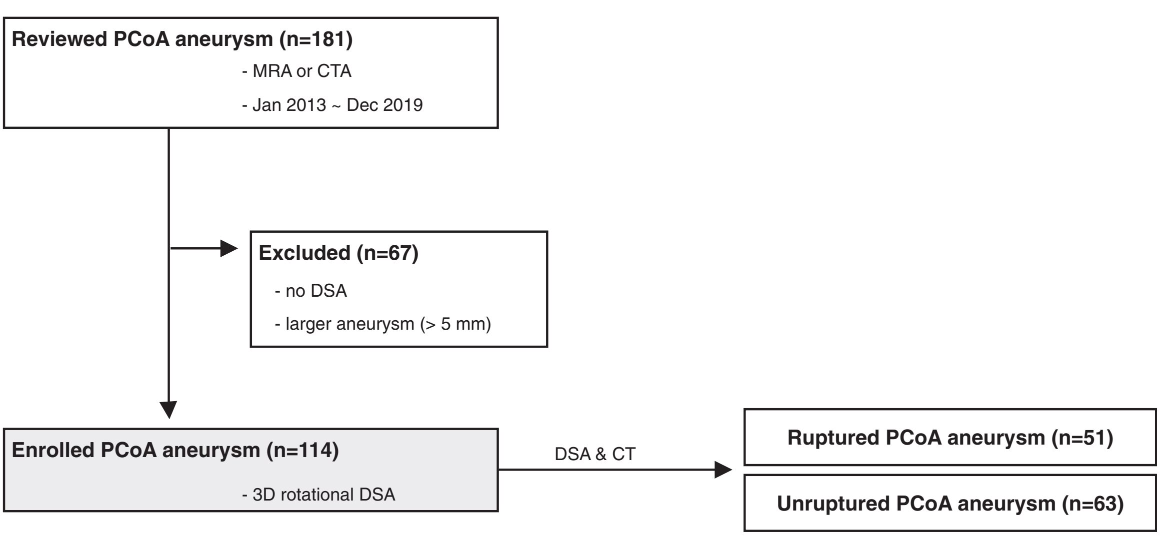


Figure 1. The flowchart of the patient enrollment.

