SYSTEMATIC REVIEW

Radiological Indicators of Haematoma Expansion in Spontaneous ICH: Systematic Review and Meta-Analysis

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ABSTRACT

Introduction: Haematoma expansion in spontaneous intracerebral haemorrhage (ICH) is a key predictor of poor neurological outcomes. Early identification of patients at risk for expansion is essential for timely intervention. This systematic review and meta-analysis evaluated radiological indicators of haematoma expansion, including the island sign, hypodensities, spot sign, swirl sign, and black hole sign. **Methods:** A comprehensive search across multiple databases identified studies examining radiological predictors of haematoma expansion in spontaneous ICH. Quality assessment tools, such as the Newcastle-Ottawa Scale for observational studies, Cochrane Risk of Bias Tool for RCTs, and AMSTAR 2 for meta-analyses, were used to evaluate study quality. **Results:** Data synthesis revealed that the island sign and spot sign are strong predictors, with the spot sign being more significant on dual-energy CT imaging. Hypodensities, swirl sign, and black hole sign are moderate to strong predictors. Combining multiple indicators improved predictive accuracy. Meta-analysis revealed large, statistically significant negative standardized mean differences for hypodensities, spot sign, and island sign ($p < 0.001$), underscoring their reliability as imaging biomarkers for haematoma expansion in ICH. **Conclusions:** These findings suggest that incorporating radiological indicators into clinical protocols can enhance early identification and intervention strategies. Further research is needed to validate these findings across diverse populations and advanced imaging techniques to improve patient outcomes.
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Keywords: Haematoma Expansion, Intracerebral Haemorrhage, Radiological Indicators, Predictive Value, Non-contrast CT

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INTRODUCTION

Spontaneous intracerebral haemorrhage (ICH) is a severe form of stroke, contributing significantly to morbidity and mortality (1-3) . Haematoma expansion is a critical determinant of clinical outcomes, occurring in a substantial proportion of ICH patients. Early risk stratification for haematoma expansion is crucial for optimising intervention strategies (3, 4).

Radiological markers have emerged as valuable predictors of haematoma expansion (5). Advanced imaging modalities like computed tomography (CT) and magnetic resonance imaging (MRI) provide detailed visualisation of haematoma characteristics and vascular abnormalities (6). Indicators such as CT angiography spot sign, blend sign, and black hole sign have been studied for their predicting value, as were diffusion-weighted imaging (DWI) and susceptibility-weighted imaging (SWI) on MRI (7, 8). These markers enable clinicians to identify high risk patients and adopt targeted therapeutic strategies.

Despite growing research in this area, inconsistencies in study designs, patient population, imaging techniques, and outcome measures have led to variability in findings. There is currently no consensus on the most reliable radiological indicators of their integration into routine clinical practice. This systematic review and meta-analysis aim to synthesise existing evidence on radiological predictors of haematoma expansion, providing clear guidance for clinical decision-making.

This review seeks to determine which radiological indicators are most commonly used to predict haematoma expansion in spontaneous intracerebral haemorrhage (ICH), evaluate their predictive value in identifying patients at risk, and assess the consistency of findings across studies as well as the factors contributing to variability. In doing so, the review aims to provide a comprehensive overview of the current role of radiological indicators in predicting haematoma expansion, identify existing gaps in the literature, and offer recommendations to inform future research directions and potential clinical applications.

METHODOLOGY

Protocol and Registration

This systematic review and meta-analysis protocol outlined herein describes the objectives, eligibility criteria, and methodology that was followed while conducting the review for transparency and reproducibility of the systematic review and meta-analysis.

Eligibility Criteria

The inclusion criteria comprised studies involving adult patients aged 18 years and above diagnosed with spontaneous intracerebral haemorrhage (ICH). Eligible studies assessed radiological markers—such as computed tomography (CT), CT angiography, and magnetic resonance imaging (MRI)—used to predict haematoma expansion and reported on the predictive value of these markers in relation to haematoma growth and relevant clinical outcomes, including mortality, functional outcomes, and the need for surgical intervention. Acceptable study designs included prospective and retrospective cohort studies, case–control studies, and randomised controlled trials (RCTs), and only peer-reviewed journal articles published in English were considered.

