Neurol Ther
https://doi.org/10.1007/s40120-025-00881-0

ORIGINAL RESEARCH

Venous Blood Cell Ratios as Predictors of Reperfusion Outcomes in Ischemic Stroke: A Systematic Review and Meta-analysis

István Szegedi · Zsolt Barnabás Éles · Attila Nagy · Zsuzsa Bagoly

Received: November 1, 2025 / Accepted: December 15, 2025
© The Author(s) 2026

ABSTRACT

Introduction: Inflammation plays a critical role in the pathophysiology of acute ischemic stroke (AIS). Ratios derived from routine blood counts, especially the neutrophil-to-lymphocyte ratio (NLR), have been proposed as prognostic biomarkers, but their value in patients receiving reperfusion therapies—intravenous thrombolysis (IVT) or mechanical thrombectomy (MT)—remains uncertain.

Methods: We systematically searched PubMed, Cochrane Library, Web of Science, and Scopus on November 30, 2024, following PRISMA guidelines. Eligible studies included patients with AIS treated with IVT or MT that reported associations between pre-treatment blood cell ratios and outcomes measured by the modified Rankin Scale (mRS). Pooled odds ratios (ORs) with 95% confidence intervals (CIs) were calculated using random-effects models.

Results: Fifty-seven studies with 17,394 patients were included. NLR was the predominantly studied biomarker. In the MT subgroup, elevated NLR predicted poor 3-month outcome (OR 1.09, 95% CI 1.04–1.15) and higher mortality (OR 1.05, 95% CI 1.01–1.08). In IVT-treated patients, higher NLR also predicted poor outcome (OR 1.11, 95% CI 1.01–1.21) with lower heterogeneity across studies. Other ratios

István Szegedi and Zsolt Barnabás Éles contributed equally to this work and share first authorship.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40120-025-00881-0.

I. Szegedi
Department of Neurology, Faculty of Medicine, University of Debrecen, Debrecen, Hungary

I. Szegedi · Z. B. Éles · A. Nagy · Z. Bagoly (✉)
Lendület "Momentum" Hemostasis and Stroke Research Group of the Hungarian Academy of Sciences, Debrecen, Hungary
e-mail: bagoly@med.unideb.hu

Z. B. Éles · Z. Bagoly
Division of Clinical Laboratory Sciences, Department of Laboratory Medicine, University of Debrecen, Faculty of Medicine, 98 Nagyerdei Krt., 4032 Debrecen, Hungary

A. Nagy
Department of Health Informatics, University of Debrecen, Faculty of Health Sciences, 4032 Debrecen, Hungary

Z. Bagoly
Hungarian Research Network (HUN-REN-DE) Cerebrovascular Research Group, Debrecen, Hungary

Published online: 13 January 2026

showed variable associations: lymphocyte-to-monocyte ratio (LMR) appeared protective, while platelet-to-lymphocyte ratio (PLR), monocyte-to-lymphocyte ratio (MLR), and platelet-to-neutrophil ratio (PNR) showed inconsistent or null results. Data regarding hemorrhagic transformation were heterogeneous and unsuitable for meta-analysis.

Conclusions: Elevated pre-treatment NLR consistently predicted poor outcome and mortality after reperfusion therapy for AIS, supporting its role as a simple biomarker for early risk stratification. Future large, prospective multicenter studies with standardized methods are needed to confirm the clinical utility of these inflammatory ratios in stroke management.

PLAIN LANGUAGE SUMMARY

Stroke is a leading cause of death and long-term disability. Two treatments, intravenous thrombolysis and mechanical thrombectomy, are used to reopen blocked brain arteries. Even when these treatments are given promptly, a large number of patients still do not recover well or die. Doctors therefore need simple and reliable tools to identify patients at high risk of a bad outcome early in the hospital stay. Blood tests taken at the time of hospital admission may give useful clues. In particular, the balance between different types of white blood cells reflects how active the immune system is. In this study, we systematically reviewed and combined results from previously published research to determine whether simple blood cell ratios—such as the neutrophil-to-lymphocyte ratio (NLR)—measured before treatment can help predict how patients will recover after these therapies. We found that a higher NLR measured on admission was consistently linked with a greater chance of disability or death after treatment. This pattern was seen in patients treated with both thrombolysis and thrombectomy. Other blood cell ratios showed weaker or inconsistent results. Because NLR comes from a routine blood count, it is cheap, fast, and available in all hospitals. Our findings suggest that NLR could be used alongside clinical judgment and brain imaging to help identify stroke patients at higher risk of poor outcomes early on. Future large studies are needed to confirm these results and to test whether combining NLR with other clinical or imaging markers improves prediction further.

Keywords: Acute ischemic stroke; Mechanical thrombectomy; Intravenous thrombolysis; Venous blood cell ratios; Neutrophil-to-lymphocyte ratio; Therapeutic outcome

Key Summary Points

Why carry out this study?

Acute ischemic stroke remains a major cause of disability and death worldwide, and accurate pre-treatment prognostic tools are needed to guide care in patients undergoing reperfusion therapy.

Systemic inflammation has been implicated in post-stroke outcomes, and venous blood cell ratios are widely available, low-cost candidates for prognostication.

This systematic review and meta-analysis examined the association between admission venous blood cell ratios and functional outcome or mortality after intravenous thrombolysis or mechanical thrombectomy in acute ischemic stroke.

What was learned from the study?

The neutrophil-to-lymphocyte ratio (NLR) consistently predicted poor functional outcome and mortality after reperfusion therapies, whereas other blood cell ratios showed weaker or inconsistent associations.

These findings support the potential clinical utility of NLR as a widely accessible inflammatory biomarker for early risk stratification in acute stroke care and highlight the need for prospective validation and integration into multimodal predictive models.

INTRODUCTION

Acute ischemic stroke (AIS) remains a leading cause of morbidity and mortality worldwide, with recanalization therapies such as intravenous thrombolysis (IVT) and mechanical thrombectomy (MT) offering the best chance for functional recovery when administered promptly [1]. However, patient outcomes after these interventions vary considerably, underscoring the need for reliable prognostic biomarkers to guide clinical decision-making, predict functional recovery and mortality and stratify risk for complications such as hemorrhagic transformation (HT).

In recent years, systemic inflammation has emerged as a key player in the pathophysiology of AIS and its clinical consequences [2, 3]. Circulating inflammatory biomarkers derived from routine blood tests—particularly blood cell ratios such as the neutrophil-to-lymphocyte ratio (NLR), platelet-to-lymphocyte ratio (PLR), monocyte-to-lymphocyte ratio (MLR), and others—have been increasingly investigated for their potential prognostic value [4–6]. These biomarkers are inexpensive, widely available, and easily obtained in the acute setting, making them attractive candidates for clinical use. Among ischemic stroke subtypes, cardioembolic and atherothrombotic infarcts show the highest in-hospital and short-term mortality, highlighting the prognostic relevance of underlying stroke etiology [7, 8].

Several observational studies have reported associations between various blood cell ratios and post-stroke outcomes, including functional independence, mortality, and hemorrhagic complications. However, findings across the literature have been inconsistent, partly due to heterogeneity in study design, timing of blood sampling, definitions of clinical endpoints, and adjustment for confounding factors [4, 6, 9]. Furthermore, many previous reviews have not specifically focused on patients undergoing recanalization therapy, despite the distinct pathophysiological and prognostic context of these interventions [5, 10].

To address this gap, we conducted a systematic review and meta-analysis to synthesize current evidence on the association between pre-treatment venous blood cell ratios and clinical outcomes in patients with AIS treated with MT or IVT.

METHODS

This systematic review and meta-analysis was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines [11].

Article Search

A comprehensive literature search was performed across the PubMed (MEDLINE), Cochrane Library, Web of Science, and Scopus electronic databases. We investigated the following blood cell ratios: neutrophil-to-lymphocyte ratio (NLR), neutrophil-to-monocyte ratio (NMR), platelet-to-lymphocyte ratio (PLR), platelet-to-neutrophil ratio (PNR), lymphocyte-to-monocyte ratio (LMR), eosinophil-to-lymphocyte ratio (ELR), eosinophil-to-neutrophil ratio (ENR), lymphocyte-to-neutrophil ratio (LNR), monocyte-to-neutrophil ratio (MNR), lymphocyte-to-platelet ratio (LPR), neutrophil-to-platelet ratio (NPR), monocyte-to-lymphocyte ratio (MLR), lymphocyte-to-eosinophil ratio (LER), and neutrophil-to-eosinophil ratio (NER). Detailed information regarding the search strategy and database-specific search filters applied is provided in the Supplementary Material. No restrictions were applied regarding the year of publication. The search was conducted as of November 30, 2024. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

Study Selection

For this systematic review and meta-analysis, studies were considered eligible when they met the following criteria: (1) inclusion of patients with AIS and treated with recanalization therapy (IVT, MT/endovascular therapy); (2) participants aged ≥ 18 years; (3) imaging performed to rule

out intracranial hemorrhage and confirm the clinical diagnosis of AIS; (4) the study investigated the association between a venous blood biomarker (blood cell ratios) and clinical outcome; and (5) venous blood samples collected prior to recanalization therapy; (6) clinical outcome assessed using the modified Rankin Scale (mRS). Patients with mRS 3–6 were defined as having poor long-term outcome [12]. The following were excluded: reviews, conference abstracts, letters, editorials, and case reports. Studies published in languages other than English and those involving animal subjects were also excluded. Duplicate records were removed using the EndNote reference management software. In the initial screening phase, two reviewers (István Szegedi and Zsolt Barnabás Éles) independently assessed studies based on titles and abstracts. Full-text articles were obtained for studies that met the initial inclusion criteria, and final eligibility was determined through full-text review. Any disagreements were resolved by consensus.

