

Original Paper

Bibliometric Analysis and Visualization of Vulnerable Carotid Plaque Research (2010-2025): From Morphological Imaging to Artificial Intelligence and Digital Twins

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Received: January 22, 2026

Accepted: February 24, 2026

Online Published: March 27, 2026

doi:10.22158/rhs.v11n1p83

URL: <http://dx.doi.org/10.22158/rhs.v11n1p83>

Abstract

Prevention of ICH in stroke has shifted to overall evaluation of carotid atheroma within the clinical context. In order to give a big picture view of this landscape, a bibliometric study was conducted to show how vulnerable carotid plaque was studied by researchers between 2010-2025. 1,193 literatures were gained from Web of Science Core Collection and analyzed by using CiteSpace to build a knowledge network and keyword bursttime timeline. It has a trend towards faster growth, which can be seen clearly in different stages: Stage one is acute ischemic event and macroscopic view, then the second stage is dealing with pathobiology and micromechanism such as vasovasorum; the third one (currently) is based on advanced non-invasive modalities like contrast-enhanced ultrasound and high-resolution MRI. Most importantly, artificial intelligence and radiomics have become the drivers of present-day research. In other words, it is moving out of reactive morphology and into proactive computational forecast. Future breakthroughs will rely heavily on multidisciplinary convergence, ultimately culminating in the development of physics-informed carotid digital twins for precise, patient-specific stroke risk management.

Keywords

Carotid plaque vulnerability, Bibliometric analysis, Artificial intelligence, Contrast-enhanced ultrasound, Digital twin, Stroke prevention.

1. Introduction

Ischemic stroke is still one of the main reasons for people's death and disability in the world [1-2]. There are many studies done clinically and histopathologically to determine that these cerebrovascular events are primarily because of the rupture of fragile atherosclerotic plaques in the carotid arteries, and then followed by subsequent thrombosis and embolization [3-4]. In the past, clinical advice given to prevent stroke mainly involved measuring how much luminal stenosis there was; but new information shows that quite a few cases happen to folks who have only mild-to-medium stenosis full of very unstable lesions [5]. It can't see that perspective as something to assess for angiographic stenoses anymore, and it becomes to assess plaque vulnerability comprehensively [6]. Vulnerable plaques can also be seen structurally, through their big lipid-rich necrotic core (LRNC), having much free cholesterol, thin and highly inflamed fibrous cap, intraplaque hemorrhage (IPH) and vast number of neovascularization from vasa vasorum [7-8]. And also it's becoming more accepted in the literature now that unhelpful angiogenesis and inflammatory macrophages degrade the extracellular matrix and then break down the structure of the fibrous cap, leading to an acutely ruptured one [9].

Over the last 15 years, there has been a great change in how to evaluate carotid plaque instability. In earlier times, it was based around the morphologic appearance of plaques and echoicitiy via standard duplex ultrasound [10]. But due to the rapid development in the field of biomedical engineering, it's now possible to widely apply HR-MRI [11], PET [12] and CEUS [13] for clinical use, which can visualize the micro pathological features in vivo without invasive methods. In more recent times, the incorporation of computational fluid dynamics (CFD) [14] and artificial intelligence (AI) [15] has brought a new level of dimension into this field. Here, computational means to let machines perform high-dimensional radiomics feature extraction [16] and accurately simulating biomechanics like wall shear stress (WSS), and structure strain, which is extremely involved with plaque rupture [17].

Despite the fact that numerous initial inquiries and narrative overviews have documented such technological leaps, there is an overall quantitative view of all this knowledge. Reviews have always been open to selection bias and seldom capture the dynamic, interdisciplinary shift in the field [18]. Bibliometrics analysis takes the approach of mathematics and statistics to evaluate academic publications. This means is a viable way to understand knowledge connections, follow changes over time, and foresee future trends in studying [19]. Therefore, this paper will carry out a bibliometric and visualization analysis of all the literature related to the topic "vulnerable carotid plaques" between 2010-2025. With respect to encouraging such an enormous leap from morphological imagining to modeling with a computational system by institutional collaboration networks, document co-citation clusters, and keyword burst timelines, so that we can all travel through time and look at interdisciplinary opportunities easily with a data-driven approach towards cardiovascular digital twins [20].

2. Materials and Methods

2.1 Data Strategy and Search Strategy

As making use of literature search, the study has applied a systematic way for that since it involves the WoSCC database, which has all possible citation metadata and thus is the best option for performing such bibliometrics [21]. In order to obtain recent advances made regarding medical image computing and biomechanics, the study time period is set between January 1st, 2010 and December 31st, 2025. The specific search string used was: (("carotid plaque" OR "carotid atherosclerosis") AND ("vulnerable" OR "vulnerability" OR "instability" OR "plaque rupture" OR "plaque stability")). The terms about carotid plaque disease and vulnerable plaques can represent the key mechanisms underlying ischemic stroke risk. Words like vulnerable, vulnerability, instability, plaque rupture, plaque stability include all the studies which talk about the instability and rupturing potential of carotid atherosclerotic plaques, so as to consider all kinds of works carried out in terms of carotid plaque morphology, biology, imaging, clinical predictions regarding risk of carotid plaques. In order to maintain the academic integrity of the dataset, only "Article" and "Review" type documents were included, and the language had to be in "English". During both the first data retrieving step as well as during further steps followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guideline to systematically exclude non-relevant or duplicate entries [22].

2.2 Bibliometric and Visual Analysis

CiteSpace (version 7.0), which is a Java application used to visualize and analyze the structure of trends in scientific literature, was employed to produce knowledge domains and cocitation networks [23]. The global parameter timespan is from 2010-2025 with year slices (1-year) for finer temp trends, there were enough slice numbers for the quick development of vascular images and risks. Notably, pre-2010 references will appear within the co-citation network as references for knowledge. Node selection used the Top 30 threshold for each slice. To make things clearer and reduce visual overlap, it used the Pathfinder algorithm along with the "Pruning sliced network" option. Finally, it merged all the synonymous nodes like "Erasmus University Rotterdam" with "Erasmus MC" by using the help of CiteSpace alias.

2.3 Statistical Metrics

In the produced network, nodes are sized according to their occurrence or citation frequency, and links show co-occurrence or co-citation relations. Betweenness centrality is used to recognize important nodes that acted as bridges between the different research areas; here are some of them with a purple trim as they have a high value (≥ 0.1). For the co-citation cluster, the LLR algorithm is used to extract semantic cluster labels. Structurally, the significance and reliability of the cluster was objectively checked by means of Modularity Q score and Mean Silhouette S score: When $Q > 0.3$, there is a large network structure present, and when $S > 0.7$, it means the clustering was very convincing and internally consistent [24]. The literature search and selection is shown in Figure 1.

