

BIBLIOMETRIC ANALYSIS OF SUSCEPTIBILITY VESSEL SIGN IN ACUTE ISCHAEMIC STROKE

A.B. Nasir Aslam^{1,2*}, Y. Yuniewati¹, A. Tharek², R.S. Perisamy², L.W. Chao³, N. Bahari⁷, N.A. Nasir⁴, A.S. Muda²

¹Radiology Department, Fakultas Kedokteran Universitas Brawijaya, Saiful Anwar Hospital, Indonesia

²Radiology Department, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia

³Neurology Department, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia

⁵Pathology Department, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia

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

Article History: Received May 10, 2026; Revised May 29, 2026; Accepted May 31, 2026

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 [1,2]. 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) [3,4]. SVS, identified by a hypointense signal in occluded arteries, indicates thrombus composition and has consequences for therapy efficacy and prognosis [5].

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 [6]. Collectively, these findings support SVS as a clinically relevant biomarker in guiding treatment, including thrombolysis and mechanical thrombectomy [7,8].

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 [9,10]. 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 [10-12]. Concurrent research has investigated SVS pertaining to collateral circulation and long-term functional recovery, establishing a connection between imaging biomarkers and clinical prognosis [13,14]. 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 [15,16].

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 [17,18].

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.

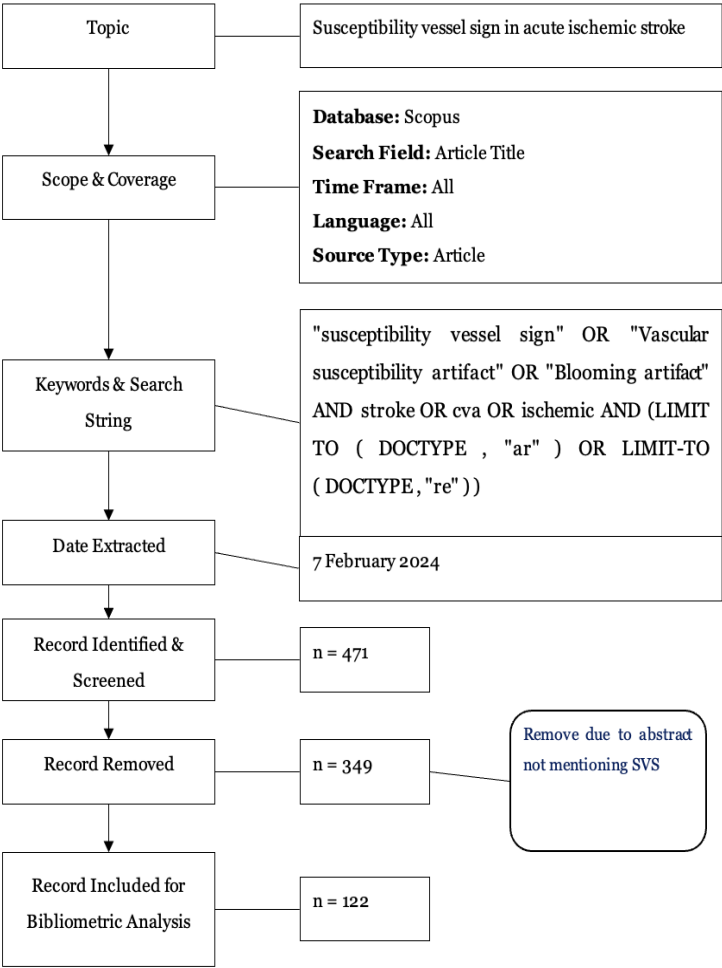


Figure 1. Flow diagram of search strategy

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 [5]. 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

