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Predictors and Clinical Impact of Major Intraoperative Rupture During Microsurgical Clipping of Intracranial Aneurysms: A Retrospective Cohort Study

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Abstract

Background: Intracranial aneurysms represent a critical neurosurgical condition due to their potential for rupture and subsequent subarachnoid hemorrhage, which carries substantial morbidity and mortality. Major intraoperative rupture (MIOR) during microsurgical clipping remains one of the most serious intraoperative complications, significantly affecting surgical safety and long-term patient outcomes.

Objective: To identify predictors of MIOR during microsurgical clipping of intracranial aneurysms and to evaluate its association with one-year postoperative functional outcomes.

Methodology: This retrospective cohort study was conducted at Hayatabad Medical Complex, Peshawar, from December 2022 to March 2024. A total of 168 patients undergoing 180 microsurgical aneurysm clipping procedures were included. Clinical variables such as age, gender, preoperative Glasgow Coma Scale (GCS), aneurysm rupture status, and surgeon experience were analyzed. MIOR was defined using standardized intraoperative criteria. Functional outcomes were assessed at one year using the modified Rankin Scale (mRS). Univariate and multivariate logistic regression analyses were performed to identify independent predictors.

Results: MIOR occurred in 23 of 180 procedures (12.8%). Multivariate analysis demonstrated that lower preoperative GCS (OR = 0.91; 95% CI: 0.84–0.99; p = 0.019) and surgeon inexperience (OR = 1.93; 95% CI: 1.10–3.51; p = 0.026) were independent predictors of MIOR. MIOR was strongly associated with poor functional outcome at one year (OR = 3.21; 95% CI: 1.74–5.93; p < 0.001).

Conclusion: Preoperative neurological status and surgeon experience are key determinants of intraoperative rupture risk during aneurysm clipping. MIOR significantly worsens long-term functional outcomes, emphasizing the importance of risk stratification, surgical expertise, and structured training to improve patient prognosis.

Keywords: Glasgow Coma Scale, Intracranial aneurysm, Intraoperative rupture, Microsurgical clipping, Predictors, Surgical experience.

Introduction

Intracranial aneurysms are pathological dilatations of cerebral arteries that carry a significant risk of rupture, often resulting in subarachnoid hemorrhage (SAH), a condition associated with high morbidity and mortality rates [1]. Despite advancements in diagnostic techniques and treatment modalities, intracranial aneurysms remain a major challenge in neurosurgical practice due to their unpredictable clinical course and potential for catastrophic complications. Microsurgical clipping continues to be a definitive treatment option for both ruptured and unruptured aneurysms, particularly in complex anatomical cases, despite the increasing use of endovascular techniques [2].

Although improvements in microsurgical techniques, perioperative care, and neuroanesthesia have enhanced surgical outcomes, the procedure remains technically demanding and carries a risk of serious intraoperative complications [3]. Among these, intraoperative rupture (IOR) is considered one of the most feared and potentially devastating events. It may occur during dissection, manipulation, or clip application, leading to sudden massive hemorrhage, brain swelling, prolonged operative time, and increased technical difficulty [4]. Importantly, IOR is strongly associated with poor neurological outcomes, increased morbidity, and higher mortality rates [5].

The reported incidence of intraoperative rupture varies widely in the literature, ranging from 8% to 35%, depending on patient characteristics, aneurysm morphology, and surgical expertise [6]. Several studies have attempted to identify factors associated with increased risk of IOR, including patient age, aneurysm size and location, rupture status at presentation, and preoperative neurological condition [7]. Additionally, surgeon experience has been recognized as a critical determinant influencing both the likelihood of rupture and the ability to effectively manage it intraoperatively [8].

Despite these findings, there remains a lack of consensus regarding the most reliable predictors of intraoperative rupture, and limited data exist on how these predictors translate into long-term functional outcomes [9]. Understanding these relationships is essential for improving preoperative risk assessment, optimizing surgical planning, and enhancing patient safety.

Given the significant clinical implications of intraoperative rupture, the present study aims to evaluate the predictors of major intraoperative rupture (MIOR) during microsurgical clipping of intracranial aneurysms and to assess its impact on one-year postoperative functional outcomes. By examining the role of preoperative neurological status, aneurysm characteristics, and surgeon experience, this study seeks to provide clinically relevant insights that may contribute to improved surgical decision-making and better patient outcomes [10].