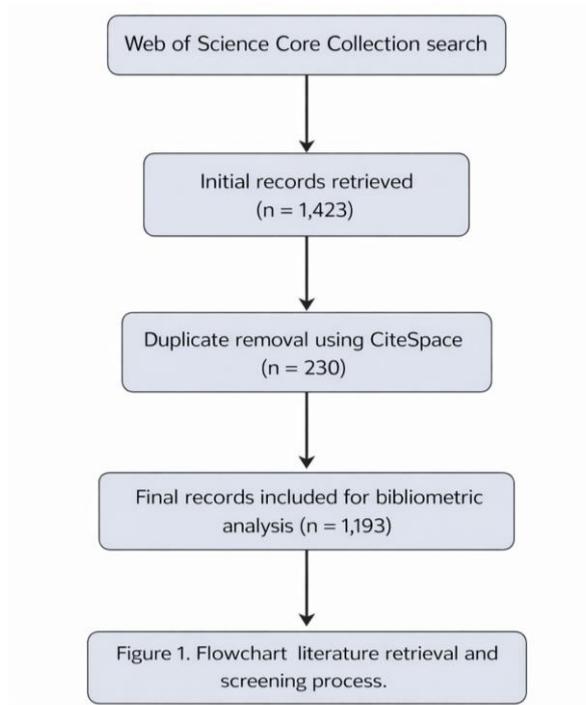


Figure 1. Flow Diagram of Literature Retrieval, Screening, and Inclusion for the Bibliometric Analysis

3. Results

There were a total number of 1,193 unique records about the vulnerable carotid plaque evaluation from 2010 to 2025. From Figure 2, it can see an obvious exponential development, which goes from steady exploration to a rapid expansion period. This huge uptick in the latter half of the decade happens at roughly the same time as when many clinical doctors started using special brain images more often, and there was a big change about how people think computational biomechanics and artificial intelligence can help study heart disease.

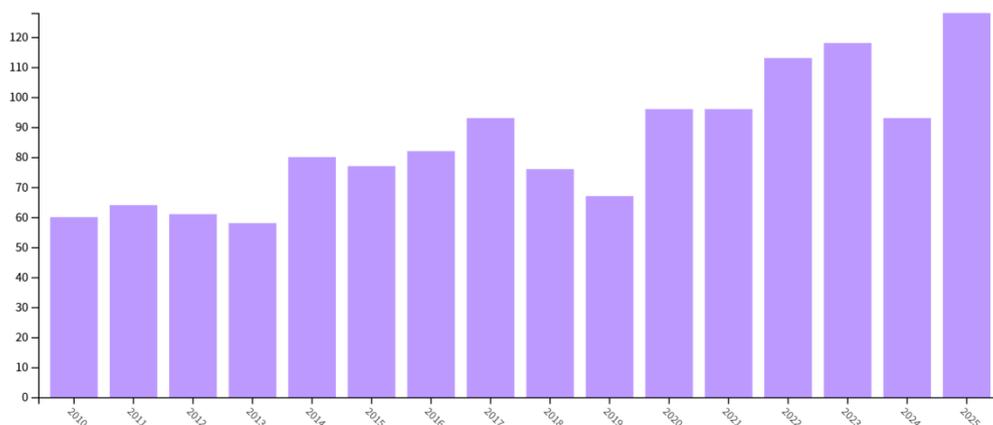


Figure 2. Annual and Cumulative Publication Trends of Vulnerable Carotid Plaque Research from 2010 to 2025

The bar is for the amount of yearly publications, and the line shows how much it has grown since 2010.

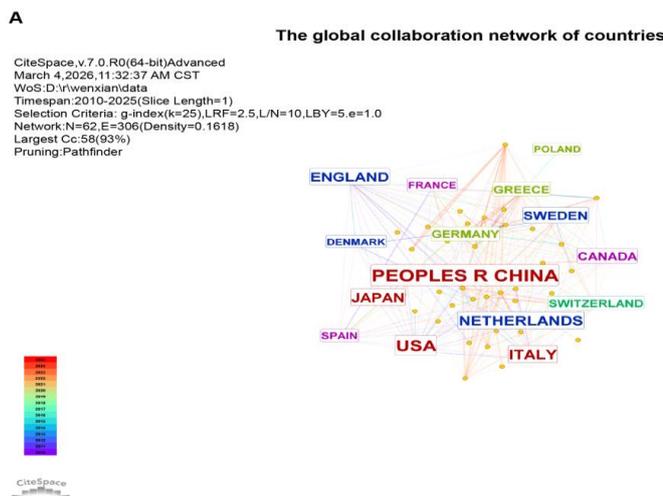
3.2 Global Collaboration Network of Countries and Institutions

From geographical cooperation topology (Figure 3), it shows a huge network of global research. The country-level network (N=62, L=306, D=0.1618), which represents 93% of all countries that were part of the larger network. There is a tri-polar situation in East Asia, North America, and Western Europe (Table 1). As for leading in absolute productivity (Count=392), it is China. The centrality of Italy is 0.38; the United Kingdom is 0.29, and the US is 0.28. Western nations have the highest betweenness centrality, which are key topological bridges to enable transcontinental knowledge flow.

Table 1. Top 5 Most Productive and Influential Countries in Vulnerable Carotid Plaque Research

Rank	Country	Count	Centrality	Year of First Appearance
1	PEOPLE'S REPUBLIC OF CHINA	392	0.13	2010
2	USA	245	0.28	2010
3	ITALY	129	0.38	2010
4	NETHERLANDS	110	0.11	2010
5	ENGLAND	98	0.28	2010

On the contrary, the micro-level institutional collaboration network is totally different. With a total of 672 organizations and 2786 collaborative links, its network density decreases greatly to 0.0124, and its biggest CC just contains 74% (498) of all the organizations. Differences at all those levels means that strategic collaboration will be very closely aligned at the state level, but institutional partnerships take a bit more of a leap, fragmented clusters and inter-institutional selectivity partners.