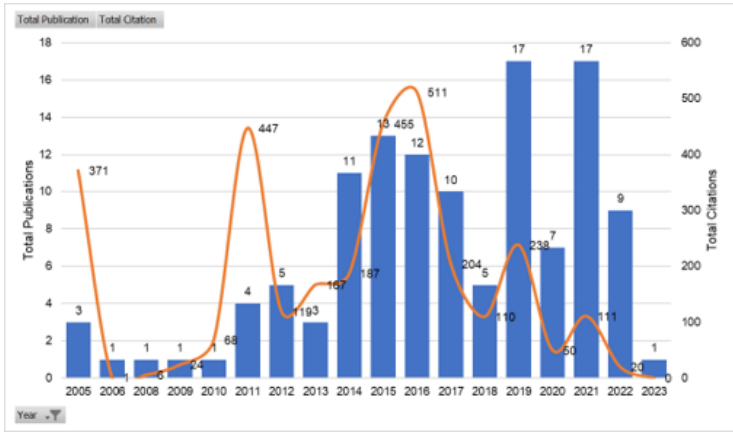


Figure 2: Total Publications and Citations by Year of SVS in Acute Stroke

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.

Table 2: Most Productive Authors (TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index; m=m-index.)

Author's Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g	m
Oppenheim, Catherine	Centre Hospitalier Sainte-Anne, Paris	France	17	17	605	35.59	35.59	12	17	0.92
Naggara, Olivier	Centre Hospitalier Sainte-Anne, Paris	France	17	17	459	27	27	13	17	1
Bourcier, Romain	CHU de Nantes, Nantes	France	13	13	252	19.38	19.38	10	13	1
Bracard, Serge	Université de Lorraine, Nancy	France	12	12	244	20.33	20.33	9	12	1.29
Legrand, Laurence	Institut de Psychiatrie et Neurosciences de Paris (IPNP), Paris	France	10	10	273	27.3	27.3	9	10	0.75
Desal, Hubert	CHU de Nantes, Nantes	France	10	10	198	19.8	19.8	8	10	0.8
Mas, Jean-Louis	Groupe Hospitalier Universitaire Paris, Paris	France	9	9	512	56.89	56.89	9	9	0.75
Cho, Tae-Hee	CHU de Lyon, Lyon	France	8	8	144	18	18	6	8	0.55
Baron, Jean-Claude	Université Paris Cité, Paris	France	8	8	410	51.25	51.25	8	8	0.67
Soize, Sebastien	CHU de Reims, Reims	France	8	8	136	17	17	6	8	0.6
Turc, Guillaume	Centre Hospitalier Sainte-Anne, Paris	France	8	8	456	57	57	8	8	0.67
Lapergue, Bertrand	Hopital Foch, Suresnes	France	8	8	184	23	23	7	8	1
Derraz, Imad	Hopital Gui de Chauillac, Montpellier	France	8	8	111	13.87	13.88	7	8	0.88

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 [19]. 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.

