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Review

Association of computed tomography–based morphological parameters with rupture status in middle cerebral artery aneurysms: a retrospective case series and literature review

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Abstract: Unruptured intracranial aneurysms are increasingly diagnosed due to the widespread use of noninvasive imaging modalities in clinical practice. Hemodynamic stress is considered an important factor in aneurysm formation and rupture, and both aneurysm geometry and surrounding vascular morphology have been reported to be associated with rupture status in the literature. Middle cerebral artery (MCA) aneurysms account for approximately 35% of intracranial aneurysms and are frequently implicated in subarachnoid hemorrhage. In this retrospective single-center case series, we evaluated computed tomography–based morphological parameters in eight patients with MCA aneurysms (four ruptured and four unruptured). Descriptive comparisons were performed to explore potential differences between groups. Additionally, a structured literature review was conducted to contextualize our findings within previously reported morphological factors associated with rupture status. Although several size- and angle-related parameters demonstrated directional differences between ruptured and unruptured aneurysms, no statistically significant associations were identified. Given the limited sample size, the findings should be interpreted as exploratory and hypothesis-generating. Accurate assessment of rupture risk remains a major clinical challenge. Larger prospective, multi-center studies integrating advanced imaging analysis are required to validate morphological markers and to better inform individualized treatment decisions.

Keywords: aneurysm, middle cerebral artery, morphology, risk factor

1. Introduction

Cerebral aneurysms are aquired focal outpouchings (either saccular or fusiform) of an intracranial artery wall [1]. It has been reported that approximately 3% of the world population harbours at least one unruptured intracranial aneurysm and these lesions are diagnosed incidentally with a growing frequency, due to the increasing availability of cerebral imaging [2], [3]. The annual incidence of aneurysm rupture is estimated at 9 per 100000 patients [4]. Although rare, aneurysmal subarrachnoid hemorrhage (aSAH) is a catastrophic ocurrence. Approximately one third of the patients presenting with a ruptured aneurysm die in the following days to weeks after the event [5], and only about 5% of the survivors are able to go back to their pre-rupture activities [6]. Nevertheless, there are alo singificant risks associated with prophylactic treatment of incidentally diagnosed intracranial aneurysms [7]–[10]. Middle cerebral artery aneurysms (MCA) are accounting for 14.4-43% of all cerebral aneurysms, with 80-85% occuring at the bifurcation, this location being the most common for unruptured intracranial aneurysms [11], [12]. The risk factors for aneurysm rupture include aneurysm- and parient-related factors. The established patient-related risk factors include age and female sex, family history of aneurysmal subarrachnoid hemorrhage (SAH), arterial hypertension, polycystic kidney disease, drugs or alcohol consumption and smoking [13]–[15]. It has been reported that the shape of cerebral aneurysm influences its growth and rupture by affecting the intra-aneurysmal hemodynamics and the wall shear stress [16]–[18]. In this study, we aim to examine the contribution of vascular morphology to aneurysm rupture in a location-specific manner.

2. Methods

This retrospective, single-center observational study included 8 consecutive patients diagnosed with middle cerebral artery (MCA) aneurysms at Bagdasar-Arseni Clinical Emergency Hospital between 2013 and 2023. Both ruptured and unruptured aneurysms were included.

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Ethics Committee of Bagdasar-Arseni Clinical Emergency Hospital (10090/27.02.2026). Given the retrospective design and the use of anonymized imaging and clinical data, the requirement for informed patient consent was waived.

We evaluated morphological parameters previously reported in the literature to be associated with aneurysm formation, growth, or rupture. Three-dimensional vascular reconstructions were performed using 3D Slicer (an open-source medical image computing platform) [19,20].

Diameters and vessel-to-vessel angles of the main arteries surrounding the MCA were measured, including the parent artery and daughter branches. Vessel diameter was calculated as the average between the diameter measured at the aneurysm neck and the diameter measured at a distance of 1.5 times the neck width from the aneurysm neck.

In addition to basic geometric measurements, two supplementary morphological indices were calculated: the bottleneck factor (aneurysm width-to-neck ratio) and the height–width ratio [21].

A literature review was performed by searching the PubMed database using combinations of the following keywords: "middle cerebral artery," "unruptured," "cerebral," "intracranial," "aneurysm," "rupture," and "risk." Inclusion criteria were: full-text articles written in English comparing morphological or anatomical parameters between ruptured and unruptured MCA aneurysms, or between stable and growing aneurysms. Exclusion criteria included: animal studies, mycotic or fusiform aneurysms, aneurysms located outside the MCA territory, studies evaluating post-treatment parameters (e.g., intraoperative findings or surgical tissue samples), and narrative literature reviews.

Due to the very small sample size, statistical analysis was considered exploratory and descriptive. The study is severely underpowered for multivariable modeling or for detecting anything other than large effect sizes. Therefore, results are presented as descriptive comparisons and exploratory analyses rather than as confirmatory or predictive findings.

3. Results

The study cohort consisted of 8 patients, each harboring a single MCA aneurysm. Four aneurysms were ruptured at presentation and four were incidentally diagnosed. Mean age at diagnosis was 52 years. A marked female predominance was observed.

