Morphological Differences between Ruptured and Unruptured Basilar Bifurcation Aneurysms

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Abstract

Background Aspect ratio (AP), daughter artery ratio (DA), and lateral angle ratio (LA) have been reported in middle cerebral artery bifurcation aneurysms to correlate with rupture status.

Objective To study the differences in AP, DA, LA, and aneurysm orientation between ruptured and unruptured basilar bifurcation aneurysms.

Methods Three-dimensional (3D) angiograms of patients with basilar bifurcation aneurysms were analyzed for AP, DA, and LA. Aneurysm projection was classified as type A if the long axis of aneurysm was along basilar artery and type-B if otherwise.

Results Thirty-one ruptured and 17 unruptured aneurysms were analyzed. The APs were significantly different ($p = 0.008$), 2.63 ± 1.1 for ruptured aneurysms and 1.7 ± 0.55 for unruptured aneurysms. $AP \geq 1.9$ correlated with rupture status with 68% sensitivity and 70% specificity. Type-A configuration was significantly associated with ruptured aneurysms with an odds ratio (OR) of 5.9. LAs were 0.9 ± 0.4 and 1.4 ± 0.8 for ruptured and unruptured aneurysms, respectively, and the difference tended to be significant ($p = 0.56$). DAs were 1.25 ± 0.22 and 1.21 ± 0.19 for ruptured and unruptured aneurysms without any statistical difference.

Conclusion $AP > 1.9$, type-A configuration, and lower LA is associated with ruptured basilar bifurcation aneurysms. DA did not differ between ruptured and unruptured aneurysms

Keywords

- rupture
- aspect ratio
- lateral angle ratio
- daughter artery ratio
- aneurysm

Introduction

Understanding the hemodynamic disturbances that lead to formation and subsequent rupture of an intracranial aneurysm is important and has implications in their management. The idea behind understanding the blood flow hemodynamics is to help develop strategies either to prevent the development or identify aneurysms with a high risk of rupture to reduce the morbidity and mortality associated with subarachnoid hemorrhage. Also, it is not known why posterior circulation aneurysms have a higher rate of rupture than anterior circulation aneurysms.¹

Bifurcation angle and daughter artery ratio (DA) have been described for bifurcation aneurysms to affect wall shear stress

(WSS), energy loss (EL), and low shear stress area (LSA). WSS is a flow-induced frictional force exerted by the blood. A high WSS has been shown to have a role in the formation of an aneurysm, whereas low WSS may contribute to the growth and rupture of aneurysm.² EL at the neck is defined as the difference between energy transport to the aneurysm by inflow of blood and EL by outflow of blood. Ruptured aneurysms have been shown to have about five times higher an EL than unruptured aneurysms.³ LSA has been shown to identify the region of the aneurysm that is exposed to abnormally low WSS. In a computational fluid hemodynamics study, the authors reported that the highest rate of inflow and EL occur at a DA of 1, when the diameters of both the branches are

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similar and symmetric flow distribution is observed between the branches.⁴ In another study involving middle cerebral artery bifurcation aneurysms, a higher aspect ratio and a lower DA was observed in ruptured compared with unruptured aneurysms.⁵

In the present study, we attempt to analyze the aspect ratio, direction of aneurysm projection, lateral angle ratio (LA), and DA of patients with basilar bifurcation aneurysms and correlate with their rupture status.

Methods

This is a retrospective study of 48 patients with basilar bifurcation aneurysms seen at our hospital between 2009 and 2012. Thirty-one aneurysms were ruptured and 17 were unruptured. The case records of these patients were examined for gender, age, and rupture status of aneurysm at presentation. All patients had three-dimensional (3D) angiograms done at presentation. Anteroposterior views of the basilar artery and its branches of all the patients were analyzed for the following parameters: (1) height of the aneurysm, (2) neck width, (3) bifurcation angle between the basilar artery and each of its branches, and (4) diameter of the branches (PCAs). Aspect ratio (AP) was calculated by dividing the height of the aneurysm with neck width and daughter artery ratio (DA) was calculated by dividing the diameter of the larger branch with that of the smaller branch. LA was calculated by dividing the angle between the basilar artery and the larger branch with the basilar artery and the smaller branch. Aneurysms were classified as type A when the maximum height of the aneurysm was in line with the terminal basilar artery and as type B when it was at an angle with the terminal basilar artery. The age, gender, height of the aneurysm, neck width, AP, DA, and LA were compared between ruptured and unruptured aneurysms.

