Vascular Health and Risk Management

Dovepress
Taylor & Francis Group

Open Access Full Text Article

REVIEW

Research Trends in Vascular Aging in the Last Decade: A Comprehensive Bibliometric Analysis

Dandan Shi*, Ziqi Ning*, Yaoyao Zhang, Xiaochen Guo, Yun Wei, Meixia Liu

Xiyuan Hospital, China Academy of Chinese Medicine Science, Beijing, People's Republic of China

*These authors contributed equally to this work

Correspondence: Meixia Liu; Yun Wei, Email liumeixia2004@126.com; weiyun_0913@163.com

Background: In recent years, vascular aging has emerged as a hot topic in become an important direction of aging research, but a comprehensive bibliometric analysis has not been conducted.

Methods: The Web of Science database was searched for articles and reviews on vascular aging from January 1, 2014, to August 20, 2024, and the literature was analyzed and knowledge maps were constructed using CiteSpace, VOSviewer, pajek and Scimago Graphica software for econometric analysis and knowledge graph construction of the literature.

Results: A total of 38,910 authors from 7622 institutions in 111 countries published 7277 papers in 1344 academic journals, with a significant increase in publication volume. The United States is the country with the highest productivity and citation rates, and Mayo Clinic is the most active institution. Tarantini S published the most papers, while Csiszar A received the most citations. *Retina-The Journal of Retinal and Vitreous Diseases* journal published the most papers, and *Circulation* journal received the most citations. The main research aspects include age-related macular degeneration, arteriosclerosis, and oxidative stress, which are the main keywords in this field. In the last decade, the term c reactive protein has attracted great attention with its strongest citation explosion.

Conclusion: In the past decade, the research focus on vascular aging has been increasing year by year. Age-related macular degeneration, arteriosclerosis, oxidative stress and vascular endothelial cells are the emerging research directions in this field.

Keywords: vascular aging, research trends, bibliometric analysis, visual analysis

Introduction

A statistical analysis reveals that vascular-related diseases, particularly cardiovascular diseases, have become the predominant cause of mortality worldwide, with one-third of all deaths attributable to cardiovascular diseases. In line with Thomas S, "A man is as old as his arteries".[1] The following are some of the reasons for this. Consequently, the identification of individuals at elevated vascular risk in the asymptomatic subclinical stage is of paramount importance in the context of disease progression and the reduction of the economic burden on society and the family.

Vascular aging (VA) is an evolutionary process involving the deterioration of vascular structure and function over time, ultimately damaging the heart, brain, kidneys, and other organs. It is most notably characterized by extensive changes in the functional and structural components of the vascular wall,[2] including increased stiffness, vessel wall remodeling, loss of angiogenic capacity, and endothelium-dependent vasodilatory dysfunction. These age-related changes may occur earlier in those at risk for or with CVD, and thus scientists are increasingly convinced that biological VA is a better predictor of cardiovascular events than actual age. VA captures features of early (and often asymptomatic) stages of vascular degeneration, and thus many international guidelines for the prevention of cardiovascular disease and the management of arterial hypertension encourage the measurement of VA-related vascular biomarkers.[3,4] There are many potential invasive and non-invasive biomarkers for clinical evaluation of VA, including intima-media thickness, arterial lumen diameter, and flow-mediated dilatation, among which pulse wave conduction velocity is the gold standard for evaluating VA.[5] Many factors contribute to VA pathogenesis, including oxidative stress, chronic low-grade inflammation, and structural changes in vascular smooth muscle cells and endothelial cells, which also influence disease progression in

Received: 20 January 2025
Accepted: 8 May 2025
Published: 21 May 2025

atherosclerosis, hypertension, and diabetes.[6,7] As a rapidly developing and promising field, VA has been the subject of continuous research and there has been a rapid increase in the number of articles on the subject; however, there is a lack of visual analysis and summary of global research trends, key authors, and research hotspots. Thus, it is necessary to review and analyze the published VA articles.