Data Extraction

Data were extracted by two authors (István Szegedi and Zsolt Barnabás Éles). The following data were collected: applied recanalization therapy, type of biomarkers (blood cell ratios), first author's name and publication year, sample size, time of outcome assessment, definition of clinical outcome and number of patients with assessed outcome, the odds ratios (OR) and their corresponding 95% confidence intervals (95% CI) representing the association between the biomarker and reported clinical outcomes, along with the confounders that were included in each study's statistical model, and finally, the number of patients who received both thrombolytic and endovascular therapy. For studies including both recanalization and non-recanalization therapy, only data from patients who received recanalization therapy were included. For studies reporting on more than one cell ratio, each cell ratio is reported separately. If clinical outcome was assessed at more than one time point, data from all time points were included in this review. In addition to the functional outcome, other clinical outcomes such as mortality and intracerebral hemorrhage (ICH) were also reported. The publications and the data collected from them were divided into two large groups, based on the fact that all of the patients received thrombolytic or endovascular therapy.

Quality Assessment

The quality of each study was evaluated using a modified version of the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) questionnaire [13]. The quality assessment and associated checklist can be found in the Supplementary Material. The checklist includes 15 items, each rated as yes (+), no (–), or unclear (?), with a maximum possible score of 15 points. All studies meeting the inclusion criteria were incorporated into this systematic review, regardless of their quality score.

Statistical Analysis

The meta-analysis was conducted using a random-effects model (DerSimonian–Laird method) to account for between-study variability. Pooled effect sizes were reported as ORs with 95% CI. Statistical heterogeneity was assessed using Cochran's Q test and quantified with the I^2 statistic, with values above 50% indicating substantial heterogeneity. Potential publication bias was evaluated qualitatively by visual inspection of a funnel plot, in which the standard error of the log odds ratio was plotted against the log odds ratio. Asymmetry in the funnel plot was used to assess the possibility of small-study effects or publication bias. In addition, Egger's regression test was applied to statistically evaluate funnel plot asymmetry, with a p value less than 0.05 considered indicative of potential publication bias. Duval and Tweedie's trim-and-fill method was used to further assess the potential impact of publication bias by estimating the number of missing studies and adjusting the overall effect size accordingly. All analyses were performed using Stata 17 (StataCorp LLC, College Station, TX, USA).

RESULTS

Study Selection

The initial search identified 391 articles, with an additional five articles retrieved through reference list screening of the included studies. After removing duplicates, 346 articles remained for title and abstract screening (Fig. 1). Following this initial screening, 113 articles were assessed in full text. Ultimately, 57 articles met the eligibility criteria for inclusion in this systematic review—33 articles on MT [14–46] and 24 articles on IVT [47–70]. Of these, 30 (20 MT and 10 IVT) were included in the subsequent meta-analysis.

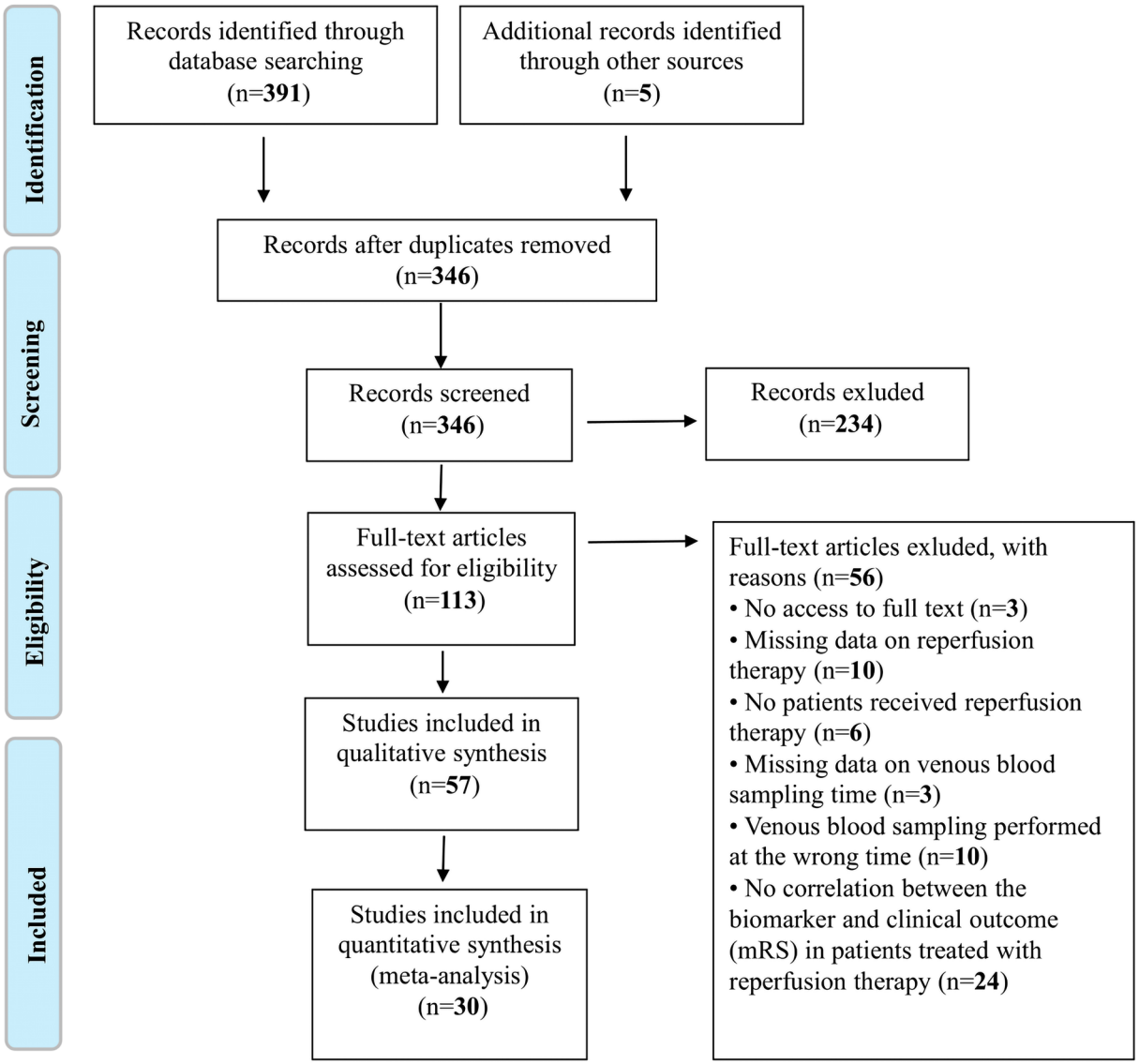

Fig. 1 PRISMA [Preferred Reporting Items for Systematic reviews and Meta-Analyses] flowchart of literature search and study selection

Study Characteristics

Fifty-seven studies, including 17,394 patients (10,270 patients treated with MT and 7124 patients treated with IVT), reported a total of seven different blood cell ratios. Among these, the following 33 publications were analyzed in relation to MT: NLR (29 studies), MLR (3), PLR (15), PNR (5), MNR (1), ELR (1), and LMR (8) (Table S1). In the context of IVT, the analyzed ratios included NLR (19 studies), MNR (1), PLR (4), PNR (3), LMR (2), and a combined NLR and LMR analysis in one study, reported in a total of 24 publications (Table S2). One study assessing both NLR and PLR was found to share an identical patient population with another NLR-focused study. To avoid duplication, this study was excluded from the NLR analysis but retained in the PLR group, as the latter analysis did not overlap with other included data [30]. The sample size of individual studies ranged from 16 to 1044 patients. A total of 20 studies reported data on more than one biomarker. All included studies assessed clinical outcomes using the mRS, while several also reported additional outcomes such as hemorrhagic transformation (HT), symptomatic intracerebral hemorrhage (sICH) and 90-day mortality. In most studies, poor outcome was defined as an mRS score greater than 2 at 3 months or at 90 days. Specifically, four studies reported mRS outcomes at discharge, three studies at 1 month, 55 studies at 3 months or 90 days, and one study at 6 months, and two studies assessed clinical outcomes at 1 year or 12 months following stroke onset. In those publications where multivariate analysis was performed, a total of 10 studies did not report the confounding factors included in the model, or the factors were not clearly specified. Among the publications related to MT, 26 studies reported the proportion of patients who also received additional IVT. In contrast, among the thrombolysis-related publications, only five reported whether MT was performed.

Quality Assessment

The overall quality of the included studies was moderate (median 8 points of a maximum of 15 points, ranging from 6 to 11 points) (Supplementary Material). The quality of the study design, as marked by the quality score, did not directly influence the results found by individual studies. All 57 studies reported that stroke diagnosis was confirmed by expert opinion and neuroimaging, that all patients underwent the same diagnostic process, and that the biomarker was not used to define the clinical endpoint. Only a few studies reported on blinding of measurement of individual biomarkers (2/57) and clinical data collection (5/57). Four studies did not report that all enrolled patients completed the study or provide an explanation for withdrawals. None of the studies used a predefined biomarker cutoff value for clinical outcome. In most of the studies, the disclosure section either declared "no conflicts of interest" or was entirely omitted (47/54). Only four studies were conducted retrospectively, and two studies did not report at least two of the following: definition of the study period, end of follow-up, or median follow-up time. All studies clearly defined clinical endpoints prior to analysis, and only one study performed a sample size calculation. A list of candidate variables along with estimated effects (OR and 95% CI) for all variables in the multivariate analysis was reported in 51 studies; however, in 10 of these, the cell ratio was not included in the model. Only a few studies (14/57) specified the assay method, and none of the studies included a case population that was fully representative; all focused on selected subgroups.