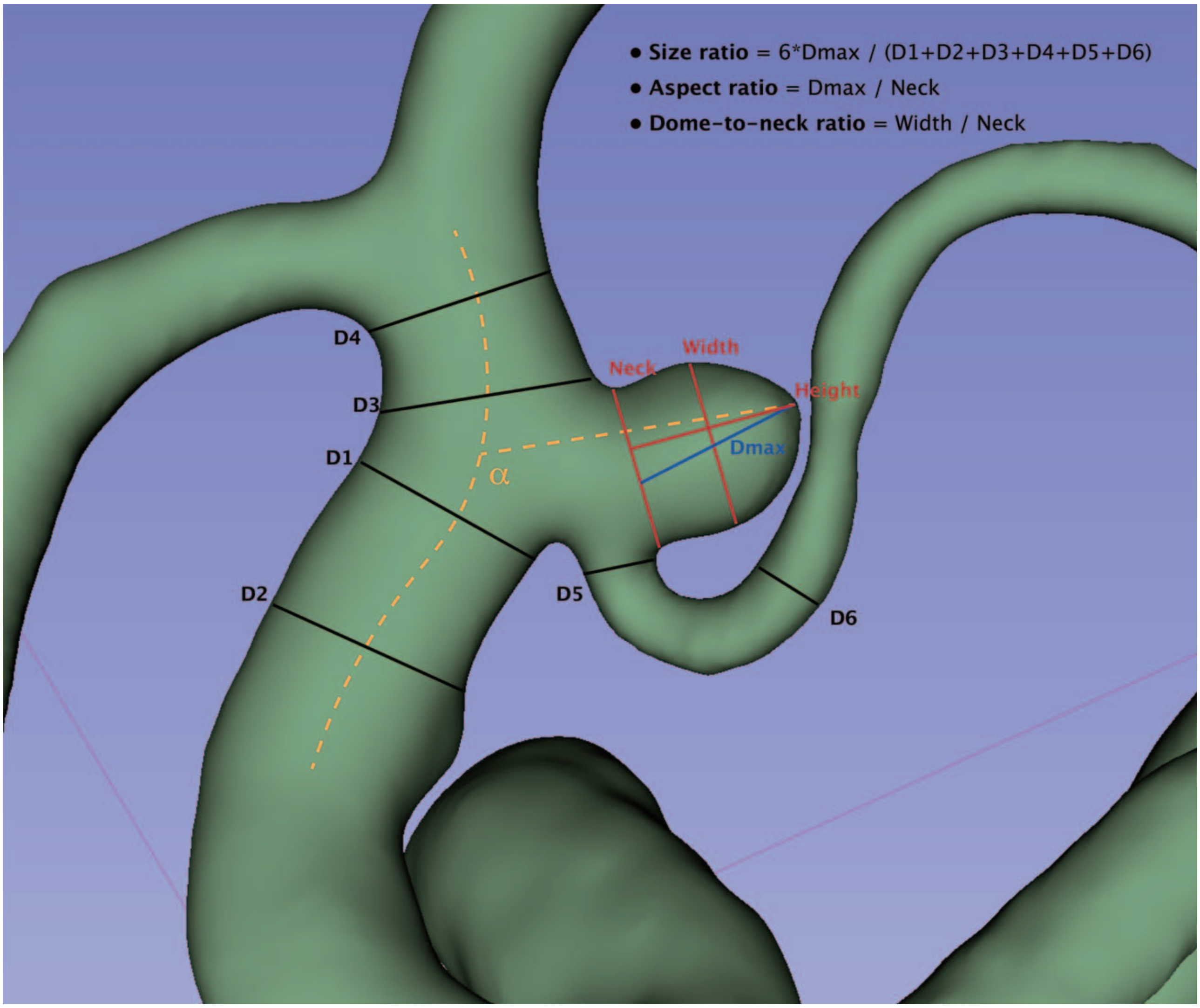


Figure 2. Illustration of the radiologic parameters. Ten radiologic parameters were measured: (1) morphologic parameters: maximal diameter, width, height, neck diameter, bleb formation, dome-to-neck ratio, and bottle neck factor, and (2) hemodynamic parameters: inflow angle, size ratio, and fetal-type PCoA. Size ratio, dome-to-neck ratio, and dome-to-neck ratio were calculated as follows: (1) size ratio = 6 D max / (D1 + D2 + D3 + D4 + D5 +D6), (2) aspect ratio = D max / neck, and (3) dome-to-neck ratio = width / neck. PCoA, posterior communication artery; α, inflow angle.

Comparison analysis was conducted between the groups using independent *t*-test, Chi-Squared test and Fisher exact test. Univariate and multivariate logistic regression analyses were conducted to identify the factors associated with the rupture. Significance was assumed if the probability value was less than 0.05. All statistical analyses were performed using commercially available statistical software (SPSS version 23.0, IBM, Chicago, IL).

3. Results

The baseline characteristics of patients' demographics and clinical data are shown in Table 1. Among the enrolled patients (n=114), 51 patients presented with ruptured PCoA aneurysms (44.7%). No significant differences in baseline characteristics were identified between the groups.

The results of radiologic parameter comparisons are presented in Table 2. In general, the maximal diameter of the enrolled aneurysms was 3.939 mm; 30.7% of bleb formation and 42.1% of fetal-type PCoA were identified. In comparison analysis, parameters of aspect ratio (P=.001), bleb formation (P=.015), and size ratio (P=.045) were significantly different between the groups. No size-related parameters were significant.