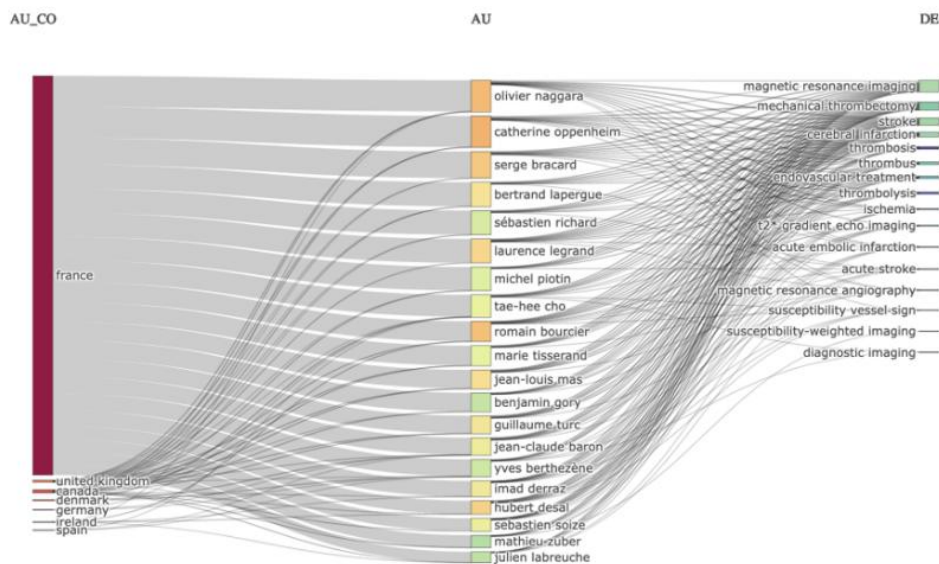


Figure 3: Patterns of collaboration

Table 3: Most productive institutions in SVS research from 2005 to 2024 (TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index; m=m-index.)

Affiliation	Country	TP	NC P	TC	C/P	C/CP	h	g	m
CHU de Nancy, Nancy	France	24	22	717	29.88	32.59	11	24	0.786
Centre Hospitalier Sainte-Anne, Paris	France	19	19	649	34.16	34.16	14	19	1.077
Université Paris Cité, Paris	France	17	17	662	38.94	38.94	12	17	0.600
Fondation Adolphe de Rothschild, Paris	France	14	14	537	38.36	38.36	13	14	0.650
Hopital Gui de Chauliac, Montpellier	France	14	14	290	20.71	20.71	11	14	1.375
CHU de Nantes, Nantes	France	13	13	252	19.38	19.38	10	13	1.000
CHU de Lille, Lille	France	11	11	212	19.27	19.27	8	11	0.727
Hopital Foch, Suresnes	France	10	10	283	28.30	28.30	9	10	0.900
Institut de Psychiatrie et Neurosciences de Paris (IPNP), Paris	France	10	10	273	27.30	27.30	9	10	0.750
Groupe Hospitalier Universitaire Paris, Paris	France	9	9	512	56.89	56.89	9	9	0.750
University of California	USA	9	8	489	54.33	61.13	6	9	0.429
CHU de Reims, Reims	France	8	8	136	17.00	17.00	6	8	0.600
CHU de Lyon, Lyon	France	8	8	144	18.00	18.00	6	8	0.545
Centre Hospitalier Regional et Universitaire de Tours, Tours	France	8	8	175	21.88	21.88	8	8	1.143
Groupe Hospitalier Paris Saint-Joseph, Paris	France	6	6	172	28.67	28.67	5	6	0.417
Beijing Tiantan Hospital, Capital Medical University, Beijing	China	6	4	20	3.33	5.00	2	4	0.222
Nippon Medical School, Tokyo	Japan	5	5	119	23.80	23.80	5	5	0.357
CHU de Montpellier, Montpellier	France	5	5	106	21.20	21.20	5	5	0.714
Bern University Hospital	Switzerland	5	4	142	28.40	35.50	4	5	0.267
the Jikei University School of Medicine	Japan	5	5	109	21.80	21.80	4	5	0.286