Association Between Venous Blood Cell Ratios and 3-Month Poor Outcome After Mechanical Thrombectomy

A total of five venous blood cell ratios were assessed for their predictive value regarding poor functional outcome at 3 months following MT in patients with AIS. In three studies, the reciprocal of the reported ORs and CIs were

calculated to maintain consistency, as either the direction of the examined marker was inverse or the studies assessed good outcomes (mRS 0–2) instead of poor outcomes [29, 32, 45].

Neutrophil-to-Lymphocyte Ratio (NLR)

Fourteen studies assessed the association between baseline NLR and poor functional outcome at 3 months after MT [18, 19, 21–24, 28, 29, 31, 32, 34, 40–42]. The pooled OR was 1.09 (95% CI 1.04–1.15), indicating a statistically significant relationship between elevated NLR and increased odds of unfavorable outcomes. Heterogeneity among studies was considerable ($I^2 = 75.7\%$, $p < 0.001$), suggesting variability in study populations or methodologies (Fig. 2). Despite this, the direction of the effect was largely consistent across studies, supporting the prognostic utility of NLR as a marker of an underlying pro-inflammatory state that contributes to poor post-thrombectomy recovery.

Lymphocyte-to-Monocyte Ratio (LMR)

Four studies were included [24, 32, 35, 41]. Higher LMR was significantly associated with better outcomes, with a pooled OR of 0.79 (95% CI 0.67–0.92) and modest heterogeneity ($I^2 = 25.3\%$, $p = 0.260$). This suggests a protective effect of elevated LMR (Fig. 3).

Platelet-to-neutrophil ratio (PNR)

Data from three studies yielded a pooled OR of 0.86 (95% CI 0.69–1.09) [18, 45, 46]. While suggestive of a trend toward improved outcomes with higher PNR, the result was not statistically significant, and heterogeneity was high ($I^2 = 74.8\%$, $p = 0.019$) (Figure S1).

Platelet-to-Lymphocyte Ratio (PLR)

Five studies reported on PLR, with a pooled OR of 1.00 (95% CI 1.00–1.00) and low-to-moderate

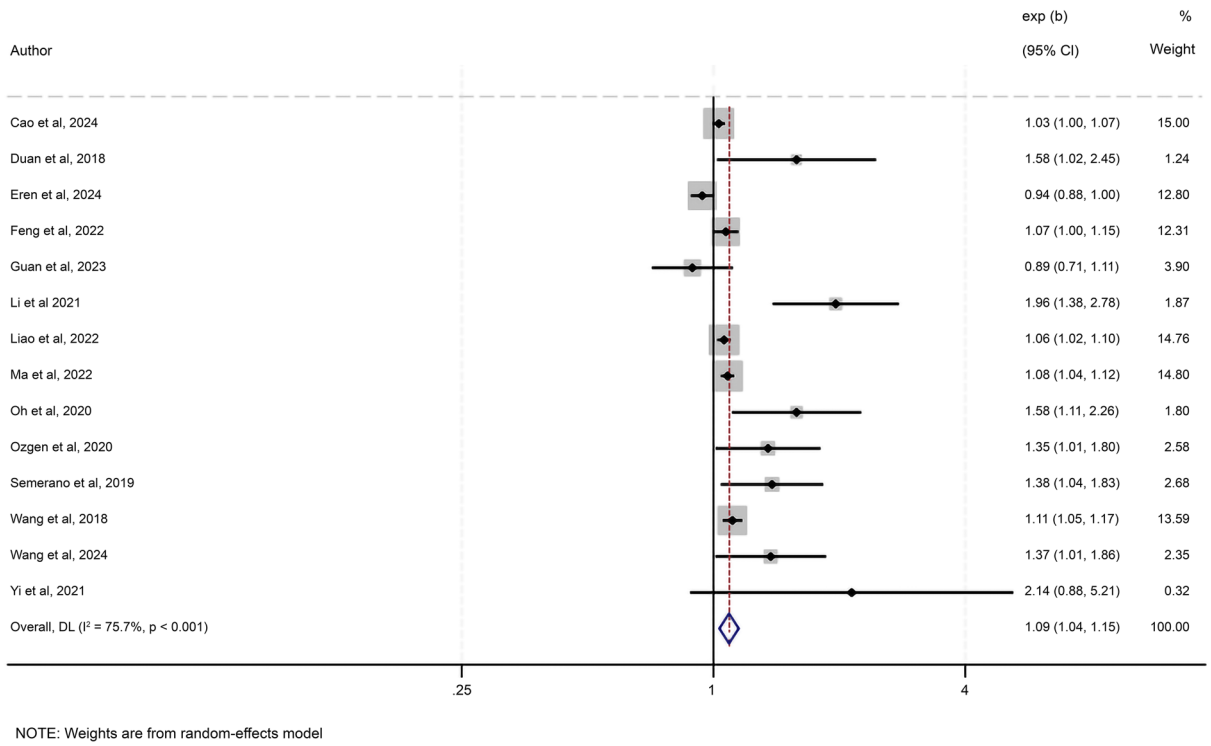

Fig. 2 Baseline NLR and poor functional outcome (mRS 3–6) 3 months after mechanical thrombectomy. NLR, neutrophil-to-lymphocyte ratio; mRS, modified Rankin Score

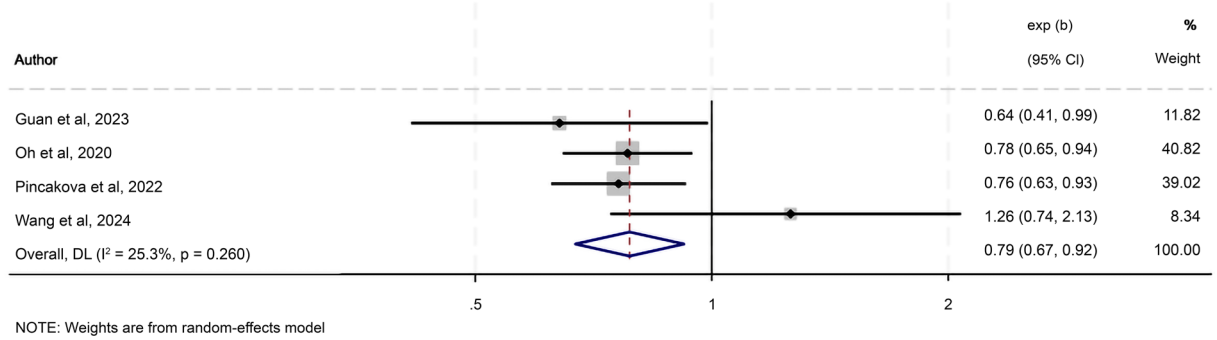

Fig. 3 Baseline LMR and poor functional outcome (mRS 3–6) 3 months after mechanical thrombectomy. LMR, lymphocyte-to-monocyte ratio; mRS, modified Rankin Score

heterogeneity (I^2 = 26.0%, p = 0.248), suggesting no meaningful association with 3-month outcome [18, 24, 31, 34, 45] (Figure S2).

Monocyte-to-Lymphocyte Ratio (MLR)

Three studies evaluated MLR, yielding a pooled OR of 1.05 (95% CI 0.80–1.39) [18, 31, 34]. The association was not statistically significant, and heterogeneity was absent (I^2 = 0.0%, p = 0.940), indicating consistent but null findings (Figure S3).

Exploratory Marker (MNR, ELR)

Two additional blood cell ratios—MNR and ELR—were assessed in a single study for their potential association with poor functional outcome (mRS 4–6) after MT, but neither of them demonstrated a significant association [43]. Due to the limited evidence, the prognostic value of these ratios remains unclear.

Association Between Venous Blood Cell Ratios and Mortality After Mechanical Thrombectomy

Five venous blood cell ratios were examined for their association with mortality following MT in patients with AIS. Among them, the NLR demonstrated the most robust and consistent association. In two studies, reciprocals of the reported ORs and CIs were calculated to maintain consistency regarding the effect of the examined marker [32, 45].

Neutrophil-to-Lymphocyte Ratio (NLR)

Eight studies assessed the association between NLR and mortality following MT [20, 21, 23, 29, 31, 32, 36, 43] (Fig. 4). The pooled OR was 1.05 (95% CI 1.01–1.08), indicating a significant relationship between elevated NLR and increased risk of death. Heterogeneity was substantial (I^2 = 71.4%, p = 0.001), suggesting some variability in study designs, populations, or adjustment models. Despite this, the effect direction was consistently positive across studies. Notably, two studies reported particularly strong associations (OR 2.08, 95% CI 1.40–3.09; OR 1.42, 95% CI 1.09–1.85), reinforcing the potential role of systemic inflammation in mortality risk. These findings support NLR as a promising and accessible biomarker for early mortality risk stratification in patients undergoing MT.

Platelet-to-Lymphocyte Ratio (PLR)

Four studies evaluated PLR and mortality [30, 31, 45, 64]. The pooled OR was 1.00 (95% CI 1.00–1.01), suggesting no overall association. However, pronounced heterogeneity was present (I^2 = 83%, p < 0.001), driven by one study reporting a significant association (OR 1.21, 95% CI 1.10–1.33). These mixed results highlight the need for further validation of PLR's prognostic utility (Figure S4).

