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Review article

Natural history of small incidental intracranial aneurysms: a systematic review and pooled analysis on the influence of follow-up duration and aneurysm location on rupture risk reporting

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ABSTRACT

Background: The rising detection of small unruptured intracranial aneurysms (sUIAs) poses a clinical challenge, requiring careful consideration between the low but real risk of rupture and the potential morbidity of intervention. Reported rupture rates vary widely across studies, influenced by heterogeneity in design, patient selection, aneurysm location, and follow-up duration. This study assessed how aneurysm location and follow-up length affect rupture rates in untreated sUIAs.

Methods: A systematic review and *meta*-analysis were conducted in line with PRISMA guidelines and registered with PROSPERO (CRD42024601692). Four databases (EMBASE, Ovid MEDLINE, EMCARE, Scopus) were searched for studies from January 2000 onwards reporting longitudinal outcomes for ≥20 untreated sUIAs ≤ 5 mm. The primary outcome was the pooled rupture rate, stratified by location and follow-up duration. Secondary analysis examined aneurysm growth. A random-effects model was used for *meta*-analysis, with heterogeneity assessed using the I^2 statistic. Sensitivity analyses evaluated the robustness of findings.

Results: From 10,694 screened records, 28 studies met inclusion criteria, encompassing 10,495 untreated sUIAs ≤ 5 mm. Over a mean follow-up of 38 months, 97 aneurysms ruptured, yielding a pooled rupture rate of 0.8 % (95 % CI, 0.6–1.2). Rupture risk did not significantly differ by location (p = 0.31): 1.1 % for middle cerebral artery, 3.9 % for anterior cerebral artery, and 0.3 % for *para*-ophthalmic artery aneurysms. Rupture rates remained consistent across follow-up durations (p = 0.53): 0.8 % for <20 months, 0.8 % for 20–40 months, and 1.2 % for >40 months. Although aneurysm growth appeared more frequent with longer follow-up, this was not statistically significant (p = 0.64).

Conclusion: This updated *meta*-analysis, incorporating novel subgroup analyses by location and follow-up duration, confirms that rupture risk for sUIAs ≤ 5 mm remains low (<1%) over an average 38-month period. However, limited long-term data restrict accurate risk estimation beyond this timeframe, and underreporting of aneurysm location impairs site-specific risk assessment. The trend towards greater aneurysm growth with extended follow-up underscores the importance of continued surveillance.

1. Introduction

Decisions surrounding the management of incidental small unruptured intracranial aneurysms (sUIAs) are inherently complex, posing a clinical challenge in balancing their low but non-negligible rupture risk against the morbidity associated with intervention [1–5]. Traditional models, such as the PHASES score, primarily emphasise aneurysm size as the key determinate of rupture risk [6]. The ISUIA study suggested a 0 %

Abbreviations: sUIAs, Small unruptured intracranial aneurysms; UIAs, Unruptured intracranial aneurysms; SAH, Subarachnoid hemorrhage; PHASES, Population, Hypertension, Age, Size of aneurysm, Earlier SAH, Site of aneurysm; NOS, Newcastle-Ottawa Scale; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; CI, Confidence interval; RCT, Randomized controlled trial; I^2, Inconsistency index (measure of heterogeneity); OR, Odds ratio; RoB 2, Cochrane Risk of Bias; ROBINS 1, Risk Of Bias In Non-randomized Studies.

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rupture risk for anterior circulation aneurysms smaller than 7 mm in patients without a prior subarachnoid haemorrhage, thereby supporting conservative management for such lesions [7].

However, emerging evidence questions the validity of a size-based treatment paradigm. Small aneurysms (≤5 mm) are implicated in up to 51 % of aneurysmal subarachnoid haemorrhages (aSAH), challenging the assumption of benignity for these lesions [2,8–10]. Furthermore, aneurysm size does not correlate with the severity of clinical outcomes, indicating that size alone is not an adequate predictor of rupture risk [11]. This paradox underscores the need for comprehensive understanding of aneurysm risk factors and contributors to reported rupture risk.

Recent studies suggest that factors such as aneurysm location, morphology, prior subarachnoid haemorrhage, and patient-specific characteristics significantly influence rupture risk [12,13]. However, inconsistent reporting of aneurysm characteristics, especially location and morphology, limits the development of reliable rupture-risk algorithms. Anteriorly located aneurysms, for example, rupture at smaller sizes, reinforcing the need for location-specific risk analysis [8]. Variability in follow-up duration further complicate rupture risk estimates, with short term studies potentially underestimating risk, as evidenced by the only long-term study on unruptured intracranial aneurysms, which reported one of the highest rupture risks in the literature [14]. The lack of long-term data limits evidence-based guidance on optimal follow-up duration and cumulative rupture risk [13].

Previous *meta*-analyses have sought to quantify rupture risk of sUIAs, but their methodological heterogeneity and lack of long-term follow-up have hindered generalizability [6,12,15]. Consequently, the natural history of sUIAs remains poorly defined. This study aims to address these gaps by systematically evaluating the rupture risk of sUIAs ≤ 5 mm, stratified by aneurysm location and follow-up duration, with secondary analyses focusing on aneurysm growth over time.

2. Methods

2.1. Search strategy

This systematic review was prospectively registered with PROSPERO (CRD42024601692) and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16]. A comprehensive search of EMBASE, Ovid MEDLINE, EMCARE, and Scopus was performed on October 16, 2024, to identify studies published between January 2000 and October 2024 that reported on the natural history of conservatively managed small unruptured intracranial aneurysms. The search strategy is available in the supplementary material. Reference lists and citations of included studies were manually screened to identify additional eligible articles. All records were uploaded to Covidence for systematic screening, with two independent reviewers (LD and CR) assessing study eligibility. Discrepancies were resolved through discussion with the senior author (LL).