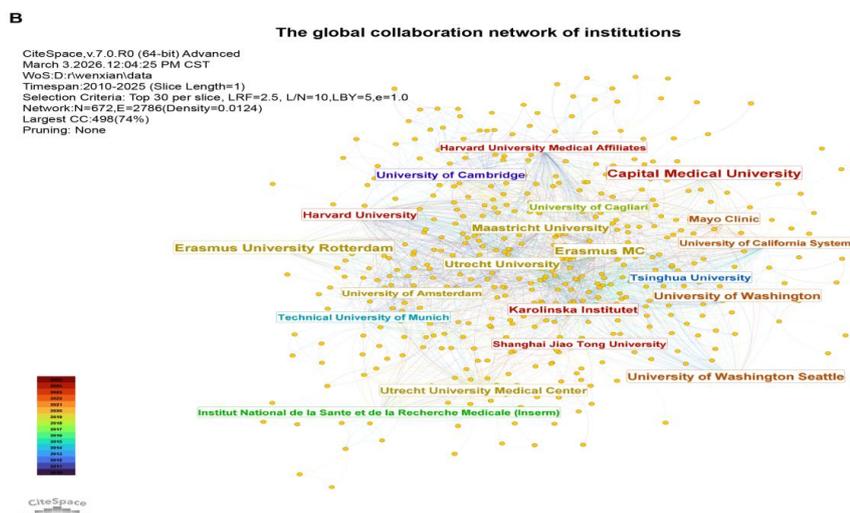


Figure 3. The Global Collaboration Network of Countries (A) and Institutions (B)

Node size is proportional to the publication volume. Links stand for co-authorship relationships. Purple trimmed node indicates that this place has high betweenness, with centrality ≥ 0.1 , and it's an important spot where borders and institutions switch places. The macroscopic institutional network parameters are $N = 672$, $E = 2,786$, and $D = 0.0124$.

Table 2. Top 10 Highly Productive Institutions after Synonym Consolidation

Rank	Institution	Count	Centrality	Year of First Appearance
1	Erasmus MC / Erasmus Univ Rotterdam*	102	0.04	2010
2	Univ Washington / Univ Washington Seattle*	78	0.06	2010
3	Capital Medical University	65	0.07	2010
4	Maastricht University	35	0.04	2010
5	Karolinska Institutet	32	0.06	2010
6	Utrecht University	30	0.03	2010
7	University of Cambridge	29	0.08	2010
8	Harvard University	28	0.16	2010
9	Mayo Clinic	27	0.02	2010
10	Tsinghua University	25	0.03	2016

The publication count for places like Erasmus MC/Erasmus University Rotterdam, and University of Washington/University of Washington Seattle, was summed up by adding the different synonymous variations so that it is correct. Centrality is the largest number in the combined entity.

Despite the fragment. The most prolific is Capital Medical University with its large scale patients. Harvard University is shown to have the most centrality (0.16) serving as the main structural bridge,

after which there are hubs such as the University of Cambridge, Mayo Clinic, Erasmus MC, and Karolinska Institutet. Moreover, engineering organizations like Tsinghua University, Shanghai Jiao Tong University, as well as clinical hospitals, which are more evident convergence between these two disciplines of diagnostics and engineering algorithms.

3.3 Document Co-citation Analysis and Knowledge Clusters

The study formed a 589 nodes, 2055 links, with a density equaling 0.0119 for the document co-citation network to understand how knowledge evolves in vulnerable carotid plaque assessment. A strong and meaningful community was observed from the network with both the validation methods, Modularity (Q) = 0.7462 and Mean Silhouette = 0.8248 (Figure 4).

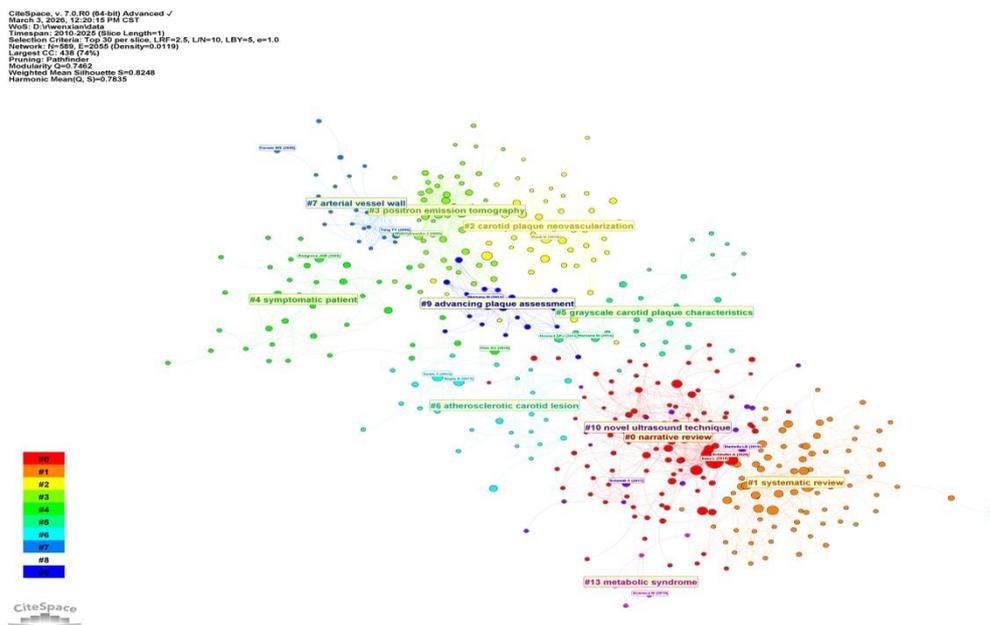


Figure 4. The Document Co-citation Network and Cluster Visualization

Different colored sections denote the main research fields which were derived from the LLR algorithm. The size of a node is the citation frequency of the references. The network has a very strong sense of community and can be reliably clustered (Modularity Q = 0.7462, Mean Silhouette = 0.8248; N = 589, E = 2,055, Density = 0.0119)

Table 3 shows the five largest clusters found with the LLR algorithm. The big clusters were all the same on their own, reflecting specific thematic concentrations.

Table 3. Top 5 Largest Document Co-citation Clusters and Their Core Evolutionary Characteristics

Cluster ID	Size	Silhouette	Mean (Year)	Top Terms (LLR Algorithm)
0	100	0.727	2017	narrative review; vulnerable carotid plaque; carotid artery stenosis; atherosclerotic cardiovascular disease; stroke risk prediction
1	83	0.845	2021	systematic review; artificial intelligence; diagnostic accuracy; diagnostic performance; carotid atherosclerosis
2	50	0.834	2010	carotid plaque neovascularization; vascular medicine; using contrast-enhanced ultrasound; intraplaque neovascularization; carotid atherosclerosis
3	48	0.768	2009	positron emission tomography; complementary value; cardiac fdg pet; investigating vulnerable atheroma; CT angiography

Cluster labels are derived from the log-likelihood ratio (LLR). If the silhouette score was larger than 0.7, this cluster is cohesive and trustworthy. Size is how many referenced within the cluster.

3.4 The Chronological Paradigm Shift: From Morphology to Artificial Intelligence

When mapping those clusters over to a timeline view (Harmonic Mean Q, S=0.7835), it's clear enough that there was a noticeable paradigm shift and this time it happens chronologically according to how biomedical engineering technologies develop (Figure 5).

