BIBLIOMETRIC ANALYSIS OF SUSCEPTIBILITY VESSEL SIGN IN ACUTE ISCHAEMIC STROKE

A.B. Nasir Aslam[1,2*], Y. Yuniewati[1], A. Tharek[2], , R.S. Perisamy[2], L.W. Chao[3], N. Bahari[7], N.A. Nasir[4], A.S. Muda[2]

[1]Radiology Department, Fakultas Kedokteran Universitas Brawijaya, Saiful Anwar Hospital, Indonesia
[2]Radiology Department, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia
[3]Neurology Department, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia
[5]PathologyDepartment, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia

[*]Corresponding Author's Email: asobri@student.upm.edu.my

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ABSTRACT: The susceptibility vessel sign (SVS) on magnetic resonance imaging (MRI) is an important biomarker in acute ischaemic stroke, but SVS research has expanded across journals and countries without a quantitative map of its development. This study aimed to provide a bibliometric analysis of global SVS research. A Scopus search (7 February 2024) identified SVS-related publications in acute ischaemic stroke. After screening, 122 peer-reviewed articles published between 2005 and 2024 were included. Bibliometric indicators and science mapping were analysed using Bibliometrix (R) with Biblioshiny, with VOSviewer for collaboration and keyword co-occurrence networks. SVS publications showed steady growth over 2005–2024, supported by collaborative authorship (1,215 authors) and 3,089 citations (25.3 per paper). Keyword mapping clustered around imaging modalities, clinical outcomes (thrombolysis/thrombectomy), and thrombus pathology, with emerging themes including artificial intelligence and multicentre thrombectomy trials. SVS research has progressed from early diagnostic validation to prognostic and treatment-focused work, and more recently toward quantitative, AI-assisted, trial-driven applications. This bibliometric map identifies key contributors, core journals, and evolving themes to guide future SVS research and clinical translation in acute stroke care.

KEYWORDS: *Susceptibility vessel sign; Acute ischaemic stroke; Magnetic resonance imaging; Mechanical thrombectomy; Bibliometric analysis*

1.0 INTRODUCTION

Acute ischaemic stroke (AIS) is a leading cause of mortality and disability globally, necessitating prompt diagnosis and efficient recanalisation to enhance patient outcomes (Li et al., 2022; Vilela & Rowley, 2017). Magnetic resonance imaging (MRI), particularly susceptibility-weighted imaging (SWI) and T2*-weighted gradient-echo (GRE), has enabled detection of thrombi through the susceptibility vessel sign (SVS) (Cho et al., 2005; Schellinger et al., 2005). SVS, identified by a hypointense signal in occluded arteries, indicates thrombus composition and has consequences for therapy efficacy and prognosis (Liebeskind et al., 2011).

Over the past two decades, research has increasingly showed the diagnostic and prognostic value of SVS in stroke. Early studies highlighted its role in detecting intracranial occlusions, while subsequent works linked SVS features with recanalisation outcomes and thrombus pathology (Seners et al., 2016). Collectively, these findings support SVS as a clinically relevant biomarker in guiding treatment, including thrombolysis and mechanical thrombectomy (Boeckh-Behrens et al., 2016; Kang et al., 2017).

Despite this growing body of work, SVS research remains fragmented across journals, institutions, and countries. Most reviews have been narrative or systematic in nature, offering qualitative synthesis but lacking quantitative mapping of research trends, collaborations, and thematic development. Bibliometric analysis provides a structured approach to assess scientific output, influential contributors, and evolving research themes.

To date, no bibliometric study has systematically evaluated the development of SVS literature. This study therefore aims to analyse global research trends in SVS, focusing on publication and citation patterns, leading authors and institutions, country contributions, journal sources, and keyword co-occurrence. The findings are expected to provide a consolidated knowledge base, highlight research hotspots, and guide future investigations and clinical translation of SVS in stroke care.

The Susceptibility Vessel Sign (SVS) was first described in the early

2000s using T2*-weighted gradient echo imaging to visualise hypointense intraluminal signals corresponding to acute thrombi in large intracranial vessels. Early studies, such as those by Cho et al. (2005) and Schellinger et al. (2005), demonstrated the potential of SVS to identify vascular occlusions with high diagnostic accuracy compared with magnetic resonance angiography. These foundational works established SVS as a surrogate marker for thrombus composition, particularly red blood cell–rich clots, and highlighted its potential role in guiding reperfusion therapy decisions.