2.2. Selection and eligibility

Studies were included if they investigated the natural history of sUIAs measuring ≤5 mm and reported on at least 20 aneurysms. This threshold was implemented to reduce the risk of exaggerated or unstable effect estimates commonly associated with small sample sizes and to improve the precision and generalizability of pooled results. Eligible study designs included randomized and non-randomized control trials, prospective and retrospective cohort studies, and case-control studies. Studies were excluded if they did not explicitly report the number of aneurysms ≤5 mm, were published before 2000, were non-English, or focused exclusively on specific conditions such as Moyamoya disease. Abstracts, case reports, conference proceedings, editorials, and review articles were also excluded to minimise publication bias. In cases of overlapping datasets, the study providing the most comprehensive and detailed data was selected to avoid unit-of-analysis errors and ensure accurate representation in pooled analyses.

2.3. Data extraction and risk of bias assessment

Two independent reviewers (LD and CR) extracted data using a pre-specified standardized datasheet, ensuring accuracy and consistency through cross-verification. Extracted variables included study author, publication year, study period, country of origin, inclusion and exclusion criteria, total number of patients and aneurysms, mean age, sex distribution, presence of multiple aneurysms, prior subarachnoid haemorrhage (SAH), aneurysm location, mean follow-up duration, number of patients lost to follow-up, total ruptures, time to rupture and aneurysm growth.

The methodological quality of observational studies was assessed using the Newcastle-Ottawa Scale (NOS), evaluating selection bias, comparability, and outcome assessment. Studies were assigned scores from 0 to 9, with scores below 5 indicating a high risk of bias. For randomised studies, Cochrane Risk of Bias (RoB 2) tool was applied, while the Risk of Bias In Non-randomized Studies (ROBINS 1) tool was used for non-randomized studies to provide an overall risk assessment.

Quality assessments were independently conducted by two reviewers based on pre-defined acceptability criteria for each tool. Discrepancies were resolved through discussion, and if consensus could not be reached, a third senior reviewer adjudicated the final decision to minimise subjective bias. To further assess the robustness of the findings, a sensitivity analysis was performed to evaluate the impact of study exclusion on pooled results, providing insight into the influence of study quality on overall conclusions.

2.4. Outcome

The primary outcome was the rupture rate of small aneurysms, stratified by anatomical location and follow up duration. Follow-up time was evaluated both as a continuous and categorical variable. Meta-regression was performed to assess follow-up duration as a continuous moderator of rupture risk. For categorical analysis, studies were grouped into three retrospectively defined follow-up intervals to ensure balanced distribution across clinically relevant timeframes. Rupture rates were further stratified by anatomical location within pre-specified categories, including the anterior communicating artery, middle cerebral artery, and posterior circulation. The secondary outcome was aneurysm growth, assessed in relation to follow-up duration. For studies reporting rupture rates per patient rather than per aneurysm, aneurysm counts were estimated based on the proportion of multiple aneurysms within each cohort. Aneurysms were classified according to their initial size, and when follow-up data specific to aneurysms measuring 5 mm or less were not available, cohort-level follow-up duration was used.

2.5. Study selection

Following the removal of duplicates, the search strategy identified 10,694 studies. After title and abstract screening, 200 articles underwent full-text review, of which 28 met the inclusion criteria. The study selection process and reasons for exclusion are detailed in Fig. 1.

2.6. Statistical analysis

Rupture rates were expressed as ruptures per 100 aneurysms or percentages. Data synthesis was performed using a random-effects generalized linear model with logit transformation, applying maximum-likelihood estimation to quantify between-study variance (τ^2). A random effects model was chosen due to the variability, both of patient and aneurysm factors, which likely underscore the rupture and growth rate of aneurysms ≤5 mm. Confidence intervals were calculated using the Wilson method to ensure robust interval estimation.