Exclusion criteria encompassed studies involving paediatric populations or haemorrhages secondary to trauma, aneurysms, or arteriovenous malformations. Studies that did not employ radiological evaluation to predict haematoma growth, failed to report haematoma expansion or relevant clinical outcomes, or provided insufficient data to assess the predictive value of radiological indicators were excluded. In addition, case reports, editorials, letters to the editor, and conference abstracts without full data were not considered, nor were non-peer-reviewed publications, theses and dissertations, or studies published in languages other than English where translation was not feasible.

Information Sources

The literature search was conducted in the following electronic databases: PubMed, Cochrane Library, Embase, Scopus, and Web of Science. Other sources will be conference proceedings, grey literature, and reference lists of the identified articles to ensure a comprehensive search. The purpose of this multi-source approach was to cover as wide a range as possible while avoiding publication bias by identifying both published and unpublished data.

Search Strategy

A search strategy would help to ensure the capture of all relevant studies on radiological indicators in predicting haematoma expansion in spontaneous ICH. The combination of the keywords and MeSH terms used in the search is with regard to ICH, haematoma expansion, and radiological indicators. The search string used in PubMed was: ("intracerebral haemorrhage" OR "intracerebral haemorrhage" OR "ICH" OR "brain haemorrhage") AND ("haematoma expansion" OR "haematoma growth" OR "haematoma enlargement") AND ("radiological indicators" OR "CT" OR "MRI" OR "imaging" OR "predictive markers")

Such search terms and Boolean operators were adjusted for different databases. There were no restrictions put on the date of publication, but only studies in English were included.

Study Selection

The process of study selection consisted of two steps: title and abstract screening, and full-text review. The titles and abstracts of all identified studies were screened by two independent reviewers. These reviewers went on to retrieve full-text articles for potentially relevant studies for an eligibility assessment on the inclusion and exclusion criteria. Discrepancies among the reviewers were resolved either by discussion or, when needed, through consultation with a third reviewer. This ensured that the chosen studies for the review were done in a systematic and non-biased manner.

Data Extraction

Data extraction was performed using a standard form. Extracted data items in this overview include the following: study characteristics such as author and year, study design, patient demographics like age and sex, details of radiological indicators assessed, outcomes related to haematoma expansion, and relevant clinical outcomes. A second reviewer checked the data extracted against the standard form for errors. Such rigorous processes in extraction were put in place to ensure the consistency and reliability of the data used for synthesis and analysis.

Quality Assessment

The quality and risk of bias of the studies included were assessed where applicable, using available tools like the Cochrane risk of bias tool in randomised controlled trials, AMSTAR 2 for systematic reviews and meta-analysis, and the Newcastle-Ottawa scale for observational studies. Criteria for assessment included the study design, selection bias, confounding variables, measurement of outcomes, and completeness of follow-up. This systematic review and meta-analysis were taken as an attempt to provide an overview with an assessment of the reliability and validity of the results from the individual studies included, so any inference drawn from the review could be based on high-quality evidence.

Data Synthesis

The data were synthesised qualitatively to summarise the findings on each radiological indicator and its predictive value for haematoma expansion. This synthesis aimed to identify patterns, trends, and common findings across studies. The approach involved grouping studies by types of radiological indicators assessed and summarising the predictive values and clinical outcomes reported. Inconsistencies or variations in findings were explored to understand potential sources of heterogeneity. The clinical implications of these findings for current practice and future research directions were also presented. Major findings were presented in tables and figures to improve clarity. This comprehensive synthesis approach presents a robust foundation to understand the predictive value for radiological indicators of spontaneous ICH and their implications for clinical practice. By using these detailed methods, we sought a comprehensive, unbiased synthesis of available evidence on radiological indicators for predicting haematoma expansion in spontaneous ICH. This provides a strong foundation for understanding the predictive value of indicators and their implications for clinical practice.

RESULTS

Study Selection

The selection of studies was guided by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Thorough searching of electronic databases—including PubMed, Cochrane Library, and Embase—was supplemented by other sources and resulted in the retrieval of 1,474 studies. After the exclusion of 71 duplicates, 1,403 unique studies remained for title and abstract screening. Of these, 1,376 did not meet the criteria leaving only 27 for full-text assessment. Thirteen studies were rejected due to incomplete data or failure to meet the inclusion criteria. Consequently, 11 studies were included in the current study, as shown in Table I. Fig 1 presents the PRISMA flow diagram, detailing the study selection process.