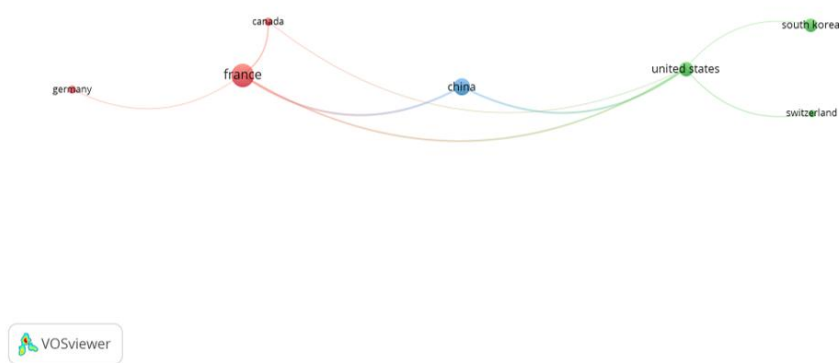


Figure 4: International collaboration network

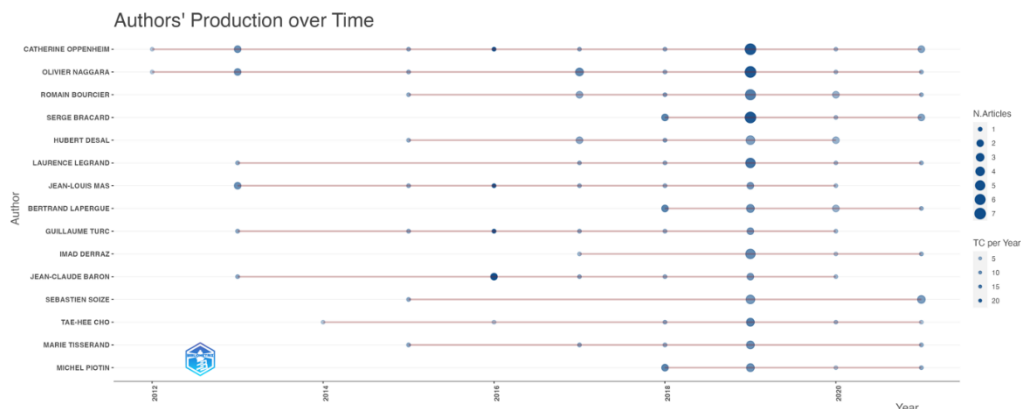


Figure 5: Author production over time in SVS research (2005-2024), showing annual publication activity of the most prolific contributors

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.

Country Collaboration Map

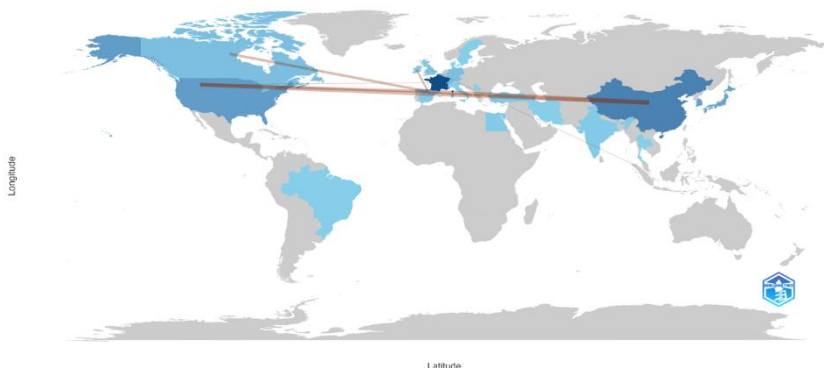


Figure 6: World map of scientific production. Countries with a darker blue shade have a higher number of publications

Country Scientific Production

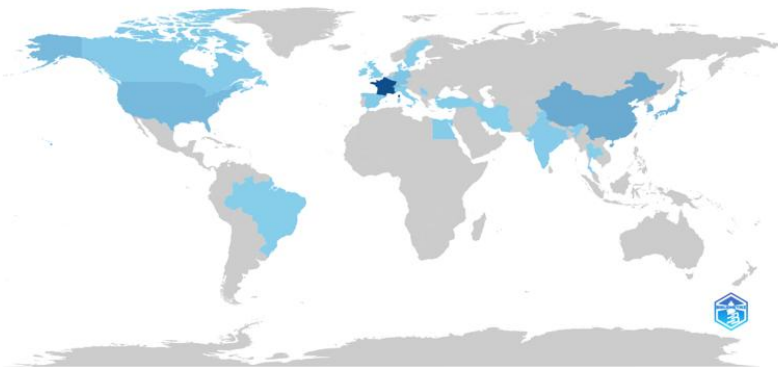


Figure 7: Country collaboration Map

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.

Table 4: Most active source titles (TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index; m=m-index.)