Statistical Analysis

Statistical analysis was performed using the SPSS 20 (IBM SPSS Inc., Armonk, New York, USA) and Open Epi online calculators (provided by the Centers for Disease Control and Prevention, Atlanta, Georgia, USA). Gender distribution between the two groups was analyzed using chi-square test. Age, height, neck width, AP, DA, and LA were compared between the two groups using Mann-Whitney test. Receiving operating curve (ROC) analysis was plotted for the variables and area under curve and standard error were calculated with confidence limits of 95%. Type of aneurysm projection was correlated with ruptured status using the chi-square test and odds ratio (OR) calculated.

Results

This study included 31 patients with ruptured and 17 patients with unruptured basilar bifurcation aneurysms. There were 35 females (72.9%) and 13 males (17%), with a mean age of 53.15 ± 13.2 years. The height of aneurysms ranged from 2 mm to 32.61 mm (mean height $11.5 \text{ mm} \pm 8.6 \text{ mm}$). The height of ruptured aneurysms ranged from 3.5 mm to

32.6 mm (mean $12.36 \pm 9.1 \text{ mm}$) and that of unruptured aneurysms ranged from 2 mm to 31.85 mm (mean $6.05 \pm 6.3 \text{ mm}$). Ruptured aneurysms tended to be larger than unruptured aneurysms, though the difference was not significant ($p = 0.412$).

AP was 2.63 ± 1.1 for ruptured aneurysms and 1.7 ± 0.55 for unruptured aneurysms. The difference was highly significant ($p = 0.008$). Further, patients were classified into two groups, based on ROC analysis and calculating the sensitivity and (1-specificity): one with $AP < 1.9$ and another with $AP \geq 1.9$, and these groups were analyzed for their rupture status. There were 21 (67.7%) ruptured aneurysms and 5 (29.4%) unruptured aneurysms with AP ratio > 1.9 . Chi-square test revealed an OR of 6.3 ($p = 0.016$). The risk of patients with $AP \geq 1.9$ to have a ruptured aneurysm was 80.77% and the risk ratio was 1.77 (95% confidence interval [CI] 61.67 to 91.95). Ruptured aneurysms had a lower mean LA ratio of 0.9 ± 0.4 than unruptured aneurysms, which had a mean ratio of 1.4 ± 0.8 . However, the difference was not significant ($p = 0.56$). This indicates that in ruptured aneurysms, the larger branch subtended a smaller angle with the parent artery than the smaller branch. DAs were similar for both the groups: 1.25 ± 0.22 for ruptured aneurysms and 1.21 ± 0.19 for unruptured aneurysms. The difference did not reach significance ($p = 0.6$).

There were 20 (64.5%) ruptured aneurysms with type-A configuration and only 4 (23.5%) unruptured aneurysm with the same configuration. Chi-square test revealed an OR of 5.9 (95% confidence limits 1.546 to 22.58) and risk ratio of 2.74 (95% confidence limits 1.12 to 6.7) for patients with type-A configuration to have a ruptured aneurysm ($p = 0.008$) (►Figs. 1, 2, 3). ►Table 1 lists the various parameters of aneurysms.

ROC Analysis

ROC analysis was performed for aspect ratios of ruptured and unruptured aneurysms and a curve was plotted with 1-specificity along the x-axis and sensitivity along the y-axis. A cutoff value of 1.9 was arrived at with a sensitivity of 68% and

Fig. 1 Ruptured aneurysms tended to have greater maximal height, though the difference was not significant ($p = 0.412$).