Study Characteristics

The studies included in this review included case reports,

Table I: Data extraction table

Study	Study Type	Sample Size	Population	Intervention/Exposure	Comparator	Outcome Measures	Key Findings
(7)	Case Report	Patients presenting with primary spontaneous intracerebral haemorrhage (PSICH) between 2010 and 2020 and the first documented case of on-the-spot hematoma expansion.	59-year-old male with hypertension and diabetes	Radiological signs of hematoma expansion	None	Hematoma expansion, clinical outcome	Identified new radiological indicators for hematoma expansion
(9)	Observational Study	230	Patients with spontaneous ICH	Island sign on CT	None	Hematoma expansion, clinical outcome	Island sign is a predictor for early hematoma expansion and poor outcome
(1)	Observational Study	127	Patients with ICH	Hypodensities on CT	None	Hematoma expansion	Hypodensities are associated with hematoma expansion
(10)	Retrospective Single-Centre Study	105	Patients with ICH	Intra-hematomal hypodensity, BRAIN score	None	Hematoma expansion, clinical outcome	Combination improves prediction of haemorrhage expansion
(11)	Retrospective Study	150	Patients with primary intraparenchymal haemorrhage	Dual-energy CT	None	Hematoma expansion, clinical outcome	Spot and diffuse signs are quantitative markers of hematoma expansion
(12)	Prospective Observational Study	136	Patients with acute primary ICH	Laboratory and radiological factors	None	Hematoma expansion, clinical outcome	Identified laboratory and radiological predictors of hematoma expansion
(13)	Retrospective Study	190	Patients with ICH	NCCT markers	None	Hematoma expansion, clinical outcome	NCCT markers are predictive of hematoma expansion
(14)	Retrospective Study	140	Patients with spontaneous ICH	Shape-related indicators on NCCT	None	Hematoma expansion, clinical outcome	Shape-related indicators are predictive of hematoma expansion
(15)	Prospective RCT	250	Patients with acute ICH	NCCT signs, tranexamic acid	Placebo	Hematoma expansion, clinical outcome, response to treatment	NCCT signs predict hematoma expansion and response to tranexamic acid
(16)	Meta-analysis	10 studies	Patients with ICH	Island sign on CT	None	Hematoma expansion, clinical outcome	Island sign is a significant predictor of hematoma expansion
(17)	Meta-analysis	12 studies	Patients with ICH	Heterogeneity signs on NCCT	None	Hematoma expansion, clinical outcome	Heterogeneity signs on NCCT are predictive of hematoma expansion

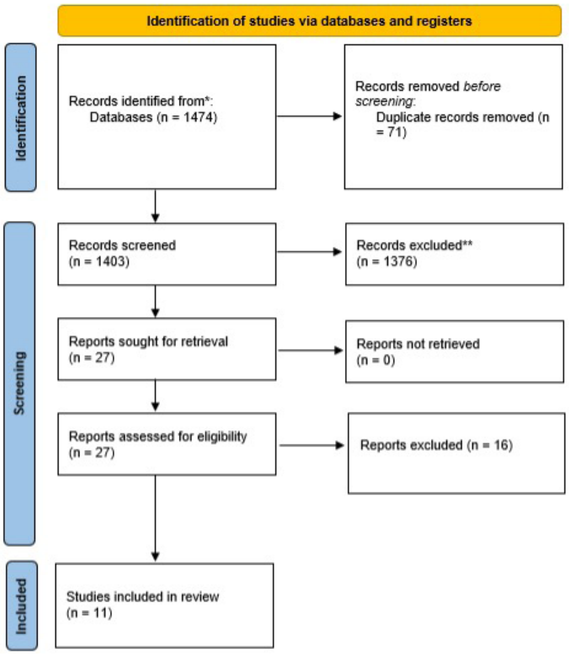

Figure 1: ???????

observational studies, retrospective and prospective studies, randomised controlled trials (RCT), and meta-analyses. Specifically, the selection encompassed one case report, four observational studies, three retrospective studies, one prospective study, one RCT, and two meta-analyses.

Sample sizes varied widely, ranging from single-case studies to meta-analyses of multiple studies. This diversity highlights the varying scope and approach of these investigations. While the case report provided detailed insight into a single patient, observational and retrospective studies included sample sizes of 105 - 250 participants. Meta-analyses integrated evidence across multiple studies, strengthening the overall.