Figure 1 illustrates the measurements performed for each aneurysm. In figure 2, we show a reconstructed aneurysm using 3D-slicer.

Figure 1. Aneurysm measurements.

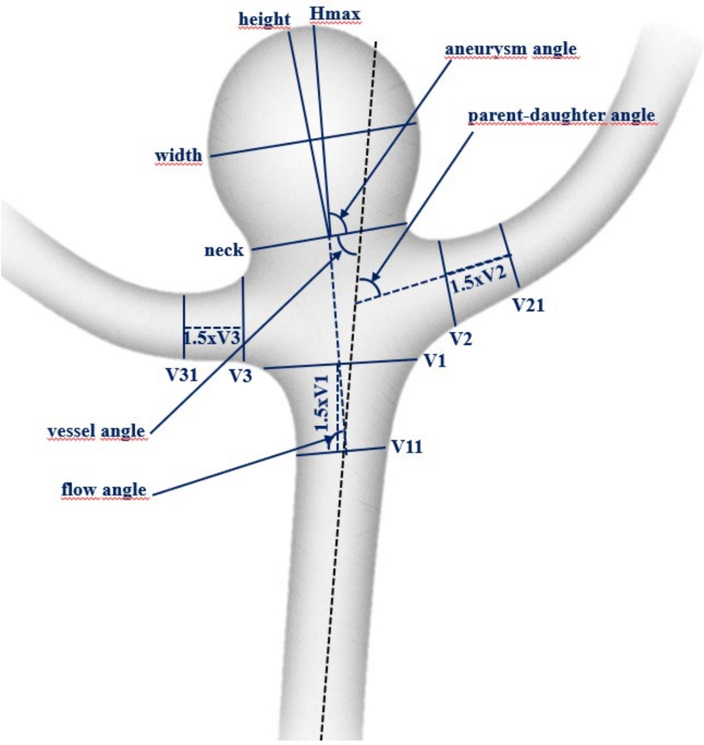
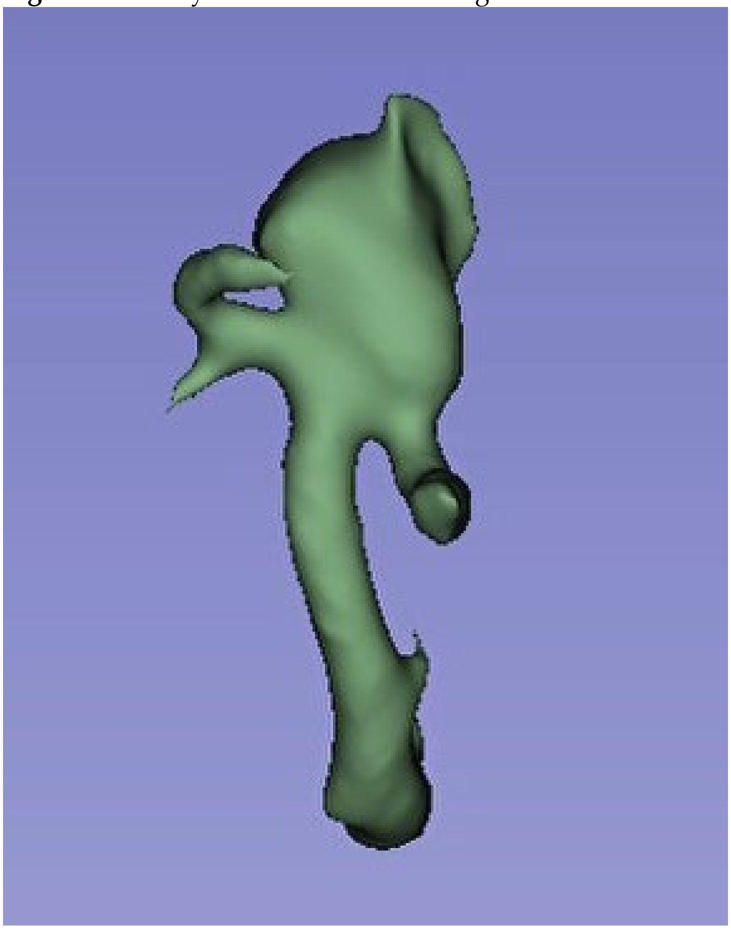


Figure 2. Aneurysm reconstruction using 3D-slicer.



Descriptive comparisons of morphological parameters between ruptured and unruptured aneurysms are presented in Table 1.

Table 1. Analysis of morphological parameters of MCA aneurysms

Parameter	Unruptured (n=4) Mean	Ruptured (n=4) Mean	p value
Perpendicular height (mm)	3.97	7.73	0.396
Maximal aneurysm height (mm)	4.43	7.73	0.615
Neck width (mm)	2.48	4.72	0.247
Dome width (mm)	3.60	6.34	0.454
Bottleneck ratio	1.98	1.28	0.381
Parent artery diameter (mm)	2.41	2.19	0.216
Parent-to-daughter angle (°)	126.30	87.92	0.945
Daughter-to-daughter branch angle (°)	38.34	60.35	0.526

Statistical comparisons were performed using the Mann–Whitney U test due to small sample size and non-normal distribution.