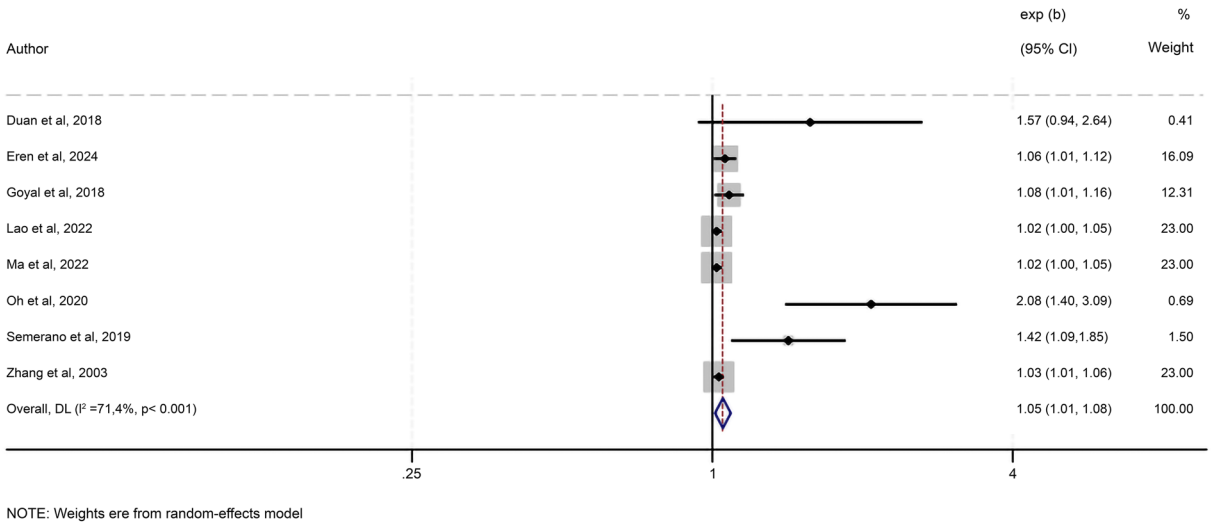

Fig. 4 Baseline NLR and mortality (mRS 6) 3 months after mechanical thrombectomy. NLR, neutrophil-to-lymphocyte ratio; mRS, modified Rankin Score

Lymphocyte-to-Monocyte Ratio (LMR)

Two studies were included, yielding a pooled OR of 1.02 (95% CI 0.96–1.09) [32, 43]. No association was observed with the outcome, without heterogeneity (I^2=0.0%, p=0.426) (Figure S5).

Platelet-to-Neutrophil Ratio (PNR)

Pooled data from two studies resulted in an OR of 0.98 (95% CI 0.95–1.01) [43, 45]. Despite being suggestive of a protective trend, the association was not statistically significant. Heterogeneity was low (I^2=23.1%, p=0.254) (Figure S6).

Exploratory Markers (MLR, ELR, MNR)

Three additional blood cell ratios—MLR, ELR, MNR—were independently evaluated in two studies [31, 43]. None of these markers showed significant association with mortality after MT. Due to the limited number of studies and lack of significance, their prognostic value remains uncertain.

Association Between Venous Blood Cell Ratios and 3-Month Poor Outcome After IVT

Four venous blood cell ratios—NLR, LMR, PLR, and PNR—were evaluated for their association with poor functional outcome in patients who received IVT. In four studies, the reciprocal of the reported ORs and CIs was calculated to maintain consistency, as either the direction of the examined marker was inverse, or the studies assessed good outcomes (mRS 0–2) instead of poor outcomes [47, 52, 60, 69].

Neutrophil-to-Lymphocyte Ratio (NLR)

Seven studies assessed NLR in the context of IVT [47, 49, 51, 52, 60, 62, 64]. The pooled OR was 1.11 (95% CI 1.01–1.21), demonstrating a statistically significant association between elevated NLR and increased risk of poor clinical outcome. Heterogeneity was considerable (I^2=62.7%, p=0.013). Three studies individually

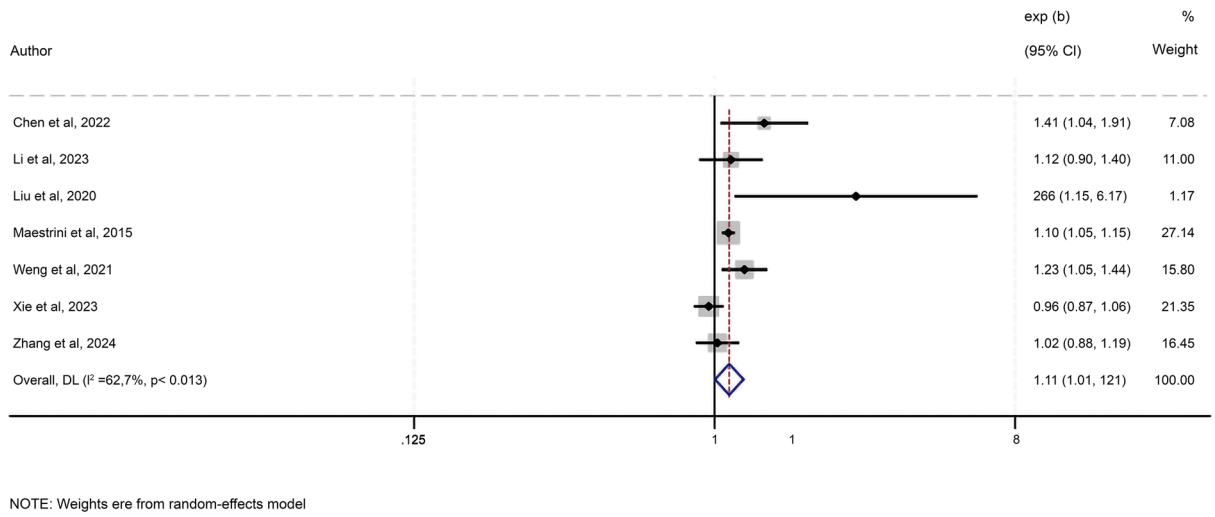

Fig. 5 Baseline NLR and poor functional outcome (mRS 3–6) 3 months after intravenous thrombolysis. NLR, neutrophil-to-lymphocyte ratio; mRS, modified Rankin Score

reported statistically significant effects, including one with a notably high odds ratio (OR 2.66, 95% CI 1.15–6.18) (Fig. 5). These findings suggest that systemic inflammation, as reflected by higher NLR values, may contribute to worse post-thrombolysis recovery.

Two additional studies reported on NLR but used log-transformed cell counts and did not provide sufficient data to convert the results into a comparable non-logarithmic format [59, 63]. Therefore, these studies were not included in the quantitative synthesis.

Platelet-to-Lymphocyte Ratio (PLR)

Three studies investigated PLR, yielding a pooled OR of 0.98 (95% CI 0.95–1.01), suggesting no overall association [47, 66, 67]. However, heterogeneity was very high ($I^2 = 90.6\%$, $p < 0.001$). One study showed a significant protective effect (OR 0.77, 95% CI 0.69–0.86), while the others demonstrated null associations. These conflicting findings indicate that PLR is not a reliable predictor of post-IVT outcome (Figure S7).

Lymphocyte-to-Monocyte Ratio (LMR)

Two studies examined the prognostic role of LMR [64, 69]. The pooled OR was 1.21 (95% CI 0.78–1.86), indicating no association with 3-month poor outcome. Heterogeneity was moderate ($I^2 = 57.8\%$, $p = 0.124$). One study reported a significant association (OR 1.46, 95% CI 1.05–2.04), whereas the other found no effect, highlighting inconsistency in the evidence (Figure S8).

Exploratory Markers (PNR, NLR + LMR)

Regarding the PNR, a formal meta-analysis was not performed due to a null effect reported in one of the two included studies, where the OR and 95% CI were both equal to 1.00 [68]. This indicates no measurable association and precludes statistical combination with other estimates. Consequently, only the findings from the other study were considered, in which higher PNR was associated with a lower likelihood of poor functional outcome at 3 months (OR 0.97, 95% CI 0.94–1.00), suggesting a modest protective effect [55].

Our research group investigated the paired effect of NLR and LMR, revealing that the combination of high NLR and low LMR substantially increased risk of poor outcome (mRS 2–6) in patients with this profile (OR 3.049, 95% CI 1.205–7.714) [70]. This preliminary finding underscores the potential relevance of rarely

used and composite inflammatory markers, though further validation in larger cohorts is needed.

Association Between Venous Blood Cell Ratios and Mortality After Intravenous Thrombolysis

Two venous blood cell ratios—NLR and PLR—were evaluated for their association with poor functional outcome at 3 months in patients treated with IVT.

Neutrophil-to-Lymphocyte Ratio (NLR)

Two studies investigated the association between NLR and mortality in patients treated with IVT [52, 60]. The pooled OR was 1.17 (95% CI 0.96–1.41), indicating a nonsignificant association between higher NLR and mortality. Heterogeneity was substantial ($I^2 = 72.7\%$, $p = 0.056$). Of the two included studies, one showed a statistically significant association (OR 1.32, 95% CI 1.08–1.62), while the other reported a more modest but still significant effect (OR 1.08, 95% CI 1.03–1.13). Despite these individual findings, the pooled estimate did not reach statistical significance (Figure S9). The observed heterogeneity likely reflects differences in study design, patient characteristics, or definitions of mortality endpoints. These findings suggest a possible trend toward increased mortality with elevated NLR after IVT, but the current evidence remains inconclusive.

One more study also assessed NLR in relation to mortality; however, due to the use of log-transformed values without convertible data, it was likewise not included in the mortality meta-analysis [59].

Exploratory Marker (PLR)

One additional study assessed PLR in the context of IVT and mortality but found no significant association [66]. As only a single study is available, the result should be considered exploratory.