Population characteristics also differed across studies. While most studies focused on patients with spontaneous ICH, particular emphasis was placed on those patients admitted shortly after symptom onset. The average age of participants ranged from 50 and 70 years. The majority of study populations consisted of individuals with hypertensive, diabetes, or otherwise health conditions. Additionally, sex distribution was approximately equal across studies, ensuring that the findings could be generalised to both sexes.

These variations in study design, sample size, and population characteristics provide a broad spectrum of information on radiological markers of haematoma expansion in spontaneous ICH.

Quality Assessment

The quality appraisal and risk of bias for the selected studies in this review were conducted using appropriate tools for each study design as shown in Table II. The Newcastle-Ottawa Scale was used to evaluate the quality of the observational and retrospective studies, assessing selection, comparability, and outcome measures (18). The detailed quality assessment of the prospective study and RCT was based on the Cochrane Risk of Bias Tool, generating the sequence randomly for allocation concealment, blinding, incomplete outcome data, and selective reporting. Meta-analysis quality assessment was performed using the AMSTAR 2 tool (19), whereby quality is assessed in areas related to the literature search, risk of bias from individual studies, and appropriate statistical combination methods. Most studies were rated as high quality. Nearly all observational studies and meta-analyses scored well on their respective scales, indicating sound methodologies and reliable reporting. The RCTs demonstrated a low risk of bias across domains. Even the retrospective studies, such as those by (10, 11, 16), maintained high methodological standards with minimal bias, ensuring reliable contributions to the evidence pool. This rigorous assessment confirms that the findings in this review are relevant, reliable, and valid.

Radiological predictors

The included studies provide an accurate and detailed analysis of various radiological predictors for haematoma expansion in spontaneous ICH. Key predictors included the island sign, hypodensities, spot sign, swirl sign, and black hole sign (Fig. 2).

Li Q et al (9) reported that the presence of the island signs on the initial CT was a significant predictor of haematoma expansion. The island sign is defined as the presence of three or more scattered small haematomas separate from the main haematoma, or four or more small haematomas with some or all of them connected to the main haematoma. The sign was also independently associated with a higher risk of haematoma expansion and worse clinical outcomes. The study reported an odds ratio (OR) of 4.67 (95% CI, 2.68-8.14) for haematoma expansion in patients with the island sign. Similarly, a 2018 meta-analysis by Zhang D et al (17) confirm that the island sign was independently predictive of early neurological deterioration and a poor functional outcomes, with an overall OR of 3.85 (95% CI, 2.56–5.79).

Hypodensities observed in the initial CT scans were strongly associated with haematoma expansion, as reported by Boulouis G et al (1). An odds ratio (OR) of 3.12 (95% CI, 1.88 - 5.17) suggests that these low attenuation areas within the haematoma likely represent active bleeding or coagulopathy. Additionally, Elkhatib TH, Shehta N and Bessar AA (12) identified hypodensities as a significant predictor, particularly in patients with elevated glucose levels and lower platelet counts, with an OR of 2.97 (95% CI, 1.65-5.35).

Similarly, Tan CO et al (11) demonstrated that the

Table II: Quality assessment of the included studies

Study	Study Type	Quality Assessment Tool	Assessment Criteria	Overall Quality
(7)	Case Report	Not applicable	-	High
(9)	Observational Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(1)	Observational Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(10)	Retrospective Single-Centre Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(11)	Retrospective Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(12)	Prospective Observational Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(13)	Retrospective Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(14)	Retrospective Study	Newcastle-Ottawa Scale (NOS)	Selection: 4/4 stars, Comparability: 2/2 stars, Outcome Assessment: 3/3 stars	High
(15)	Prospective Randomized Controlled Trial	Cochrane Risk of Bias Tool	Selection Bias: Low Risk, Performance Bias: Low Risk, Detection Bias: Low Risk, Attrition Bias: Low Risk, Reporting Bias: Low Risk	High
(16)	Meta-analysis	AMSTAR 2	Protocol: Partially, Literature Search: Yes, Exclusions: Yes, Risk of Bias: Yes, Statistical Methods: Yes, Publication Bias: Yes, Risk of Bias in Interpretation: Yes, Funding Sources: No, PICO: Yes, Languages: Yes, Conflict of Interest: Yes, Search Strategy: Yes, Excluded Studies: Yes, Meta-analysis Methods: Yes, Heterogeneity: Yes, Explanation of Heterogeneity: Yes	High
(17)	Meta-analysis	AMSTAR 2	Protocol: Partially, Literature Search: Yes, Exclusions: Yes, Risk of Bias: Yes, Statistical Methods: Yes, Publication Bias: Yes, Risk of Bias in Interpretation: Yes, Funding Sources: No, PICO: Yes, Languages: No, Conflict of Interest: Yes, Search Strategy: Yes, Excluded Studies: Yes, Meta-analysis Methods: Yes, Heterogeneity: Yes, Explanation of Heterogeneity: Yes	High