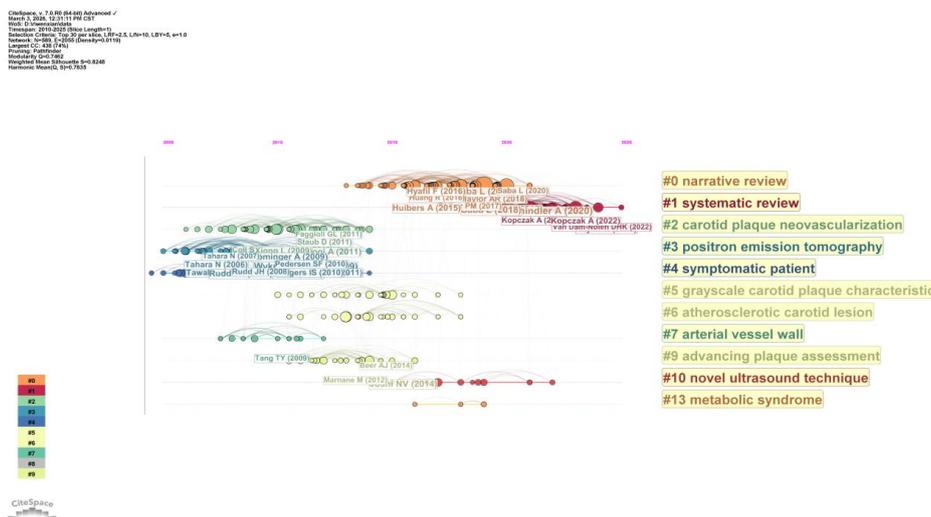


Figure 5. Timeline View of the Document Co-citation Clusters

This is the evolution of research foci for years 2008 - 2025. Same horizontal line nodes are in one group and they're placed based on when it was published. The visualisation shows the paradigm change between first morphological image and now artificial intelligence application (Harmonic Mean Q, S = 0.7835).

In the first exploratory period of year 2008-2010, which is shown by clusters 2, 3, and 4. The advanced imaging (PET, CMR) is used to correlate macroscopic pathology (such as neovasculature and rupture) with patient symptoms. The next one was in the theoretical solidification phase (Cluster 0, ~2017), where it became a descriptive term like narrative reviews and stroke risks, which shows a different set of criteria to form into a clinical risk model. Cluster 1 (2021-present) is the age of AI. Diagnostic performances have been proved, modern research goes beyond simple visual checks with automated deep learning radiomic features and maintains much better prediction of risks for strokes

3.5 Keyword Co-occurrence and Burst Detection

Keyword co-occurrence network (114 nodes, 144 links, density 0.1528; Figure6) shows a lot of structure close together. The most important terms at the heart include atherosclerosis, carotid plaque, intima-media thickness and carotid stenosis. Intraplaque hameorrhages and inflammation show up as main pathologic hallmarks in risk and ischemic strokes: Furthermore , the words such as classification , progression and endarterectomy illustrate that research covers all aspects of pathobiological processes and treatment approaches.\

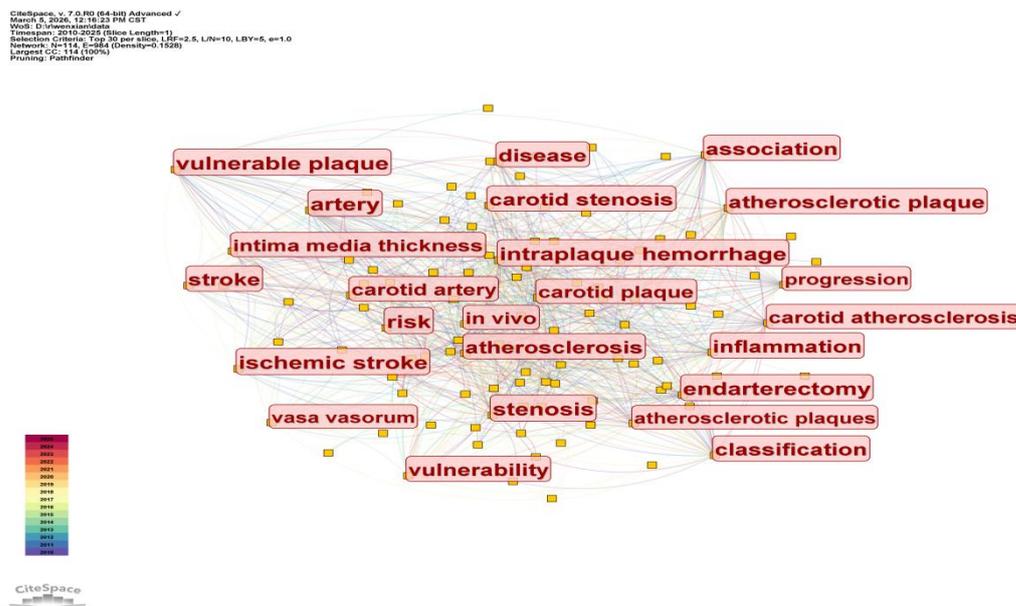


Figure 6. Keyword Co-occurrence Network of Carotid Plaque Vulnerability Research

Figure 6 is made with CiteSpace (2010-2025). Nodes are keywords, and size shows how often they appear. Links stand for cooccurrence of keywords. Colors go from old (blue) to new (red). Corresponds with the years of appearance, there are 114 nodes and 144 links (density=0.1528), which shows a lot of

the big theme words like atherosclerosis, ischemic stroke, intraplaque hemorrhage, carotid stenosis. The keywords are the main academic ideas in this literature corpus. To chase after development trends and where they are headed, it first makes the keyword cooccurrence network: a burst-detecting analysis using Klinkers' algorithm (Figure 7).

