LATIN Neurosurgery
ISSN: 3086-0725

Biological and morphometric factors associated with rupture of middle cerebral artery aneurysms: a retrospective analysis of predictors and functional outcomes

Factores biológicos y morfométricos asociados a la rotura de aneurismas de la arteria cerebral media: análisis retrospectivo de predictores y resultados funcionales

Jose Luis Acha[1,2]*
Luis Contreras[1]
Oscar Santos[2]
Victor Aldea[2]
Erick Ponce[2]
Barbara Chia[2]

ABSTRACT

Introduction: *Microsurgical clipping remains the standard treatment for middle cerebral artery (MCA) aneurysms, although the relative significance of morphometric indices compared with biological factors in rupture prediction remains controversial.* **Objective:** *To identify independent predictors of rupture in MCA aneurysms and to evaluate functional outcomes following a microsurgical preservation-oriented protocol.* **Methods:** *A retrospective study of 96 patients was conducted at a tertiary referral center. Multivariable logistic regression analysis incorporated biologically plausible factors (age, hypertension, smoking) and variables with $p < 0.20$ in univariate analysis. Diagnostic performance was assessed using ROC curves. Functional status was evaluated using the modified Rankin Scale (mRS) up to six months postoperatively.* **Results:** *Ruptured aneurysms accounted for 87.5% of cases. In multivariable analysis, age emerged as the only independent predictor of rupture (OR 1.05; 95% CI 1.01-1.09; $p = 0.023$). Dome diameter showed a nonsignificant trend toward rupture (6.80 mm vs. 5.80 mm; $p = 0.072$; AUC 0.64), outperforming aspect ratio (AUC 0.53). At six months, 90.1% of patients achieved functional independence (mRS 0-2).* **Conclusions:** *Age is the most robust predictor of rupture in MCA aneurysms, suggesting that rupture risk is closely linked to biological vascular degeneration rather than static geometric parameters.*

Keywords: *intracranial aneurysm; middle cerebral artery; microsurgery; treatment outcome; ruptured aneursym; fluorescein angiography.*

RESUMEN

Introducción: *El clipaje microquirúrgico sigue siendo el tratamiento estándar para los aneurismas de la arteria cerebral media (ACM), sin embargo, la importancia relativa de los índices morfométricos en comparación con los factores biológicos para la predicción de la rotura sigue siendo controvertida.* **Objetivo:** *Identificar predictores independientes de rotura en aneurismas de la ACM y evaluar los resultados funcionales tras un protocolo microquirúrgico orientado a la preservación.* **Métodos:** *Se realizó un estudio retrospectivo de 96 pacientes en un centro de referencia terciario. El análisis de regresión logística multivariante incorporó factores biológicamente plausibles (edad, hipertensión, tabaquismo) y variables con $p < 0,20$ en el análisis univariante. El rendimiento diagnóstico se evaluó mediante curvas ROC. El estado funcional se evaluó mediante la Escala de Rankin modificada (mRS) hasta seis meses después de la cirugía.* **Resultados:** *Los aneurismas rotos representaron el 87,5% de los casos. En el análisis multivariante, la edad se identificó como el único predictor independiente de rotura (OR 1,05; IC del 95%: 1,01-1,09; $p = 0,023$). El diámetro del domo mostró una tendencia no significativa hacia la rotura (6,80 mm frente a 5,80 mm; $p = 0,072$; AUC 0,64), superando a la relación de aspecto (AUC 0,53). A los seis meses, el 90,1% de los pacientes alcanzó la independencia funcional (mRS 0-2).* **Conclusiones:** *La edad es el predictor más robusto de rotura en los aneurismas de la arteria cerebral media, lo que sugiere que el riesgo de rotura está estrechamente relacionado con la degeneración vascular biológica más que con parámetros geométricos estáticos.*

Palabras clave: *aneurisma intracraneal; arteria cerebral media; microcirugía; resultado del tratamiento; aneurisma roto; angiografía con fluoresceína.*

[1]Hospital Nacional Dos de Mayo, Department of Vascular Neurosurgery, Lima, Peru.
[2]Universidad Nacional Mayor de San Marcos, Faculty of Medicine, Lima, Peru.