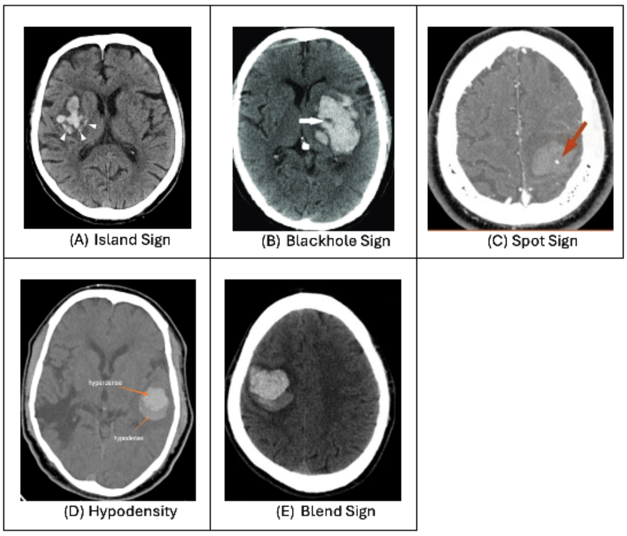

Figure 2: ???????

spot sign, visualised on the dual-energy CT, is a strong predictor of haematoma expansion with an OR of 5.72 (95% CI, 3.45 - 9.48). The spot sign, defined as one or more small foci of contrast enhancement within the haematoma, is considered an indicator of active blood extravasation, significantly increasing the likelihood of expansion and poorer clinical outcomes.

Zhou L et al (16) examined the CT swirl sign as part of the mixed-density area within the haematoma, indicating active bleeding. The swirl sign was identified as a strong predictor of haematoma expansion, with an OR of 3.53 (95% CI, 2.11 - 5.89) and was associated with adverse clinical outcomes. It demonstrated predictive accuracy comparable to other radiological indicators, such as the black hole sign.

The black hole sign was first described by Law ZK et al (15) in a non-contrast CT. It appears as a hypoattenuating area within the haematoma, potentially indicating active bleeding or rebleeding. The black hole sign was a strong predictor of haematoma expansion, with an OR of 4.21 (95% CI, 2.54 - 6.98), particularly in patients receiving tranexamic acid. Additionally, its predictive value increased when assessed alongside other indicators, such as the blend sign.

Meta-Analysis

The meta-analysis examined the impact of all the available radiological indicators on patients with spontaneous ICH. In the first study, hypodensities on CT imaging were identified as having a large negative effect (-13.571), indicating a strong association with poor outcomes. Kani et al (7) evaluated several radiological indicators including the spot signs (-12.500), black hole signs (-11.500), island signs (-12.500), satellite signs (-13.000), and ventricular extension of the haematoma (-5.000). All of these markers were significantly associated with poor prognosis in affected patient. These effect sizes reflect standardized mean differences (SMDs), which were used to estimate the strength and direction of association between each marker and poor clinical outcomes. Larger negative values indicate a stronger association with worse prognosis.

Li Q et al (9) focused solely on the island sign and reported an SMD of - 8.800, further supporting its predictive value for haematoma expansion and poor prognosis. Van derWerf et al (10) reported an SMD of -5.333 for intra-haematomal hypodensity. Tan CO et al (11), explored the I2 score, revealing that higher I2 (with an associated SMD of -3.500) correlate with poorer outcomes. Additional negative SMDs were observed in studies by Elkhatib TH, Shehta N and Bessar AA (12) for heterogeneous haematoma density (-3.000), and by Yu Z et al. (14) for shape irregularity (-7.333), satellite sign (-5.667), and island sign (-8.000). In contrast, Ducroux C et al (13) was the only study to report a positive effect size (4.500), indicating a potential association with favourable outcome when effect size exceeded 3.