Table 3 presents the results of multivariate logistic regression analyses to identify the factors associated with the rupture of a small PCoA aneurysm (<5 mm). Parameters of aspect ratio (P=.045) and bleb formation (P=.004) were identified as independent risk factors in both univariate and multivariate analyses.

4. Discussion

The current study suggested that 2 parameters of "high aspect ratio" and "bleb formation" are highly associated with the rupture of small PCoA aneurysm (<5 mm). Physicians should carefully consider the treatment of patients with these morphologic features (rather than observation) despite their small size (<5 mm).

Table 1

Statistical analysis of the baseline characteristics of the patients.

Clinical variables	Overall Patients (n=114)	Unruptured (n=63)	Ruptured (n=51)	*P* value
General				
Mean age (year-old)	52.85±11.15	55.69±9.89	51.56±11.54	.121
Male	24 (32.4%)	10 (43.5%)	14 (27.5%)	.283
Past medical history				
Uncontrolled hypertension	23 (31.1%)	7 (30.4%)	16 (31.4%)	.580
Diabetes mellitus	10 (13.5%)	4 (17.4%)	6 (11.8%)	.490
Hypercholesterolemia	9 (12.2%)	3 (13.0%)	6 (11.8%)	.575
Habitual history				
Current smoking	18 (24.3%)	4 (17.4%)	14 (27.5%)	.398
Alcohol abuse	18 (24.3%)	5 (21.7%)	13 (25.5%)	.486
Medication history				
Antiplatelet or anticoagulants	14 (18.9%)	7 (30.4%)	7 (13.7%)	.113
Family history				
SAH of family members	5 (6.76%)	1 (4.35%)	4 (7.84%)	.503
Clinical features				
3rd nerve palsy	15 (20.2%)	3 (13.0%)	12 (23.5%)	.365
Multiple aneurysms	17 (22.9%)	8 (34.8%)	9 (17.6%)	.138

SAH = subarachnoid hemorrhage.

Table 2

Statistical analysis of the imaging parameters of the patients.

Radiologic parameters	Overall patients (n=114)	Unruptured (n=63)	Ruptured (n=51)	*P* value
Size-related parameters				
Maximum diameter (mm)	3.939±0.699	3.852±0.860	4.069±0.577	.109
Width (mm)	3.149±0.843	3.257±1.001	3.1±0.767	.437
Height (mm)	3.580±0.741	3.387±0.751	3.667±0.727	.221
Neck width (mm)	2.597±0.648	2.8±0.739	2.506±0.688	.064
Morphologic parameters				
Aspect ratio	1.669±0.423	1.425±0.318	1.778±0.422	.001*
Bleb formation	35 (30.7%)	6 (9.5%)	29 (56.9%)	.015*
Dome-to-neck ratio	1.252±0.369	1.169±0.198	1.289±0.420	.351
Hemodynamic parameters				
Inflow angle (°)	102.42±10.22	102.22±10.32	102.51±10.28	.984
Fetal-type PCoA	48 (42.1%)	28 (44.4%)	20 (39.2%)	.188
Size ratio	1.637±0.368	1.392±0.354	1.703±0.358	.045*

PCoA = posterior communicating artery.
* Significance at $P \leq .05$.

It is generally believed that the size of the aneurysm is a significant parameter for predicting the rupture risk of aneurysms, and small aneurysms were found to have a relatively low risk of rupture.[19–21] However, 85.6% of ruptured aneurysms in some studies were small aneurysms,[8,22] and Jagadeesan et al reported that most of the ruptured PCoA aneurysms were small aneurysms (<7 mm) and very small aneurysms (<3 mm).[2] Even allowing for the large possibility of missed small unruptured PCoA aneurysms (in the out-patient clinic levels),[23] the rupture rate in the current study is much higher than we expected (44.7%). It is now accepted that the size of an aneurysm is no longer an absolute indication of treatment of an intracranial aneurysm.[2,12] Therefore, numerous studies have been conducted to stratify other risk factors for rupture of intracerebral aneurysms, and clinical, hemodynamic, and morphological variables have been investigated.