Publication Bias

Funnel plots were generated for comparisons that yielded statistically significant pooled results and included the largest number of studies. Among these, only the analysis of NLR and 3-month functional outcomes in the MT subgroup met the commonly accepted threshold for a meaningful evaluation of publication bias. Accordingly, both a funnel plot and Egger's regression test were performed for this comparison. Visual inspection of the funnel plot revealed notable asymmetry, with smaller studies tending to report larger effect sizes—suggesting the presence of small-study effects or selective reporting (Fig. 6). Egger's test supported this impression, yielding a statistically significant intercept (bias coefficient = 1.68, $p = 0.028$), indicative of asymmetry in the distribution of effect sizes. Duval and Tweedie's trim-and-fill method further supported the presence of publication bias by imputing five potentially missing studies on the left side of the funnel plot. After adjusting for these missing studies, the pooled effect estimate was attenuated to logOR = 0.066 (95% CI –0.066 to 0.197), which was no longer statistically significant. These findings suggest that the initially observed association between baseline NLR and poor functional outcome following MT may be, at least in part, influenced by publication bias.

In contrast, the analyses on mortality after MT ($n = 8$) and on 3-month outcomes in the IVT subgroup ($n = 7$) each included fewer than 10 studies. Due to the limited number of studies, formal statistical tests for publication bias were not performed; instead, only funnel plots were generated. Visual inspection of the funnel plot for the MT and mortality analysis (Figure S10) revealed marked asymmetry, suggesting potential small-study effects or publication bias in this subgroup. In comparison, the funnel plot for the IVT subgroup (Figure S11) appeared more symmetric, although interpretation remains limited due to the small number of studies included.

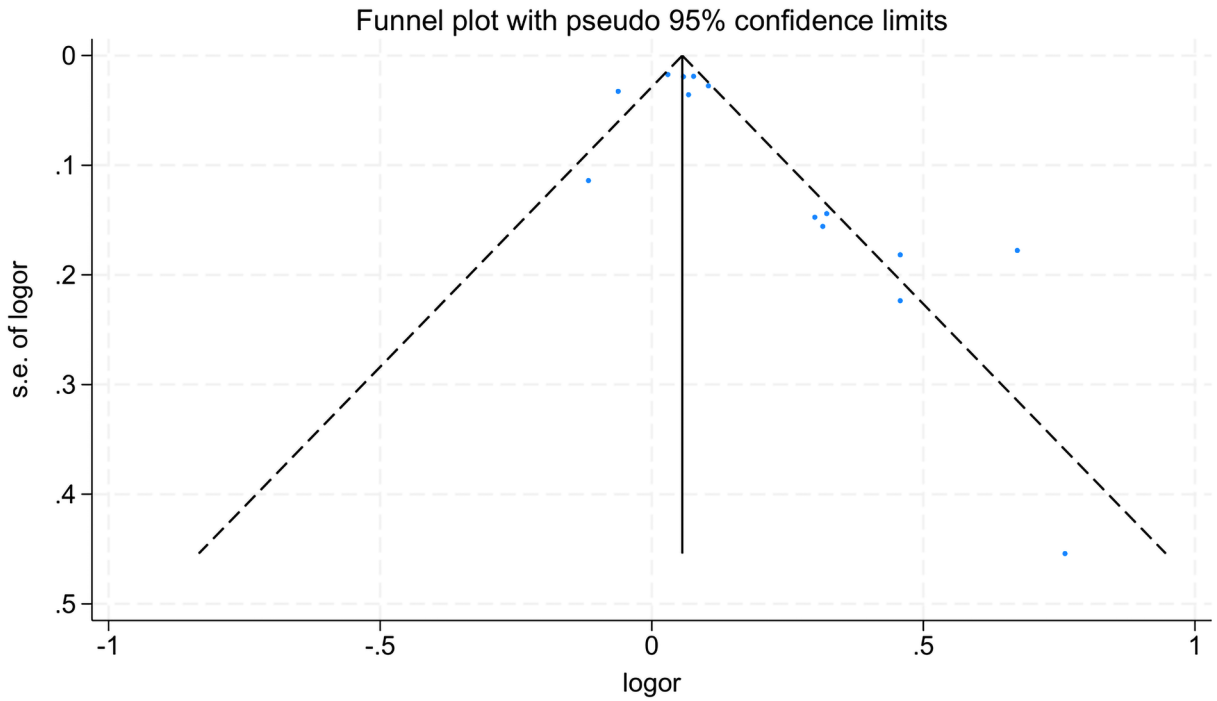

Fig. 6 Funnel plot of meta-analysis: baseline NLR and 3-month poor outcome (mRS 3–6) after mechanical thrombectomy. NLR, neutrophil-to-lymphocyte ratio; mRS, modified Rankin Score

DISCUSSION

To the best of our knowledge, this systematic review and meta-analysis provides the most comprehensive synthesis to date of the prognostic value of venous blood cell ratios measured at admission in patients with AIS undergoing reperfusion therapy. A key methodological strength that distinguishes this work from previous reviews is that we focused exclusively on studies in which blood samples were collected before reperfusion therapy; therefore, our analysis uniquely captures the true pre-treatment inflammatory state of patients. This timing is critically important, as it ensures that the biomarkers evaluated reflect baseline immune dysregulation rather than downstream effects of reperfusion, treatment-related complications, or early post-stroke infections. As such, the present study offers novel and clinically relevant insights into the utility of simple, widely available inflammatory markers as prognostic tools in the most time-sensitive phase of stroke management. Across all evaluated ratios, the NLR consistently emerged as the most informative and reproducible prognostic indicator. In patients treated with MT, elevated NLR was strongly and uniformly associated with poor 3-month functional outcome, reinforcing the central role of systemic inflammation in shaping recovery even after technically successful recanalization. While effect sizes varied among studies (likely reflecting differences in patient selection criteria, timing of blood sampling, or adjustment for confounders), the near-universal direction of association underscores the robustness of the finding. Other venous blood cell ratios showed more limited or inconsistent associations. Higher LMR appeared to be associated with better outcomes, suggesting a possible protective effect mediated by adaptive immunity or reduced monocytic inflammation. In contrast, MLR, PLR, and PNR did not show meaningful or consistent relationships with outcome. These findings imply that while some components of the peripheral immune profile

may be relevant for prognosis, not all blood cell ratios carry equal predictive value.

In patients treated with IVT, the prognostic role of venous blood cell ratios was less well established, largely due to the smaller number of available studies. Still, NLR again demonstrated a significant association with poor functional outcome. Although the strength of association appeared weaker than in the MT subgroup, and heterogeneity was also present, the consistency in effect direction supports the generalizability of NLR as a prognostic marker across treatment modalities. In contrast, LMR and PLR did not show statistically significant associations with outcome after IVT, and the available data were limited and heterogeneous. Regarding PNR, formal meta-analysis was not feasible due to a null effect in one of the two included studies. However, findings from the other study suggested a modest protective effect of higher PNR. Our group also reported that the combined profile of high NLR and low LMR was associated with substantially increased risk of poor outcome, highlighting the potential value of composite inflammatory markers, which require further validation in larger cohorts.

When assessing mortality as the outcome, NLR once again showed the most consistent and statistically supported association. In patients undergoing MT, higher baseline NLR was associated with increased odds of death. Despite some variability between studies, the direction of the association remained uniform, further reinforcing the potential role of NLR as an independent marker of systemic inflammatory burden and poor prognosis. Other markers—including PLR, LMR, MLR, and PNR—did not demonstrate consistent or significant associations with mortality after MT. Several of these analyses were based on small numbers of studies and were subject to considerable heterogeneity, limiting the reliability of their conclusions.

In the IVT subgroup, the evidence for associations between venous blood cell ratios and mortality was even more limited. Only a few studies examined NLR, and while individual results were often statistically significant, the pooled effect did not reach significance, likely due to heterogeneity and small sample sizes. Nonetheless, the observed trend toward increased mortality with higher NLR values suggests a possible link, warranting further investigation in larger, more uniform cohorts. Data on other ratios, such as PLR, were very limited and did not show a clear prognostic value.

It should also be noted that major patient-related factors—particularly age and sex—substantially influence stroke severity, functional recovery, and mortality. Older age is a well-established predictor of poor outcomes, and women generally experience worse post-stroke recovery and have a higher lifetime risk of stroke than men [71, 72]. However, age- and sex-specific prognostic effects were not examined in our study, as this was beyond the primary scope of our analysis and most included publications did not report sufficiently detailed stratified outcome data.

Although HT is a clinically significant complication after acute reperfusion therapies, we did not perform a formal meta-analysis on its association with venous blood cell ratios due to substantial heterogeneity in HT definitions and the timing of imaging assessment across studies.

Nonetheless, several studies investigated the association between inflammatory blood cell ratios and the risk of HT. In the MT subgroup, NLR was the most frequently examined marker. While some studies reported significant associations using cutoff values such as NLR > 5.1 or ≥ 7 [20, 32], others found nonsignificant or inconsistent results. These variations likely reflect differences in patient populations, thresholds, and outcome definitions. Other markers, including PLR, LMR, MLR, PNR, and ELR, were evaluated in individual studies with mixed findings, some showing point estimates suggestive of risk or protection, but often without statistical significance.

In the IVT subgroup, NLR was again the most commonly reported marker. One study demonstrated a significant association between elevated NLR and increased risk of HT [52], while others reported nonsignificant findings with wide confidence intervals. The observed variability may result from differences in sample sizes, statistical adjustments, or diagnostic criteria for HT. PNR was also assessed in one study, but no significant association was found [68].

Overall, while NLR appears to be a promising candidate for predicting hemorrhagic complications as well, especially in the MT population, current evidence remains inconsistent. The lack of standardized outcome definitions and methodological differences across studies underscore the need for future research using harmonized criteria and prospective validation to clarify the predictive value of these markers in the context of HT.