Fig. 2 Ruptured aneurysms were observed to have a higher aspect ratio ($p = 0.008$), type A configuration of aneurysm ($p = 0.008$), and smaller lateral angle ratio ($p = 0.56$). Aneurysms with aspect ratio > 1.9 were more frequently presented with rupture (odds ratio 6.3, $p = 0.016$).

specificity of 71%. Twenty-two (70.9%) ruptured aneurysms had $AP > 1.9$, whereas only 5 (29.4%) unruptured aneurysms had values > 1.9 . The power of the study was 81.1% with 95% CI ($p = 0.008$). When 99% CI (0.55 to 0.92) was considered, the difference was still significant ($p = 0.008$). ▶ **Fig. 1** shows the ROC for AP of ruptured and unruptured aneurysms (▶ **Figs. 4, 5**).

Discussion

Morphological differences between ruptured and unruptured aneurysms have been studied extensively. Several morphological and hemodynamic parameters have been proposed to identify aneurysms with greater risk of rupture. Important among these are the size of aneurysm, AP, size ratio, and bottleneck factor. Sidewall aneurysms (originating from only one parent vessel or from the origin of a branch that is much smaller than the parent vessel) and bifurcation aneurysms

have been reported to have different morphology and hemodynamic characteristics. Computational fluid dynamics analysis has shown striking differences between sidewall and bifurcation aneurysms. Increasing inflow angle in sidewall aneurysms has been shown to increase flow, WSS, and flow velocity inside the dome of the aneurysm, whereas a higher inflow angle decreases these parameters in bifurcation aneurysms.⁶ Furthermore, bifurcation aneurysms seem to be less variable in their AP, size ratio, and height/width ratio than the sidewall aneurysms. Thus, the prediction of rupture in bifurcation aneurysms is more challenging than in the sidewall aneurysms.

Among the bifurcation aneurysms, those arising at the basilar bifurcation have a higher prevalence of rupture than internal carotid artery (ICA) bifurcation and middle cerebral artery (MCA) bifurcation aneurysms. In a systematic review of literature, basilar bifurcation aneurysms were more often found and observed to rupture more commonly than ICA bifurcation aneurysms.⁷ Various studies attempted to explain this difference by the difference in embryological development of basilar artery and ICA and MCA, pulsatile blood flow, structural differences in the arterial wall and aneurysm wall, and effects of perianeurysmal environment during growth of aneurysms.⁷

Blood flow pattern, EL, and WSS in an aneurysm have been shown to influence the growth and risk of rupture of an aneurysm.⁸ Farnoush et al studied the amount of blood flow entering the aneurysm with increasing differences in the diameter of branches. The authors reported that increasing the DA ratio from 1 to 2 decreased the blood flow into the aneurysm by up to 38%.⁴ Similarly Sadatomo et al also observed lower DA ratios in ruptured aneurysms, indicating that the more the difference in diameters of branches, the higher the risk of rupture. However, in our study of basilar bifurcation aneurysms, we did not find any difference in DA ratios between ruptured and unruptured aneurysms. Although hypoplasia of one of the branches of basilar artery is more common than that of ICA branches (A1), both P1 branches more commonly have similar diameters than the ICA branches (ACA and MCA).⁹ It is possible that the DA ratio does not play a significant role in rupture of basilar bifurcation aneurysms. On the other hand, frequent occurrence of hypoplasia of one of the P1s may account for a higher prevalence of basilar bifurcation aneurysms when compared with ICA bifurcation aneurysms.

We have observed that aneurysms with AP ratio ≥ 1.9 were 6.3 times more likely to be ruptured than those with AP ratio < 1.9 . Similar findings were observed by Sadatomo et al in MCA bifurcation aneurysms⁵ and Ujiie et al,¹⁰ though the cutoff in these two studies was 1.8 and 1.6, respectively. AP has come to be one of the most important parameters to associate an aneurysm with rupture.

Interestingly, we found that ruptured aneurysms had lower LAs than unruptured aneurysms, though the difference did not reach significance ($p = 0.56$). This indicates that the symmetry of angle subtended by both the branches with the parent artery has more influence on blood flow hemodynamics of rupture of basilar bifurcation aneurysms than the

Fig. 3 Mean daughter artery ratio was 1.25 ± 0.22 and 1.21 ± 0.19 for ruptured and unruptured aneurysms ($p = 0.6$).