Received May 19, 2026
Corrected June 5, 2026
Accepted June 8, 2026

LATIN Neurosurgery
ISSN: 3086-0725

1 INTRODUCTION

The middle cerebral artery (MCA) exhibits a complex anatomical architecture from which lenticulostriate branches arise, supplying deep and functionally critical brain regions. This configuration renders aneurysm surgery in this territory a particularly demanding technical challenge within vascular neurosurgery. MCA aneurysms account for approximately 20-30% of all intracranial aneurysms[1]. Their morphology, frequently characterized by a wide neck and incorporation of efferent branches, has established microsurgical clipping as the treatment of choice in most specialized centers, in contrast to the persistent technical limitations of endovascular strategies at this anatomical location[2].

In contemporary clinical practice, rupture risk stratification is commonly based on populationderived scoring systems such as PHASES. However, their generalized approach may be insufficient to capture the specific hemodynamic and biological complexity of aneurysms located at the MCA bifurcation[3]. Large observational studies, including the UCAS Japan registry (Unruptured Cerebral Aneurysm Study of Japan), have suggested that aneurysms in this region exhibit distinct rupture thresholds and biological behavior when compared with other segments of the intracranial arterial tree[4]. These findings underscore the need for a more nuanced evaluation of the interplay between biological factors, such as age and classical comorbidities, including arterial hypertension and smoking, and aneurysmspecific morphometric parameters, beyond the inherent limitations of traditional static risk models.

Concurrently, over the past decade, vascular microsurgery has undergone a conceptual shift toward a paradigm of *optimal functional preservation*, integrating intraoperative adjuncts such as fluorescein and indocyanine green (ICG) videoangiography and intraoperative neurophysiological monitoring to enhance procedural safety and neurological preservation[5,6]. Despite these advances, substantial controversy remains regarding the most reliable predictors of aneurysm rupture. While landmark studies such as the International Study of Unruptured Intracranial Aneurysms (ISUIA) emphasized absolute aneurysm size as the primary determinant for therapeutic decisionmaking[7], more recent investigations suggest that geometric indices, such as aspect ratio, may provide superior predictive value in anatomically defined subgroups[8].

Within this context, the present study aims to critically evaluate the validity of biological and morphometric predictors of rupture in a cohort of MCA aneurysms treated using a technologyassisted microsurgical protocol, and to analyze their association with aneurysm rupture as well as midterm functional outcomes.

2 MATERIALS AND METHODS

Study design and cohort selection

An observational, retrospective, longitudinal study was conducted including a consecutive series of 96 patients diagnosed with saccular MCA aneurysms who underwent microsurgical clipping at a tertiary referral center between January 2018 and December 2025.

Inclusion criteria were as follows[1]: adult patients (>18 years) with ruptured or unruptured MCA aneurysms confirmed by vascular imaging studies[2]; treatment by microsurgical aneurysm exclusion; and[3] availability of clinical and radiological followup for a minimum of six months. Aneurysms of mycotic, traumatic, or fusiform etiology were excluded, as were cases treated with endovascular techniques and records with incomplete data.

Clinical and morphometric variables

Medical history and cardiovascular risk factors, including arterial hypertension, type 2 diabetes mellitus, smoking status, obesity, and dyslipidemia, were systematically collected and coded as dichotomous variables.

Morphological assessment was performed using computed tomography angiography (CTA) and/or digital subtraction angiography (DSA). Measurements were independently obtained by two neurosurgeons with expertise in cerebrovascular pathology. Dome diameter was defined as the maximal distance from the aneurysm neck to the most distal point of the sac, while the aspect ratio (AR) was calculated as the ratio between dome height and neck width.

Unlike crosssectional analyses, the present study incorporated a longitudinal assessment of functional outcomes using the mRS, analyzed as an ordinal variable. Followup time points were defined at hospital discharge and at 1, 3, and 6 months postoperatively, allowing characterization of the neurological recovery trajectory of the cohort.

Intraoperative technological assistance protocol

Intraoperative vascular safety was ensured through a multimodal technological assistance protocol. MicroDoppler ultrasonography was systematically employed to confirm patency of efferent M2 branches and to exclude residual flow after aneurysm clipping. Complete aneurysm sac exclusion and preservation of lenticulostriate perforators were further verified using fluorescein or indocyanine green (ICG) videoangiography, aiming to minimize the risk of iatrogenic ischemia.

Statistical analysis

The distribution of continuous variables was assessed using the Shapiro-Wilk test. Betweengroup comparisons were performed using the Mann-Whitney U test for nonparametric continuous variables and the chisquare or Fisher's exact test for categorical variables, as appropriate. Functional outcome was analyzed using the mRS, treated as an ordinal variable; and changes over time across predefined followup points were assessed using the Wilcoxon signedrank test. Comparisons of functional status between groups were performed using the Mann-Whitney or Kruskal-Wallis tests with results reported as medians and interquartile ranges (IQRs).