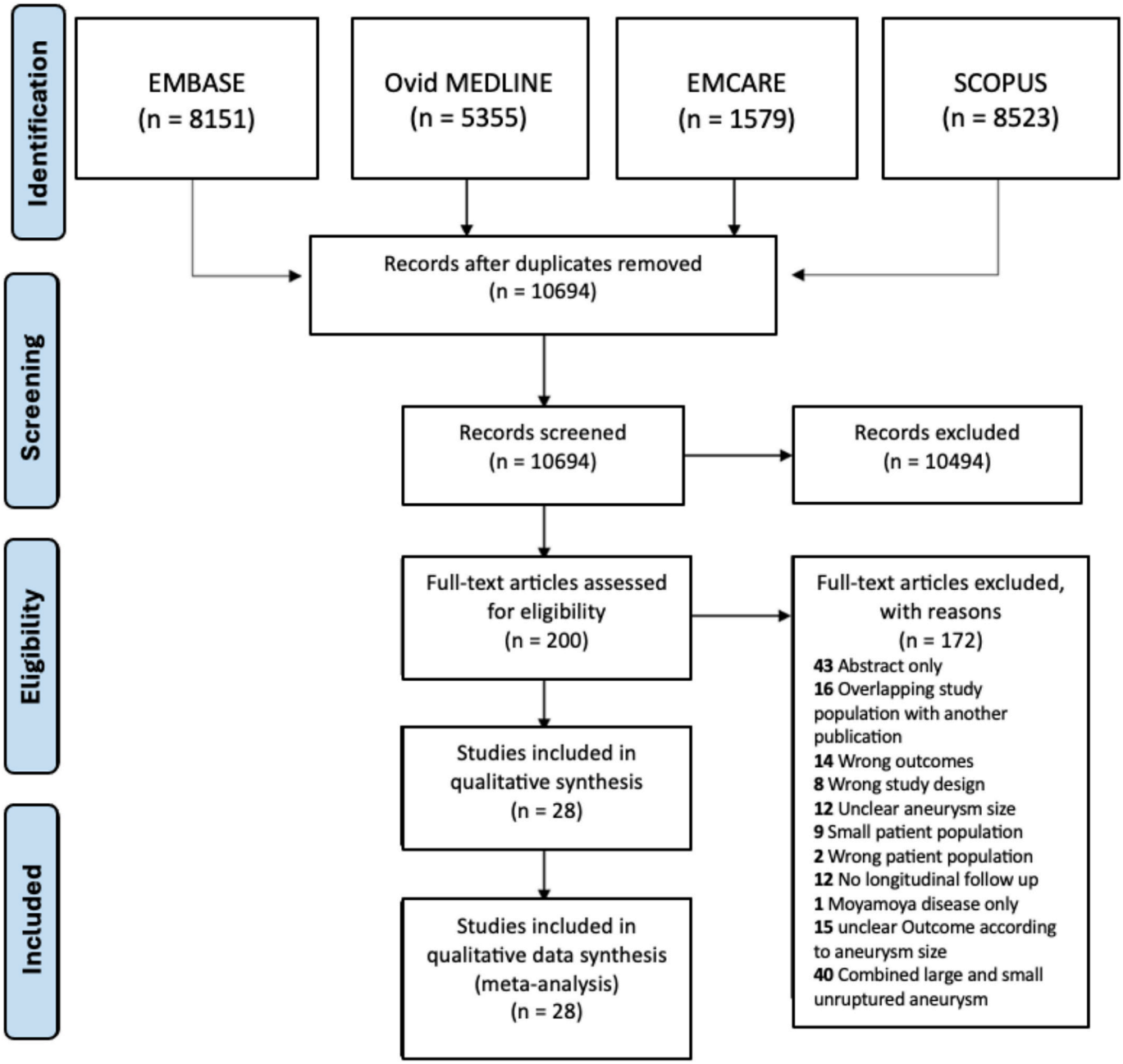

Fig. 1. PRISMA flowchart of study inclusion pathway.

Heterogeneity across studies was assessed with the I^2 statistic, with thresholds of low (<25 %), moderate (25–50 %), and high (>50 %) heterogeneity. When heterogeneity was high, both qualitative and quantitative analyses were conducted. Sensitivity analyses were performed to assess the influence of individual studies on pooled estimates, evaluating the impact of leave-one-out analysis on effect size and heterogeneity. Due to the absence of raw patient-level data, *meta*-regression to adjust for potential confounders was not conducted. All statistical analyses were conducted using R (version 4.3.3, February 2024). A two-sided significance threshold of $p < 0.05$ was applied for all tests.

3. Results

3.1. Study characteristics

The characteristics of the 28 included studies are summarised in Table 1. These studies encompassed diverse populations across multiple geographic regions, with most (n = 17) being retrospective in design. All were observational studies except for two clinical trials that evaluated the impact of mineralocorticoid blockers [17] and statins [18] on rupture risk of sUIAs. The study period ranged from 1976 to 2022, with 16 studies published within the last decade.

A total of 10,495 sUIAs ≤ 5 mm were identified. However, demographic and clinical characteristics specific to small aneurysms were inconsistently reported. Across a broader cohort of 11,920 patients, including those with aneurysms larger than 5 mm, the mean age was 57.4 years. A prior subarachnoid haemorrhage was reported in 5.6 % (617/10828) of cases, while 22.1 % (2340/10599) had multiple aneurysms.

Table 1
Characteristics of included studies and distribution of aneurysm sizes.