Table 1 Lists the Aneurysm Parameters

Serial number	Rupture status	Aspect ratio	Lateral angle ratio	Daughter artery ratio	Type of projection
1	Ruptured	2.39	1.43	1.33	A
2	Unruptured	3.06	2.66	1.28	B
3	Unruptured	1.93	0.42	1.1	B
4	Unruptured	1.89	2.78	1.29	B
5	Unruptured	1.42	0.88	1	B
6	Ruptured	1.69	0.49	1.23	B
7	Ruptured	6.38	0.59	1.18	B
8	Ruptured	2.76	2.29	1.2	B
9	Ruptured	3.16	0.71	1.07	A
10	Ruptured	1.17	0.63	1.17	A
11	Ruptured	1.62	1.13	1.33	B
12	Unruptured	1.86	1.14	1.16	B
13	Unruptured	1.75	0.55	1.1	B
14	Unruptured	1.85	1.22	1.34	B
15	Ruptured	1.80	1	1.33	A
16	Unruptured	1.64	0.71	1.08	B
17	Ruptured	3.69	1.1	1.21	A
18	Ruptured	2.32	0.77	1.5	B
19	Ruptured	4.62	0.68	1.4	A
20	Ruptured	1.77	1.37	1.28	B
21	Unruptured	1.48	1.07	1.3	A
22	Ruptured	3.36	0.18	1.26	A
23	Ruptured	3.00	0.71	1.01	A
24	Unruptured	1.15	2.78	1.27	A
25	Ruptured	3.70	1.54	1.07	A
26	Ruptured	2.78	0.72	1.48	A
27	Unruptured	1.43	2.79	1.25	B
28	Ruptured	1.70	0.65	1.44	B
29	Unruptured	1.05	1.3	1.14	B
30	Ruptured	3.14	0.8	1.5	A
31	Ruptured	2.30	0.66	1.17	A
32	Unruptured	1.12	1.46	1.04	B
33	Ruptured	2.04	1.43	1.16	B
34	Unruptured	2.63	1.12	1.23	B
35	Ruptured	1.71	1	1.02	A
36	Ruptured	2.94	0.82	1.08	B
37	Ruptured	2.34	0.97	1.18	B
38	Ruptured	5.12	1	1.2	A
39	Ruptured	2.20	0.57	1.12	B
40	Ruptured	1.26	0.94	2.21	A
41	Ruptured	3.17	1.34	1.2	A
42	Ruptured	1.25	1.62	1.19	A
43	Unruptured	2.43	0.26	1.87	B

Table 1 (Continued)

Serial number	Rupture status	Aspect ratio	Lateral angle ratio	Daughter artery ratio	Type of projection
44	Ruptured	3.00	0.84	1.01	A
45	Unruptured	1.50	1.03	1.04	A
46	Unruptured	2.33	1.75	1.18	A
47	Ruptured	2.17	0.72	1	A
48	Ruptured	1.17	0.73	1.27	A

Note: A, long axis of aneurysm in line with basilar artery; B, long axis of aneurysm at an angle with basilar artery.

Fig. 4 The area under receiving operating curve for aspect ratio is 0.73 (95% confidence interval [CI] 0.59 to 0.87) (99% CI 0.55 to 0.92). The cutoff value for aspect ratio is 1.9 with 68% sensitivity and 71% specificity.

difference in diameters of the branches. We further observed that aneurysms that have their long axis in line with the basilar artery (type A) are more likely to be ruptured than those directed at an angle (type B). This may be explained

because of the increased blood flow into the aneurysms and consequently more EL.

We understand that our study, being a retrospective, has some limitations. Nevertheless, it adds to the current understanding of factors contributing to aneurysmal rupture. A prospective study measuring hemodynamic and morphological parameters will add to the existing knowledge.

Conclusion

AP > 1.9, type-A configuration, and small LA are associated with rupture of basilar bifurcation aneurysm. DA does not differ between ruptured and unruptured aneurysms. Morphological characteristics of basilar bifurcation aneurysms differ from that of other bifurcation aneurysms reported in literature.

Disclosure

The authors have not received funding from any organization in relation to the study and preparation of manuscript.

Conflict of Interest

Nil.

Fig. 5 (A) Type A configuration of aneurysm in which maximum height of aneurysm is in line with the axis of terminal basilar artery. (B) Type B configuration in which maximum height of the aneurysm is at an angle to the axis of terminal basilar artery.

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