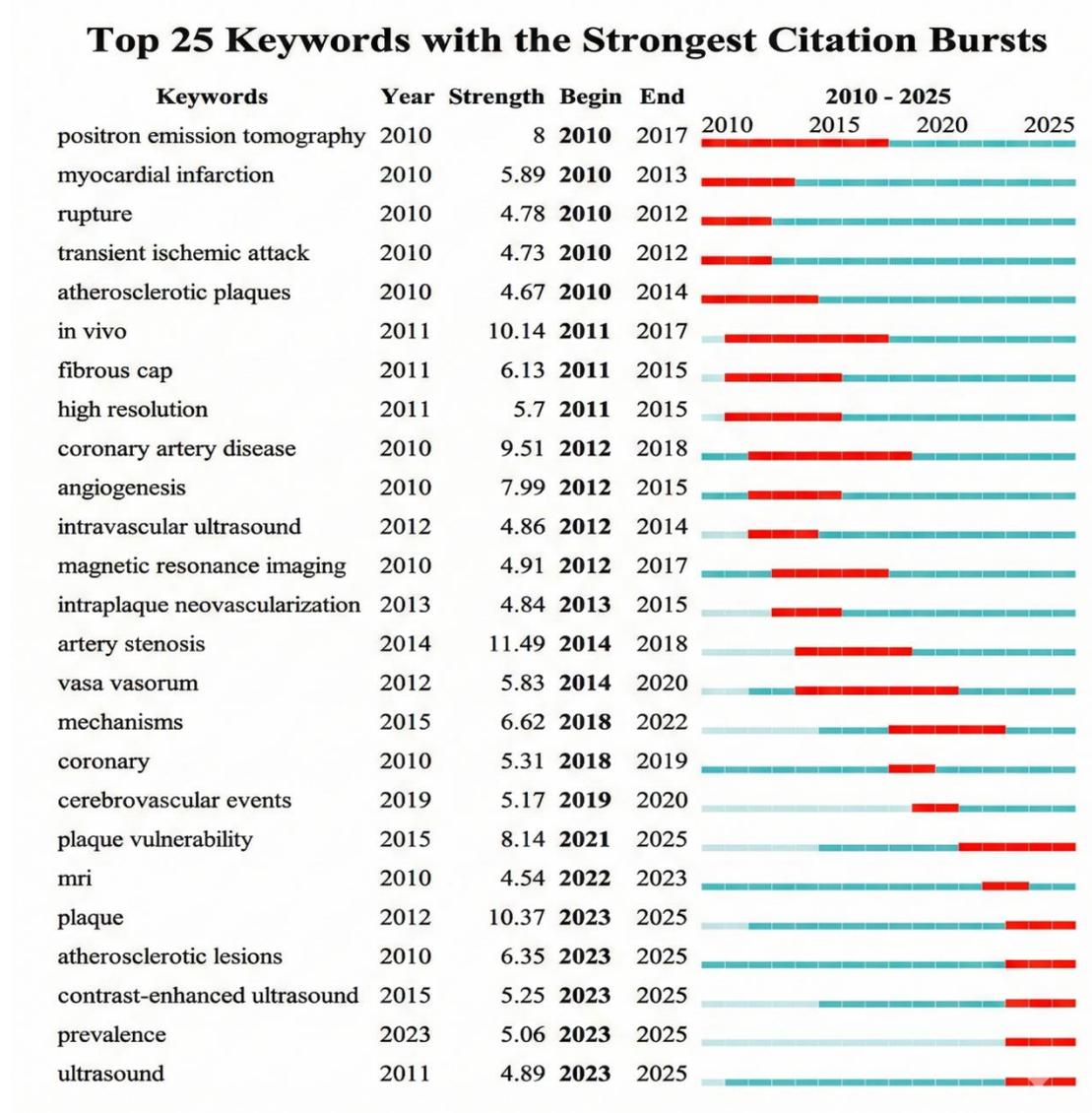


Figure 7. Top 25 Keywords with the Strongest Citation Bursts from 2010 to 2025

The Figure 7 finds bursts using an algorithm called Kleinberg. The dark blue line is for the whole study period, and the red lines are for when citations were really increasing. Those were periods of great interest in academia.

Keywords bursting means progression on 3 levels. The first one is the early event driven (2010-2014) and this one was mostly about positron emission tomography, rupture, transient ischemic attack. The second micro-mechanisms era (2012-2018) shifted focus to underlying pathobiology. The words such

as vasa vasorum, intraplaque neo-vascularization, angiogenesis and in-travascular ultrasounograph bursting led to the conclusion that the micro-environmental pro-liferation was the root cause of instability. Very importantly within the recent advance image period (2018-2025), it can observe active bursts in the research area for contrast-enhanced ultrasound, mri as well as plaque vulnerability. The frontier is signifiant transition fro invansive quanitative risk characterization.

4. Discussion

4.1 The Evolution of Plaque Assessment: From Events to Biological Mechanisms

Now, all this bibliometric analysis is painting some certain developmental trajectory during the last 15 years. At first, it was rather reactive in the field of clinical, mainly concerning acute ischemic events that happened and noticing big plaque ruptures [25]. However, it is fairly convincing about medium-term bursts such as vasa vasorum and intraplacental neovascularization. The scientific community now thinks in terms of the continuum of pathology and not an abrupt mechanical break [26]. The maladaptive angiogenesis is the big culprit for the fibrous cap's breaking down, and it's because there's such little oxygen in the thick part of the artery [27]. When oxygen is low, there's creation of immature and breakable vessels coming from adventital vasa vasorum, which set up the stage for recurring IPH, rapid lipid core expansion, and subsequent rapid progression [28]. Intravascular ultrasound (IVUS), optical coherence tomography (OCT), histologically confirmed the microscopic act, however, this kind of invasive technique at a great deal of cost and narrow fields of view should not be used in preventive wide-screen if the person has no clinical signs [29].

4.2 Current Frontiers: Advanced Modalities and Non-invasive Characterization

The study is limited by constrained invasive histology, the authors have experienced times where non-invasive diagnosis has giant steps forward due to progress in biomedical engineering. CEUS+MRI consistent citation burst aligns with the medical need to see what lies inside of intraplaque micro-environments [30]. For all these reasons, high-resolution MRI has been considered the reference technique to evaluate all main plaque components and most precisely, volumetric quantification of IPH as well as the lipid-rich necrotic core [31]. However, CEUS with intravascular microbubbles that was proved as one of the strongest real-time neovascularization quantifiers, which is an easy to come by cheap surrogate marker that replaces vasovator proliferation and also can overcome the spatial limitations of normal Doppler Ultrasound [32]. And it's at the very same time that moving from a plaque vulnerability measurement to a larger one (strong prevalence burst) is also a strategy. To examine systemic and overall examination of population rather than localized mechanism investigations based on their level for predicting individuals at epidemiological risk aims to individuals having a cerebrovascular before it happens [33].

4.3 Future Perspectives: Multidisciplinary Convergence and the Digital Twin

Despite CEUS and HR-MRI being super famous now in hospitals, one huge problem keeps popping up again: it is still subjective about these cool new scans' measurements, just like doctors did before and it

is forgotten all about blood pressure constantly pushing [34]. Plaque rupture is actually a biophysical event which happens whenever the pressure exceeds the stuff power in that fibrous cover. Bringing the current hot high-end imaging keyword with the co-citation cluster result of AI (cluster 1) and it's now clear what its path is heading towards a multi-discipline.