Taken together, our findings indicate that among the venous blood cell ratios examined, the NLR stands out as the most robust and consistent predictor of both poor functional outcome and mortality following acute reperfusion therapies. These findings are particularly important because they validate a biomarker that is inexpensive, universally available, rapidly measurable, and easily interpretable in every acute care setting. These attributes distinguish NLR from many emerging molecular, imaging, or genomic predictors. Its reliability across both MT and IVT cohorts, paired with its easy, cheap, and quick measurement and widespread availability in routine clinical practice, supports its potential use as a practical biomarker worldwide in all hospital settings for early risk stratification in patients with AIS. In the context of modern reperfusion therapies, where treatment decisions must be made within minutes and where early prognostication may influence monitoring intensity, resource allocation, and family counseling, such practical biomarkers are of exceptional value. This meta-analysis therefore not only synthesizes the existing evidence but also provides a compelling argument for the clinical adoption of NLR as part of early risk assessment in reperfusion-treated stroke.

The biological plausibility of NLR as a prognostic marker is strongly supported by established stroke immunopathology. The prognostic value of NLR likely reflects its role as a surrogate marker of systemic inflammation and immune dysregulation in acute ischemic stroke. Stroke triggers an immediate and complex inflammatory cascade involving both the innate and adaptive immune systems. Neutrophils are among the earliest immune cells to infiltrate the ischemic brain, typically within hours of vessel occlusion [73]. Once activated, they release a variety of pro-inflammatory mediators, including reactive oxygen species, matrix metalloproteinases, and cytokines, which contribute to blood–brain barrier disruption, neuronal injury, and increased risk of HT [74–77]. In parallel, lymphocyte counts often decrease in the acute phase of stroke, a phenomenon sometimes referred to as stroke-induced immunodepression [78, 79]. This reduction, particularly in T cells, may impair the adaptive immune response and leave patients more vulnerable to infections—another factor linked to worse outcomes [80, 81]. The combination of elevated neutrophils and reduced lymphocytes, as reflected by a high NLR, thus presents a dual pathological process: excessive pro-inflammatory activity and suppressed immune regulation. Overall, the consistent association between elevated NLR and adverse outcomes following reperfusion therapies in AIS underscores the crucial role of systemic inflammation in stroke pathophysiology.

To conclude, our findings support the potential clinical utility of the NLR as an accessible and inexpensive biomarker for early risk stratification in AIS. In parallel, higher LMR was significantly associated with better treatment outcomes, further underscoring its promise as a prognostic marker. As eligibility for IVT and MT continues to broaden [82, 83], accurate early prognostication is increasingly important to guide clinical management, rehabilitation planning, and communication with patients and families. Although existing clinical and imaging predictors remain central to prognostic assessment in AIS, reliable and readily accessible laboratory biomarkers may provide valuable complementary prognostic information [84–86]. Future research should aim to validate NLR and LMR as components of integrated prognostic models that combine clinical, imaging, and laboratory parameters. Given the limited number of studies on other inflammatory cell ratios, further well-designed investigations are warranted on this topic.

Limitations

This systematic review and meta-analysis has several limitations that should be acknowledged.

The included studies were primarily observational in nature, which may introduce residual confounding and limits the ability to draw definitive causal conclusions. Although most studies adjusted for key covariates, the adjustment sets varied considerably, and many failed to report the specific confounders included in their multivariable models. In addition, stroke etiology is also a major determinant of clinical outcome, but etiological subgroups could not be evaluated in our analysis, as most included studies did not report outcome data stratified by stroke subtype. We focused on studies reporting outcomes in patients treated with MT or IVT; however, several studies included mixed treatment modalities, and analyzing these heterogeneous patient populations may have influenced the results. In addition, the definition and assessment of HT varied markedly across studies, precluding quantitative synthesis. The lack of standardized criteria for HT and inconsistent imaging time points limit our ability to draw firm conclusions regarding the association between blood cell ratios and hemorrhagic complications. Lastly, most studies were conducted in a single-center design, which may limit the generalizability of our findings. Future multicenter, prospective studies with standardized protocols and more diverse populations are needed to validate the prognostic utility of blood cell ratios in acute stroke care.

CONCLUSION

IVT and MT are essential reperfusion treatments for AIS, and as their use expands, early and reliable prognostication remains critical. In this systematic review and meta-analysis, admission NLR consistently predicted poor functional outcomes and mortality after reperfusion therapy, highlighting the role of systemic inflammation in stroke. In contrast, higher LMR was associated with better outcomes, suggesting additional prognostic value. Our findings support these blood cell ratios as a simple, accessible biomarker that may complement existing prognostic tools in IVT- and MT-treated patients. Future work should validate these markers within integrated prognostic models that incorporate key patient-level factors—such as age, sex, and stroke etiology—and further investigate the prognostic utility of other inflammatory cell ratios, for which current evidence is still limited.

Medical Writing/Editorial Assistance. No medical writing or editorial assistance, including AI-based assistance, was used.

Authors' Contributions. István Szegedi and Zsolt Barnabás Éles were responsible for writing the original draft of the manuscript. István Szegedi and Zsolt Barnabás Éles contributed to the literature review and data curation. Attila Nagy performed formal analysis. Zsolt Barnabás Éles and Attila Nagy prepared the figures and tables. Zsuzsa Bagoly was responsible for the conceptualization of the study, supervised the project, and contributed to writing through review and editing.

Funding. This study was supported by the MTA-DE Lendület "Momentum" Hemostasis and Stroke Research Group of the Hungarian Academy of Sciences and the Hungarian Research Network (HUN-REN-DE) Cerebrovascular Research Group. IS was supported by the EKÖP-24-O University Research Scholarship Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Fund (EKÖP-24-4-II-DE-325). The Rapid Service Fee was funded by MTA-DE Lendület "Momentum" Hemostasis and Stroke Research Group of the Hungarian Academy of Sciences.

Data Availability. All data analyzed in this study are derived from previously published articles and are available within the tables presented in this manuscript.

Declarations

Conflict of Interest. István Szegedi, Zsolt Barnabás Éles, Attila Nagy and Zsuzsa Bagoly have nothing to disclose.

Ethical Approval. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

Open Access. This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License, which permits any non-commercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc/4.0/.

REFERENCES

1. Powers WJ, Rabinstein AA, Ackerson T, Adeoye OM, Bambakidis NC, Becker K, et al. Guidelines for the early management of patients with acute ischemic stroke: 2019 update to the 2018 guidelines for the early management of acute ischemic stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2019;50(12):e344–418.

2. Pacinella G, Ciaccio AM, Tuttolomondo A. Molecular links and clinical effects of inflammation and metabolic background on ischemic stroke: an update review. J Clin Med. 2024. https://doi.org/10.3390/jcm13247515.

3. Xie L, He M, Ying C, Chu H. Mechanisms of inflammation after ischemic stroke in brain-peripheral crosstalk. Front Mol Neurosci. 2024;17:1400808.

4. Bi Y, Shen J, Chen SC, Chen JX, Xia YP. Prognostic value of neutrophil to lymphocyte ratio in acute ischemic stroke after reperfusion therapy. Sci Rep. 2021;11(1):6177.

5. Zhang J, Ren Q, Song Y, He M, Zeng Y, Liu Z, et al. Prognostic role of neutrophil–lymphocyte ratio in patients with acute ischemic stroke. Medicine Baltimore. 2017;96(45):e8624.

6. Sharma D, Bhaskar SMM. Prognostic role of the platelet-lymphocyte ratio in acute ischemic stroke patients undergoing reperfusion therapy: a meta-analysis. J Cent Nerv Syst Dis. 2022;14:11795735221110372.

7. Arboix A, Alio J. Cardioembolic stroke: clinical features, specific cardiac disorders and prognosis. Curr Cardiol Rev. 2010;6(3):150–61.

8. Pujadas Capmany R, Arboix A, Casanas-Munoz R, Anguera-Ferrando N. Specific cardiac disorders in 402 consecutive patients with ischaemic cardioembolic stroke. Int J Cardiol. 2004;95(2–3):129–34.

9. Wang L, Song Q, Wang C, Wu S, Deng L, Li Y, et al. Neutrophil to lymphocyte ratio predicts poor outcomes after acute ischemic stroke: a cohort study and systematic review. J Neurol Sci. 2019;406:116445.

10. Yan YK, Huang H, Li DP, Ai ZY, Li X, Sun Z. Prognostic value of the platelet-to-lymphocyte ratio for outcomes of stroke: a systematic review and meta-analysis. Eur Rev Med Pharmacol Sci. 2021;25(21):6529–38.

11. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097.

12. van Swieten JC, Koudstaal PJ, Visser MC, Schouten HJ, van Gijn J. Interobserver agreement for the assessment of handicap in stroke patients. Stroke. 1988;19(5):604–7.

13. García-Berrocoso T, Giralt D, Bustamante A, Etgen T, Jensen JK, Sharma JC, et al. B-type natriuretic peptides and mortality after stroke: a systematic review and meta-analysis. Neurology. 2013;81(23):1976–85.

14. Aly M, Abdalla RN, Batra A, Shaibani A, Hurley MC, Jahromi BS, et al. Follow-up neutrophil–lymphocyte ratio after stroke thrombectomy is an independent biomarker of clinical outcome. J Neurointerv Surg. 2021;13(7):609–13.

15. Aytaç E, Balgetir F, Genç ŞK, Gönen M, Dogan H, Akpinar CK. Effect of inflammatory response before mechanical thrombectomy on prognosis in stroke patients. Ideggyogy Sz. 2024;77(9–10):323–7.