Size-related parameters were numerically higher in ruptured aneurysms. Mean dome width was 6.34 mm in ruptured aneurysms compared to 3.60 mm in unruptured aneurysms. Mean neck width was 4.72 mm versus 2.48 mm, respectively. Maximal aneurysm height was 7.73 mm in ruptured aneurysms and 4.43 mm in unruptured aneurysms. Similarly, perpendicular height averaged 7.73 mm in ruptured cases versus 3.97 mm in unruptured cases.

The bottleneck factor was lower in ruptured aneurysms (1.28) compared to unruptured aneurysms (1.98), while the height–width ratio showed minimal difference between groups (1.15 vs. 1.14).

Parent artery diameter was slightly smaller in ruptured aneurysms (2.19 mm) compared to unruptured aneurysms (2.41 mm).

Angular parameters showed notable directional differences. The mean parent-to-daughter angle was lower in ruptured aneurysms (87.92°) compared to unruptured aneurysms (126.30°). Conversely, the mean flow angle was higher in ruptured aneurysms (60.35°) compared to unruptured aneurysms (38.34°).

However, none of the evaluated parameters reached statistical significance. Given the very small sample size, these findings should be interpreted as descriptive trends rather than evidence of independent associations.

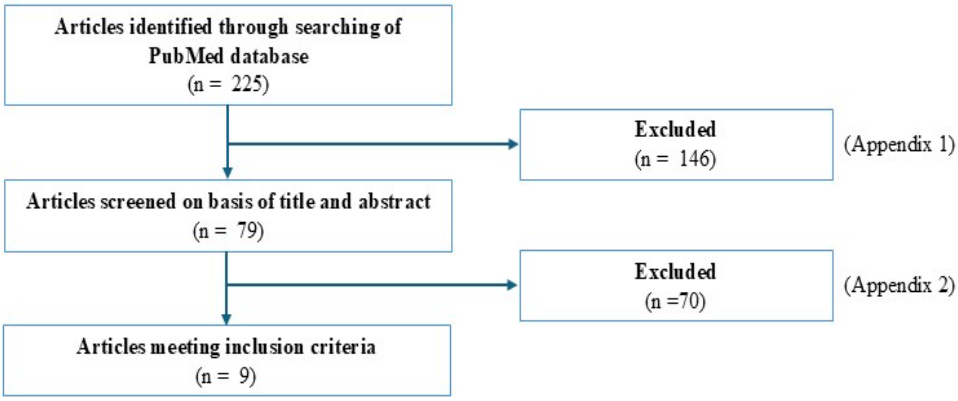
4. Discussion

The decision whether to treat or observe unruptured cerebral aneurysms remains challenging, requiring interpreting of an extremely large amount of literature reports regarding risk factors and applying it to a specific aneurysm of a specfic patient. Although remarkable efforts have been made to develop tools to guide decision making in the clinical settings, a validated instrument broadly accepted remains elusive [22]. We performed a structured literature search of the PubMed database to identify morphological factors reported to be associated with rupture status in MCA aneurysms. By researching PubMed using different combinations of ″middle cerebral artery″, ″unruptured″, ″cerebral″, ″intracranial″, ″aneurysm″, ″rupture″, ″risk″ we first retrieved 225 articles analyzing morphological factors that seem to influence rupture risk in unruptured MCA aneurysms.

Figure 3 illustrates the literature search according to PRISMA guidelines [23].

Nine articles met the inclusion criteria and were further included in the literature review.

Figure 3. Flow chart of literature search according to PRISMA guidelines [23].



Appendix 1 – Preliminary inclusion criteria:

- Abstract and full text available
- Article written in english

Appendix 2

Inclusion criteria:

- Comparing potential risk factors in either unruptured vs. ruptured aneurysms, stable vs. growing aneurysms

Exclusion criteria:

- Animal models
- Analyzing mycotic or fusiform aneurysms
- Analyzinc aneurysms located on arteries other than MCA
- Analyzing factors that can only be assessed after treatment (eg. tissue sam-