The next step is, of course, more deep embedding of AI, radiomics, and multiple modalities of imaging. The use of deep learning algorithms for automatically discovering high-dimensional textural and morphological feature spaces can generate strong causative relationships between imaging biomarkers and longitudinal clinical outcomes with minimal inter-observer variation [35]. The final step in the algorithmic leapfrogging mentioned previously is to finally achieve personalization and the creation of a personalized carotid digital twin [36]. The traditional CFD model is quite accurate in calculating WSS but very expensive in terms of computation and thus cannot be used in real-time clinic applications. By integrating physics-informed neural networks (PINNs) with CFD, it can embed the Navier-Stokes equation inside the loss functions of deep learning models. In this way, there would be no translation gap between static radiomics features and dynamic physical laws [37]. In a merged type calculation like integrated computational framework, it could be feasible for constant and immediate non-puncture simulation of how plaque grows in many distinct physiological situations switching stroke peril dealing with from reactive morphological inspection into proactive individualizing computations. But getting all these fancy computation models used in everyday doctors' workflow is a big problem. As technology moves forward with AI radiomics and PINN space, there is some work to be done on generalizing algorithms, data heterogeneity from other centers running different protocols for imaging studies, and inevitably a blackbox of deep learning models [38]. In the future, it will have to do more explainable AI or XAI as well as larger, prospective, and multicenter clinical trials. And setting up the standard picture gathering plans as well as federated learning operation should be important to confirm the validity of the predicted model while safeguarding people's health information [39].

4.4 Limitations of the Study

It provides an overall review though the paper is limited. Firstly, the search limited to the WoSCC will miss some papers in databases such as PubMed or Scopus. Secondly, language constraints will bring some publication bias. Thirdly, because it was done through citation accumulation via CiteSpace, which means that the topological impact of recent publications is underestimated. Future work could use NLP for full text mining to fill in with our citations-based mapping.

5. Conclusion

Over the last 15 years, characterizing vulnerable carotid plaques has moved forward from its beginning roots of event-driven characterization to the future leading of interdisciplinary areas with state-of-the-art non-invasive imagination and computing intelligence. In all, it has been seen that the current driving force, which includes artificial intelligence, CEUS, and MRI, is used to quantify plaque

vulnerability. Looking forward, breakthroughs in science will hinge on deep interdisciplinary effort—weaving clinical images together with clever engineering formulas—to form integrated prediction models, bringing about those physics-armed digital twins for accurate stroke prediction.

Funding

The study was supported by the National Natural Science Foundation of China (82270522), and Specialized Disease Characteristics of Pudong New Area Health Commission (PWZzb2022-03).

References

- [1] GBD 2019 Stroke Collaborators (2021). Global, regional, and national burden of stroke and its risk factors, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet. Neurology*, 20(10), 795-820. [https://doi.org/10.1016/S1474-4422\(21\)00252-0](https://doi.org/10.1016/S1474-4422(21)00252-0)
- [2] Tsao, C. W., Aday, A. W., Almarazgo, Z. I., Anderson, C. A. M., Arora, P., Avery, C. L., Baker-Smith, C. M., Beaton, A. Z., Boehme, A. K., Buxton, A. E., Commodore-Mensah, Y., Elkind, M. S. V., Evenson, K. R., Eze-Nliam, C., Fugar, S., Generoso, G., Heard, D. G., Hiremath, S., Ho, J. E., Kalani, R., ... American Heart Association Council on Epidemiology and Prevention Statistics Committee and Stroke Statistics Subcommittee (2023). Heart Disease and Stroke Statistics-2023 Update: A Report From the American Heart Association. *Circulation*, 147(8), e93-e621. <https://doi.org/10.1161/CIR.0000000000001123>
- [3] Bentzon, J. F., Otsuka, F., Virmani, R., & Falk, E. (2014). Mechanisms of plaque formation and rupture. *Circulation research*, 114(12), 1852-1866. <https://doi.org/10.1161/CIRCRESAHA.114.302721>
- [4] Kopczak, A., Schindler, A., Bayer-Karpinska, A., Koch, M. L., Sepp, D., Zeller, J., Strecker, C., Hempel, J. M., Yuan, C., Malik, R., Wollenweber, F. A., Boeckh-Behrens, T., Cyran, C. C., Helck, A., Harloff, A., Ziemann, U., Poli, S., Poppert, H., Dichgans, M., & Saam, T. (2020). Complicated Carotid Artery Plaques as a Cause of Cryptogenic Stroke. *Journal of the American College of Cardiology*, 76(19), 2212-2222. <https://doi.org/10.1016/j.jacc.2020.09.532>
- [5] Naylor, R., Rantner, B., Ancetti, S., de Borst, G. J., De Carlo, M., Halliday, A., Kakkos, S. K., Markus, H. S., McCabe, D. J. H., Sillesen, H., van den Berg, J. C., Vega de Ceniga, M., Venermo, M. A., Vermassen, F. E. G., Esvs Guidelines Committee, Antoniou, G. A., Bastos Goncalves, F., Bjorck, M., Chakfe, N., Coscas, R., ... Stone, D. H. (2023). Editor's Choice - European Society for Vascular Surgery (ESVS) 2023 Clinical Practice Guidelines on the Management of Atherosclerotic Carotid and Vertebral Artery Disease. *European journal of vascular and endovascular surgery : the official journal of the European Society for Vascular Surgery*, 65(1), 7-111. <https://doi.org/10.1016/j.ejvs.2022.04.011>
- [6] Finn, A. V., Nakano, M., Narula, J., Kolodgie, F. D., & Virmani, R. (2010). Concept of vulnerable/unstable plaque. *Arteriosclerosis, thrombosis, and vascular biology*, 30(7), 1282-1292.