Throughout the following decade, SVS research has expanded in scope. Investigators explored correlations between SVS presence and response to intravenous thrombolysis, showing that clot composition could influence recanalisation rates. The emergence of mechanical thrombectomy further reinforced the prognostic value of SVS, as studies identified relationships between thrombus characteristics, retrieval difficulty, and treatment outcomes. This body of studies established SVS as a diagnostic marker and a possible predictor of therapy response.

Recently, the literature on SVS has expanded to include sophisticated applications and methodological enhancements. A primary study emphasis has been the quantitative evaluation of SVS, encompassing assessments of clot length, diameter, and overestimation ratio in comparison to contralateral vessels (Bourcier et al., 2019; Legrand et al., 2013). These efforts aim to improve reproducibility and integrate SVS into clinical decision-making tools.

A secondary focus has been the relationship between SVS and clot burden, with research indicating that larger or elongated SVS is associated with greater clot burden (lower score) and analysed its association to recanalisation outcomes (Derraz et al., 2019; Legrand et al., 2013; Soize et al., 2015). Concurrent research has investigated SVS pertaining to collateral circulation and long-term functional recovery, establishing a connection between imaging biomarkers and clinical prognosis (Bourcier et al., 2015, 2018).

The integration of artificial intelligence and radiomics in SVS analysis represents an emerging frontier. Machine learning techniques are increasingly used to automate the detection and characterisation of SVS, thereby minimizing interobserver variability and facilitating large-scale, multicentre applications. This reflects a broader trend in neuroradiology toward AI-assisted workflows, where SVS may serve as a test case for translating imaging biomarkers into precision medicine (Belachew et al., 2021; Christiansen et al., 2024).

Despite the clinical and research importance of SVS, the scientific landscape remains fragmented across diverse specialties and publication outlets. Existing reviews have primarily been narrative, focusing on clinical outcomes, imaging protocols, or thrombus pathology. While bibliometric analyses have been conducted in related domains—such as acute stroke imaging, endovascular therapy, and diffusion-weighted MRI—no study has systematically mapped the research output, collaboration networks, and thematic evolution specific to SVS.

This absence of bibliometric synthesis represents a critical gap. Without a structured overview, researchers and clinicians lack a consolidated understanding of the field’s growth trajectory, influential contributors, and emerging directions. Addressing this gap through bibliometric analysis can provide a strategic knowledge framework, highlighting not only the state of the art but also guiding future empirical investigations and clinical translation.

2.0 METHODOLOGY

2.1 Data Source and Search Strategy

The bibliometric dataset was retrieved from the Scopus database, which provides comprehensive coverage of peer-reviewed literature across medicine, imaging, and neuroscience. The search was performed on 7 February 2024, without restrictions on language or publication year. The following query was applied in the title field: ("susceptibility vessel sign" OR "vascular susceptibility artifact" OR "blooming artefact") AND (stroke OR CVA OR ischaemic). The initial search yielded 471 records. After screening for relevance based on abstracts and full texts, 349 documents were excluded because they did not specifically address SVS in acute ischaemic stroke. Only peer-reviewed articles were included, resulting in a final dataset of 122 articles for analysis.

2.2 Data Cleaning and Preparation

Bibliographic records were exported in CSV and TXT formats with full metadata, including cited references. Data preprocessing was carried out using OpenRefine to standardise author names, institutional affiliations, and keywords, thereby reducing duplication and inconsistencies. Additional filtering and descriptive statistics were performed in Excel, and the biblioMagika tool was used to facilitate structured tabulation of citation metrics (Ahmi, 2024; Aria & Cuccurullo, 2017).

2.3 Analytical Tools and Indicators

Bibliometric indicators were computed using the Bibliometrix package in R, supported by its web-based interface, Biblioshiny. The analysis was structured along three main dimensions. First, a performance analysis was undertaken to examine annual publication and citation trends, as well as to identify the most productive authors, institutions, countries, and journals. Citation-based metrics, including citation counts, h-index, g-index, and m-index, were calculated at both corpus and entity levels. Second, a science mapping approach was applied to characterise collaboration and intellectual linkages in the field. This involved co-authorship and collaboration networks across authors, institutions, and countries, together with co-citation analysis of references and journals. Bibliographic coupling and dual-map overlays were further employed to reveal structural connections among sources. Finally, a thematic and trend analysis was conducted. This included keyword frequency and co-occurrence networks, thematic mapping to position clusters according to centrality and density, temporal trend topic analysis, and citation burst detection to identify emerging or transient themes.