Source Title	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
Stroke	18	275	18	1395	77.5	77.5	16	18	0.8
American Journal of Neuroradiology	13	109	13	494	38	38	9	13	0.45
European Neurology	5	37	5	92	18.4	18.4	3	5	0.2
Journal of Stroke and Cerebrovascular Diseases	5	35	5	56	11.2	11.2	5	5	0.5
Journal of the Neurological Sciences	4	29	4	62	15.5	15.5	3	4	0.18
European Radiology	4	49	4	90	22.5	22.5	4	4	0.36
Journal of Neuroradiology	4	26	3	81	20.25	27	3	4	0.3
European Journal of Neurology	4	86	4	76	19	19	4	4	0.4
Journal of NeuroInterventional Surgery	4	59	4	41	10.25	10.25	4	4	0.44
Journal of Clinical Neuroscience	3	16	3	55	18.3	18.33	2	3	0.22
Frontiers in Neurology	3	45	2	23	7.67	11.5	2	3	0.29
Journal of Neuroimaging	3	30	3	32	10.67	10.67	3	3	0.33
Quantitative Imaging in Medicine and Surgery	3	23	3	18	6	6	2	3	0.33
Journal of Stroke	3	72	3	100	33.33	33.33	3	3	0.33
Clinical Neuroradiology	3	22	3	13	4.33	4.33	2	3	0.11
International Journal of Stroke	2	22	2	29	14.5	14.5	2	2	0.18
PLoS ONE	2	24	2	103	51.50	51.5	2	2	0.17
Cerebrovascular Diseases	2	18	2	77	38.50	38.50	2	2	0.10
Chinese Journal of Medical Imaging Technology	2	12	0	0	0.00	0.00	0	0	0.000

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 [20].

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.

Table 6: Top 20 highly cited articles

No.	Authors	Title	Source Title	Cites	Cites per Year
1	Liebeskind D.S.,et al (2011)	CT and MRI early vessel signs reflect clot composition in acute stroke	Stroke	394	28.14
2	Boeckh-Behrens T., et al(2016)	Thrombus histology suggests cardioembolic cause in cryptogenic stroke	Stroke	198	22.00
3	Seners P.,et al (2016)	Incidence and Predictors of Early Recanalization after Intravenous Thrombolysis: A Systematic Review and Meta-Analysis	Stroke	185	20.56
4	Cho K.-H.,et al (2005)	Significance of susceptibility vessel sign on T2*-weighted gradient echo imaging for identification of stroke subtypes	Stroke	164	8.20
5	Kim S.K., et al (2015)	Histologic analysis of retrieved clots in acute ischemic stroke: Correlation with stroke etiology and gradient-echo MRI	American Journal of Neuroradiology	158	15.80
6	Schellinger P.D.,et al (2005)	Diagnostic and prognostic value of early MR imaging vessel signs in hyperacute stroke patients imaged <3 hours and treated with recombinant tissue plasminogen activator	American Journal of Neuroradiology	149	7.45
7	Huang P., et al (2012)	Clinical applications of susceptibility weighted imaging in patients with major stroke	Journal of Neurology	74	5.69
8	Viallon M., et al (2010)	Combined use of pulsed arterial spin- labeling and susceptibility-weighted imaging in stroke at 3T	European Neurology	68	4.53
9	Legrand L., et al (2013)	Clot burden score on admission T2*- MRI predicts recanalization in acute stroke	Stroke	64	5.33
10	Weisstanner C.,et al (2014)	Thrombus imaging in acute stroke: Correlation of thrombus length on susceptibility-weighted imaging with endovascular reperfusion success	European Radiology	58	5.27
11	Assouline E., et al(2005)	Intra-arterial thrombus visualized on T2* gradient echo imaging in acute ischemic stroke	Cerebrovascular Diseases	58	2.90
12	Naggara O., et al (2013)	T2* "Susceptibility Vessel Sign" Demonstrates Clot Location and Length in Acute Ischemic Stroke	PLoS ONE	56	4.67