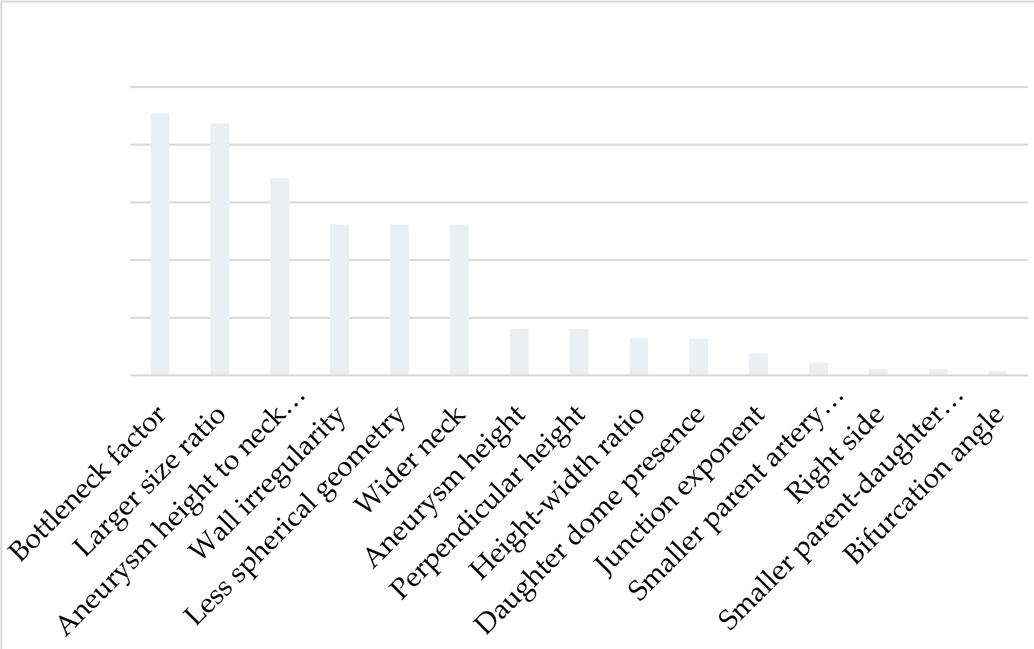
The variables found tinfluence rupture risk are listed in Table 2.

Table 2. Morphological variables associated with rupture.

Reference	Can, 2015[24]	Chen, 2020[25]	Elsharkawy, 2013[11]	Huang, 2020[26]	Kaspera, 2022[27]	Liu, 2021[28]	Matsukawa, 2018[29]	Song, 2017[30]	Zhang, 2019[31]
Number of patients	110	317	1309	54	190	403	286	36	561
Smaller parent artery diameter	p < 0.001	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Larger aspect ratio	N/A	p =0.001	p <0.001	N/A	N/A	p <0.001	N/A	N/A	p <0.001
Daughter dome presence	N/A	p =0.002	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wall irregularity	N/A	N/A	p <0.001	N/A	N/A	N/A	N/A	N/A	N/A
Less spherical geometry	N/A	N/A	p <0.001	N/A	N/A	N/A	N/A	N/A	N/A
Bottleneck factor	N/A	N/A	p <0.001	N/A	N/A	p <0.001	N/A	N/A	p <0.001
Aneurysm height to neck width ratio	N/A	N/A	p <0.001	N/A	N/A	p <0.001	N/A	N/A	N/A
Right side	N/A	N/A	N/A	p <0.001	N/A	N/A	NA	N/A	N/A
Smaller parent-daughter angles	N/A	N/A	N/A	p <0.001	N/A	N/A	N/A	N/A	N/A
Bifurcation angle	p=0. 04	N/A	N/A	N/A	N/A	N/A	N/A	p <0.001	N/A
Junction exponent	N/A	N/A	N/A	N/A	p <0.001	N/A	N/A	N/A	N/A
Aneurysm height	N/A	N/A	N/A	N/A	N/A	p <0.001	N/A	N/A	N/A
Perpendicular height	N/A	N/A	N/A	N/A	N/A	p <0.001	N/A	N/A	N/A
Height-width ratio	N/A	N/A	N/A	N/A	N/A	N/A	p <0.001	p <0.001	N/A

The factor that has been found to be statistically significant in four different studies, equaling 2213 patients, was larger size ratio. Bottleneck factor was found to be statistically signifficant in three studies, totalling 2273 patients. The following morphological factors were considered significant in two different studies: height to neck width ratio (with a total of 1172 patients) and height-width ratio (a total of 322 patients). The distribution according to the number of studies that found a specific factor to be significant (and the total number of patients).

Figure 3. Risk factors distribution according to the number of studies / number of patients included.



The main middle cerebral artery bifurcation is the most frequent location for MCA aneurysm formation [32]–[40]. Elsharkawy et al. found that, out of the 1309 MCA aneurysms studied, 63% were located at the main MCS bifurcation and were associated with a higher rupture rate (38%) than aneurysms in other locations along the MCA (20% for M1 aneurysms and 16% for distal MCA aneurysms [11]. Considering that MCA bifurcation has the highest rate for aneurysm formation as well as aneurysm rupture, one may consider that both events are caused by the same factors, perhaps hemodynamic features such as flow direction and pressure distribution along the MCA.

Smaller parent artery diameter and larger daughter-to-daughter branch angle

Can et al. [24] analyzed the contribution of MCA morphology to aneurysm formation. They examined diameters and vessel-to-vessel angles of the M1 artery and daugher branches. This study concluded that smaller parent artery diameter and a larger daughter-to-daughter branch angle are associated with MCA bifurcation aneurysms formation.

Aspect ratio

A number of studies have shown that the aspect ratio (i.e.aneurysm hight to aneurysm neck width ratio) is notably higher in ruptured than in unruptured aneurysms [41]–[44]. The aspect ratio has been reported as being associated with rupture status across multiple aneurysm locations, MCA included 38. Some authors advised active treatment in aneurysms with a high aspect ratio, regardless of their size [44]. The treshold value suggested was 1.6 [41]. Elsharkawy et al. [11] found a 58% rupture rate for MCA aneurysms with an aspect ratio over 1.6. Increasing the treshold value could increase the specificity, but with the cost of reducing sensitivity [11].