2.4 Visualization

Biblioshiny and *VOSviewer* produced visuals to support numeric findings. A flow diagram of the literature screening and inclusion procedure, annual output charts demonstrating publication and citation increase, and network maps showing author, institution, and country collaboration were included. In addition, keyword co-occurrence maps, thematic maps, and plots of citation bursts and trending topics were produced. Together, these visualisations provided both macro-level insights into global research structures and micro-level perspectives on thematic development within SVS literature.

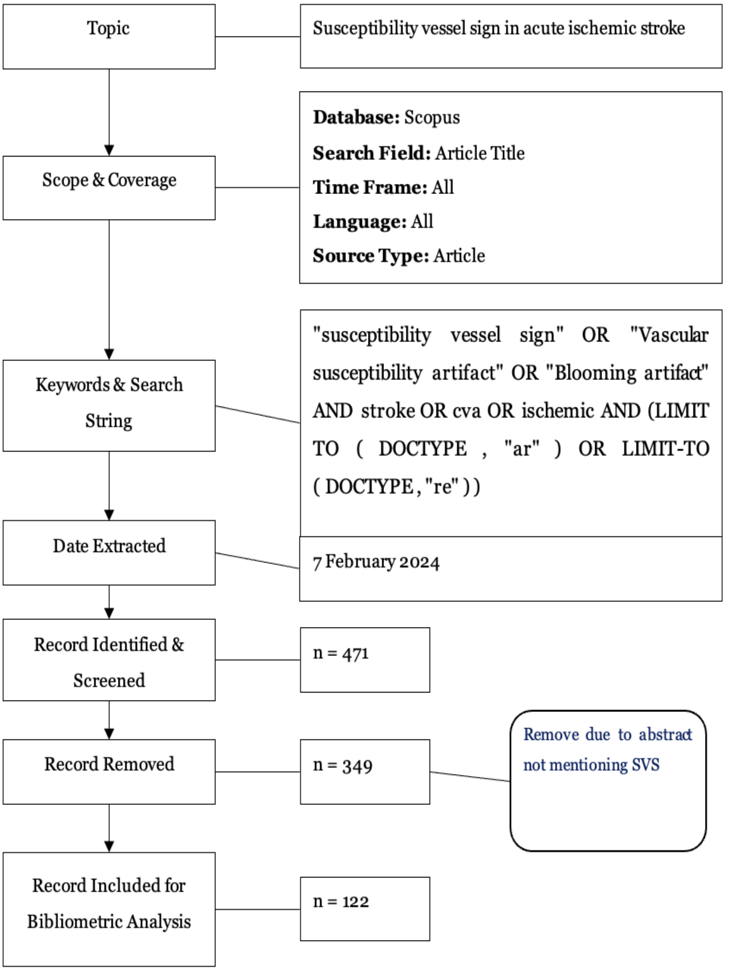

Figure 1. Flow diagram of search strategy

3.0 RESULT

3.1 Publication and Citation Trends

The Between 2005 and 2024, 122 SVS articles in acute ischaemic stroke were identified. The work had 1,215 authors and 3,089 citations, averaging 25.3 per piece. The dataset showed continuous scholarly influence across the discipline with an h-index of 29 and a g-index of 52.

Table 1 presents the descriptive metrics of the corpus, summarising the overall productivity and citation performance of the SVS literature. The annual publication output exhibited a steady increase, with significant peaks observed in 2015, 2019, and 2021, corresponding to advancements in mechanical thrombectomy and clot imaging research. A citation spike in 2011 (447 citations) was largely driven by the landmark article by Liebeskind et al., which remains a cornerstone of SVS-related studies (Liebeskind et al., 2011). Figure 2 illustrates the annual distribution of publications and citations, emphasising the cumulative growth and temporal fluctuations in scholarly attention.