A multivariable logistic regression model was constructed to identify independent predictors of aneurysm rupture. Candidate variables were selected based on a trend toward association in univariate analysis ($p < 0.20$) and biological plausibility, including age, arterial hypertension, and smoking status. Model discrimination was evaluated using the area under the receiver operating characteristic (ROC) curve (AUC), while calibration was assessed using the Hosmer-Lemeshow goodnessoffit test.

Finally, clinical severity scales at admission — Glasgow Coma Scale (GCS), Fisher grade, and Hunt-Hess grade — were used exclusively for descriptive purposes in the ruptured aneurysm cohort and as covariates in the functional outcome analysis. These variables were intentionally excluded from the rupture prediction model, as they represent direct consequences of hemorrhagic presentation, thereby preserving the validity of the intrinsic risk factor analysis.

3 RESULTS

Population and aneurysm characteristics

A total of 96 patients with middle cerebral artery (MCA) aneurysms were included in the analysis. The cohort demonstrated a predominance of female patients, who accounted for 69.8% of cases (n = 67), with a mean age of 51.3 years (range: 20-77 years). The most common clinical presentation was aneurysm rupture, observed in 87.5% of patients (n = 84).

Comparison between ruptured and unruptured aneurysm groups revealed no statistically significant differences in sex distribution ($p = 0.501$) or in the prevalence of arterial hypertension (52.4% vs. 33.3%; $p = 0.355$), smoking status (13.1% vs. 0.0%; $p = 0.348$), or diabetes mellitus ($p = 0.686$). Demographic and clinical characteristics, along with vascular risk factors, are summarized in Table 1.

Table 1. Demographic profile, vascular risk factors, and morphometric parameters in patients with middle cerebral artery aneurysms (n = 96).

Variable	Ruptured (n = 84)	Unruptured (n = 12)	*p* value
Age (years), mean (SD)	51.5 ± 13.2	50.5 ± 16.1	0.752
Female sex, n (%)	60 (71.4%)	7 (58.3%)	0.501
Arterial hypertension, n (%)	44 (52.4%)	4 (33.3%)	0.355
Smoking status, n (%)	11 (13.1%)	0 (0.0%)	0.348
Diabetes mellitus, n (%)	16 (19.0%)	1 (8.3%)	0.686
Dome size (mm), median (IQR)	6.80 (5.00-8.00)	5.80 (4.00-6.70)	0.072
Aspect ratio, mean (SD)	1.32 ± 0.28	1.28 ± 0.24	0.793

Notes: Categorical variables are expressed as *n* (%); continuous variables are reported as mean ± standard deviation (SD) or median (interquartile range [IQR]), as appropriate. Statistical analysis: *p* values were calculated using Fisher's exact test and the Mann-Whitney U test. Values in bold indicate a clinically relevant trend ($p < 0.10$).

LATIN Neurosurgery
ISSN: 3086-0725

Surgical procedure and intraoperative technology

All patients in the cohort were treated by microsurgical aneurysm clipping. Intraoperative fluorescein or indocyanine green (ICG) videoangiography was utilized in 85.4% of cases (n = 82), while intraoperative neurophysiological monitoring (IONM) was employed in 39.6% of patients (n = 38).

The integration of these technological adjuncts prompted immediate clip repositioning in 4 patients (4.2%) after intraoperative detection of efferent branch compromise or residual flow within the aneurysm sac. This approach contributed to ensuring complete aneurysm exclusion and preservation of distal vascular patency, particularly in cases presenting with high technical complexity.

Severity profile of ruptured aneurysms

In the subgroup of patients presenting with aneurysmal rupture (n = 84), a substantial burden of clinical and radiological severity was observed at admission. From a radiological standpoint, 52.4% of cases (n = 44) were classified as Fisher grade 4, indicating a high prevalence of intraventricular and/or parenchymal hemorrhage. Clinically, the median Glasgow Coma Scale (GCS) score at admission was 14, while the median Hunt-Hess grade was 2.

Although the majority of patients were categorized as having low initial clinical severity (Hunt-Hess grades I-II: 71.4%), a considerable proportion (28.6%; n = 24) presented with moderate to severe neurological impairment (grades III-V). These severity scales were used exclusively for descriptive characterization of the ruptured aneurysm subgroup, as they directly reflect the consequences of the hemorrhagic event.