Bibliometry is an interdisciplinary science that provides quantitative analysis using mathematical and statistical techniques. The application of bibliometric methods can help researchers quickly assess published research results, identify hotspots and trends in a particular field, and lay the foundations for future research.[8] In this study, we will conduct a literature search for VA-related studies based on the Web of Science database, and bibliometric and visualization analyses of the search results will be carried out through software such as VOSviewer and CiteSpace to comprehensively, objectively, and show the current status and development trend of VA research and promote the development of the field.

Materials and Methods

Data Sources

Bibliometric analysis was performed using the Web of Science Core Collection. The search strategy was TS=(vascular OR blood vessels OR arterial OR aortic OR vascular smooth muscle cell OR vascular endothelial cell) AND TI=(aging OR senescence). The period is January 1, 2014, to August 1, 2024. A complete search was performed on one day, August 3, 2024, to avoid errors caused by daily database updates. A total of 7277 articles were obtained, including articles and reviews published in English. Data were selected and recorded by two researchers and discussed to ensure that the content and topics were relevant.

Data Sources

Scimago Graphica (version 1.0.38), VOSviewer (version 1.6.19), CiteSpace (version 6.2.R6), and pajek (version 5.18) were used to analyze and visualize all studies obtained.

Scimago Graphica is used to visualize national collaborative networks on a world map. The size of each node is an indicator of the number of publications, while the color of the nodes and lines is an indicator of the intensity of cooperation.

VOS viewer is used to construct bibliometric networks that include collaboration between countries/regions, institutions, and authors. The colors of the nodes indicate different periods or clusters, the size of the nodes indicates the number of publications, and the thickness of the line indicates the intensity of the collaboration.

CiteSpace is used for the analysis and visualization of knowledge domains and emerging trends, including co-citation analysis, cluster analysis, timeline sailing of references, co-occurrence analysis of keywords, and citation bursts of references and keywords. Node size indicates the total number of co-citations or frequency of occurrence of an element, and various colors indicate different clusters or years. Rows between nodes indicate co-citations or co-occurrences. Centrality is a metric used to measure the importance of an element. When the element centrality value > 0.1, a purple outer ring is added. Citation bursts represent dramatic changes in citation age over time.

In addition, the main research trajectories were analyzed by Pajek 10 software, a software program used to analyze and visualize major paths in large networks. By examining these main pathways, we can effectively understand the main research trajectories in the field. This helps us to better understand current hotspots and predict future trends.

Results

Trend Analysis of Publications and Citations

A total of 7727 documents were retrieved, involving 11 languages. English was the dominant language, with 7113 documents, accounting for 97.75%. Following that, there were 40 German documents, accounting for 0.55%, and 34 Russian documents, accounting for 0.47%. A field's development and future trends can be directly determined by analyzing the changes in the number of publications in the field. As shown in Figure 1, the number of publications has continued to grow over the past decade, with an overall upward trend, indicating that VA research will be of increasing