Table 1: Main Citation Metrics of the SVS Literature (2005-2024)

Main Information	**Data**
Publication Years	2005 - 2024
Total Publications	122
Citable Year	20
Number of Contributing Authors	1215
Number of Cited Papers	110
Total Citations	3089
Citation per Paper	25.32
Citation per Cited Paper	28.08
Citation per Year	162.58
Citation per Author	2.54
Author per Paper	9.96
Citation sum within h-Core	2958
h-index	29
g-index	52
m-index	1.45

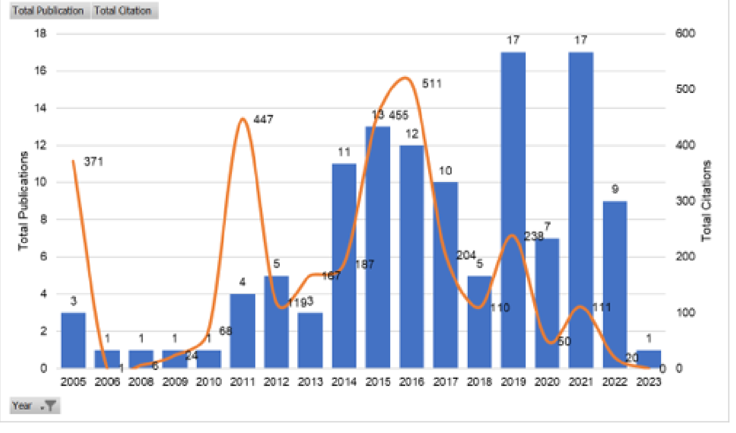

Figure 2: Total Publications and Citations by Year of SVS in Acute Stroke

The improved model demonstrated meaningful performance gains, relative to the initial 20-epoch baseline, which achieved precision and recall of about 0.40, mAP@0.5 in the range 0.35–0.40, and mAP@0.5:0.95 near 0.10–0.12. Precision increased to approximately 0.55–0.60, recall improved to roughly 0.45–0.50, and mAP@0.5 reached 0.45–0.48, while mAP@0.5:0.95 rose to 0.15–0.17. The precision–recall curve yielded an mAP@0.5 of 0.474, indicating moderate overall detection capability given the low-contrast, small-scale nature of FHVS lesions and the limited training cohort.

3.2 Authorship and Collaboration Patterns

The field is marked by significant multi-authorship, averaging nearly 10 authors per article, which underscores the collaborative nature of stroke imaging research.

The most prolific contributors were Catherine Oppenheim and Olivier Naggara (17 articles each), followed by Raphaël Bourcier (13 articles), Serge Bracard (12 articles), and Laurent Legrand (10 articles). These researchers also ranked among the most cited, with Oppenheim and Naggara achieving over 600 and 450 citations, respectively. Their output and high h-indices underscore their pivotal roles in advancing SVS research. Table 2 lists the most productive authors along with their publication and citation metrics.

Figures 3 and 4 illustrate patterns of collaboration, revealing dense clusters centred in France, particularly connecting institutions in Paris, Nancy, and Nantes. This suggests the existence of robust national consortia advancing SVS research. The temporal distribution of author productivity is illustrated in Figure 5, which demonstrates how leading contributors have maintained consistent output over nearly two decades.

3.3 Country and Institutional Contributions

Analysis of country contributions revealed that France led the field, producing 48 publications with 1,417 citations (h-index 19). China (26 publications) ranked second in output, while the United States (18 publications) and South Korea (16 publications) recorded the highest citation-per-paper ratios (41 and 46, respectively), demonstrating strong global impact despite lower publication counts. These findings are detailed in Table 3.

The United States contributed 18 publications but demonstrated one of the highest citation-per-paper values (41), indicating that American contributions, though fewer in number, are disproportionately influential. Similarly, South Korea produced 16 publications with an even higher citation-per-paper ratio (46), reflecting concentrated but impactful research efforts.

Other countries, including Japan, Switzerland, and Germany, contributed smaller outputs, yet their work often supported methodological or clinical refinements within the field. Collectively, these findings suggest that while SVS research is dominated by European centres, particularly France, select Asian and North American countries play a crucial role in shaping high-impact studies and diversifying the research landscape.

Institutional analysis confirmed the dominance of French research centres, with CHU de Nancy (24 papers, 717 citations, h-index 11) and Centre Hospitalier Sainte-Anne (19 papers, h-index 14) at the forefront. Other highly productive institutions included Université Paris Cité, Fondation Rothschild, and CHU Montpellier. These results are presented in Table 3.

International collaboration networks are illustrated in Figure 4, generated using Vosviewer (Van Eck & Waltman, 2010). France emerged as the central hub, collaborating strongly with Germany, Canada, and China, while the United States formed a separate cluster with South Korea and Switzerland. The findings indicate that SVS research is primarily rooted in European networks, while also establishing growing connections with partners in North America and Asia. The limited nature of intercontinental connections underscores potential avenues for enhanced global cooperation.