Daughter dome presence

Multiple studies have stated that the presence of a daughter dome was reported as being independently associated with rupture in several series [25], [31], [45]. The development of daugher domes could be caused by an increase of the intra-aneurysmal pressure, determining local protrusions of the aneurysm wall [46]. Thus considered, aneurysms harboring daughter domes seem to be in a more progressive development stage, associated with a higher rupture risk.

Wall irregularity

Aneurysm wall irregularity and protrusions, possibly developed from a weak scar at a previous rupture site [46], [47], were associated with rupture risk in studies previously published in the literature [48] [49]. Elsharkawy et al. [11]found that the rupture rate in MCA aneurysms with irregular wall was 6 times higher than in MCA aneurysms with smooth wall [11]. Some studies indicated that neither the size nor the aneurysm shape was much affected by rupture [41], [49], [50], suggesting that aneurysm wall irregularity might be a suitable factor for rupture risk prediction.

Less spherical geometry (height-width ratio) and bottleneck factor (aneurysm width to neck width)

It has been stated that the aneurysm geometry influences its growth and rupture by affecting the intra-aneurysmal hemodynamics and wall shear stress [16]–[18]. Height-width ratio and aneurysm width to neck width were other morphological indices reported in the literature as morphological parameters associated with rupture status in unruptured aneurysms [21]. Elsharkawy et al. [11] found that height-width ratio was higher in ruptured than in unruptured MCA aneurysms. In their study, spherical aneurysms (i.e. height-width ratio = 1) were less likely to rupture than more oval aneurysms (i.e. height-width ratio ≠ 1). Additionally, elongated oval aneurysms (i.e. height-width ratio > 1) had a higher rupture rate than wide oval aneurysms (i.e. height-width ratio < 1).

Wider neck

Aneurysms of the MCA are usually broad necked and often have branches originating at their base [51], [52]. In one study published by Elsarkawy et al. MCA ruptured aneurysms seemed to have a larger neck than their unruptured counterparts, but this was not a significant rupture risk factor [11]. However, the large neck is affecting the aneurysm shape and the options of occlusive treatment. A large neck-to-dome ratio is a disadvantage, particularly for endovascular treatment [51], [52].

Management of unruptured MCA aneurysms

Although the dillema regarding unruptured intracranial aneurysms management has been highly adressed [8], [13], [53]–[60], this remains a topic for debate. Our results and literature review contribute exploratory data that may assist clinical reasoning when evaluating unruptured MCA aneurysms. The morphological aspects analyzed in this article, together with those identified in previous studies, should be interpreted as complementary descriptive parameters rather than definitive predictors of rupture. Studies addressing morphological correlates of aneurysm rupture, including ours, are inherently limited by retrospective design and incomplete characterization of all potential biological and hemodynamic determinants. Importantly, our study is severely underpowered for multivariable modeling and cannot detect anything other than large effect sizes. Therefore, the present findings should be interpreted strictly as exploratory and hypothesis-generating.

Current evidence remains insufficient to determine with certainty which unruptured MCA aneurysm will rupture or when this may occur. Larger prospective, multi-center studies are required to validate potential cut-off values for morphological parameters. Future research may benefit from integrating high-resolution imaging datasets and advanced analytical approaches, including machine learning–based modeling, to better characterize complex geometric–hemodynamic interactions.

5. Conclusions

In this study, the literature review consistently identified several morphological parameters—particularly size-related indices, aspect ratio, bottleneck factor, and selected angular measurements—as being associated with rupture status in MCA aneurysms across multiple cohorts.

Our small retrospective case series demonstrated directional trends consistent with previously published findings but did not identify statistically significant differences, reflecting the limited statistical power of the cohort.
Overall, current evidence suggests that morphological assessment represents a relevant component of aneurysm evaluation; however, definitive cut-off values and predictive models require validation in larger prospective, multi-center studies.

6. Patents

Author Contributions:

Conceptualization, Paslaru Francesca Gabriela and Iliescu Adrian;

Methodology, Petrescu George Dragos Emil;

Validation, Brehar Felix Mircea, Gorgan Radu Mircea;

Formal analysis, Paslaru Francesca Gabriela;

Investigation, Stanoaia Oana Elena;

Data curation, Iliescu Adrian;

Writing—original draft preparation, Paslaru Francesca Gabriela;

Writing—review and editing, Stanoaia Oana Elena;

Visualization, Brehar Felix Mircea and Gorgan Radu Mircea;

Supervision, Brehar Felix Mircea and Gorgan Radu Mircea;

All authors have read and agreed to the published version of the manuscript.