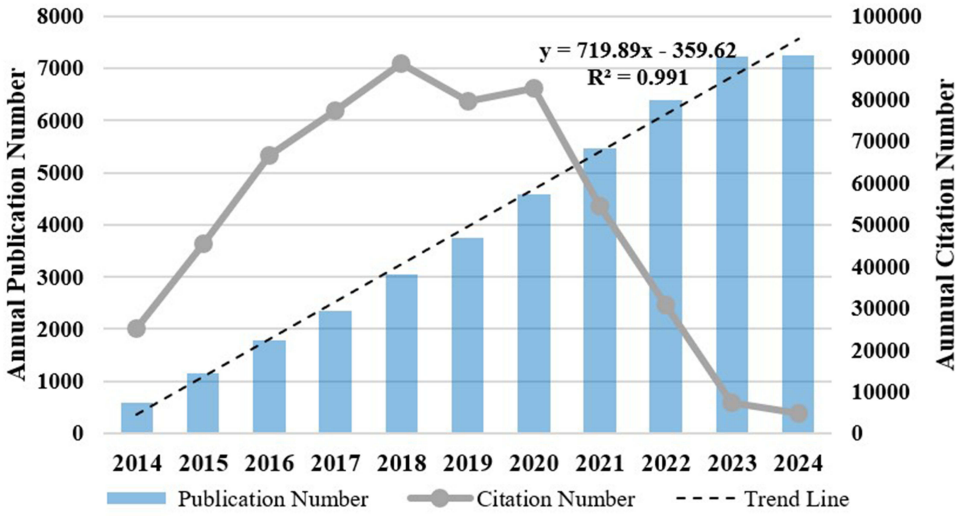

Figure 1 Analysis of annual publications and annual citations in the field of vascular aging in the last decade.

interest over the 2014–2024 period. Since 2014, the number of publications has shown an exponential growth trend, and as of 1 August 2024, 7277 articles have been published and will continue to be published. We therefore hypothesize that annual articles will exceed 720 in 2024. The total number of citations to these documents up to the date of retrieval is 155364 with an average of 21.35 citations per citation. 2018 witnessed the highest number of citations at 88,676 indicating a high level of research during this period. Other years with relatively high citation factors include 2020 (82,578), 2019 (79,720), and 2017 (77,244). Due to the proximity of 2023 and 2024 to the retrieval time (August 1, 2024), their citation frequency is lower than the other years. The yearly increase in the number of published articles and citations reflects the field's rapid development.

Analysis of High-Volume Countries

Eleven countries have conducted research related to VA, as detailed in Figure 2. Each node in the figure represents the country, the line connecting two nodes represents the link between the two countries, and the node size is the number of publications. To better understand the node hierarchy in the field, deeper data mining was performed, as detailed in Table 1. The highest number of publications was in the United States (32.42%), followed by China (14.94%) and the United Kingdom (8.88%). The United States had the highest number of citations (70,863), followed by the United Kingdom (21,256) and China (17,335). This may be related to the results shown in Figure 3, where the United States started the study the earliest and therefore had the highest number of publications and citations. Chinese researchers should pay more attention to improving the impact of their articles and strengthening foreign cooperation, as China was relatively late in the research and had a high number of publications but a low number of citations. North America, Europe, and East Asia are the main sources of articles in this field.

Analysis of High-Publishing Authors and Institutions

The top 10 authors based on the number of publications in vascular senescence are listed in Table 2. The top 10 authors have published a total of 360 papers or 4.95% of the total number of papers. Among these authors, Tarantini S published the most papers (53), followed by Csiszar A (52) and Ungvari, Zoltan (51). Csiszar A was the most cited author. As can be seen in Figure 3, the three of them are a major research force in the field of VA, as they have published several highly cited papers despite their short research period, but they have worked closely together. Nine of the top 10 are in the United States and six of them are from the University of Oklahoma Health Sciences Center.

A total of 7922 institutions have conducted relevant research on VA, and Table 3 shows the top 10 institutions with the most publications. The issuing institutions were higher education or research institutions, with 60% located in the United States. The most prolific institutions are the Mayo Clinic and Univ Sydney, and the most cited institution is the