Methodology

Study Design

This investigation was conducted as a retrospective cohort study at the Department of Neurosurgery, Hayatabad Medical Complex, Peshawar, over a defined study period from December 2022 to March 2024. The primary objective was to identify predictors of major intraoperative rupture (MIOR) during microsurgical clipping of intracranial aneurysms and to evaluate its association with postoperative functional outcomes at one year. The retrospective design enabled comprehensive evaluation of routinely collected clinical and operative data to explore real-world surgical outcomes and complications.

Ethics

The study protocol received formal approval from the Institutional Review Board (IRB) of Hayatabad Medical Complex (Approval No. 2796). All procedures were conducted in accordance with established ethical standards and institutional guidelines. Informed consent had been obtained from all participants prior to their inclusion in clinical care, and patient confidentiality was strictly maintained throughout data handling and analysis.

Setting

The study was carried out in a tertiary care neurosurgical center, Hayatabad Medical Complex, Peshawar, which serves as a major referral hospital for neurosurgical cases in the region. The institution provides advanced surgical facilities and specialized neurosurgical expertise, ensuring standardized operative protocols and postoperative care for patients undergoing intracranial aneurysm clipping.

Participants

A total of 168 patients who underwent 180 microsurgical clipping procedures for intracranial aneurysms were included in the study. Both ruptured and unruptured aneurysms were considered. Inclusion criteria comprised patients with radiologically confirmed intracranial aneurysms who underwent microsurgical clipping within the study period. Patients treated with endovascular techniques, those with incomplete clinical records, or those lost to follow-up prior to one-year outcome assessment

were excluded. Because intraoperative rupture is a procedure-specific event, each surgical procedure was treated as an independent unit of analysis. In cases where multiple aneurysms were clipped in a single patient, each procedure was analyzed separately, acknowledging potential clustering effects inherent in retrospective designs.

Variables

The study evaluated a combination of demographic, clinical, and surgical variables. These included patient age, sex, preoperative neurological status assessed using the Glasgow Coma Scale (GCS), rupture status of the aneurysm at presentation, and surgeon experience. Surgeon experience was categorized based on predefined criteria, including years of independent surgical practice and the number of aneurysm clipping procedures performed. The primary dependent variable was the occurrence of major intraoperative rupture (MIOR), while secondary outcomes included postoperative functional status at one year, assessed using the modified Rankin Scale (mRS).

Data Sources/Measurement

Data were extracted from hospital electronic medical records, operative notes, anesthetic charts, and perioperative documentation. MIOR was rigorously defined as aneurysmal rupture occurring during surgical dissection or clip application leading to uncontrolled bleeding requiring temporary clipping, adenosine-induced flow arrest, prolonged hemostasis exceeding 10 minutes, or estimated blood loss ≥300 mL. This standardized definition minimized subjective variability in identifying intraoperative rupture events. Postoperative outcomes were assessed through follow-up clinical records, with mRS scores categorized into favorable (0–2) and unfavorable outcomes (3–6). Due to incomplete documentation, aneurysm-specific variables such as size, location, neck configuration, and radiological grading scales (e.g., Fisher grade, Hunt–Hess/WFNS classification) were not included in the multivariable analysis.

Bias

Several potential sources of bias were considered. Selection bias was minimized by including all eligible consecutive cases during the study period. However, information bias may exist due to reliance on retrospective data recording. The absence of detailed aneurysm morphological variables introduces the possibility of residual confounding, particularly in evaluating the effect of surgeon experience. Additionally, because some patients underwent multiple procedures, clustering effects may violate the assumption of independence, although this was considered minimal given the low frequency of such cases.

Study Size

The study included 180 surgical procedures performed in 168 patients. The sample size was determined by the total number of eligible cases during the study period rather than a priori calculation. While sufficient for primary analyses, the relatively small number of MIOR events (n = 23) necessitated cautious model selection to avoid overfitting in multivariable regression analysis.

Quantitative Variables

Continuous variables such as age and GCS scores were analyzed as numerical data, with GCS additionally treated as an ordinal predictor in regression models. Categorical variables included sex, aneurysm rupture status, surgeon experience, and MIOR occurrence. Outcome variables were dichotomized into clinically meaningful categories (e.g., favorable vs. unfavorable mRS outcomes) to facilitate interpretation and statistical modeling.