Table 3

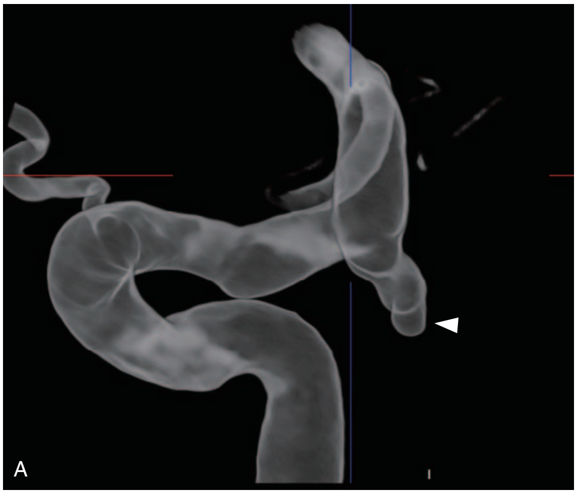
Multivariate logistic regression analysis for risk factors of small (<5 mm) PCoA aneurysm rupture.

Parameters	Odds ratio	95% Confidential index	*P* value
Aspect ratio	10.89	1.050–80.743	.045*
Bleb formation	9.209	2.145–-55.317	.004*

PCoA = posterior communicating artery.
* Significance at $P \leq .05$.

In our study, we collected all the available clinical and radiologic parameters investigated and identified as a risk factor for rupture in the previous studies. From our results, 2 important predictors are verified as significant: bleb formation and high aspect ratio. Representative cases showing small PCoA aneurysms with bleb formation and high aspect ratio are shown in Figure 3.

Bleb formation is a morphological indicator that best reflects the anomalous shape of an aneurysm (Fig. 3A). The result of our study is consistent with that of previous studies, which reported that the aneurysms with more than 1 bleb formation had a higher risk of future rupture.[4,8,22] This can be applied to patients with a relatively small size of PCoA aneurysms (<5 mm). According to recent studies using computational fluid dynamics techniques, a bleb is usually formed at the site at which blood enters the blood vessel wall with a high wall shear stress. Consequently, they induce a low wall shear stress that can affect rupture.[24]



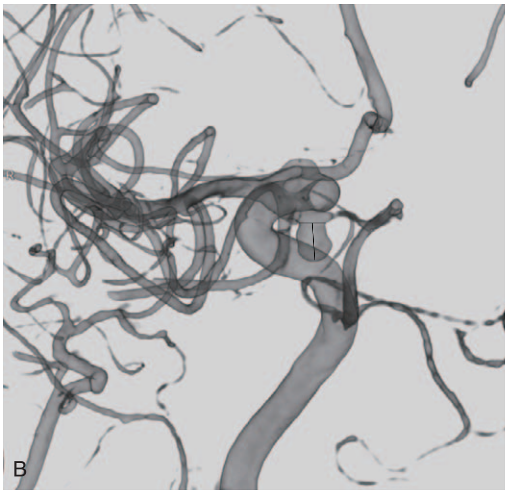


Figure 3. The illustrative images of bleb formation and high dome-to-neck ratio. A. Bleb formation of aneurysm on 3-dimensional reconstructed angiography in the patients with ruptured aneurysm with subarachnoid hemorrhage. The maximal diameter and neck width of the aneurysm was 4.9 mm and 3.2 mm, respectively. Bleb formations were indicated by a white arrowhead. B. Angiogram of a ruptured posterior communicating artery aneurysm with high dome-to-neck ratio. The maximal diameter and neck width of the aneurysm were 4.1 and 2.4 mm, respectively. The dome-to-neck ratio was calculated to be 1.7.