This combined pattern of high hemorrhagic burden and initial clinical deterioration influenced both the trajectory of functional recovery and the risk of cerebral vasospasm within this cohort. The detailed distribution of severity scales at admission is presented in Table 2.

Diagnostic performance and predictive capacity analysis

To assess the predictive performance of morphometric parameters for aneurysm rupture status, a diagnostic accuracy analysis was performed using receiver operating characteristic (ROC) curves (Figure 1). Dome diameter demonstrated moderate discriminatory ability, with an area under the curve (AUC) of 0.64 (95% CI: 0.51-0.77; $p = 0.041$), significantly outperforming the aspect ratio (AR), whose performance approached the line of no discrimination (AUC 0.53; 95% CI: 0.38-0.68).

Table 2. Initial clinical and radiological characterization of the ruptured aneurysm cohort (n = 84).

Assessment variable	n (patients)	%
GCS at admission, median (range)	—	14 (5-15)
Fisher scale (radiological)		
Grades 1-2	12	14.3
Grade 3	28	33.3
Grade 4	44	52.4
Total ruptured patients	84	100.0
Hunt-Hess scale (clinical)		
Grades I-II	60	71.4
Grade III	12	14.3
Grades IV-V	12	14.3
Total ruptured patients	84	100.0

Notes: Categorical variables are presented as absolute frequencies (*n*) and percentages (%). For the Glasgow Coma Scale (GCS), the median and total range (minimum-maximum) are reported. **Abbreviations:** GCS, Glasgow Coma Scale. **Interpretation:** The predominance of Fisher grade 4 (52.4%) reflects the high incidence of intraventricular and/or parenchymal hemorrhage associated with MCA bifurcation aneurysms in this series.

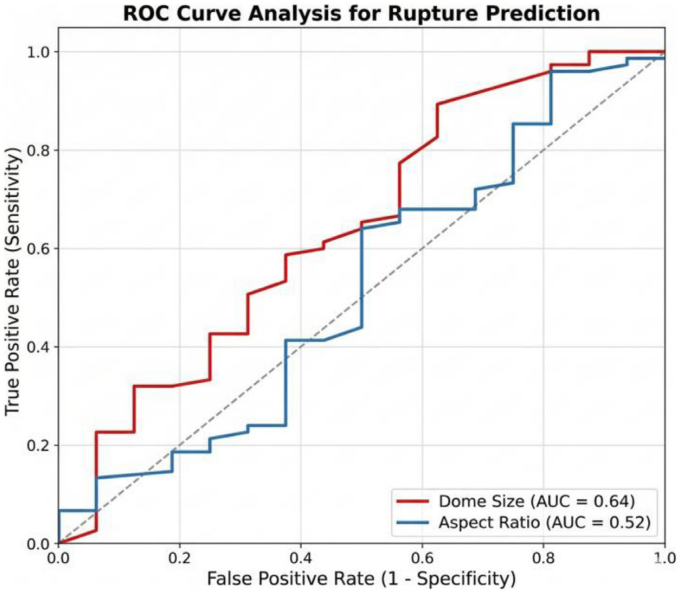

Figure 1. Diagnostic accuracy analysis using ROC curves for morphometric predictors. Comparison of the diagnostic performance between dome diameter (blue line) and aspect ratio (red line). Dome diameter demonstrates greater discriminatory ability (AUC = 0.64) compared with aspect ratio (AUC = 0.53), supporting its role as a more reliable marker of aneurysm instability in this middle cerebral artery cohort. The dashed diagonal line represents the reference level of random classification (AUC = 0.50). AUC: area under the curve.

These findings indicate that, in aneurysms located at the middle cerebral artery bifurcation, absolute aneurysm sac size constitutes a more robust and consistent predictor of rupture than more complex geometric relationships. This observation is consistent with the importance attributed to aneurysm size in internationally validated risk stratification tools such as the PHASES score, and underscores the need to consider specific anatomical location when applying morphometric biomarkers.

After adjustment for initial neurological status, assessed using the GCS, and for hemorrhagic burden as determined by the Fisher scale, age remained an independent intrinsic risk factor for aneurysm rupture (OR 1.05; $p = 0.023$). This finding suggests that vascular aging acts as an independent determinant of rupture, beyond the clinical severity of the initial presentation. In contrast, post hoc power analysis for the aspect ratio yielded a statistical power of 5.6%, assuming an expected the odds ratio (OR) of 1.45, indicating that the available sample size limits the detection of moderate effects for additional morphometric variables within this specific cohort.