Statistical Methods

Descriptive statistics were used to summarize baseline characteristics, with continuous variables presented as mean ± standard deviation or median (range), and categorical variables as frequencies and percentages. Comparative analyses were performed using the chi-square test for categorical variables and Student's t-test for continuous variables. Univariate logistic regression analysis was initially conducted to identify potential predictors of MIOR. Variables demonstrating statistical significance ($p < 0.05$) were subsequently included in a multivariate logistic regression model. Given the limited number of outcome events, the number of predictors in the multivariable model was restricted in accordance with the events-per-variable principle to reduce the risk of overfitting. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated, and statistical significance was defined as $p < 0.05$. All analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Due to sample size limitations, advanced clustering methods such as generalized estimating equations or mixed-effects modeling were not applied, and this limitation was acknowledged in the interpretation of results.

Results

Participants

A total of 168 patients undergoing 180 microsurgical clipping procedures for intracranial aneurysms were included in the final analysis. Each surgical procedure was treated as an independent observational unit due to the procedure-specific nature of major intraoperative rupture (MIOR). A small proportion of patients underwent multiple procedures; however, the number was limited and did not substantially affect the overall distribution. A few patients were excluded from the one-year outcome analysis due to loss to follow-up. The overall study flow and participant distribution are summarized in Table 1.

Descriptive Data

The study cohort comprised 64 male (38.1%) and 104 female (61.9%) patients, with a mean age of 55.4 ± 13.7 years (range: 15–86 years). Among the 180 procedures, the majority were performed for ruptured aneurysms (85.6%), while 14.4% involved unruptured aneurysms. Major intraoperative rupture (MIOR) occurred in 23 procedures, yielding an overall incidence of 12.8%.

Baseline comparisons between procedures with and without MIOR demonstrated that patients experiencing MIOR had a significantly lower median preoperative Glasgow Coma Scale (GCS) score (13 vs. 15, $p = 0.002$). Additionally, MIOR was more frequently observed in procedures performed by less experienced surgeons (74% vs. 56%, $p = 0.009$) and in cases involving ruptured aneurysms (91.3% vs. 84.7%, $p = 0.044$). No statistically significant differences were observed with respect to age or gender distribution. Detailed baseline characteristics and comparisons are presented in Table 1.

Outcome Data

The primary outcome of interest, MIOR, was identified in 23 of 180 procedures. Regarding secondary outcomes, functional status at one year was assessed using the modified Rankin Scale (mRS). Patients with lower preoperative GCS scores, those operated on by less experienced surgeons, and those experiencing MIOR demonstrated a higher likelihood of poor functional outcomes (mRS 3–6).

Specifically, MIOR was strongly associated with adverse postoperative prognosis, with a significantly higher proportion of poor outcomes observed among affected cases. Furthermore, surgeon experience appeared to influence both intraoperative complication rates and postoperative recovery, as poorer outcomes were more frequently noted in procedures performed by less experienced surgeons. The relationship between MIOR and one-year functional outcomes is summarized in Table 3 and Table 4.

Main Results

In univariate analysis, lower preoperative GCS score, surgeon inexperience, and aneurysm rupture at presentation were identified as significant predictors of MIOR. However, in multivariate logistic regression analysis, only preoperative GCS and surgeon experience remained independent predictors.

A one-point increase in preoperative GCS was associated with a 9% reduction in the odds of MIOR (OR = 0.91; 95% CI: 0.84–0.99; $p = 0.019$), indicating a protective effect of better neurological status. Conversely, procedures performed by less experienced surgeons were associated with nearly double the risk of MIOR compared to those performed by experienced surgeons (OR = 1.93; 95% CI: 1.10–3.51; $p = 0.026$). Although aneurysm rupture at presentation showed an increased odds ratio, it did not reach statistical significance in the multivariate model ($p = 0.187$). These findings are detailed in Table 2.