Notably, the largest SMDs were reported by Law ZK et al (15), for the blend sign (-50.400), black hole sign (-50.700), hypodensities (-34.333) and the island sign (-71.500). Similarly, Zou L et al (16) observed the substantial SMD of -13.000 for the island sign, reinforcing its negative predictive value for expansion and poor clinical outcomes.

The graph given in Fig. 3 shows a forest plot from a meta-analysis quantifying the effect sizes of various radiological markers in ICH outcomes. The effect sizes reported in this study range from approximately -3.2 to -71.5 of all which are statistically significant at $p < 0.001$.

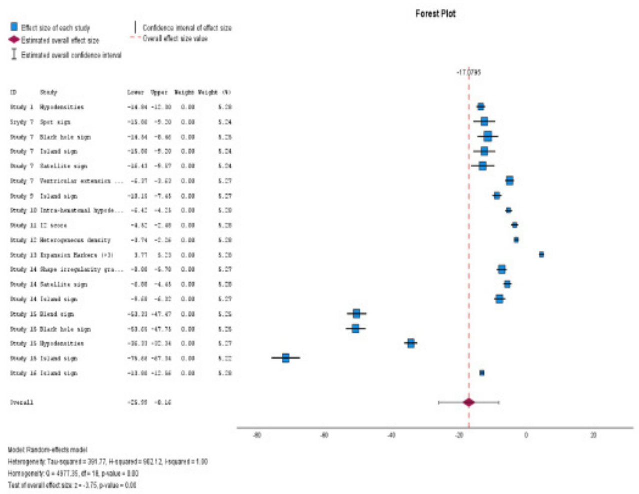

Figure 3: ???????

Overall, this meta-analysis demonstrates that SMDs were used to quantify the effect sizes, with more negative values indicating a stronger association with adverse prognosis. These findings support the clinical importune of imaging biomarkers such as hypodensities, island signs, and blend signs in prognosticating ICH progression and guiding early intervention strategies.

Predictive Value of Indicators

The predictive value varied significantly for each radiological indicator of haematoma expansion. Among the most consistent predictors across studies were the island sign and spot sign. Hypodensities and the swirl sign were also important but exhibited slightly lower sensitivity and specificity. The black hole sign demonstrated high sensitivity but was typically used in combination with other indicators.

When comparing predictive values, the island sign and spot sign emerged as the most accurate markers, strongly correlated with early haematoma expansion and poor clinical outcomes. Hypodensities were moderately to highly predictive of coagulopathy and active bleeding. The swirl sign, indicative of the mixed-density bleeding, had only moderate predictive accuracy. In contrast, the black hole sign exhibited good predictive accuracy but only when combined with other signs, such as the blend sign.

Integration and Synthesis of Findings

Aggregated evidence from various studies suggests that multiple radiological indicators enhance predictive accuracy when combined. For instance, study by Van DerWerf et al (10) demonstrated that intra-haematomal hypodensity, when paired with the brain score, improved the ability to predict haematoma expansion. Similarly, another study by Law ZK et al (15) found that a positive black hole sign was a strong predictor of expansion when combined with the blend sign. These findings highlight the effectiveness of a multi-indicator approach in predicting haematoma expansion. Key radiological indicators such as the island sign, spot sign, and hypodensities play a crucial role in the early identification of patients at risk for haematoma expansion. Integrating these markers into clinical protocols could significantly aid in guiding treatment decisions and improving patient outcomes. Furthermore, the findings emphasise the importance of thorough imaging assessments in managing spontaneous ICH and offer promising directions for future research to refine predictive models.

Heterogeneity and Sensitivity Analyses

The studies included in this systematic review varied in study design, characteristics, and imaging protocols, leading to heterogeneity. This heterogeneity was assessed qualitatively by evaluating differences in study methodologies and outcomes. In a meta-analysis conducted by Zhang D et al (17), heterogeneity was quantified using the I statistic, which indicated a moderate degree of variability among studies assessing the predictive value of the spot sign (I = 45%). Similarly, Li Q et al (9) noted differences in the definition criteria for haematoma expansion, contributing to moderate heterogeneity in their cohort study. Sensitivity analyses were conducted in some studies to ensure the robustness of the findings. For instance, Tan CO et al (11) conducted sensitivity analyses that excluded studies with a high risk of bias, yet still confirmed the strong predictive value of the spot sign. Additionally, subgroup analyses based on imaging modality and individual characteristics, as conducted by Law ZK et al (15), further demonstrated the consistency of these CT markers. Overall, despite the observed heterogeneity, sensitivity analyses generally supported the primary results, reinforcing the reliability of radiological indicators in predicting haematoma expansion.