- <https://doi.org/10.1161/ATVBAHA.108.179739>
- [7] Virmani, R., Burke, A. P., Farb, A., & Kolodgie, F. D. (2006). Pathology of the vulnerable plaque. *Journal of the American College of Cardiology*, 47(8 Suppl), C13-C18. <https://doi.org/10.1002/9780470987575.ch2>
- [8] Michel, J. B., Virmani, R., Arbustini, E., & Pasterkamp, G. (2011). Intraplaque haemorrhages as the trigger of plaque vulnerability. *European heart journal*, 32(16), 1977-1985c. <https://doi.org/10.1093/eurheartj/ehr054>
- [9] Ajoolabady, A., Pratico, D., Lin, L., Mantzoros, C. S., Bahijri, S., Tuomilehto, J., & Ren, J. (2024). Inflammation in atherosclerosis: pathophysiology and mechanisms. *Cell death & disease*, 15(11), 817. <https://doi.org/10.1038/s41419-024-07166-8>
- [10] Saba, L., Cau, R., Murgia, A., Nicolaidis, A. N., Wintermark, M., Castillo, M., Staub, D., Kakkos, S. K., Yang, Q., Paraskevas, K. I., Yuan, C., Edjlali, M., Sanfilippo, R., Hendrikse, J., Johansson, E., Mossa-Basha, M., Balu, N., Dichgans, M., Saloner, D., Bos, D., ... Saam, T. (2024). Carotid Plaque-RADS: A Novel Stroke Risk Classification System. *JACC. Cardiovascular imaging*, 17(1), 62-75. <https://doi.org/10.1016/j.jcmg.2023.09.005>
- [11] Kaczynski, J., Sellers, S., Seidman, M. A., Syed, M., Dennis, M., Mcnaught, G., Jansen, M., Semple, S. I., Alcaide-Corral, C., Tavares, A. A. S., MacGillivray, T., Debono, S., Forsythe, R., Tambyrajaa, A., Slomka, P. J., Leipsic, J., Dweck, M. R., Whiteley, W., Wardlaw, J., van Beek, E. J. R., ... Williams, M. C. (2022). 18F-NaF PET/MRI for Detection of Carotid Atheroma in Acute Neurovascular Syndrome. *Radiology*, 305(1), 137-148. <https://doi.org/10.1148/radiol.212283>
- [12] Thomas H. Schindler, Brittany Varney, & Sudhir Jain (2020). Molecular imaging of active coronary micro-calcification with 18F-NaF and PET: emergence of a new biomarker of the vulnerable atherosclerotic plaque?. *European journal of preventive cardiology*, 28(15), e6-e7. <https://doi.org/10.1177/2047487320912627>
- [13] Cao, J., Zeng, Y., Zhou, Y., Yao, Z., Tan, Z., Huo, G., Zhang, L., & Zhou, D. (2025). The value of contrast-enhanced ultrasound in assessing carotid plaque vulnerability and predicting stroke risk. *Scientific reports*, 15(1), 5850. <https://doi.org/10.1038/s41598-025-90319-2>
- [14] Cao, J., Tan, Z., Tang, Y., Liu, Z., Huang, J., Huo, G., Yao, Z., Zhou, Y., & Zhou, D. (2025). Hemodynamic simulation analysis of tandem carotid artery stenosis based on a patient-specific case. *Journal of biomechanics*, 191, 112907. <https://doi.org/10.1016/j.jbiomech.2025.112907>
- [15] Ankush D. Jamthikar, Deep Gupta, Luca Saba, Narendra N. Khanna, Klaudija Višković, Sophie Mavrogeni, John R. Laird, Naveed Sattar, Amer M. Johri, Gyan Pareek, Martin Miner, Petros P. Sfikakis, Athanase D. Protogerou, Vijay Viswanathan, Aditya Sharma, George D. Kitas, Andrew Nicolaides, Raghu Kolluri, & Jasjit S. Suri. (2020). Artificial intelligence framework for predictive cardiovascular and stroke risk assessment models: A narrative review of integrated approaches using carotid ultrasound. *Computers in biology and medicine*, 126(0), 104043-104043. <https://doi.org/10.1016/j.compbiomed.2020.104043>

- [16] Yangfei Long, Rui Guo, Keyu Jin, Jijia An, Ying Wu, Qing Ma, Bo Ying, Zehua Wang, & Jing Ma (2024). Diagnostic performance of radiomics for predicting arterial plaque vulnerability: a systematic review and meta-analysis. *Chinese Journal of Academic Radiology*, 0(0), 0-0. <https://doi.org/10.1007/s42058-024-00159-8>
- [17] Shaoxiong Yang, Qinghu Wang, Weihao Shi, Wencheng Guo, Zong-Lai Jiang, & Xiaobo Gong (2019). Numerical study of biomechanical characteristics of plaque rupture at stenosed carotid bifurcation: a stenosis mechanical property-specific guide for blood pressure control in daily activities. *ACTA MECHANICA SINICA*, 35(6), 1279-1289. <https://doi.org/10.1007/s10409-019-00883-w>
- [18] Hannah Snyder (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104(0), 333-339. <https://doi.org/10.1016/j.jbusres.2019.07.039>
- [19] Naveen Donthu, Satish Kumar, Debmalaya Mukherjee, Nitesh Pandey, & Weng Marc Lim (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133(0), 285-296. <https://doi.org/10.1016/j.jbusres.2021.04.070>
- [20] Jorge Corral Acero, Francesca Margara, M Marciniak, Cristóbal Rodero, F Loncaric, Yingjing Feng, Andrew Gilbert, João Filipe Fernandes, Syed Hassaan Ahmed Bukhari, Ali Wajdan, Manuel Villegas Martinez, Mariana Sousa Santos, Mehrdad Shamohammdi, Hongxing Luo, Philip Westphal, Paul Leeson, Paolo DiAchille, Viatcheslav Gurev, Manuel Mayr, Liesbet Geris, Pras Pathmanathan, Tina Morrison, Richard Cornelussen, Frits W. Prinzen, Tammo Delhaas, Adelina Doltra, Marta Sitges, Edward J. Vigmond, Ernesto Zacur, Vicente Grau, Blanca Rodríguez, Espen W. Remme, Steven Niederer, Peter Mortier, Kristin McLeod, Mark Potse, Esther Pueyo, Alfonso Bueno-Orovio, & Pablo Lamata (2020). The 'Digital Twin' to enable the vision of precision cardiology. *European Heart Journal*, 41(48), 4556-4564. <https://doi.org/10.1093/eurheartj/ehaa159>
- [21] Caroline Birkle, David Pendlebury, Joshua D. Schnell, & Jonathan Adams (2020). Web of Science as a data source for research on scientific and scholarly activity. *Quantitative Science Studies*, 1(1), 363-376. https://doi.org/10.1162/qss_a_00018
- [22] Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., ... Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical research ed.)*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- [23] Chaomei Chen (2005). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, 57(3), 359-377. <https://doi.org/10.1002/asi.20317>
- [24] Chaomei Chen, Fidelia Ibekwe-Sanjuan, & Jianhua Hou (2010). The structure and dynamics of