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References

1. Frösen J, Tulamo R, Paetau A, Laaksamo E, Korja M, Laakso A et al. Saccular intracranial aneurysm: pathology and mech-anisms. Acta Neuropathol. 2012;123(6):773-86
2. Vlak MH, Algra A, Brandenburg R, Rinkel GJ. Prevalence of unruptured intracranial aneurysms, with emphasis on sex, age, comorbidity, country, and time period: a systematic review and meta-analysis. Lancet Neurol. 2011;10(7):626-36
3. Gabriel RA, Kim H, Sidney S, McCulloch CE, Singh V, Johnston SC, Ko NU, Achrol AS, Zaroff JG, Young WL. Ten-year detection rate of brain arteriovenous malformations in a large, multiethnic, defined population. Stroke. 2010;41(1):21-6
4. de Rooij NK, Linn FH, van der Plas JA, Algra A, Rinkel GJ. Incidence of subarachnoid haemorrhage: a systematic review with emphasis on region, age, gender and time trends. J Neurol Neurosurg Psychiatry. 2007;78(12):1365-72
5. Rinkel GJ, Ruigrok YM. Preventive screening for intracranial aneurysms. Int J Stroke. 2022;17(1):30-36
6. Passier PE, Visser-Meily JM, van Zandvoort MJ, Post MW, Rinkel GJ, van Heugten C. Prevalence and determinants of cognitive complaints after aneurysmal subarachnoid hemorrhage. Cerebrovasc Dis. 2010;29(6):557-63
7. Khanna RK, Malik GM, Qureshi N. Predicting outcome following surgical treatment of unruptured intracranial aneurysms: a proposed grading system. J Neurosurg. 1996;84(1):49-54
8. Wiebers DO, Whisnant JP, Huston J 3rd, Meissner I, Brown RD Jr, Piepgras DG, Forbes GS, Thielen K, Nichols D, O'Fallon WM, Peacock J, Jaeger L, Kassell NF, Kongable-Beckman GL, Torner JC; International Study of Unruptured Intracranial An-eurysms Investigators. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet. 2003;362(9378):103-10
9. de Tribolet N, Bijlenga P. Intracranial aneurysms: is there still a place for neurosurgery? Acta Neurochir (Wien). 2006;148(2):121-4; discussion 124-6
10. Orz Y, Kobayashi S, Osawa M, Tanaka Y. Aneurysm size: a prognostic factor for rupture. Br J Neurosurg. 1997;11(2):144-9
11. Elsharkawy A, Lehečka M, Niemelä M, Kivelev J, Billon-Grand R, Lehto H, Kivisaari R, Hernesniemi J. Anatomic risk factors for middle cerebral artery aneurysm rupture: computed tomography angiography study of 1009 consecutive patients. Neurosurgery. 2013;73(5):825-37; discussion 836-7
12. Huttunen T, von und zu Fraunberg M, Frösen J, Lehecka M, Tromp G, Helin K, Koivisto T, Rinne J, Ronkainen A, Hernesniemi J, Jääskeläinen JE. Saccular intracranial aneurysm disease: distribution of site, size, and age suggests different eti-ologies for aneurysm formation and rupture in 316 familial and 1454 sporadic eastern Finnish patients. Neurosurgery. 2010;66(4):631-8; discussion 638