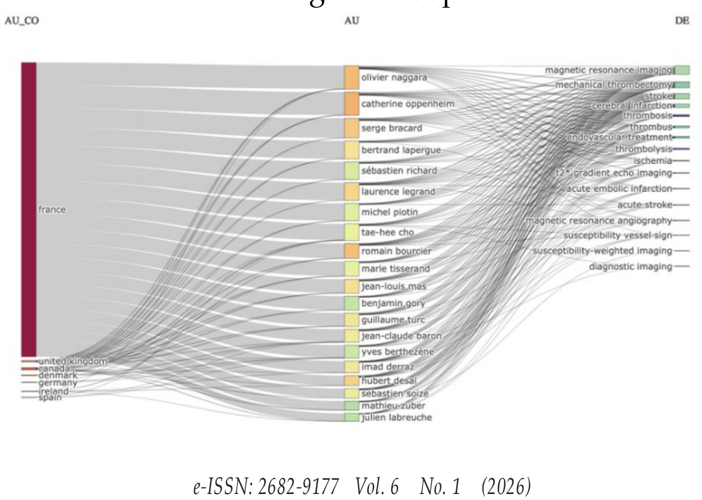

Figure 3: Patterns of collaboration

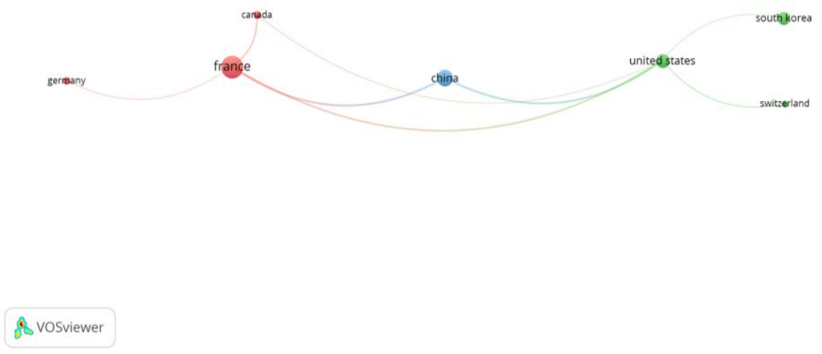

Figure 4: International collaboration network

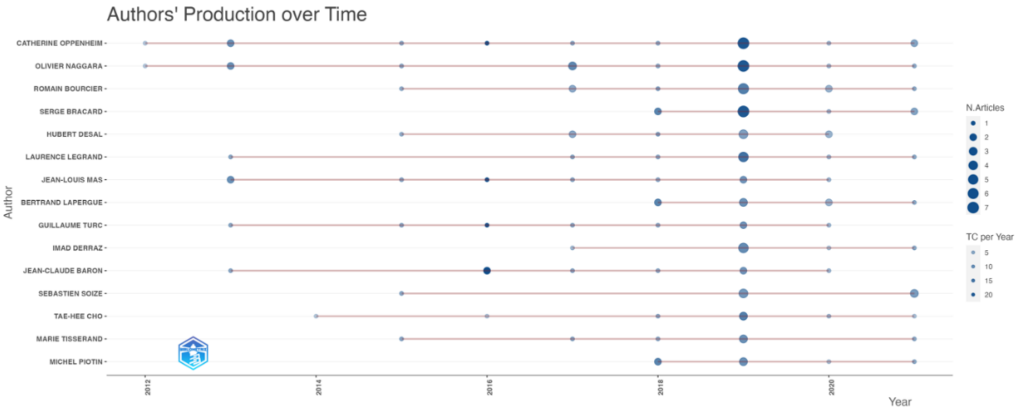

Figure 5: Author production over time in SVS research (2005-2024), showing annual publication activity of the most prolific contributors

The institutional analysis verified the pre-eminence of French research centres in studies related to SVS. CHU de Nancy led the list with 24 publications and 717 citations (h-index = 11), followed by Centre Hospitalier Sainte-Anne with 19 publications and 649 citations, and Université Paris Cité with 17 publications and 662 citations. Additional significant contributors were Fondation Rothschild and CHU Montpellier, both of which exhibited consistent productivity and influence.