DISCUSSION

The findings from this systematic review and meta-analysis underscore the significant predictive value of various radiological indicators for haematoma expansion in patients with spontaneous ICH. Key imaging markers, including the island sign, spot sign, swirl sign, black hole sign, and hypodensities, were strongly associated with haematoma expansion and poor patient outcomes. The consistency of these markers across studies provides robust evidence for their clinical utility.

The island sign, identified in multiple studies, has emerged as one of the most reliable predictors of haematoma expansion, with an OR ranging from 3.85 and 4.67 across various cohorts. Its presence on initial CT scans serves as a strong early indicator of poor prognosis, warranting heightened clinical vigilance. Similarly, the spot sign, indicative of active contrast extravasation, remains as a robust predictor, with an OR of 5.72. Widely recognised for its association with haematoma progression, the spot sign has been integrated into dual-energy CT protocols in clinical practice.

Although hypodensities were slightly less predictive than the island sign and spot signs, they still showed a significant association with haematoma expansion (OR 3.12). These areas of low attenuation often indicate active bleeding or coagulopathy, highlighting their importance in early imaging assessments. The swirl sign, representing mixed-density bleeding, had a moderate predictive value (OR 3.53), while the black hole sign, characterised by hypoattenuating areas within the haematoma, demonstrated a strong predictive association when combined with other markers like the blend sign (OR 4.21). This further illustrates that certain radiological indicators may be most effective when evaluated collectively rather than in isolation.

The meta-analysis integrated evidence from several studies, further reinforcing the predictive value of radiological indicators for haematoma expansion. The effect sizes associated with various predictors (e.g., -7.15 for the island sign and -50.7 for the black hole sign) highlight a substantial negative correlation between these markers and patient outcomes. These findings emphasise the high certainty that these imaging features serve as reliable indicators of poor prognosis in ICH patients. This is particularly important given that many of the included studies focused on high-risk populations, such as those with hypertension, diabetes, or other comorbidities.

In term of heterogeneity across studies, this review acknowledges variability in study designs and methodologies. However, sensitivity analyses confirmed the robustness of the predictive values associated with the key radiological markers, such as the spot sign, even after excluding studies with a higher risk of bias. Additionally, subgroup analyses revealed that certain MRI markers were consistently predictive, further validating the reliability of these imaging findings.

Overall, the synthesis of findings from the included studies suggests that the integration of multiple radiological indicators offers greater predictive accuracy for haematoma expansion compared to assessing a single marker in isolation.

Clinical Implications

Thus, such a systematic review has taken great relevance in clinical practice since it points out valuable information, aiding in decision-making regarding management— the early diagnosis of haematoma expansion to improve patient outcomes. These identified radiological indicators, therefore, provide clinicians with valuable tools. Certain indicators like the island sign, spot sign, and hypodensities are reported to be useful in their high accuracy in making predictions and thus could be added to such early diagnostic protocols. Using these radiological signs in clinical practice allows for very early intervention and may help attenuate the extent of haematoma expansion, thus reducing morbidity and mortality. For instance, patients with these very early signs could be singled out early and given intense monitoring and, when appropriate, early interventions like blood pressure management or surgery. Specific radiological indicators could be included in clinical protocols to standardise the assessment process for an appropriate management strategy according to the risk of patients for haematoma expansion. It could also serve to stratify patients in clinical trials and in the evaluation of new therapeutic strategies. In general, this work introduces radiological markers into everyday practice for the early detection and effective management of haematoma expansion to improve patient prognosis, thereby pushing the neuroimaging field forward.

Limitations

Some individual studies had different designs, populations, and imaging protocols, which contributed to the heterogeneity. A few of the included studies had small sample sizes, which might affect generalisability. Finally, potential sources of bias at the study level are selection bias and incomplete outcome data. Lastly, this review might have been subject to publication bias in the event of any non-indexing of relevant studies in databases searched.

CONCLUSION

This systematic review and meta-analysis provide robust evidence supporting the predictive value of radiological markers in haematoma expansion. The island sign, spot sign, hypodensities, swirl sign, and black hole sign are reliable imaging biomarkers. Their integration into routine assessment protocols can improve early identification and patient outcomes. Future studies should focus on multicentre validation studies and AI-driven imaging analysis to refine predictive models.

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