With respect to long-term outcomes, MIOR emerged as a strong independent predictor of poor functional outcome at one year, increasing the odds by more than threefold (OR = 3.21; 95% CI: 1.74–5.93; $p < 0.001$). Additionally, higher preoperative GCS remained a significant protective factor for favorable recovery (OR = 0.70 per point increase; 95% CI: 0.65–0.75; $p < 0.001$), while surgeon inexperience was associated with worse outcomes (OR = 1.90; 95% CI: 1.13–2.90; $p = 0.012$). These results are summarized in Table 3.

Further subgroup analysis demonstrated that MIOR occurred more frequently in procedures performed by inexperienced surgeons (16.2%) compared to experienced surgeons (8.0%), and the proportion of poor outcomes among MIOR cases was substantially higher in the inexperienced group (59% vs. 17%). These associations reinforce the combined impact of surgical expertise and intraoperative complications on patient prognosis and are illustrated in Table 4.

Table 1. Baseline Characteristics of Procedures and Risk Factors for Major Intraoperative Rupture (MIOR)

Variable		Total (n = 180) %	No MIOR (n = 157) %	MIOR (n = 23) %	p-Value
Age (years), mean ± SD		55.4 ± 13.7	55.4 ± 13.5	55.2 ± 15.5	0.904
Preoperative GCS, median (range)		15 (3–15)	15 (3–15)	13 (3–15)	0.002
Gender	**Male**	64	59	5	1.000
	Female	104	98	18	
Surgeon experience					0.009
Experienced		75 (42)	69 (44)	6 (26)	
Inexperienced		105 (58)	88 (56)	17 (74)	
Ruptured aneurysm					0.044
No		26 (14.4)	24 (15.3)	2 (8.7)	
Yes		154 (85.6)	133 (84.7)	21 (91.3)	

All percentages are calculated per procedure. Absolute counts are provided to ensure transparency of statistical comparisons.

Table 2. Multivariate Logistic Regression for Risk Factors of MIOR

Variable	OR	95% CI	p-Value
Inexperienced surgeon	1.93	1.10–3.51	0.026
Preoperative GCS	0.91	0.84–0.99	0.019
Ruptured aneurysm	2.06	0.78–7.10	0.187

Abbreviations: OR = odds ratio; CI = confidence interval; GCS = Glasgow Coma Scale; MIOR = major intraoperative rupture.

Table 3. Predictors of Poor Outcome at One Year

Variable	OR	95% CI	p-Value
Inexperienced surgeon	1.90	1.13–2.90	0.012
MIOR	3.21	1.74–5.93	<0.001
Preoperative GCS	0.70	0.65–0.75	<0.001

Table 4. Association Between MIOR and One-Year Functional Outcome

Surgeon Experience	MIOR	No MIOR	Total
Experienced	6	69	75
Inexperienced	17	88	105
Total	23	157	180

Discussion

In this retrospective cohort study, we identified lower preoperative Glasgow Coma Scale (GCS) scores and surgeon inexperience as independent predictors of major intraoperative rupture (MIOR) during microsurgical clipping of intracranial aneurysms. Furthermore, MIOR was found to be strongly associated with poor functional outcomes at one year. These findings emphasize the critical interplay between preoperative neurological status, surgical expertise, and intraoperative safety, ultimately influencing long-term patient prognosis [6,10].

The observed incidence of MIOR (12.8%) in our cohort falls within the range reported in previous literature, which varies widely depending on patient characteristics, aneurysm morphology, and institutional expertise [6]. While some studies report lower rates in selected populations, particularly for unruptured aneurysms, higher rates have been observed in more complex or high-risk cases [11]. This variability highlights the importance of contextual factors such as case mix and surgeon experience when interpreting incidence rates across different settings.

Preoperative neurological status, as assessed by GCS, emerged as a significant protective factor against MIOR. Patients presenting with higher GCS scores demonstrated a reduced likelihood of intraoperative rupture, suggesting that better baseline neurological condition may contribute to greater physiological stability and improved tolerance to surgical stress. This finding is consistent with previous studies demonstrating a strong association between GCS and surgical outcomes in aneurysm patients. For instance, Gotoh et al. reported a significant correlation between preoperative GCS and postoperative outcomes, with higher GCS scores predicting more favorable recovery [12]. Our results extend these findings by demonstrating that GCS not only predicts postoperative recovery but also influences intraoperative risk, reinforcing its value as a critical component of preoperative risk stratification.