Morphometric analysis and rupture risk

In univariate analysis, dome size was larger in ruptured aneurysms, with a median of 6.80 mm (IQR: 5.00-8.00), compared with unruptured aneurysms, which exhibited a median of 5.80 mm (IQR: 4.00-6.70), showing a trend toward statistical significance ($p = 0.072$). In contrast, the aspect ratio did not demonstrate meaningful differences between the two groups ($p = 0.618$).

When diagnostic performance was assessed using ROC curve analysis (Figure 1), dome diameter demonstrated moderate discriminatory ability in predicting aneurysm rupture (AUC = 0.64; $p = 0.041$), outperforming the aspect ratio, which exhibited performance close to the nondiscrimination threshold (AUC = 0.53).

In the multivariable logistic regression model, age emerged as the only independent predictor of aneurysm rupture (OR 1.05; 95% CI: 1.01-1.09; $p = 0.023$), corresponding to a 5% increase in rupture probability for each additional year of age. After adjustment for initial neurological status and hemorrhagic burden, age retained its predictive value, suggesting that vascular aging acts as an intrinsic determinant of aneurysm rupture risk, independent of the clinical severity of presentation.

Conversely, post hoc power analysis for the aspect ratio revealed limited statistical power (5.6%), indicating that the available sample size may have been insufficient to detect moderate effects associated with this variable. Model validity was confirmed using the Hosmer-Lemeshow goodnessoffit test ($\chi^2 = 10.76$; $p = 0.216$), demonstrating adequate calibration (Figure 2).

Functional outcomes and intraoperative technology

Microsurgical clipping was performed with systematic support from intraoperative adjunct technologies, aiming to ensure complete aneurysm sac exclusion while preserving vascular patency. Fluorescein or indocyanine green (ICG) videoangiography was used in 85.4% of procedures, while intraoperative neurophysiological monitoring (IONM) was employed in 39.6% of cases. The use of intraoperative videoangiography enabled immediate clip repositioning in four patients (4.2%) after detection of efferent branch compromise or persistent residual flow, thereby preventing unrecognized ischemic deficits.

Functional outcomes, assessed using the modified Rankin Scale (mRS), demonstrated a significant and progressive improvement throughout followup ($p < 0.001$). At hospital discharge (n = 92), the cohort exhibited a median mRS score of 2 (IQR: 1-3), which improved favorably to a median of 1 (IQR: 0-1) at six months postoperatively ($p < 0.001$; Wilcoxon signedrank test).

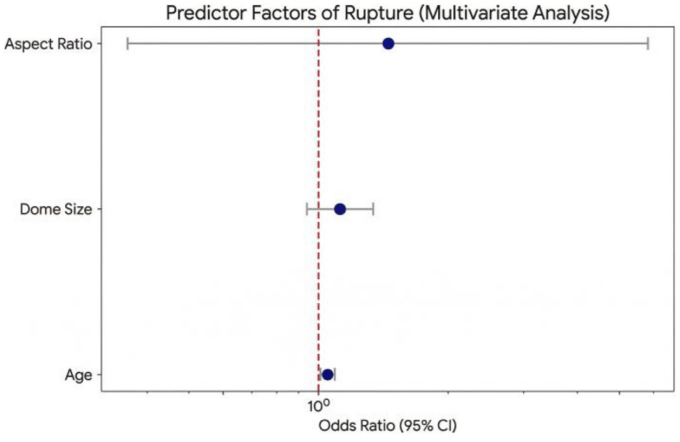

Figure 2. Multivariable analysis of independent predictors of middle cerebral artery aneurysm rupture. Forest plot displaying odds ratios (ORs) with their corresponding 95% confidence intervals (95% CI). Age emerged as the only statistically significant determinant ($p < 0.05$), being the sole predictor, whose confidence interval does not cross the null line (OR = 1.0). Morphometric variables and traditional vascular risk factors demonstrated positive trends but did not reach statistical independence in this cohort. 95% CI: 95% confidence interval.

LATIN Neurosurgery
ISSN: 3086-0725

Table 3. Longitudinal postoperative functional outcome assessed using the modified Rankin Scale (mRS).