No.	Authors	Title	Source Title	Cites	Cites per Year
13	Soize S., et al. (2015)	Susceptibility vessel sign on T2* magnetic resonance imaging and recanalization results of mechanical thrombectomy with stent retrievers: A multicentre cohort study	European Journal of Neurology	54	5.40
14	Luo S., et al (2015)	Comparison of susceptibility-weighted and perfusion-weighted magnetic resonance imaging in the detection of penumbra in acute ischemic stroke	Journal of Neuroradiology	51	5.10
15	Bourcier R., et al (2018)	Susceptibility vessel sign in the ASTER trial: Higher recanalization rate and more favourable clinical outcome after first line stent retriever compared to contact aspiration	Journal of Stroke	47	6.71
16	Radbruch A., et al (2013)	Comparison of Susceptibility Weighted Imaging and TOF-Angiography for the Detection of Thrombi in Acute Stroke	PLoS ONE	47	3.92
17	Kang D., et al (2017)	Prediction of Stroke Subtype and Recanalization Using Susceptibility Vessel Sign on Susceptibility-Weighted Magnetic Resonance Imaging	Stroke	46	5.75
18	Seners F., et al (2017)	Is Unexplained Early Neurological Deterioration after Intravenous Thrombolysis Associated with Thrombus Extension?	Stroke	45	5.63
19	Kimura K., et al (2011)	Clinical and MRI predictors of no early recanalization within 1 hour after tissue-type plasminogen activator administration	Stroke	44	3.14
20	Bourcier R., et al (2015)	Susceptibility vessel sign on MRI predicts favorable clinical outcome in patients with anterior circulation acute stroke treated with mechanical thrombectomy	American Journal of Neuroradiology	43	4.30

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.

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 [3,20]. 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 [6,8]. 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 [5,7,10]. 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 [15,16]. 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 [12,13]. 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.

6.0 ACKNOWLEDGMENTS

The authors express their gratitude to the radiology, and neurointerventional radiology teams at Hospital Sultan Abdul Aziz

Shah (HSAAS), Universiti Putra Malaysia, for their support in data acquisition, clinical interpretation, and workflow insights. The authors further acknowledge the institutional research and ethics committees for facilitating the conduct of this study and the computing team for providing and maintaining the computational resources used for model training and evaluation.

7.0 REFERENCES

1. Li Z, Bai X, Gao P, Lin Y, Ju Y, Sui B. Changes of prominent vessel sign and susceptibility vessel sign in acute ischemic stroke patients with and without successful recanalization: A study based on susceptibility weighted images. *Neurol Res.* 2022;44(7):583-590. doi: 10.1080/01616412.2021.2024729.
2. Vilela P, Rowley HA. Brain ischemia: CT and MRI techniques in acute ischemic stroke. *Eur J Radiol.* 2017;96:162-172. doi: 10.1016/j.ejrad.2017.08.014.
3. Cho KH, Kim JS, Kwon SU, Cho A, Kang D. Significance of susceptibility vessel sign on T2*-weighted gradient echo imaging for identification of stroke subtypes. *Stroke.* 2005. doi: 10.1161/01.str.0000185932.73486.7a.
4. Schellinger PD, Chalela JA, Kang DW, Latour LL, Warach S. Diagnostic and prognostic value of early MR imaging vessel signs in hyperacute stroke patients imaged <3 hours and treated with recombinant tissue plasminogen activator. *AJNR Am J Neuroradiol.* 2005;26(3):618-624.
5. Liebeskind DS, Sanossian N, Yong WH, Starkman S, Tsang MP, Moya AL, et al. CT and MRI Early Vessel Signs Reflect Clot Composition in Acute Stroke. *Stroke.* 2011;42(5):1237-1243. doi: 10.1161/STROKEAHA.110.605576.
6. Seners P, Turc G, Maïer B, Mas JL, Oppenheim C, Baron JC. Incidence and predictors of early recanalization after intravenous thrombolysis: A systematic review and meta-analysis. *Stroke.* 2016. doi: 10.1161/STROKEAHA.116.014181.
7. Boeckh-Behrens T, Schubert M, Förchler A, Prothmann S, Kreiser K, Zimmer C, et al. The Impact of Histological Clot Composition in Embolic Stroke. *Clin Neuroradiol.* 2016;26(2):189-197. doi: 10.1007/s00062-014-0347-x.
8. Kang DW, Jeong HG, Kim DY, Yang W, Lee SH. Prediction of Stroke Subtype and Recanalization Using Susceptibility Vessel Sign on