Author, Year	Patients (n)	Female (%)	Total Aneurysms	No. of Aneurysms ≤5 mm (%)	Mean Age (years)	Mean/Median Follow Up reported (months)	NOS total
Tsutsumi 2000 (1)	62	33 (53)	83	66 (80)	70.8	51.6	6
Matsubara 2004 (2)	140	96 (69)	166	125 (75)	62.8	17.7	7
Tsukahara 2005 (3)	181	NR	209	107 (51)	NR	NR	5
Wermer 2006 (4)	93	70 (75)	125	125 (100)	51	19.2	6
Broderick 2009 (5)	113	75 (66)	148	94 (75)	51.4	NR	6
Sonobe 2010 (6)	374	238 (64)	448	448 (100)	61.9	42.5	8
So 2010 (7)	208	154 (74)	285	213 (75)	51.1	21.8	7
Irazabal 2011(8)	38	23 (61)	45	34 (76)	NR	94.8	6
Morita 2012 (9)	2998	2480 (68)	3647	2000 (55)	65	20.9	7
Guresir 2013 (10)	263	204 (78)	384	284 (74)	55	48.5	6
Ishibashi 2013 (11)	603	527 (87)	741	534 (72)	NR	23.08	7
Matsumoto 2013 (12)	111	65 (59)	136	79 (58)	65	NR	7
Bor 2014 (13)	363	NR	468	269 (57)	NR	25.2	5
Jeon 2014 (14)	524	410 (78)	568	568 (100)	59.4	35.4	6
Serrone 2016 (15)	192	152 (79)	234	48 (21)	61.1	38.4	8
Murayama 2016 (16)	1556	1334 (86)	1960	1717 (88)	66	46.2	8
Nagahiro 2018 (17)	80	59 (74)	88	62 (70)	68	21.3	Moderate risk of bias (ROBINS I)
Molenberg 2019 (18)	206	153 (74)	267	186 (70)	NR	12.0	6
Chien 2020 (19)	382	315 (82)	520	361 (69)	61.8	32.7	6
Huang 2020 (20)	193	144 (75)	255	136 (53)	NR	58.2	7
Yoshida 2021 (21)	209	133 (64)	247	247 (100)	NR	36	6
Weng 2021 (22)	1866	820 (44)	1866	1732 (93)	61.9	NR	Some concerns (RoB 2)
Kwon 2021 (23)	147	58 (39)	169	93 (55)	54	54.0	8
Aubertin 2022 (24)	536	469 (88)	662	396 (60)	55.7	51.3	8
Wojtowicz 2023 (25)	64	40 (63)	64	49 (77)	NR	71.5	7
Spencer 2023 (26)	274	208 (76)	445	324 (73)	54.8	75.0	8
Villamizar 2024 (27)	112	NR	150	150 (100)	NR	NR	6
Khatri 2024 (28)	32	15 (47)	49	48 (98)	14.69	61.0	4

NR; Not Reported, NOS; Newcastle-Ottawa Score, ROBINS; Risk of Bias In Non-randomized Studies, RoB 2; Risk of Bias 2.
Above values relate to all untreated aneurysms of included papers, not always specific to small aneurysms (≤5mm).

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3.2. Quality assessment

The quality of the included studies is summarised in Table 1. Among observational studies, the mean NOS score was 6.5 (range: 4–8). Three studies were classified as fair-quality, with the remainder considered high-quality. However, none achieved the maximum score of 9, as no study had a follow-up period exceeding 12 years. The two randomized studies were assessed as having moderate bias, both with follow up durations of less than 12 years.

Fig. 2 illustrates the distribution of population size and follow up duration across included studies. Ten studies [19–28] did not report mean follow-up duration, though seven provided median follow-up times ranging from 12 months to 75 months. Four studies [20,24,27,28] did not report any follow-up duration. For subgroup analysis, studies reporting a mean follow-up length were categorised into three groups: less than 20 months, 20 to 40 months, and greater than 40 months. The shortest reported mean follow-up was 17.7 months [29]. The longest was 94.8 months (7.9 years), reported by Irazabal et al. [30], in a study evaluating 34 small aneurysms in patients with polycystic kidney disease.

3.3. Data synthesis

3.3.1. Rupture and growth rate

Across the 28 studies, 97 ruptures were reported among 10,495 untreated UIAs measuring ≤5 mm, resulting in a pooled rupture rate of 0.8 % (95 % CI: 0.6–1.2) over a mean follow-up period of 38.4 months (Fig. 3). Heterogeneity across studies was low (I^2 = 0 %, p = 0.8), indicating consistency in reported rupture rates.

Sixteen studies reported growth rates for untreated sUIAs, yielding a pooled growth rate of 4.8 % (95 % CI: 2.9–7.9) over a mean follow up period of 37.6 months. Heterogeneity was high (I^2 = 85 %, p < 0.01), indicating substantial variability in reported rates across studies. Sensitivity analysis demonstrated that this heterogeneity was not driven by a single study (Supplementary material, Fig. 1).

3.3.2. Follow-up duration

The upper panel of Fig. 4 presents rupture rates stratified by follow-up duration. Rupture risk was highest in aneurysms followed for more than 40 months (1.2 %, 95 % CI: 0.8–1.8), while studies not reporting mean follow-up duration recorded the lowest rupture rate of 0.6 % (95 % CI: 0.2–1.4). Follow-up duration did not significantly influence rupture risk in subgroup analysis (p = 0.53), or when assessed as a