13. Juvela S, Porras M, Poussa K. Natural history of unruptured intracranial aneurysms: probability of and risk factors for aneurysm rupture. J Neurosurg. 2008;108(5):1052-60
14. Feigin VL, Rinkel GJ, Lawes CM, Algra A, Bennett DA, van Gijn J, Anderson CS. Risk factors for subarachnoid hemorrhage: an updated systematic review of epidemiological studies. Stroke. 2005;36(12):2773-80
15. Ruigrok YM, Rinkel GJ. From GWAS to the clinic: risk factors for intracranial aneurysms. Genome Med. 2010;2(9):61
16. Hassan T, Timofeev EV, Saito T, Shimizu H, Ezura M, Matsumoto Y, Takayama K, Tominaga T, Takahashi A. A proposed parent vessel geometry-based categorization of saccular intracranial aneurysms: computational flow dynamics analysis of the risk factors for lesion rupture. J Neurosurg. 2005;103(4):662-80
17. Hoi Y, Meng H, Woodward SH, Bendok BR, Hanel RA, Guterman LR, Hopkins LN. Effects of arterial geometry on aneurysm growth: three-dimensional computational fluid dynamics study. J Neurosurg. 2004;101(4):676-81
18. Ujiie H, Tachibana H, Hiramatsu O, Hazel AL, Matsumoto T, Ogasawara Y, Nakajima H, Hori T, Takakura K, Kajiya F. Effects of size and shape (aspect ratio) on the hemodynamics of saccular aneurysms: a possible index for surgical treatment of intracranial aneurysms. Neurosurgery. 1999;45(1):119-29; discussion 129-30
19. Kikinis R, Pieper SD, Vosburgh KG. 3D Slicer: a platform for subject-specific image analysis, visualization, and clinical support. In: Jolesz FA, editor. Intraoperative Imaging and Image-Guided Therapy. New York: Springer. 2014;277-289
20. Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin JC, Pujol S, Bauer C, Jennings D, Fennessy F, Sonka M, Buatti J, Aylward S, Miller JV, Pieper S, Kikinis R. 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magn Reson Imaging. 2012;30(9):1323-41
21. Hoh BL, Sistrom CL, Firment CS, Fautheree GL, Velat GJ, Whiting JH, Reavey-Cantwell JF, Lewis SB. Bottleneck factor and height-width ratio: association with ruptured aneurysms in patients with multiple cerebral aneurysms. Neurosurgery. 2007;61(4):716-22; discussion 722-3
22. Etminan N, Brown RD Jr, Beseoglu K, Juvela S, Raymond J, Morita A et al. The unruptured intracranial aneurysm treatment score: a multidisciplinary consensus. Neurology. 2015;85(10):881-9
23. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev. 2021 Mar 29;10(1):89
24. Can A, Ho AL, Dammers R, Dirven CM, Du R. Morphological parameters associated with middle cerebral artery aneurysms. Neurosurgery. 2015;76(6):721-6; discussion 726-7
25. Chen Y, Lin B, Zhou J, Chen L, Yang Y, Zhao B. Morphological predictors of middle cerebral artery bifurcation aneurysm rupture. Clin Neurol Neurosurg. 2020;192:105708
26. Huang Z, Zeng M, Tao WG, Zeng FY, Chen CQ, Zhang LB, Chen FH. A Hemodynamic Mechanism Correlating with the Initiation of MCA Bifurcation Aneurysms. AJNR Am J Neuroradiol. 2020;41(7):1217-1224
27. Kaspera W, Ćmiel-Smorzyk K, Wolański W, Kawlewska E, Hebda A, Gzik M, Ładziński P. Morphological and Hemodynamic Risk Factors for Middle Cerebral Artery Aneurysm: a Case-Control Study of 190 Patients. Sci Rep. 2020;10(1):2016
28. Liu Q, Jiang P, Wu J, Li M, Gao B, Zhang Y, Ning B, Cao Y, Wang S. Intracranial aneurysm rupture score may correlate to the risk of rebleeding before treatment of ruptured intracranial aneurysms. Neurol Sci. 2019;40(8):1683-1693
29. Matsukawa H, Kamiyama H, Miyazaki T, Kinoshita Y, Ota N, Noda K, Shonai T, Takahashi O, Tokuda S, Tanikawa R. Surgical Treatment of Middle Cerebral Artery Aneurysms: Aneurysm Location and Size Ratio as Risk Factors for Neurologic Worsening and Ischemic Complications. World Neurosurg. 2018;117:e563-e570
30. Song J, Zhu F, Qian Y, Ou C, Cai J, Zou X, Wu Z, Zhu W, Chen L, Mao Y. Morphological and Hemodynamic Differences Between Aneurysmal Middle Cerebral Artery Bifurcation and Contralateral Nonaneurysmal Anatomy. Neurosurgery. 2017;81(5):779-786
31. Zhang J, Can A, Mukundan S, Steigner M, Castro VM, Dligach D, Finan S, Yu S, Gainer V, Shadick NA, Savova G, Murphy S, Cai T, Wang Z, Weiss ST, Du R. Morphological Variables Associated With Ruptured Middle Cerebral Artery Aneu-rysms. Neurosurgery. 2019;85(1):75-83
32. Elsharkawy A, Lehečka M, Niemelä M, Billon-Grand R, Lehto H, Kivisaari R, Hernesniemi J. A new, more accurate classification of middle cerebral artery aneurysms: computed tomography angiographic study of 1,009 consecutive cases with 1,309 middle cerebral artery aneurysms. Neurosurgery. 2013;73(1):94-102; discussion 102
33. Yasargil MG. Microneurosurgery. Vol. II: Clinical considerations, surgery of the intracranial aneurysms and results. Stuttgart: Georg Thieme Verlag; 1984
34. Dashti R, Hernesniemi J, Niemelä M, Rinne J, Lehecka M, Shen H, Lehto H, Albayrak BS, Ronkainen A, Koivisto T, Jääskeläinen JE. Microneurosurgical management of distal middle cerebral artery aneurysms. Surg Neurol. 2007;67(6):553-63
35. Dashti R, Hernesniemi J, Niemelä M, Rinne J, Porras M, Lehecka M, Shen H, Albayrak BS, Lehto H, Koroknay-Pál P, de Oliveira RS, Perra G, Ronkainen A, Koivisto T, Jääskeläinen JE. Microneurosurgical management of middle cerebral artery bifurcation aneurysms. Surg Neurol. 2007;67(5):441-56