The University of California exhibited significant influence outside of France, producing 9 publications that garnered 489 citations and achieving the highest citation-per-paper ratio of 54.3, highlighting the prominent role of North American institutions despite a lower volume of output. Contributions were recorded from institutions in China (Beijing Tiantan Hospital), Japan (Nippon Medical School, Juntendo University School of Medicine), and Switzerland (Bern University Hospital), though their output was relatively modest.

Overall, the data highlight how SVS research remains anchored in a concentrated European network, while select international centres contribute disproportionately high-impact studies. Figure 6 illustrates the geographical distribution of contributions by country, highlighting Europe's dominance and significant input from Asia and North America. Figure 7 illustrates collaborative relationships among countries, emphasising strong intra-European connections while indicating comparatively weak transcontinental partnerships.

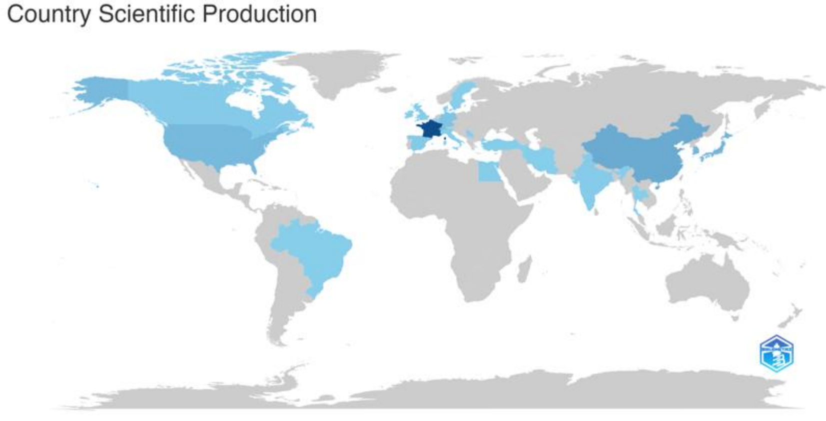

Figure 6: World map of scientific production. Countries with a darker blue shade have a higher number of publications

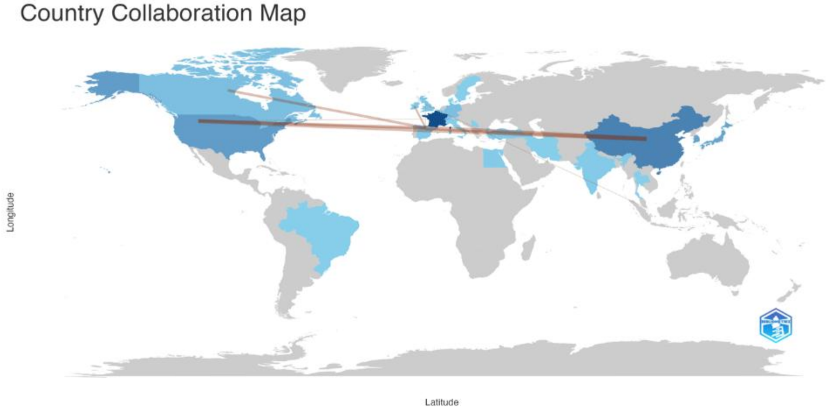

Figure 7: Country collaboration Map

The journal "Stroke" has established itself as the primary publication for SVS research, featuring 18 articles that achieved a total of 1,395 citations, averaging 77.5 citations per article, with an h-index of 16. The American Journal of Neuroradiology (AJNR) achieved a ranking of second, publishing 13 articles that garnered a total of 494 citations, resulting in an average of 38 citations per article. Additional active journals comprised European Neurology, European Radiology, Journal of Stroke and Cerebrovascular Diseases, and Journal of Neuro Interventional Surgery. The results are summarised in Table 4.

The analysis of author keywords yielded insights into the conceptual framework of SVS research. Table 5 presents the most frequent terms, with magnetic resonance imaging (55 occurrences), stroke (41), cerebral infarction (33), susceptibility vessel sign (33), and mechanical thrombectomy (21) identified as the predominant descriptors. Terms such as susceptibility-weighted imaging, thrombus, and T2* gradient echo imaging underscore the technical focus on imaging modalities and clot characterisation. Infrequent yet significant terms comprised acute embolic infarction (7) and endovascular treatment (7), indicating the increasing convergence of SVS research with therapeutic approaches.