Surgeon experience was another key determinant of MIOR in this study. Procedures performed by less experienced surgeons were associated with a significantly higher risk of intraoperative rupture. This observation aligns with prior research indicating that surgical expertise plays a pivotal role in minimizing intraoperative complications and managing unexpected events effectively [8,12]. Studies such as those by Tomatis et al. have demonstrated that increased surgical experience is associated with lower rates of intraoperative rupture and improved patient outcomes, reflecting the cumulative benefits of technical skill development and clinical decision-making [13]. Similarly, long-term analyses have shown a decline in intraoperative rupture rates with increasing surgeon experience, underscoring the importance of structured training and mentorship [14].

Interestingly, although aneurysm rupture at presentation was associated with MIOR in univariate analysis, it did not remain significant in the multivariate model. This suggests that factors such as neurological status and surgical expertise may exert a stronger independent influence on intraoperative risk. Previous studies have reported mixed findings regarding the role of rupture status as a predictor of intraoperative complications [14], and our results support the notion that its effect may be confounded by other clinical variables.

The prognostic impact of MIOR on long-term outcomes was substantial in this study. Patients experiencing MIOR had a markedly increased likelihood of poor functional outcomes at one year, with more than a threefold increase in risk. This finding is consistent with existing literature demonstrating the detrimental effects of intraoperative rupture on neurological recovery and survival [5,15]. MIOR can lead to significant intraoperative instability, prolonged operative time, and secondary brain injury, all of which contribute to poorer outcomes. The observed association between surgeon experience, MIOR, and postoperative prognosis further highlights the importance of technical expertise not only in preventing complications but also in mitigating their consequences when they occur.

The findings of this study reinforce the need for comprehensive preoperative assessment and strategic surgical planning. Identifying high-risk patients based on neurological status and ensuring that complex cases are managed by experienced surgeons may significantly reduce the incidence of MIOR and improve long-term outcomes.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the retrospective design inherently introduces the possibility of selection bias and information bias due to reliance on existing medical records. Although efforts were made to include all eligible cases within the study period, incomplete or inconsistent documentation may have influenced data accuracy. Second, this was a single-center study conducted in a tertiary care institution, which may limit the generalizability of the findings to other settings with different patient populations, surgical practices, or resource availability. While the sample size was adequate for primary analyses, it may not have been sufficient to detect less common predictors or subtle associations.

A significant limitation of this study is the absence of detailed aneurysm-specific variables, including aneurysm size, location, neck configuration, and radiological grading systems such as Fisher grade or Hunt–Hess/WFNS classification. These factors are well-recognized contributors to intraoperative rupture risk and postoperative outcomes. Their exclusion from multivariable analysis may have resulted in residual confounding, particularly in assessing the impact of surgeon experience.

Additionally, the unit of analysis was the surgical procedure rather than the individual patient, as some patients underwent multiple procedures. This introduces potential clustering effects and may violate the assumption of independence in statistical analysis. Although the proportion of such cases was small, advanced statistical methods such as mixed-effects modeling or generalized estimating equations could not be applied due to the limited number of outcome events. Consequently, standard errors may have been underestimated.

Finally, surgeon experience was categorized based on years of practice and number of procedures performed, which may not fully capture other relevant aspects such as subspecialty training, technical proficiency, or case complexity. Future studies incorporating more granular measures of surgical expertise may provide a more comprehensive understanding of its impact.

Conclusion

This retrospective cohort study demonstrates that lower preoperative Glasgow Coma Scale (GCS) scores and surgeon inexperience are independent predictors of major intraoperative rupture (MIOR) during microsurgical clipping of intracranial aneurysms. MIOR, in turn, is strongly associated with a significantly increased risk of poor functional outcomes at one year. These findings underscore the critical importance of preoperative neurological assessment and surgical expertise in minimizing intraoperative complications and improving patient prognosis. Risk stratification based on GCS and careful case allocation to experienced surgeons may play a key role in reducing the incidence of MIOR.

Authors' Contributions:

All authors meet the ICMJE criteria for authorship.

Author 1: Substantial contribution to conception and design, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 2: Substantial contribution to conception and design, data acquisition, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 3: Analysis and interpretation of data, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 4: Analysis and interpretation of data, critical revision, final approval, agreed to be accountable for all the work.

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