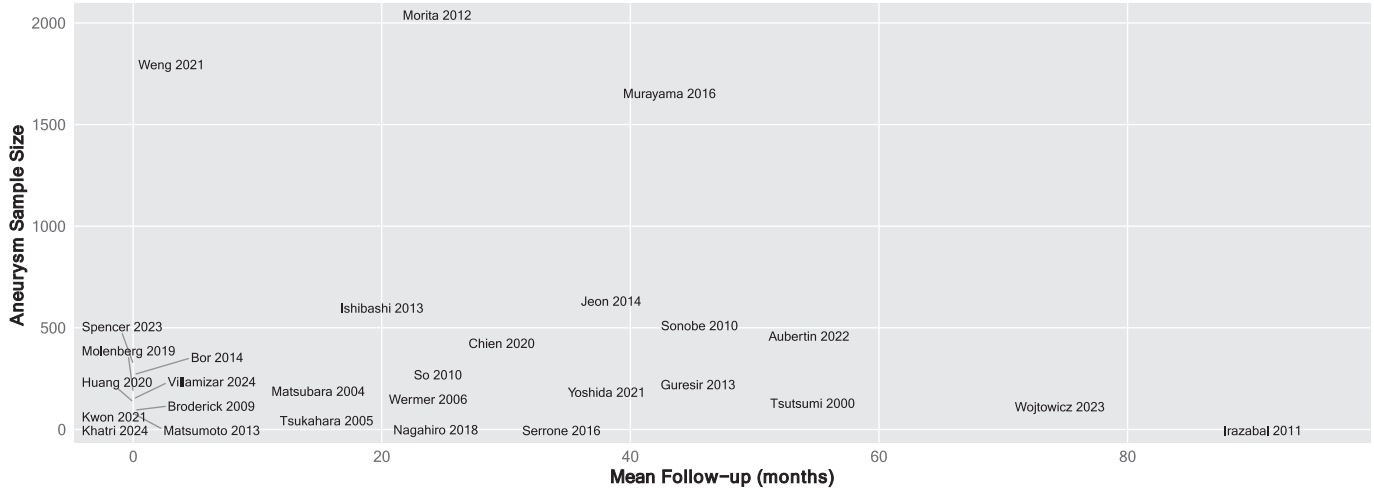

Fig. 2. Study sample size by length of follow-up.

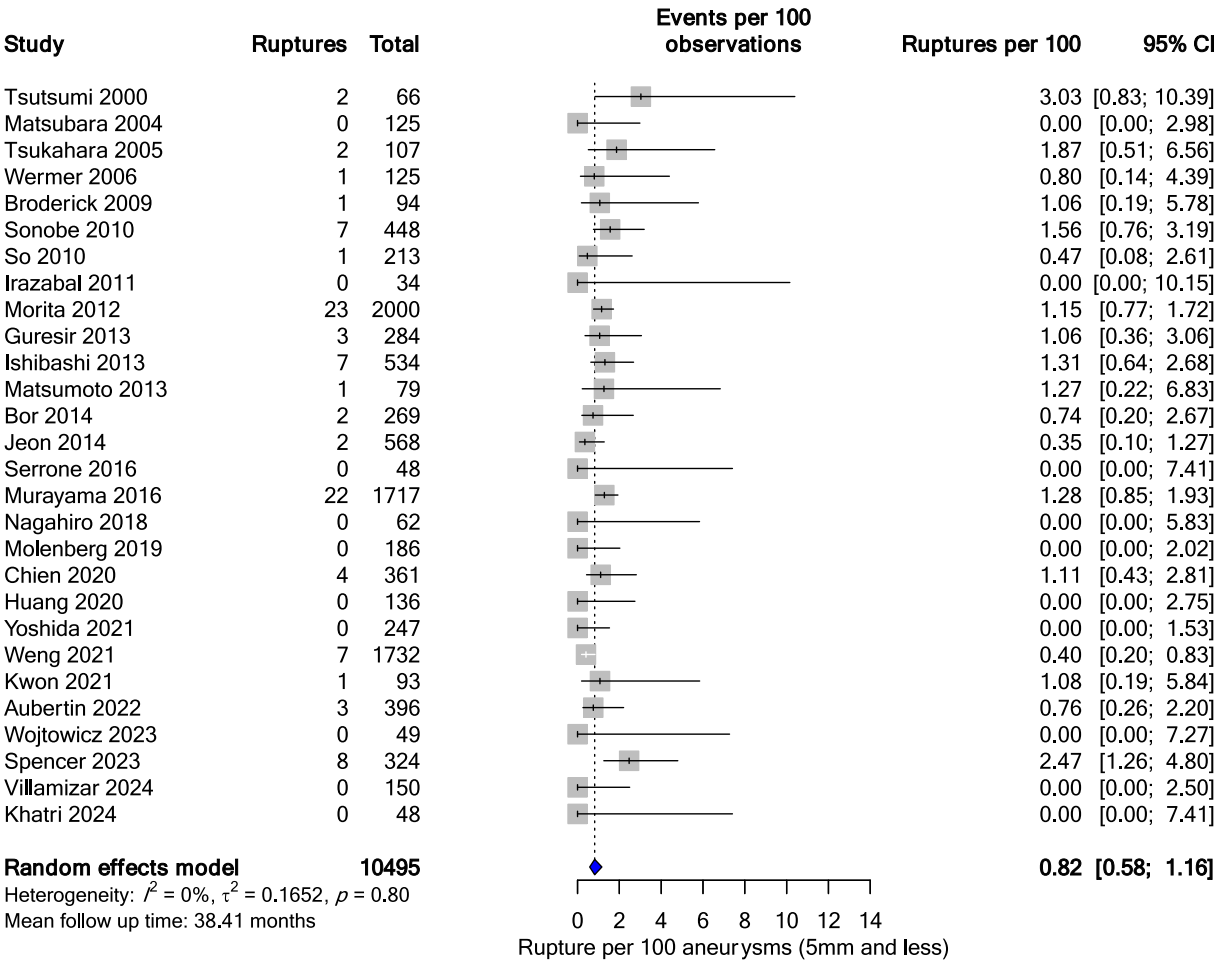

Fig. 3. Forest plot of rate of rupture for small unruptured intracranial aneurysms ≤5 mm.

continuous variable (p = 0.56).

The lower panel of Fig. 4 illustrates the relationship between aneurysm growth and follow-up duration. Aneurysms monitored for more than 40 months exhibited the highest growth rate of 6.6 % (95 % CI; 0.7–42.1), compared to 2.4 % (95 % CI; 1.1–5.1) in those followed for less than 20 months. However, this difference was not statistically significant (p = 0.64), and follow-up duration was not a significant moderator of growth rate effect size in *meta*-regression analysis (p = 0.43).

Additionally, rupture and growth rates remained consistent when studies were grouped into tertiles based on follow-up duration (Supplementary material, Fig. 2).