https://doi.org/10.2147/VHRM.S517302

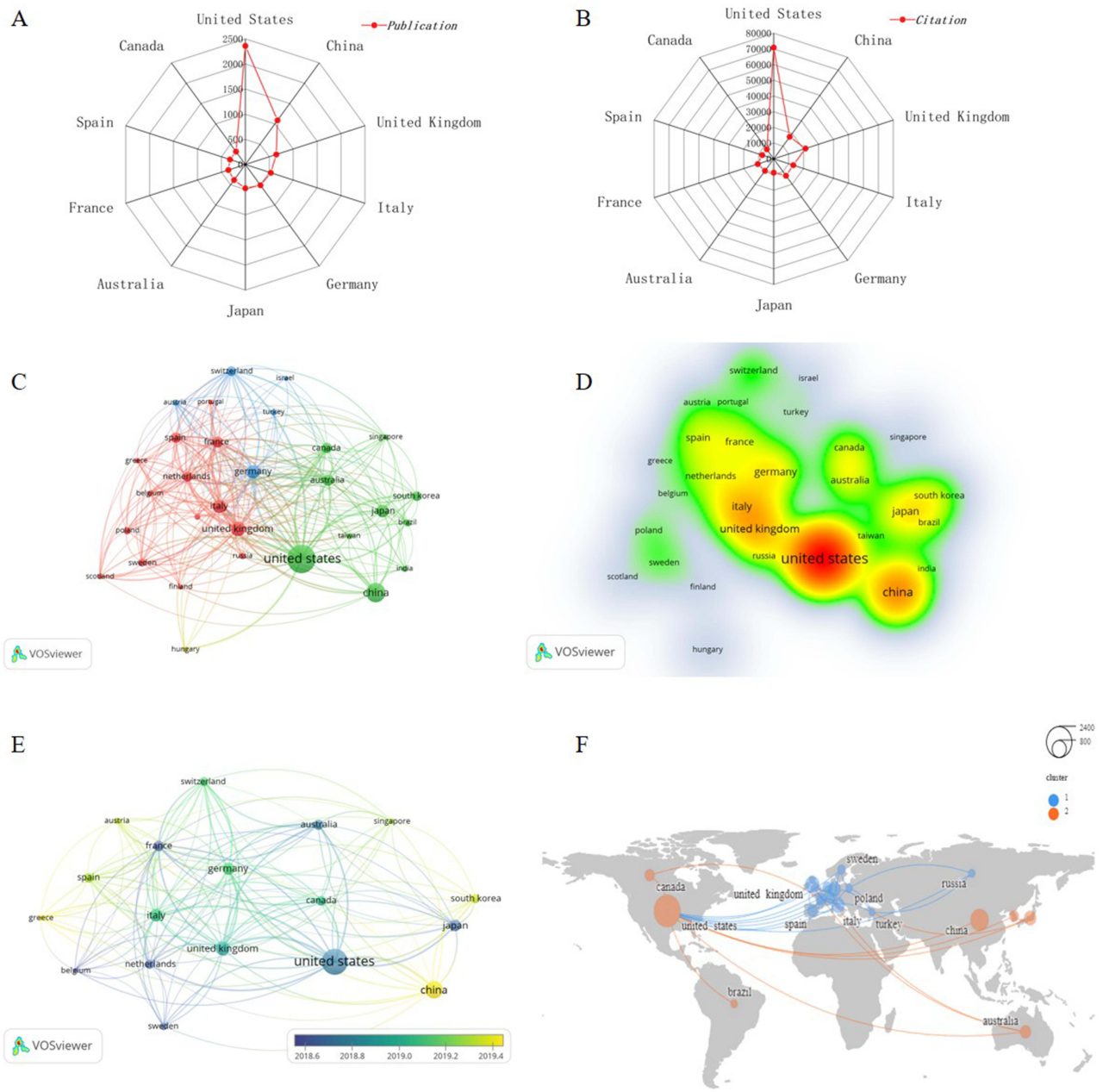

Figure 2 Visual analysis of countries with high publications in the field of vascular aging in the last decade (**A**) radar plot of the number of publication by the top 10 countries; (**B**) radar plot of the total citation scores of the top 10 countries; (**C**) visual cluster analysis of inter-country cooperation; (**D**) plot of the density of cooperation among countries; (**E**) plot of the duration of cooperation among countries; (**F**) plot of the strength of cooperation among countries around the world.