16. Bartt R, Sercy E, Pirahanchi Y, Frei D, Bar-Or D. Associations of neutrophil–lymphocyte ratios with reperfusion and functional outcomes in ischemic stroke after endovascular therapy. J

Stroke Cerebrovasc Dis. 2022. https://doi.org/10.1016/j.jstrokecerebrovasdis.2022.106843.

17. Brooks SD, Spears C, Cummings C, VanGilder RL, Stinehart KR, Gutmann L, et al. Admission neutrophil–lymphocyte ratio predicts 90 day outcome after endovascular stroke therapy. J Neurointerv Surg. 2014;6(8):578–83.

18. Cao W, Song Y, Bai X, Yang B, Li L, Wang X, et al. Systemic-inflammatory indices and clinical outcomes in patients with anterior circulation acute ischemic stroke undergoing successful endovascular thrombectomy. Heliyon. 2024. https://doi.org/10.1016/j.heliyon.2024.e31122.

19. Du M, Xu L, Zhang X, Jiang H, Huang X, Cao H, et al. Association between inflammatory burden index and unfavorable prognosis after endovascular thrombectomy in acute ischemic stroke. J Inflamm Res. 2023;16:3009–17.

20. Duan ZH, Wang HM, Wang Z, Hao YG, Zi WJ, Yang D, et al. Neutrophil–lymphocyte ratio predicts functional and safety outcomes after endovascular treatment for acute ischemic stroke. Cerebrovasc Dis. 2018;45(5–6):221–7.

21. Eren A, Giray S. Value of the red blood cell distribution width (RDW) and neutrophil lymphocyte ratio (NLR) in the prediction of functional recovery and 3-month mortality following endovascular treatment for acute anterior circulation ischemic stroke. Heliyon. 2024. https://doi.org/10.1016/j.heliyon.2024.e38030.

22. Feng Y, Bai X, Li W, Cao W, Xu X, Yu F, et al. Postoperative neutrophil–lymphocyte ratio predicts unfavorable outcome of acute ischemic stroke patients who achieve complete reperfusion after thrombectomy. Front Immunol. 2022. https://doi.org/10.3389/fimmu.2022.963111.

23. Goyal N, Tsivgoulis G, Chang JJ, Malhotra K, Pandhi A, Ishfaq MF, et al. Admission neutrophil-to-lymphocyte ratio as a prognostic biomarker of outcomes in large vessel occlusion strokes. Stroke. 2018;49(8):1985–7.

24. Guan JC, Wang Q, Zhao QS. Lymphocyte to monocyte ratio is independently associated with futile recanalization in acute ischemic stroke after endovascular therapy. Neuropsychiatr Dis Treat. 2023;19:2585–96.

25. Kim H, Kim JT, Choi KH, Yoon W, Baek BH, Kim SK, et al. Futile recanalization after endovascular treatment in acute ischemic stroke with large ischemic core. BMC Neurol. 2024. https://doi.org/10.1186/s12883-024-03912-9.

26. Li R, Yin Y, Cai X, Zhu Y, Feng S, Sun J, et al. Effect of routine inflammatory markers on clinical outcomes in acute basilar artery occlusion after endovascular thrombectomy: Results from ATTENTION registry. Int J Stroke. 2023;18(8):976–85.

27. Li SJ, Cao SS, Huang PS, Nie X, Fu Y, Liu JR. Postoperative neutrophil-to-lymphocyte ratio and outcome after thrombectomy in acute ischemic stroke. Front Neurol. 2022. https://doi.org/10.3389/fneur.2022.990209.

28. Li XB, Wu F, Jiang C, Feng XK, Wang R, Song ZW, et al. Novel peripheral blood cell ratios: effective 3-month post-mechanical thrombectomy prognostic biomarkers for acute ischemic stroke patients. J Clin Neurosci. 2021;89:56–64.

29. Liao MF, Li FL, Hu JR, Yang J, Wu DP, Xie DJ, et al. High neutrophil counts before endovascular treatment for acute basilar artery occlusion predict worse outcomes. Front Aging Neurosci. 2022. https://doi.org/10.3389/fnagi.2022.978740.

30. Liao J, Guo C, Zhang B, Yang J, Zi W, Li J. Low neutrophil-to-lymphocyte and platelet-to-lymphocyte ratios predict favorable outcomes after endovascular treatment in acute basilar artery occlusion: subgroup analysis of the BASILAR registry. BMC Neurol. 2023. https://doi.org/10.1186/s12883-023-03161-2.

31. Ma J, Guo WT, Xu JL, Li SJ, Ren CH, Wu LF, et al. Association of platelet-to-lymphocyte ratio and neutrophil-to-lymphocyte ratio with outcomes in stroke patients achieving successful recanalization by endovascular thrombectomy. Front Neurol. 2022. https://doi.org/10.3389/fneur.2022.1039060.

32. Oh SW, Yi HJ, Lee DH, Sung JH. Prognostic significance of various inflammation-based scores in patients with mechanical thrombectomy for acute ischemic stroke. World Neurosurg. 2020;141:e710–7.

33. Ozdogru D, Uysal OK, Erdem M, Soker EB, Ozturk I, Avci A, et al. Fibrinogen to albumin ratio's prognostic value in ischemic stroke patients who underwent mechanical thrombectomy. Ideggyogy Sz. 2024. https://doi.org/10.18071/isz.77.0167.

34. Ozgen E, Guzel M, Akpinar CK, Yucel M, Demir MT, Baydin A. The relationship between neutrophil/lymphocyte, monocyte//lymphocyte, platelet/lymphocyte ratios and clinical outcomes after ninety days in patients who were diagnosed as having acute ischemic stroke in the emergency room and underwent a mechanical thrombectomy. Bratisl Med J. 2020;121(9):634–9.

35. Pincáková K, Krastev G, Haring J, Mako M, Mikulásková V, Bosák V. Low lymphocyte-to-monocyte ratio as a possible predictor of an unfavourable clinical outcome in patients with acute ischemic stroke after mechanical thrombectomy. Stroke Res Treat. 2022;2022(2022):9243080. https://doi.org/10.1155/2022/9243080.

36. Semerano A, Laredo C, Zhao Y, Rudilosso S, Renu A, Llull L, et al. Leukocytes, collateral circulation, and reperfusion in ischemic stroke patients treated with mechanical thrombectomy. Stroke. 2019;50(12):3456–64.

37. Sun D, Huo X, Jia B, Tong X, Wang A, Ma G, et al. Endovascular treatment for acute ischaemic stroke due to medium vessel occlusion: data from ANGEL-ACT registry. Stroke Vasc Neurol. 2023;8(1):51–8.

38. Sun DP, Yang XG, Huo XC, Jia BX, Tong X, Wang AX, et al. Incidence and predictors of futile recanalisation after endovascular therapy in acute vertebrobasilar artery occlusion patients: insight from the ANGEL-ACT registry. Stroke Vasc Neurol. 2024;9(3):289–94.

39. Wang H, Tian XB, Liao ZY, Yue XY, Sun LB, Li XR, et al. Inflammatory biomarkers may be associated with poor outcomes after mechanical thrombectomy. Thromb J. 2024. https://doi.org/10.1186/s12959-024-00630-7.

40. Wang HM, Zhang M, Hao YG, Zi WJ, Yang D, Zhou ZM, et al. Early prediction of poor outcome despite successful recanalization after endovascular treatment for anterior large vessel occlusion stroke. World Neurosurg. 2018;115:E312–21.

41. Wang LR, Li BH, Zhang Q, Cheng XD, Jia LJ, Zhou S, et al. Predictors of futile recanalization after endovascular treatment of acute ischemic stroke. BMC Neurol. 2024. https://doi.org/10.1186/s12883-024-03719-8.

42. Yi HJ, Sung JH, Lee DH. Systemic inflammation response index and systemic immune-inflammation index are associated with clinical outcomes in patients treated with mechanical thrombectomy for large artery occlusion. World Neurosurg. 2021;153:e282–9.

43. Zhang P, Xu P, Duan Z, Zhang F, Fang Y, Yan D, et al. Effects of admission systemic inflammatory indicators on clinical outcomes in patients with vertebrobasilar artery occlusion: insight from the PERSIST registry. J Neurointerv Surg. 2023;15(e2):E270–6.

44. Altintas O, Altintas MO, Tasal A, Kucukdagli OT, Asil T. The relationship of platelet-to-lymphocyte ratio with clinical outcome and final infarct core in acute ischemic stroke patients who have undergone endovascular therapy. Neurol Res. 2016;38(9):759–65.

45. Kim SY, Yi HJ, Shin DS, Kim BT. Prognostic significance of platelet-to-lymphocyte and platelet-to-neutrophil ratios in patients with mechanical thrombectomy for acute ischemic stroke. J Cerebrovasc Endovasc Neurosurg. 2022;24(3):221–31.

46. Wang L, Cheng Q, Peng M, Lv D, Zi W, Xu G, et al. The relationship between the platelet to leukocyte ratio and mechanical thrombectomy outcomes in acute ischemic stroke patients. Neurol Res. 2020. https://doi.org/10.1080/01616412.2020.1790868.

47. Chen CT, Li LH, Su PY, Chang YC, Lee IH, Yen DHT, et al. Neutrophil-to-lymphocyte ratio in predicting neurologic outcome of patients with acute ischemic stroke treated with intravenous thrombolytics. J Chin Med Assoc. 2022;85(1):102–8.

48. Chu YW, Chen PY, Lin SK. Correlation between immune-inflammatory markers and clinical features in patients with acute ischemic stroke. Acta Neurol Taiwan. 2020;29(4):103–13.

49. Li LZ, Han ZP, Wang RL, Fan JF, Zheng YM, Huang YY, et al. Association of admission neutrophil serine proteinases levels with the outcomes of acute ischemic stroke: a prospective cohort study. J Neuroinflamm. 2023. https://doi.org/10.1186/s12974-023-02758-1.