3.3.3. Anatomical location

Eight studies reported aneurysm location, comprising 1,748 untreated sUIAs and 12 documented ruptures. Rupture risk by anatomical location is presented in Fig. 5. Aneurysms arising from the anterior cerebral artery exhibited the highest rupture rate of 3.9 % (95 % CI; 0.4–28.4); however, the wide confidence interval reflects substantial uncertainty attributable to limited sample size. Subgroup analysis did not demonstrate a statistically significant difference in rupture rates by location (p = 0.31), and heterogeneity across location-based subgroups was low (I^2 = 0 %). Data was insufficient to calculate posterior circulation aneurysm rupture risk. Additionally, no studies reported aneurysm growth rates stratified by anatomical location, precluding further analysis in this domain.

4. Discussion

This *meta*-analysis of 10,495 untreated sUIAs ≤ 5 mm across 28 studies estimated a pooled rupture risk of 0.82 % (95 % CI: 0.58–1.16) over a mean follow-up of 38.4 months. This estimate is comparable to the 0.81 %-1.27 % range reported by Chandra et al. [31] over a slightly longer follow-up period of 42 months. The inclusion of 11 additional studies [17,18,22,23,26–28,32–35], five of which were published after the Chandra et al. review, contributed 1694 untreated sUIAs to the dataset, further reinforcing the stability of these estimates.

Despite pooled calculations, long-term rupture risk of sUIAs remains uncertain. Subgroup analysis by follow-up length likely failed to reveal differences in rupture risk as most available data is limited to short-term follow-up, averaging 38 months, with small patient populations. Follow-up periods rarely exceeded 50 months, inhibiting extrapolation of reported risk to one's lifetime. This duration is significantly shorter than the expected lifespan for patients diagnosed in middle age [36]. Only two studies [30,35] in this analysis followed patients for more than five years, collectively including 83 aneurysms with no recorded ruptures. These findings highlight the gaps of prolonged follow-up in the literature, and given the rarity of rupture events, future studies will require large patient cohorts to yield meaningful and precise conclusions.

The importance of long-term data is underscored by Korja et al. [14], who reported an estimated 25 % lifetime rupture risk over 21.6 years for aneurysms ≤7 mm, and a median time to rupture of 28.5 years. However, this estimate may be inflated due to population-specific factors, a small sample size, and outdated management practices that historically favoured observation over treatment. Given these limitations, stratifying