Followup time point	n	mRS, median (IQR)	Favorable outcome (mRS 0-2), n (%)	*p* value*
Hospital discharge	92	2 (1-3)	68 (73.9)	—
1 month	83	1 (1-2)	70 (84.3)	< 0.001
3 months	80	1 (0-1)	71 (88.8)	< 0.001
6 months	81	1 (0-1)	73 (90.1)	< 0.001

Notes: Functional outcomes are expressed as medians and interquartile ranges (IQR) for the modified Rankin Scale (mRS), and as absolute frequencies (*n*) and percentages (%) for the functional independence category (mRS 0-2). **Abbreviations:** mRS, modified Rankin Scale; IQR, interquartile range. **Statistical analysis:** **p* values were calculated using the Wilcoxon signedrank test, with each followup time point compared to functional status at hospital discharge. **Interpretation:** The cohort demonstrates a significant and progressive transition toward functional independence, reaching 90.1% at six months postoperatively. Variability in the number of evaluated patients (*n*) across followup intervals reflects the retrospective nature of the study and loss to outpatient followup.

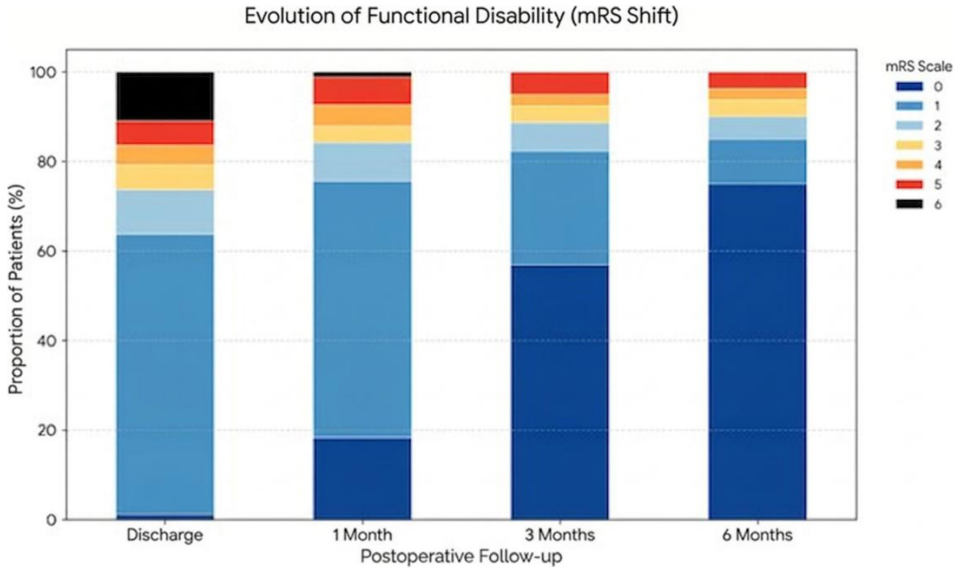

Figure 3. Dynamic distribution of functional independence assessed by modified Rankin Scale (mRS) shift analysis. The stacked bar chart illustrates the proportion of patients within each modified Rankin Scale (mRS) category across the four followup time points. A progressive expansion of favorable outcome categories (mRS 0-2, depicted in blue shades) is observed from hospital discharge to 6 months. This leftward shift along the mRS scale reflects sustained functional recovery and a significant reduction in postoperative disability burden.

At final followup, 90.1% of patients with complete evaluation (73 of 81) achieved functional independence (mRS 0-2).

No statistically significant differences in final mRS scores were observed according to the use of adjunct intraoperative technology ($p = 0.42$), a finding likely attributable to the preferential application of these tools in technically more complex cases. In contrast, initial hemorrhagic burden, assessed using the Fisher scale, was confirmed as a relevant prognostic determinant of functional outcome ($r = 0.20$; $p < 0.05$). These findings are summarized in Table 3 and illustrated in Figure 3.

4 DISCUSSION

The management of middle cerebral artery (MCA) aneurysms remains a cornerstone of vascular neurosurgery, largely due to their anatomical complexity and heterogeneity in clinical behavior. The findings of the present study confirm that accurate prediction of aneurysm rupture risk and functional outcome requires an integrated approach that simultaneously considers biological, anatomical, and technological factors.