The aspect ratio was also identified as a significant risk factor for rupture in the multivariate logistic regression analysis. Usually, the aneurysm originates in a perpendicular direction from the parent artery; a high aspect ratio (D max/neck) means the "tall or tubular" morphology of the aneurysm, as illustrated in Figure 3B. In the previous reports, the aspect ratio is an independent risk factor for rupture, and tubular aneurysms are more likely to rupture than short mushroom-shaped ones.[4,6,15,25] Hemodynamically, as the intracranial aneurysm enlarges, the blood flow velocity becomes slower within the intracranial aneurysm, reducing the wall shear stress and making the intracranial aneurysm prone to rupture. Since the aneurysm area is proportional to the volume of blood contained by the aneurysm per unit of time, the area of the parent artery in the neck is proportional to the aneurysm blood flow per unit of time provided by the parent artery via the aneurysm neck.[5,18] Therefore, the narrow neck and high aspect ratio is associated with high volume status per unit in the aneurysm and is regarded as a useful factor for rupture prediction, which is consistent with our results.

In our results, the clinical parameters of the ruptured and unruptured groups have no significant differences. In the literature review, clinical features have been recognized as important factors affecting the pathophysiology of aneurysms, including their initiation, growth, and rupture.[6,15,26,27] Because of the small number of patients, we failed to identify the significant differences in the clinical features.

In addition, other radiologic parameters associated with the size of an aneurysm (maximal diameter, width, height, and neck width) were not significantly associated with rupture. This contrast with previous results that the size of the intracranial aneurysm was significantly correlated with their rupture status.[6,28,29] The differences might occur due to the special enrollment of our study (PCoA aneurysm in size under 5 mm). According to our results on specific conditions, the rupture of aneurysms has less correlation with the size. However, it is significantly affected by other morphologic factors (bleb formation or high aspect ratio).

Currently, hemodynamics is believed to play an important role in the growth and rupture of intracerebral aneurysms. The inflow angle and fetal-type PCoA are important factors affecting the bloodstream toward the aneurysms.[17,21] The velocity, flow rate, and volume of blood flow can largely affect the aneurysmal wall hemodynamics closely related to the rupture. Also, the size ratio is used to calculate the diameter of the local cerebral artery to assess the relationship between aneurysm size and geometry;[3,4,25] in aneurysms with a higher size ratio, more complex flow, multiple vortices, and lower aneurysmal wall shear were observed. Unfortunately, we failed to identify the meaningful hemodynamic parameters in the current design of the study. However, the association between the hemodynamic parameters and the rupture of small PCoA aneurysms could not be determined because aneurysms' hemodynamics are much more complex than anticipated. We were limited to investigating the 3 parameters that can be obtained by the 3-dimensional rotational angiograms. A recent advanced technique, computational fluid dynamics, might ascertain the local hemodynamic factors such as wall shear stress or oscillatory shear index, which directly affect the wall of the aneurysm.

4.1. Study limitations

There are several limitations to the present study. First, there may be errors in measuring radiologic factors because the shape of the blood vessels is not constant, as the aneurysms were too small. Second, the conclusion cannot be generalized because of the retrospectively designed nature: the morphologic parameters implying the high rupture risk should be regarded as "references." Third, as mentioned in the discussion section, the advanced hemodynamics parameters such as wall shear stress are not investigated. A radiologic and hemodynamic study with a large patient cohort of small PCoA aneurysms of which a significant percentage are ruptured is warranted.

5. Conclusion

In respect to small (<5 mm) PCoA aneurysms of our cohort, morphologic parameters of "bleb formation" and "a high aspect ratio" are present more often in ruptured aneurysms compared to unruptured aneurysms.

Author contributions

Conceptualization: Jang Hun Kim, Jong-Il Choi, Dong-Jun Lim.
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Validation: Jang Hun Kim, Dong-Jun Lim.
Visualization: Jang Hun Kim.
Writing – original draft: Jang Hun Kim.
Writing – review & editing: Jong-Il Choi.

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