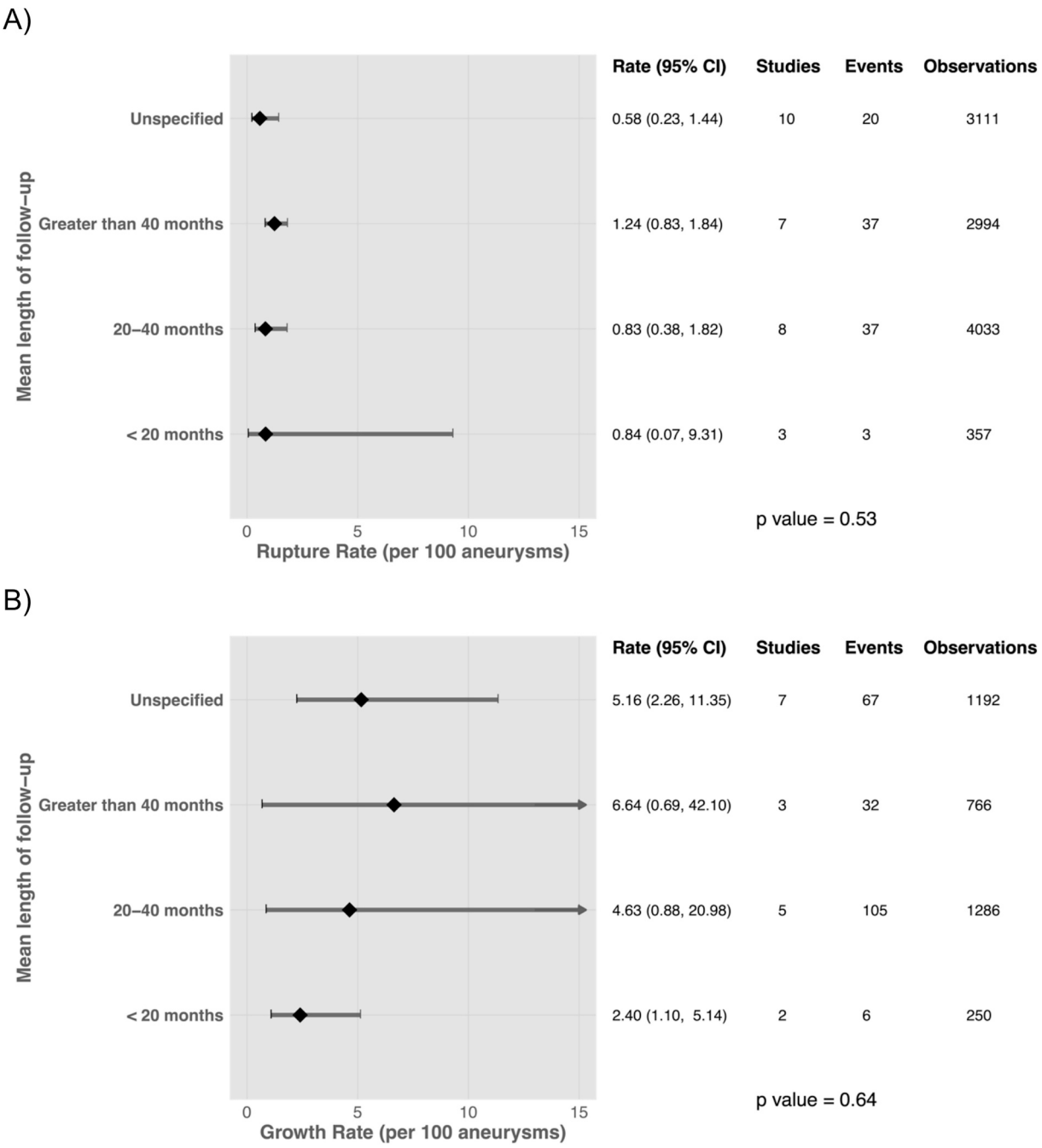

Fig. 4. Rupture rate (A) and growth rate (B) of small unruptured intracranial aneurysms ≤5 mm categorised by length of follow up.

rupture risk based on follow-up duration remains the most practical method for assessing rupture over time. However, the short duration of follow-up in this analysis may not be sufficient to demonstrate meaningful differences in rupture risk over time.

Prior *meta*-analyses suggest an increasing rupture risk with longer follow-up. Wermer et al. [12] reported an annual rupture rate of 0.6 % in studies with a mean follow-up of 5–10 years, rising to 1.3 % in studies exceeding 10 years. In contrast, Juvela et al. [37] observed that over a median follow up of 21 years, rupture risk declined with prolonged observation, signifying that aneurysm risk may not be linearly proportional to time. Unfortunately, this *meta*-analysis could not determine cumulative risk, as 20 % of recorded aneurysm ruptures lacked follow-up data. Additionally, time-to-rupture information was available for only 13 of 97 ruptured aneurysms. These findings highlight the scarcity of long-term data on sUIAs and emphasise the need for extended follow-up to improve risk stratification.

This study observed a trend of increasing aneurysm growth rates with longer follow-up. Growth is frequently regarded as a surrogate marker for rupture risk, with growing aneurysms demonstrating a 12-fold higher rupture risk than stable ones [38]. Matsubara et al. [29] reported that aneurysm growth rates accumulate over time, suggesting the need for lifelong surveillance of sUIAs. Similarly, Chen et al. [39] found that 13.3 % of small aneurysms increased in size over a mean follow-up of 36.2 months, with an associated higher risk of rupture. However, the predictive value of aneurysm growth remains uncertain, as rupture can still occur in stable aneurysms, and growth itself is a heterogeneous process influenced by multiple patient- and aneurysm-specific factors [40,41].

Selection bias may also contribute to reported growth rates. Clinicians often recommend intervention when aneurysm growth is detected,

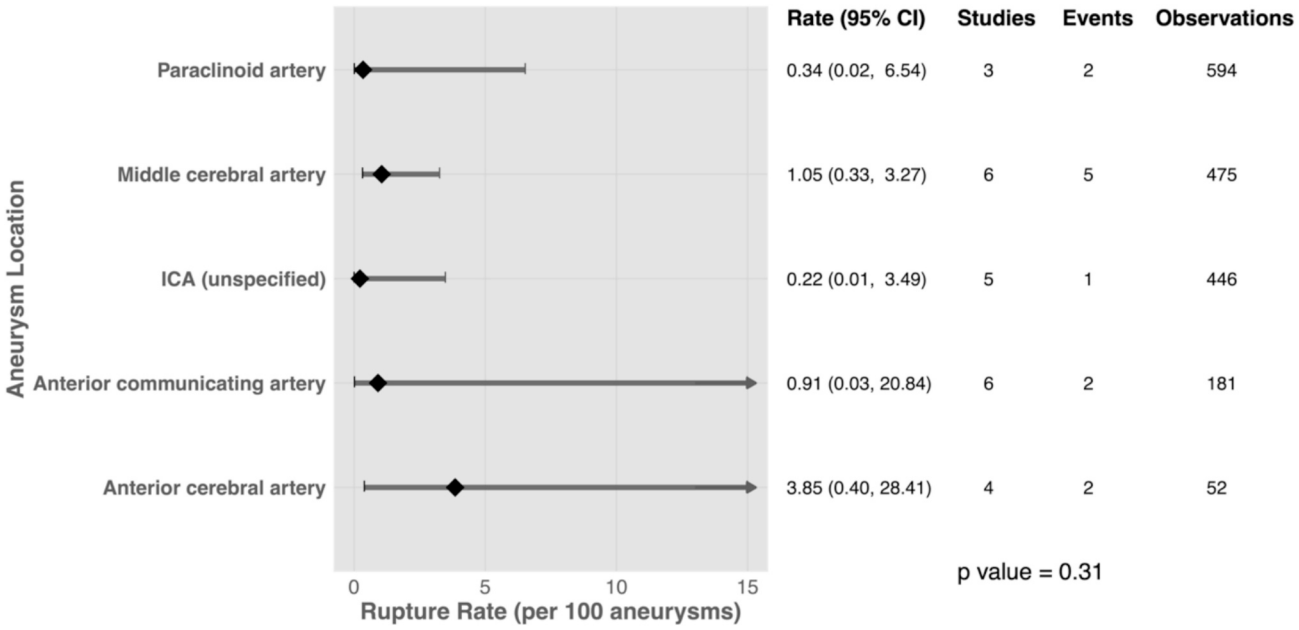

Fig. 5. Rupture rate of small unruptured intracranial aneurysms ≤5 mm categorised by aneurysm location.

thereby selectively removing higher-risk lesions from observation. Most studies censored aneurysms at the time of intervention and rarely provided data on time to treatment or characteristics of aneurysms undergoing intervention. This may explain why rupture rates in this analysis appeared to plateau across different follow-up durations. The potential for intervention-related bias in observational studies underscore the need for cautious interpretation of rupture and growth data.