- cocitation clusters: A multiple-perspective cocitation analysis. *Journal of the American Society for Information Science and Technology*, 61(7), 1386-1409. <https://doi.org/10.1002/asi.21309>
- [25] Gupta, A., Baradaran, H., Schweitzer, A. D., Kamel, H., Pandya, A., Delgado, D., Dunning, A., Mushlin, A. I., & Sanelli, P. C. (2013). Carotid plaque MRI and stroke risk: a systematic review and meta-analysis. *Stroke*, 44(11), 3071-3077. <https://doi.org/10.1161/STROKEAHA.113.002551>
- [26] van Dijk, A. C., Truijman, M. T., Hussain, B., Zadi, T., Saiedie, G., de Rotte, A. A., Liem, M. I., van der Steen, A. F., Daemen, M. J., Koudstaal, P. J., Nederkoorn, P. J., Hendrikse, J., Kooi, M. E., & van der Lugt, A. (2015). Intraplaque Hemorrhage and the Plaque Surface in Carotid Atherosclerosis: The Plaque At RISK Study (PARISK). *AJNR. American journal of neuroradiology*, 36(11), 2127-2133. <https://doi.org/10.3174/ajnr.A4414>
- [27] Sluimer, J. C., Gasc, J. M., van Wanroij, J. L., Kisters, N., Groeneweg, M., Sollewijn Gelpke, M. D., Cleutjens, J. P., van den Akker, L. H., Corvol, P., Wouters, B. G., Daemen, M. J., & Bijnens, A. P. (2008). Hypoxia, hypoxia-inducible transcription factor, and macrophages in human atherosclerotic plaques are correlated with intraplaque angiogenesis. *Journal of the American College of Cardiology*, 51(13), 1258-1265. <https://doi.org/10.1016/j.jacc.2007.12.025>
- [28] Saba, L., Anzidei, M., Marincola, B. C., Piga, M., Raz, E., Bassareo, P. P., Napoli, A., Mannelli, L., Catalano, C., & Wintermark, M. (2014). Imaging of the carotid artery vulnerable plaque. *Cardiovascular and interventional radiology*, 37(3), 572-585. <https://doi.org/10.1007/s00270-013-0711-2>
- [29] Tearney, G. J., Regar, E., Akasaka, T., Adriaenssens, T., Barlis, P., Bezerra, H. G., Bouma, B., Bruining, N., Cho, J. M., Chowdhary, S., Costa, M. A., de Silva, R., Dijkstra, J., Di Mario, C., Dudek, D., Falk, E., Feldman, M. D., Fitzgerald, P., Garcia-Garcia, H. M., Gonzalo, N., ... International Working Group for Intravascular Optical Coherence Tomography (IWG-IVOCT) (2012). Consensus standards for acquisition, measurement, and reporting of intravascular optical coherence tomography studies: a report from the International Working Group for Intravascular Optical Coherence Tomography Standardization and Validation. *Journal of the American College of Cardiology*, 59(12), 1058-1072. <https://doi.org/10.1016/j.jacc.2011.09.079>
- [30] Wang, Y., Wang, T., Luo, Y., & Jiao, L. (2022). Identification Markers of Carotid Vulnerable Plaques: An Update. *Biomolecules*, 12(9), 1192. <https://doi.org/10.3390/biom12091192>
- [31] Saba, L., Saam, T., Jäger, H. R., Yuan, C., Hatsukami, T. S., Saloner, D., Wasserman, B. A., Bonati, L. H., & Wintermark, M. (2019). Imaging biomarkers of vulnerable carotid plaques for stroke risk prediction and their potential clinical implications. *The Lancet. Neurology*, 18(6), 559-572. [https://doi.org/10.1016/S1474-4422\(19\)30035-3](https://doi.org/10.1016/S1474-4422(19)30035-3)
- [32] Staub, D., Schinkel, A. F., Coll, B., Coli, S., van der Steen, A. F., Reed, J. D., Krueger, C., Thomenius, K. E., Adam, D., Sijbrands, E. J., ten Cate, F. J., & Feinstein, S. B. (2010). Contrast-enhanced ultrasound imaging of the vasa vasorum: from early atherosclerosis to the identification of unstable plaques. *JACC. Cardiovascular imaging*, 3(7), 761-771.

- <https://doi.org/10.1016/j.jcmg.2010.02.007>
- [33] Song, P., Fang, Z., Wang, H., Cai, Y., Rahimi, K., Zhu, Y., Fowkes, F. G. R., Fowkes, F. J. I., & Rudan, I. (2020). Global and regional prevalence, burden, and risk factors for carotid atherosclerosis: a systematic review, meta-analysis, and modelling study. *The Lancet. Global health*, 8(5), e721-e729. [https://doi.org/10.1016/S2214-109X\(20\)30117-0](https://doi.org/10.1016/S2214-109X(20)30117-0)
- [34] Cao, J., Tan, Z., Tang, Y., Liu, Z., Huang, J., Huo, G., Yao, Z., Zhou, Y., & Zhou, D. (2025). Hemodynamic simulation analysis of tandem carotid artery stenosis based on a patient-specific case. *Journal of biomechanics*, 191, 112907. <https://doi.org/10.1016/j.jbiomech.2025.112907>
- [35] Lambin, P., Leijenaar, R. T. H., Deist, T. M., Peerlings, J., de Jong, E. E. C., van Timmeren, J., Sanduleanu, S., Larue, R. T. H. M., Even, A. J. G., Jochems, A., van Wijk, Y., Woodruff, H., van Soest, J., Lustberg, T., Roelofs, E., van Elmpt, W., Dekker, A., Mottaghy, F. M., Wildberger, J. E., & Walsh, S. (2017). Radiomics: the bridge between medical imaging and personalized medicine. *Nature reviews. Clinical oncology*, 14(12), 749-762. <https://doi.org/10.1038/nrclinonc.2017.141>
- [36] Sarani Rad, F., Bitaraf, E., Jafarpour, M., & Li, J. (2026). Technologies, Clinical Applications, and Implementation Barriers of Digital Twins in Precision Cardiology: Systematic Review. *JMIR Cardio*, 10, e78499. <https://doi.org/10.2196/78499>
- [37] George Em Karniadakis, Ioannis G. Kevrekidis, Lu Lu, Paris Perdikaris, Sifan Wang, & Liu Yang (2021). Physics-informed machine learning. *Nature Reviews Physics*, 3(6), 422-440. <https://doi.org/10.1038/s42254-021-00314-5>
- [38] Kelly, C. J., Karthikesalingam, A., Suleyman, M., Corrado, G., & King, D. (2019). Key challenges for delivering clinical impact with artificial intelligence. *BMC medicine*, 17(1), 195. <https://doi.org/10.1186/s12916-019-1426-2>
- [39] Wiens, J., Saria, S., Sendak, M., Ghassemi, M., Liu, V. X., Doshi-Velez, F., Jung, K., Heller, K., Kale, D., Saeed, M., Ossorio, P. N., Thadaney-Israni, S., & Goldenberg, A. (2019). Do no harm: a roadmap for responsible machine learning for health care. *Nature medicine*, 25(9), 1337-1340. <https://doi.org/10.1038/s41591-019-0548-6>