- Susceptibility-Weighted Magnetic Resonance Imaging. *Stroke*. 2017;48(6):1554-1559. doi: 10.1161/STROKEAHA.116.016217.
9. Bourcier R, Legrand L, Soize S, Labreuche J, Beaumont M, Desal H, et al. Validation of overestimation ratio and TL-SVS as imaging biomarker of cardioembolic stroke and time from onset to MRI. *Eur Radiol*. 2019;29(5):2624-2631. doi: 10.1007/s00330-018-5835-y.
10. Legrand L, Naggara O, Turc G, Mellerio C, Roca P, Calvet D, et al. Clot Burden Score on Admission T2*-MRI Predicts Recanalization in Acute Stroke. *Stroke*. 2013;44(7):1878-1884. doi: 10.1161/STROKEAHA.113.001026.
11. Derraz I, Bourcier R, Soudant M, Soize S, Hassen WB, Hossu G, et al. Does clot burden score on baseline T2*-MRI impact clinical outcome in acute ischemic stroke treated with mechanical thrombectomy? *J Stroke*. 2019;21(1):91-100. doi: 10.5853/jos.2018.01921.
12. Soize S, Batista AL, Rodriguez Regent C, Trystram D, Tisserand M, Turc G, et al. Susceptibility vessel sign on T2* magnetic resonance imaging and recanalization results of mechanical thrombectomy with stent retrievers: A multicentre cohort study. *Eur J Neurol*. 2015;22(6):967-972. doi: 10.1111/ene.12693.
13. Bourcier R, Volpi S, Guyomarch B, Daumas-Duport B, Lintia-Gaultier A, Papagiannaki C, et al. Susceptibility Vessel Sign on MRI Predicts Favorable Clinical Outcome in Patients with Anterior Circulation Acute Stroke Treated with Mechanical Thrombectomy. *AJNR Am J Neuroradiol*. 2015;36(12):2346-2353. doi: 10.3174/ajnr.A4483.
14. Bourcier R, Mazighi M, Labreuche J, Fahed R, Blanc R, Gory B, et al. Susceptibility vessel sign in the ASTER trial: Higher recanalization rate and more favourable clinical outcome after first line stent retriever compared to contact aspiration. *J Stroke*. 2018. doi: 10.5853/jos.2018.00192.e1.
15. Belachew NF, Dobrocky T, Aleman EB, Thomas C, Meinel TR, Hakim A, et al. SWI Susceptibility Vessel Sign in Patients Undergoing Mechanical Thrombectomy for Acute Ischemic Stroke. *AJNR Am J Neuroradiol*. 2021. doi: 10.3174/ajnr.a7281.
16. Christiansen SD, Liu J, Bullrich MB, Sharma M, Boulton M, Pandey SK, et al. Deep learning prediction of stroke thrombus red blood cell content from multiparametric MRI. *Interv Neuroradiol*. 2024. doi: 10.1177/15910199221140962.

17. Ahmi A. Bibliometric Analysis using biblioMagika. 2nd ed. Academic Research Society of Malaysia (ARMS); 2024.
18. Aria M, Cuccurullo C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J Informetr.* 2017;11(4):959-975. doi: 10.1016/j.joi.2017.08.007.
19. Van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics.* 2010;84(2):523-538. doi: 10.1007/s11192-009-0146-3.
20. Huang P, Chen CH, Lin WC, Lin RT, Khor GT, Liu CK. Clinical applications of susceptibility weighted imaging in patients with major stroke. *J Neurol.* 2012;259(7):1426-1432. doi: 10.1007/s00415-011-6369-2.