Aneurysm location is a well-recognised risk factor for rupture, with posterior circulation aneurysms historically associated with higher risk [6,7,36,42]. Prior *meta*-analyses have also suggested a greater likelihood of growth in posteriorly located aneurysms [43]. However, the influence of location on small unruptured intracranial aneurysms remains less clearly defined. Suzuki et al. [44] reported that bifurcation location in aneurysms measuring 10 mm or less was associated with a significantly increased rupture risk (OR; 5.45, 95 % CI; 1.87–15.85). Carter et al. [45] proposed that aneurysm size and location are interdependent, with rupture thresholds modulated by local vessel wall thickness and haemodynamic stress. This highlights the importance of location and size specific risk stratification, for as in contrast to the ISUIA study, anterior circulation aneurysms, particularly those in the anterior communicating artery, appear to rupture at smaller sizes than other locations [46,47].

Although rupture risk appeared relatively consistent across anatomical locations in this *meta*-analysis, limited data precludes precise risk assessment. Only 12 % of reported ruptures could be classified by location, and no study provided growth data stratified by anatomical site. These gaps are reflected in the wide confidence intervals observed in location-based risk estimates, reducing their reliability. While the absence of data on posterior circulation aneurysms is a notable limitation, the potentially higher rupture risk in anterior communicating artery aneurysms warrants prioritization.

Importantly, the aim of this study was not to redefine rupture risk or resolve the well-recognised paradox between the high proportion of ruptured aneurysms measuring less than 10 mm and the very low rupture rates reported in prospective studies. Rather, we sought to evaluate how the duration of follow-up and the quality of reporting influence rupture rates in the current literature. Our findings suggest that variability in study design, inconsistency in follow-up intervals, and under-reporting of anatomical location may contribute to the disconnect between retrospective clinical observations and prospective natural history data. By drawing attention to these methodological limitations, we hope to provide a foundation for improving the design and reporting of future natural history studies and guiding more accurate lifetime risk estimation.

4.1. Limitations

The findings of this review must be interpreted in the context of its limitations. The volume of available data is relatively limited, particularly given the infrequency of rupture events in small unruptured intracranial aneurysms, which reduces the precision of effect estimates and limits the ability to conduct detailed subgroup analysis, including those based on anatomical location. Differences in population selection across included studies limits generalizability, as most lacked data on morphological features such as aspect ratio and irregularity, which are key predictors of rupture risk [38,44]. Substantial heterogeneity in growth rate analysis ($I^2 > 80$ %), likely reflects variation in imaging techniques, definitions of aneurysm growth, and follow-up durations, and of which affect the reliability and comparability of these results. The mean follow-up of 38 months is insufficient to estimate cumulative or lifetime rupture risk. Longer-term studies, including those by Korja et al. [14] and Juvela et al. [37], suggest greater cumulative rupture risk with extended follow-up, although these cohorts primarily involved larger aneurysms.

Categorising studies by mean follow up duration may introduce bias, as mean values are susceptible to the influence of outliers and may not accurately reflect individual follow up times within each study. The average follow-up within each stratum varied substantially, with 19.9 months in the less than 20-month group, 34.7 months in the 20-to-40-month group, and 60.6 months in the more than 40-month group. This variability may obscure time dependent differences in rupture or growth rates and limits the interpretability of stratified analyses.

The absence of individual patient data precluded analysis of demographic and clinical factors such as age, hypertension, smoking, familial history, and prior subarachnoid haemorrhage, all of which influence rupture risk [12]. Incorporating patient-level data in future *meta*-analyses would allow for more nuanced understanding of these variables. Selection bias inherent to non-randomized studies may also contribute to underestimation of rupture risk, as unstable aneurysms were often treated or censored from observation. Ethical constraints limit the feasibility of experimental studies in this area, resulting in a

research focus on intervention rather than conservative management, which complicates efforts to define the natural history of untreated aneurysms. Contemporary management trends favour early intervention, further reducing the representation of high-risk aneurysms in observational cohorts and introducing confounding between treated and conservatively managed groups [31]. Addressing these challenges requires standardised protocols, conscientious reporting, and extended follow-up to refine rupture risk models and improve clinical decision-making for small UIAs.

5. Conclusion

Small incidental intracranial aneurysms (sUIAs) measuring ≤5 mm demonstrate a low rupture risk, with stability across anatomical locations and follow-up durations. However, increased growth over time supports the need for continued monitoring. Limitations in current literature, particularly short follow-up and inconsistent anatomical reporting, impede accurate risk assessment. Future long-term studies of conservatively managed sUIAs, with detailed location specific data, are needed to improve clinical decision making and lifetime rupture risk estimation.

Author contributions

CR, LD, and LL contributed to the conception and design of the study. CR carried out the systematic search. Data abstraction was performed independently by CR and LD. CR and LD independently conducted the risk of bias assessment and statistical analysis. LD completed the first draft of the manuscript with further additions by CR and LL. All authors contributed to data interpretation and subsequent revisions and approved the final version of the manuscript.

CRediT authorship contribution statement

Lily Davies: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cyrus Raki:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Leon T. Lai:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jocn.2025.111241.

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