Figure 8 presents a word cloud of author keywords, with terms displayed in larger font sizes signifying greater frequency of occurrence. This visualisation underscores the significance of magnetic resonance imaging, stroke, cerebral infarction, and susceptibility vessel sign in the research domain.

The analysis of these keywords indicates three primary thematic clusters. The imaging modality cluster, comprising magnetic resonance imaging, SWI, and T2* GRE, highlights the technical foundation of SVS research. The clinical outcome cluster, which includes stroke, cerebral infarction, mechanical thrombectomy, and endovascular treatment, represents the application of SVS findings in patient care and treatment assessment. The pathophysiological cluster, comprising susceptibility vessel sign, thrombus, and acute embolic infarction, underscores the significance of SVS in elucidating clot composition and stroke mechanisms (Huang et al., 2012).

Overall, the keyword analysis reveals that SVS research is firmly rooted in advanced MRI techniques and closely linked to therapeutic outcomes, while emerging intersections with mechanical thrombectomy and clot pathology indicate ongoing clinical relevance and expansion of the field.

The article by Liebeskind et al. (2011, Stroke) is the most cited, with 394 citations, and it established SVS as a marker for clot composition and treatment response. Additional significant studies comprised Boeckh-Behrens et al. (2016, Stroke; 198 citations), Seners et al. (2016, Stroke; 185 citations), and Cho et al. (2005, Stroke; 164 citations). Table 6 presents the 20 most cited articles, which constitute the foundational knowledge base of SVS research.

The bibliometric analysis indicates a consistent increase in research regarding the susceptibility vessel sign over the last twenty years, with France identified as the primary contributor. The journals Stroke and AJNR serve as the principal publication venues, while the most cited studies concentrate on clot composition, recanalisation outcomes, and prognostic applications. Keyword analysis identified three primary thematic clusters: (i) imaging modalities, including SWI and T2*-GRE, (ii) clinical outcomes associated with thrombectomy and thrombolysis, and (iii) thrombus pathology, encompassing clot burden and embolic infarction.

These results indicate that SVS research has progressed through three distinct phases: initial diagnostic validation in the early 2000s, prognostic and treatment-focused studies in the 2010s, and the rise of AI-driven analytics and advanced thrombectomy applications in the 2020s. The findings establish a foundation for an in-depth examination of research hotspots, emerging trends, future directions, and the limitations associated with this study.

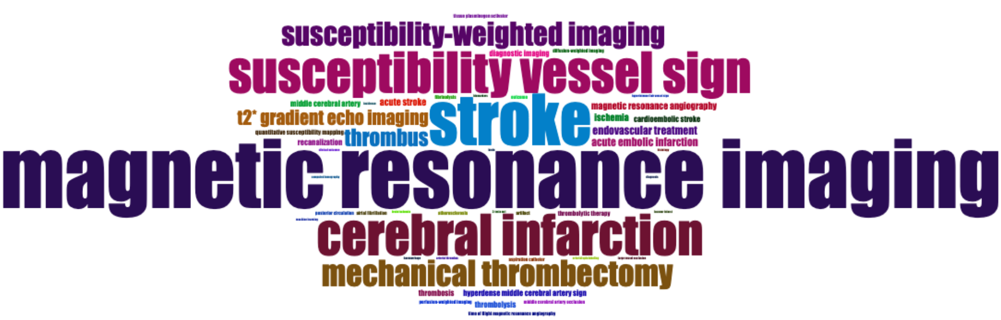

Figure 8: Word cloud of author keywords in SVS research (2005–2024).

4.0 DISCUSSION

4.1 Summary of Findings

This research represents the first bibliometric analysis of studies concerning the susceptibility vessel sign (SVS) in acute ischaemic stroke. Between 2005 and 2024, a total of 122 publications were identified, indicating a consistent increase in scholarly output, with notable peaks aligning with significant advancements in endovascular therapy and stroke imaging. France has established itself as the most productive country, bolstered by robust institutional networks including CHU de Nancy, Centre Hospitalier Sainte-Anne, and Université Paris Cité. The United States and South Korea, despite producing fewer publications, exhibited higher citation-per-paper ratios, indicating a greater relative impact. Catherine Oppenheim and Olivier Naggara emerged as the most prolific authors, with Stroke and AJNR serving as the primary publication venues. Prominent studies, notably Liebeskind et al. (2011) and Boeckh-Behrens et al. (2016), established the intellectual framework for SVS research. Analysis of keywords identified three conceptual clusters: imaging modalities (SWI, T2*-GRE), clinical outcomes (mechanical thrombectomy, thrombolysis), and thrombus pathology (clot burden, embolic infarction).