University of Oklahoma, followed by the University of Sydney. From Figure 4, it can be observed that there is a closer cooperation among institutions, which can make full use of the literature from various universities and research institutes, thus stimulating new research horizons, and making more in-depth and rapid meaningful Research.

Analysis of the Distribution of Highly Published Journals and Disciplines

A total of 1344 journals were counted as having accepted articles from studies related to VA. The top ten journals, ranked by number of articles published and by co-citation and centrality, are listed in Tables 4 and 5, respectively. The journal with the highest number of articles in this area is *Retina-The Journal of Retinal and Vitreous Diseases* (140 articles), followed by *International Journal of Molecular Sciences* (114 articles). Among the top 10 most published journals,

Table 1 Analysis of the Top 10 Countries in the WOS Core Set in the Area of Vascular Aging Over the Last Decade

Rank	Country	Publications	Citations	Total Link Strength
1	United States	2359 (32.42%)	70,863	884
2	China	1087 (14.94%)	17,335	323
3	United Kingdom	646 (8.88%)	21,256	631
4	Italy	533 (7.32%)	13,073	461
5	Germany	511 (7.02%)	13,281	472
6	Japan	473 (6.50%)	8785	212
7	Australia	381 (5.24%)	9409	344
8	France	354 (4.86%)	10,679	369
9	Spain	321 (4.41%)	7675	258
10	Canada	316 (4.34%)	7477	298

*Hypertension*had the highest IF. An analysis of the number of scientific journals with co-citations shows that *Circulation* has the highest number of co-citations, followed by *Ophthalmology*. Of the top 10 most cited scientific journals, 80% were categorized as Q1, with *New England Journal of Medicine* having the highest IF of 158.5. The analysis indicates that these journals possess strong academic credibility and impact in the field.