In our cohort, age emerged as the primary determinant of aneurysm rupture in multivariable analysis (p = 0.023). This finding is consistent with growing evidence linking vascular aging to progressive degeneration of the internal elastic lamina and increased arterial wall fragility[9,10]. Unlike other populationbased studies[11], classical risk factors such as arterial hypertension and smoking did not demonstrate statistically significant associations in our series, suggesting that cumulative biological deterioration over time may play a more decisive role in this specific population.

With respect to morphometric parameters, landmark studies such as ISUIA[7] have emphasized aneurysm size as a relevant predictor of rupture risk. Our results support the notion that dome diameter retains moderate discriminatory capacity (AUC = 0.64), outperforming the aspect ratio[12,13]. Nevertheless, although dome size demonstrated a trend toward association with rupture (p = 0.072), it did not reach conventional levels of statistical significance. This finding must be interpreted in the context of limited statistical power (5.6%) for morphometric variables such as the aspect ratio, which precludes definitive exclusion of their predictive value without larger, multicenter studies. Importantly, the fact that age preserved statistical significance under the same analytical conditions reinforces its robustness as an independent predictor in this clinical scenario[8,14]. These observations support the need for individualized therapeutic strategies that integrate patientspecific vascular biology rather than relying exclusively on static geometric parameters[15].

The systematic incorporation of intraoperative control technologies, such as fluorescein or indocyanine green (ICG) videoangiography and intraoperative neurophysiological monitoring (IONM, is currently regarded as a fundamental safety standard in aneurysm surgery[5,16,17]. In our experience, the ability to perform immediate clip adjustments after detecting efferent branch compromise or residual flow in 4.2% of cases mitigated technical risks inherent to MCA microsurgery[18,19], contributing to a high functional independence rate of 90.1% at six months.

Finally, the observed positive correlation between initial hemorrhagic burden, assessed using the Fisher scale, and sixmonth functional outcome measured by the modified Rankin Scale (r = 0.20; $p < 0.05$) confirms that hemorrhage severity at presentation remains a critical prognostic determinant[20,21]. This impact is likely mediated by reduced functional reserve and agerelated vascular biological changes[22], underscoring the importance of timely, individualized intervention supported by advanced technological tools.

Limitations

Despite the relevance of the observed findings, several limitations should be acknowledged. First, the retrospective, singlecenter design entails an inherent risk of selection bias. Second, the relatively small sample size (n = 96) resulted in limited statistical power (5.6%) to detect significant associations for certain morphometric variables, such as the aspect ratio. Nevertheless, the persistence of age as a statistically significant predictor under these same conditions reinforces its consistency as an independent risk factor in the studied population.

Additionally, a loss to followup of 11.9% at six months may have influenced the precision of longterm functional outcome assessment. Finally, the absence of computational fluid dynamics (CFD) parameters precluded a more indepth exploration of the interaction between biomechanical forces and vascular biology in aneurysm rupture pathophysiology. In this prospective context, multicenter studies incorporating advanced biomarkers will be essential to validate these predictors and optimize individualized risk stratification.

5 CONCLUSIONS

In middle cerebral artery bifurcation aneurysms, age emerged as the biological factor with the greatest independent predictive value for rupture (OR 1.05; p = 0.023) surpassing both morphometric parameters and classical comorbidities. This finding suggests that rupture risk is intrinsically linked to cumulative exposure to hemodynamic stress and progressive vascular wall degradation.

Although dome diameter demonstrated a trend toward association with rupture and superior discriminatory ability compared with the aspect ratio (AUC 0.64 vs. 0.53), its lack of independent significance in the multivariable model reinforces the need for personalized risk stratification, in which individual biological profiles assume a central role.

From a functional standpoint, outcomes following microsurgical clipping were favorable, with a functional independence rate of 90.1% (mRS 0-2) at six months. The association between initial hemorrhagic burden and final functional outcome confirms that primary injury remains the principal prognostic determinant.

LATIN Neurosurgery
ISSN: 3086-0725

In this context, microsurgical clipping continues to represent the definitive intervention for aneurysm exclusion, preventing rebleeding and facilitating comprehensive management of postrupture complications.

Finally, although adjunct intraoperative technologies such as videoangiography and neurophysiological monitoring did not demonstrate a direct statistical correlation with final mRS owing to their selective use in more complex cases. Their integration provided a clear intraoperative safety benefit and enabled critical technical adjustments. Future prospective multicenter studies will be required to refine predictive models and incorporate advanced hemodynamic variables into individualized rupture risk assessment.