36. Dashti R, Rinne J, Hernesniemi J, Niemelä M, Kivipelto L, Lehecka M, Karatas A, Avci E, Ishii K, Shen H, Peláez JG, Albayrak BS, Ronkainen A, Koivisto T, Jääskeläinen JE. Microneurosurgical management of proximal middle cerebral artery aneurysms. Surg Neurol. 2007;67(1):6-14
37. Heros RC, Fritsch MJ. Surgical management of middle cerebral artery aneurysms. Neurosurgery. 2001;48(4):780-5; discussion 785-6
38. Rinne J, Hernesniemi J, Niskanen M, Vapalahti M. Analysis of 561 patients with 690 middle cerebral artery aneurysms: anatomic and clinical features as correlated to management outcome. Neurosurgery. 1996;38(1):2-11
39. Pásztor E, Vajda J, Juhász J, Tóth S, Orosz E, Horváth M. The surgery of middle cerebral artery aneurysms. Acta Neurochir (Wien). 1986;82(3-4):92-101
40. Suzuki J, Yoshimoto T, Kayama T. Surgical treatment of middle cerebral artery aneurysms. J Neurosurg. 1984;61(1):17-23
41. Ujiie H, Tamano Y, Sasaki K, Hori T. Is the aspect ratio a reliable index for predicting the rupture of a saccular aneurysm? Neurosurgery. 2001;48(3):495-502; discussion 502-3
42. Nader-Sepahi A, Casimiro M, Sen J, Kitchen ND. Is aspect ratio a reliable predictor of intracranial aneurysm rupture? Neurosurgery. 2004;54(6):1343-7; discussion 1347-8
43. Sadatomo T, Yuki K, Migita K, Taniguchi E, Kodama Y, Kurisu K. Evaluation of relation among aneurysmal neck, parent artery, and daughter arteries in middle cerebral artery aneurysms, by three-dimensional digital subtraction angiography. Neurosurg Rev. 2005;28(3):196-200
44. Weir B, Amidei C, Kongable G, Findlay JM, Kassell NF, Kelly J, Dai L, Karrison TG. The aspect ratio (dome/neck) of ruptured and unruptured aneurysms. J Neurosurg. 2003;99(3):447-51
45. UCAS Japan Investigators; Morita A, Kirino T, Hashi K, Aoki N, Fukuhara S et al. The natural course of unruptured cerebral aneurysms in a Japanese cohort. N Engl J Med. 2012;366(26):2474-82
46. Meng H, Feng Y, Woodward SH, Bendok BR, Hanel RA, Guterman LR, Hopkins LN. Mathematical model of the rupture mechanism of intracranial saccular aneurysms through daughter aneurysm formation and growth. Neurol Res. 2005;27(5):459-65
47. Suzuki J, Ohara H. Clinicopathological study of cerebral aneurysms. Origin, rupture, repair, and growth. J Neurosurg. 1978;48(4):505-14
48. Hademenos GJ, Massoud TF, Turjman F, Sayre JW. Anatomical and morphological factors correlating with rupture of in-tracranial aneurysms in patients referred for endovascular treatment. Neuroradiology. 1998;40(11):755-60
49. Beck J, Rohde S, el Beltagy M, Zimmermann M, Berkefeld J, Seifert V, Raabe A. Difference in configuration of ruptured and unruptured intracranial aneurysms determined by biplanar digital subtraction angiography. Acta Neurochir (Wien). 2003;145(10):861-5; discussion 865
50. Raghavan ML, Ma B, Harbaugh RE. Quantified aneurysm shape and rupture risk. J Neurosurg. 2005;102(2):355-62
51. Paulo MS, Edgardo S, Fernando M, Pablo P, Alejandro T, Verónica V. Aneurysms of The Middle Cerebral Artery Proximal Segment (M1) · Anatomical and Therapeutic Considerations · Revision of A Series. Analysis of a series of the pre bifur-cation segment aneurysms. Asian J Neurosurg. 2010;5(2):57-63
52. Jayaraman MV, Do HM, Versnick EJ, Steinberg GK, Marks MP. Morphologic assessment of middle cerebral artery aneurysms for endovascular treatment. J Stroke Cerebrovasc Dis. 2007;16(2):52-6
53. Wiebers DO, Whisnant JP, O'Fallon WM. The natural history of unruptured intracranial aneurysms. N Engl J Med. 1981;304(12):696-8
54. Horowitz M. Guidelines for the surgical treatment of unruptured intracranial aneurysms: the first annual J. Lawrence Pool Memorial Research Symposium--Controversies in the management of cerebral aneurysms. Neurosurgery. 2009;64(3):E577; author reply E577
55. Lawson MF, Neal DW, Mocco J, Hoh BL. Rationale for treating unruptured intracranial aneurysms: actuarial analysis of natural history risk versus treatment risk for coiling or clipping based on 14,050 patients in the Nationwide Inpatient Sam-ple database. World Neurosurg. 2013;79(3-4):472-8
56. Loewenstein JE, Gayle SC, Duffis EJ, Prestigiacomo CJ, Gandhi CD. The natural history and treatment options for unruptured intracranial aneurysms. Int J Vasc Med. 2012;2012:898052
57. Wiebers DO. Unruptured intracranial aneurysms: natural history and clinical management. Update on the international study of unruptured intracranial aneurysms. Neuroimaging Clin N Am. 2006;16(3):383-90, vii
58. Juvela S, Poussa K, Lehto H, Porras M. Natural history of unruptured intracranial aneurysms: a long-term follow-up study. Stroke. 2013;44(9):2414-21
59. Juvela S. Natural history of unruptured intracranial aneurysms: risks for aneurysm formation, growth, and rupture. Acta Neurochir Suppl. 2002;82:27-30
60. Juvela S, Porras M, Poussa K. Natural history of unruptured intracranial aneurysms: probability of and risk factors for aneurysm rupture. J. Neurosurg. 2000;93(3):379–387.