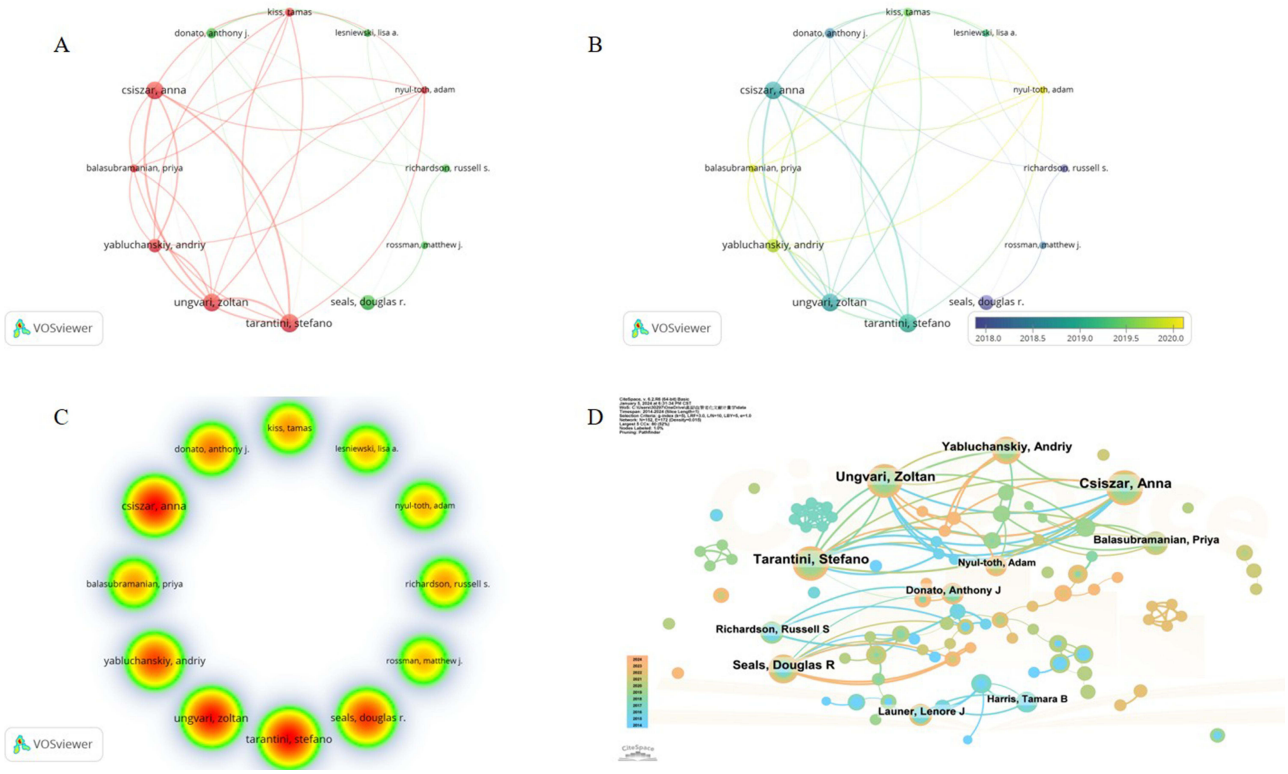

Figure 3 Visualization of authors of highly published articles in the field of vascular aging in the last decade (**A**) Clustering analysis of high-publication authors; (**B**) temporal overlay analysis of high-publication authors; (**C**) density analysis of high-publication authors; (**D**) CiteSpace visualization of high-publication authors.

https://doi.org/10.2147/VHRM.S517302

Table 2 Top 10 Authors in the Field of Vascular Aging in the Last Decade

Rank	Author	Publications	Country	Affiliation	Citations	Total Link Strength
1	Tarantini S	53 (0.73%)	United States	University of Oklahoma Health Sciences Center	3708	180
2	Csiszar A	52 (0.71%)	United States	University of Oklahoma Health Sciences Center	3712	180
3	Ungvari Z	51 (0.70%)	United States	University of Oklahoma Health Sciences Center	3674	175
4	Seals DR.	42 (0.58%)	United States	University of Colorado Boulder	2174	4
5	Yabluchanskiy A	39 (0.54%)	United States	University of Oklahoma Health Sciences Center	1757	149
6	Donato AJ.	28 (0.38%)	United States	University of Utah	1805	13
7	Launer LJ.	25 (0.34%)	United States	NIH National Institute on Aging	961	20
8	Kiss T	24 (0.33%)	United States	University of Oklahoma System	1496	114
9	Balasubramanian P	23 (0.32%)	United States	University of Oklahoma System	1082	101
10	Gillies MC.	23 (0.32%)	Australia	University of Sydney	883	0

Table 3 Top 10 Highly Published Institutions in the Last 10 Years

Rank	Organization	Country	Publications	Citations	Total Link Strength
1	Mayo clinic	United States	106	3291	16
2	Univ Sydney	Australia	105	3458	27
3	Harvard Medical sch	United States	100	2560	37
4	Johns Hopkins Univ.	United States	96	3577	31
5	Univ Melbourne	Australia	81	2445	35
6	Univ Pittsburgh	United States	81	1918	36
7	Univ Oklahoma	United States	77	4532	51
8	Capital Medical Univ.	China	75	1338	12
9	NIA	United States	74	3211	35
10	Shanghai Jiao Tong Univ.	China	74	1648	12

Statistically, VA-related research is mainly distributed among 75 fields. Figure 5 summarizes the top 10 related disciplines, and it can be seen that VA-related research is as long as concentrated in the fields of cardiovascular system cardiology, ophthalmology, neurology, and geriatrics. This points to the main future research direction of VA.