50. Li Y, Li L, Qie T. Developing a nomogram model for 3-month prognosis in patients who had an acute ischaemic stroke after intravenous thrombolysis: a multifactor logistic regression model approach. BMJ Open. 2024. https://doi.org/10.1136/bmjopen-2023-079428.

51. Liu YL, Wu ZQ, Qu JF, Qiu DH, Luo GP, Yin HP, et al. High neutrophil-to-lymphocyte ratio is a predictor of poor short-term outcome in patients with mild acute ischemic stroke receiving intravenous thrombolysis. Brain Behav. 2020. https://doi.org/10.1002/brb3.1857.

52. Maestrini I, Strbian D, Gautier S, Haapaniemi E, Moulin S, Sairanen T, et al. Higher neutrophil counts before thrombolysis for cerebral ischemia predict worse outcomes. Neurology. 2015;85(16):1408–16.

53. Malhotra K, Goyal N, Chang JJ, Broce M, Pandhi A, Kerro A, et al. Differential leukocyte counts on admission predict outcomes in patients with acute ischaemic stroke treated with intravenous thrombolysis. Eur J Neurol. 2018;25(12):1417–24.

54. Pagram H, Bivard A, Lincz LF, Levi C. Peripheral immune cell counts and advanced imaging as

biomarkers of stroke outcome. Cerebrovasc Dis Extra. 2016;6(3):120–8.

55. Pan H, Fu M, Ge WQ, Zhou CY. The effects of changes in platelet-to-neutrophil ratios 24 hours after intravenous thrombolysis on prognosis in acute ischemic stroke patients. Clin Neurol Neurosurg. 2020. https://doi.org/10.1016/j.clineuro.2020.105739.

56. Pektezel MY, Yilmaz E, Arsava EM, Topcuoglu MA. Neutrophil-to-lymphocyte ratio and response to intravenous thrombolysis in patients with acute ischemic stroke. J Stroke Cerebrovasc Dis. 2019;28(7):1853–9.

57. Qian K, Hu J, Wang C, Xu C, Chen Y, Feng Q, et al. Dynamic change of neutrophil-to-lymphocyte ratio and its predictive value of prognosis in acute ischemic stroke. Brain Behav. 2024. https://doi.org/10.1002/brb3.3616.

58. Shahin MA, Melake MS, Ibrahim SS, Hamdey AMED. Prognostic value of neutrophil /lymphocyte ratio in acute ischemic stroke patients either received reperfusion therapy or not. Egypt J Hosp Med. 2021;84(1):1662–6.

59. Shi J, Peng H, You S, Liu Y, Xu J, Xu Y, et al. Increase in neutrophils after recombinant tissue plasminogen activator thrombolysis predicts poor functional outcome of ischaemic stroke: a longitudinal study. Eur J Neurol. 2018;25(4):687-e45.

60. Weng Y, Hu J, Ren J, Huang H, Yang C, Shen J, et al. Dynamic neutrophil–lymphocyte ratios predict short-term prognostic outcome of thrombolysis in patients with acute ischemic stroke. Neurotoxic Res. 2021;39(5):1678–87.

61. Wu Q, Chen HS. Neutrophil-to-lymphocyte ratio and its changes predict the 3-month outcome and mortality in acute ischemic stroke patients after intravenous thrombolysis. Brain Behav. 2023. https://doi.org/10.1002/brb3.3162.

62. Xie J, Pang C, Yu H, Zhang W, Ren C, Deng B. Leukocyte indicators and variations predict worse outcomes after intravenous thrombolysis in patients with acute ischemic stroke. J Cereb Blood Flow Metab. 2023;43(3):393–403.

63. Ying AN, Cheng YN, Lin YY, Yu JR, Wu XY, Lin YS. Dynamic increase in neutrophil levels predicts parenchymal hemorrhage and function outcome of ischemic stroke with r-tPA thrombolysis. Neurol Sci. 2020;41(8):2215–23.

64. Zhang TR, Fu S, Cao XF, Xia YJY, Hu MY, Feng QH, et al. Correlation of peripheral blood inflammatory indicators to prognosis after intravenous thrombolysis in acute ischemic stroke: a retrospective study. Int J Gen Med. 2024;17:985–96.

65. Zhao FF, Wang RL, Huang YY, Li LZ, Zhong LY, Hu Y, et al. Elevated plasma syndecan-1 as glycocalyx injury marker predicts unfavorable outcomes after rt-PA intravenous thrombolysis in acute ischemic stroke. Front Pharmacol. 2022. https://doi.org/10.3389/fphar.2022.949290.

66. Sun YY, Wang MQ, Wang Y, Sun X, Qu Y, Zhu HJ, et al. Platelet-to-lymphocyte ratio at 24h after thrombolysis is a prognostic marker in acute ischemic stroke patients. Front Immunol. 2022. https://doi.org/10.3389/fimmu.2022.1000626.

67. Yao Y, Cao X, Zou R, Wen H, Zhang S, Xu H, et al. Study on the baseline factors and platelet indices that predict outcome of acute ischemic stroke patients after thrombolytic therapy. Cerebrovasc Dis. 2022;51(3):357–64.

68. Wang MQ, Sun YY, Wang Y, Yan XL, Jin H, Sun X, et al. Platelet-to-neutrophil ratio after intravenous thrombolysis predicts unfavorable outcomes in acute ischemic stroke. Curr Neurovasc Res. 2020;17(4):411–9.

69. Ren H, Han L, Liu HB, Wang L, Liu X, Gao YJ. Decreased lymphocyte-to-monocyte ratio predicts poor prognosis of acute ischemic stroke treated with thrombolysis. Med Sci Monit. 2017;23:5826–33.

70. Sadeghi F, Sarkady F, Zsóri KS, Szegedi I, Orbán-Kálmándi R, Székely EG, et al. High neutrophil–lymphocyte ratio and low lymphocyte–monocyte ratio combination after thrombolysis is a potential predictor of poor functional outcome of acute ischemic stroke. J Pers Med. 2022. https://doi.org/10.3390/jpm12081221.

71. Rexrode KM, Madsen TE, Yu AYX, Carcel C, Lichtman JH, Miller EC. The impact of sex and gender on stroke. Circ Res. 2022;130(4):512–28.

72. Russo T, Felzani G, Marini C. Stroke in the very old: a systematic review of studies on incidence, outcome, and resource use. J Aging Res. 2011;2011:108785.

73. Planas AM. Role of immune cells migrating to the ischemic brain. Stroke. 2018;49(9):2261–7.

74. Candelario-Jalil E, Dijkhuizen RM, Magnus T. Neuroinflammation, stroke, blood-brain barrier dysfunction, and imaging modalities. Stroke. 2022;53(5):1473–86.

75. Guo P, Li H, Zhang X, Liu Y, Xue S, Yong VW, et al. Matrix metalloproteinase-9 in hemorrhagic transformation after acute ischemic stroke (review).

Mol Med Rep. 2025. https://doi.org/10.3892/mmr.2025.13590.

76. Qiu YM, Zhang CL, Chen AQ, Wang HL, Zhou YF, Li YN, et al. Immune cells in the BBB disruption after acute ischemic stroke: targets for immune therapy? Front Immunol. 2021;12:678744.

77. Turner RJ, Sharp FR. Implications of MMP9 for blood brain barrier disruption and hemorrhagic transformation following ischemic stroke. Front Cell Neurosci. 2016;10:56.

78. Meisel C, Schwab JM, Prass K, Meisel A, Dirnagl U. Central nervous system injury-induced immune deficiency syndrome. Nat Rev Neurosci. 2005;6(10):775–86.

79. Haeusler KG, Schmidt WU, Fohring F, Meisel C, Helms T, Jungehulsing GJ, et al. Cellular immunodepression preceding infectious complications after acute ischemic stroke in humans. Cerebrovasc Dis. 2008;25(1–2):50–8.

80. Liu DD, Chu SF, Chen C, Yang PF, Chen NH, He X. Research progress in stroke-induced immunodepression syndrome (SIDS) and stroke-associated pneumonia (SAP). Neurochem Int. 2018;114:42–54.

81. Vogelgesang A, Grunwald U, Langner S, Jack R, Broker BM, Kessler C, et al. Analysis of lymphocyte subsets in patients with stroke and their influence on infection after stroke. Stroke. 2008;39(1):237–41.

82. Bendszus M, Fiehler J, Subtil F, Bonekamp S, Aamodt AH, Fuentes B, et al. Endovascular thrombectomy for acute ischaemic stroke with established large infarct: multicentre, open-label, randomised trial. Lancet. 2023;402(10414):1753–63.

83. Sarraj A, Hassan AE, Abraham MG, Ortega-Gutierrez S, Kasner SE, Hussain MS, et al. Trial of endovascular thrombectomy for large ischemic strokes. N Engl J Med. 2023;388(14):1259–71.

84. Choi KH, Kim JH, Kang KW, Kim JT, Choi SM, Lee SH, et al. HbA1c (glycated hemoglobin) levels and clinical outcome post-mechanical thrombectomy in patients with large vessel occlusion. Stroke. 2019;50(1):119–26.

85. Heiss WD, Kidwell CS. Imaging for prediction of functional outcome and assessment of recovery in ischemic stroke. Stroke. 2014;45(4):1195–201.

86. Zhang W, Xing W, Lin W, Liu Y, He X, Wen Y, et al. Plasma D-dimer can predict all-cause mortality after mechanical thrombectomy of anterior circulation noncardioembolic acute cerebral infarction. Langenbecks Arch Surg. 2025;410(1):60.