4.2 Research Hotspots

The analysis identifies several central themes prevalent in SVS research. Imaging techniques are fundamental to the field, with MRI-based methods, particularly SWI and T2*-GRE, acting as the main modalities for thrombus visualisation (Cho et al., 2005; Huang et al., 2012). Secondly, treatment-related outcomes represent a coherent area of investigation, utilizing SVS to assess recanalisation success and patient prognosis following intravenous thrombolysis or mechanical thrombectomy (Kang et al., 2017; Seners et al., 2016). Third, clot pathology and burden remain a focal point of research, with SVS characteristics including length, diameter, and overestimation ratio correlated to clot composition and therapeutic responsiveness (Boeckh-Behrens et al., 2016; Legrand et al., 2013; Liebeskind et al., 2011). These hotspots demonstrate the dual role of SVS as a diagnostic marker and a prognostic tool in the management of acute stroke.

4.3 Emerging Trends

Recent developments indicate a transition towards quantitative and computational methodologies. Research is increasingly directed towards the standardization of SVS measurement techniques, minimizing interobserver variability, and the integration of SVS with additional imaging biomarkers, including the clot burden score (CBS). A notable emerging direction involves the utilization of artificial intelligence and radiomics for the automation of SVS detection and analysis, facilitating more reproducible and extensive assessments (Belachew et al., 2021; Christiansen et al., 2024). This is especially visible in multiple radiology and clinical journals assessed in this study. The integration of SVS into multicentre thrombectomy trials indicates its increasing importance in assessing device performance, recanalisation strategies, and treatment outcomes (Bourcier et al., 2018; Soize et al., 2015). These trends indicate that future research will focus on precision imaging, data-driven analytics, and the clinical translation of SVS into stroke care pathways.

4.4 Limitations

This research presents multiple limitations. The analysis was limited to the Scopus database, which, although comprehensive, may omit pertinent publications indexed in other databases. Secondly, the inclusion criteria were limited to peer-reviewed articles, excluding reviews, conference proceedings, and grey literature, potentially restricting the coverage of emerging concepts. Third, citation-based indicators exhibit an inherent time-lag bias, which may lead to an underestimation of the impact of recently published works. Ultimately, keyword analysis relies on terms provided by the author, which can differ in specificity and consistency, thereby influencing clustering outcomes.

4.5 Implications for Future Research and Practice

This bibliometric analysis offers a strategic overview of SVS research, regardless of its limitations. The findings identify key authors, institutions, and journals that function as collaboration hubs, underscore research hotspots integral to clinical practice, and elucidate emerging trends that may inform future research endeavours. The study offers a framework for investigating underrepresented domains, including the standardization of SVS metrics and the integration with AI-driven image analysis. The analysis highlights the significance of SVS as an indicator of clot composition and recanalisation potential, which may be utilized in patient stratification and treatment decision-making for clinicians. The findings underscore the potential for policymakers and funding agencies to foster international collaborations, especially to mitigate the predominance of European centres by incorporating contributions from diverse regions.

5.0 CONCLUSION

This paper offers a thorough review of the research landscape on the susceptibility vessel sign (SVS) in acute ischaemic stroke from 2005 to 2024 and presents the first bibliometric analysis of the SVS. The results indicate consistent growth in publications, with France at the forefront of productivity and Stroke and AJNR as the main journals for dissemination. Significant contributions from authors including Oppenheim, Naggara, and Liebeskind, as well as pivotal studies on clot composition and recanalisation outcomes, have established the intellectual foundation of the field.

Keyword analysis identified three dominant research clusters: imaging modalities, treatment and clinical outcomes, and thrombus pathology. Recent trends indicate the integration of quantitative SVS metrics, artificial intelligence, and multicentre thrombectomy trials, highlighting a shift in the field towards standardisation and translational applications.

By mapping research hotspots, collaboration networks, and emerging directions, this study establishes a strategic knowledge base that can guide future research, foster international collaboration, and support the clinical application of SVS in precision stroke care. Continued efforts to harmonise methodologies and expand AI-driven approaches will be essential for realising the full potential of SVS as an imaging biomarker in stroke management.

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