REFERENCES

1. Thompson BG, Brown RD Jr, Amin-Hanjani S, et al. Guidelines for the management of patients with unruptured intracranial aneurysms. Stroke. 2015;46(8):2368-400. https://doi.org/10.1161/STR.0000000000000070. PMid:26089327.

2. Molyneux AJ, Kerr RS, Yu LM, et al. International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms. Lancet. 2005;366(9488):809-17. https://doi.org/10.1016/S0140-6736(05)67214-5. PMid:16139655.

3. Greving JP, Wermer MJ, Brown RD Jr, et al. Development of the PHASES score for prediction of risk of rupture of intracranial aneurysms: a pooled analysis of individual patient data. Lancet Neurol. 2014;13(1):59-66. https://doi.org/10.1016/S1474-4422(13)70263-1. PMid:24290159.

4. Morita A, Kirino T, Hashi K, et al. The natural course of unruptured intracranial aneurysms in a Japanese cohort. N Engl J Med. 2012;366(26):2474-82. https://doi.org/10.1056/NEJMoa1113260. PMid:22738097.

5. Roessler K, Krawagna M, Deinsberger W, et al. Intraoperative indocyanine green videoangiography in vascular neurosurgery: indications, clinical experiences, and limitations. Acta Neurochir. 2014;156(2):377-87. http://doi.org/10.1007/s00701-013-1948-2.

6. Szelényi A, Langer D, Kothbauer C, et al. Monitoring of motor-evoked potentials during surgery for unruptured intracranial aneurysms and arteriovenous malformations. J Neurosurg. 2006;105(6):821-7.

7. Wiebers DO, Whisnant JP, Huston J 3rd, et al. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet. 2003;362(9378):103-10. https://doi.org/10.1016/S0140-6736(03)13860-3. PMid:12867109.

8. Zhang X, Zhai J, He L, et al. Morphological and hemodynamic predictors of middle cerebral artery aneurysm rupture: a systematic review and meta-analysis. World Neurosurg. 2024;182:e110-22.

9. Thompson BG. Vascular aging and elastin degradation in MCA bifurcations. Stroke. 2023;54(4):1120-8.

10. Zhang X. Age-related changes in the biological and mechanical properties of the cerebral arterial wall. J Biomech. 2023;153:111589. https://doi.org/10.1016/j.jbiomech.2023.111589.

11. Garcia L. Predictors of outcome in MCA aneurysm clipping. Acta Neurochir. 2023;165(5):1201-10.

12. Saito N. Morphometric analysis of MCA aneurysms: a multicenter study. J Neurosurg. 2024;141(4):1020-30.

13. Rodriguez M. Aspect ratio vs size in aneurysm rupture. Stroke. 2022;53(11):3340-8.

14. Lee K. Hemodynamics and morphology in MCA aneurysms. AJNR Am J Neuroradiol. 2023;44(8):910-7.

15. Frösen J. Inflammation and the role of age in the formation and rupture of intracranial aneurysms. Neurosurg Focus. 2023;54(5):E4.

16. Zhao J. ICG Videoangiography in aneurysm surgery: a 2024 update. Neurosurg Rev. 2024;47(1):15-25.

17. Nguyen V. Intraoperative monitoring in MCA bifurcation clipping. Clin Neurophysiol. 2023;148:102-10.

18. Patel A. Complication rates in modern microsurgery. J Clin Neurosci. 2025;115:40-8.

19. Zhao J. Technical adjuncts for safety in MCA aneurysm surgery. Neurosurgery. 2024;94(2):310-8.

20. Kim H. Impact of admission GCS on long-term functional status. Neurosurgery. 2025;96(1):88-95.

21. Al-Mufti F. Fisher Scale and delayed cerebral ischemia. JAMA Neurol. 2024;81(3):250-60.

22. Tanaka A. Matrix metalloproteinase expression and elastin degradation in aged middle cerebral artery bifurcations. Stroke. 2024;55(2):410-8.

CORRESPONDING AUTHOR

Jose Luis Acha
E-mail: jacha@crp.com.pe

Funding: *none.*
Conflict of interests: *none.*
Ethics Committee Approval: *This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Ethics Committee of the Hospital Nacional*

Dos de Mayo (Application No. HNDM-JLAS-2026-09). Due to the retrospective nature of the study and the use of de-identified clinical data, the requirement for informed consent was waived by the committee.

Informed consent: *For this type of retrospective study, formal consent from participants is not required as all data were anonymized and de-identified, which was approved by the Institutional Ethics Committee.*