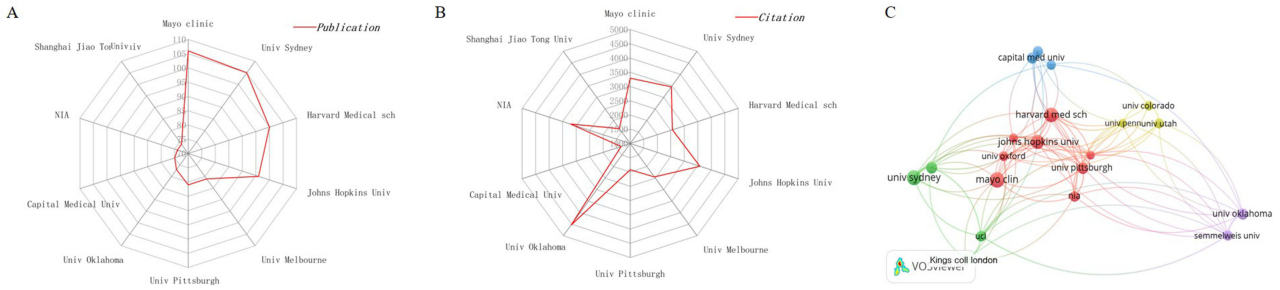

Figure 4 Visual analysis of the top 10 institutions in the field of vascular aging in the last decade (**A**) Radar chart of the number of publications of the top 10 ranked institutions; (**B**) radar chart of the number of citations of the top 10 ranked institutions; (**C**) cluster analysis of the number of publications of the top 10 ranked institutions.

Table 4 Top 10 Journals by Number of Publications

Rank	Source	Publications	Citations	JCR Partitions	Impact Factor (2022)
1	Retina-The Journal of Retinal and Vitreous Diseases	140	2458	Q2	3.3
2	International Journal of Molecular Sciences	114	1521	Q1	5.6
3	American Journal of Physiology-Heart and Circulatory Physiology	104	2884	Q2	4.3
4	Experimental Gerontology	93	1679	Q2	3.9
5	Hypertension	79	3342	Q1	8.3
6	Frontiers in Physiology	78	1300	Q2	4
7	Geroscience	78	1470	Q2	5.6
8	Frontiers in Aging Neuroscience	76	1572	Q2	4.8
9	Journal of Clinical Medicine	76	660	Q2	3.9
10	Aging-Us	73	1448	Q2	5.2

Table 5 Top 10 Journals by Co-Citation and Centrality

Rank	Source	Co-Citations	JCR Partitions	Impact Factor (2022)
1	Circulation	10409	Q1	37.8
2	Ophthalmology	8833	Q1	13.7
3	Hypertension	7600	Q1	8.3
4	Circulation Research	5837	Q1	20.1
5	Plos One	5620	Q2	3.7
6	American Journal of Physiology-Heart and Circulatory Physiology	4780	Q2	4.8
7	Journal of the American College of Cardiology	4721	Q1	24.4
8	New England Journal of Medicine	4545	Q1	158.5
9	Investigative Ophthalmology & Visual Science	4542	Q1	4.4
10	Proceedings of the National Academy of Sciences of the United States of America	4401	Q1	11.1

Analysis of Cited and Co-Cited References

Examining the referenced literature offers valuable insights into the fundamental concepts and background of the field. Table 6 lists the top ten co-cited references. The most cited study was written by Ungvari et al in 2018, which summarizes the pathophysiological mechanisms of VA, discusses the relationship between progeria over anti-aging circulating factors and the development of the VA phenotype, and suggests future directions for developing new interventions.[9]

Cluster analysis using co-citation of literature may reveal subfields that indicate major research hotspots in the field. Figure 6 shows the clustering of the reference network: “age-related macular degeneration”, “neovascular age-related macular degeneration”, “arterial stiffness”, “oxidative stress”, “cellular senescence”, “endothelial cells”, “endothelium-dependent dilation”. The modularity Q score is 0.7531, > 0.5, indicating that the network is reasonably divided into loosely coupled clusters. The weighted average profile score is 0.9248, > 0.5, implying acceptable homogeneity. Index

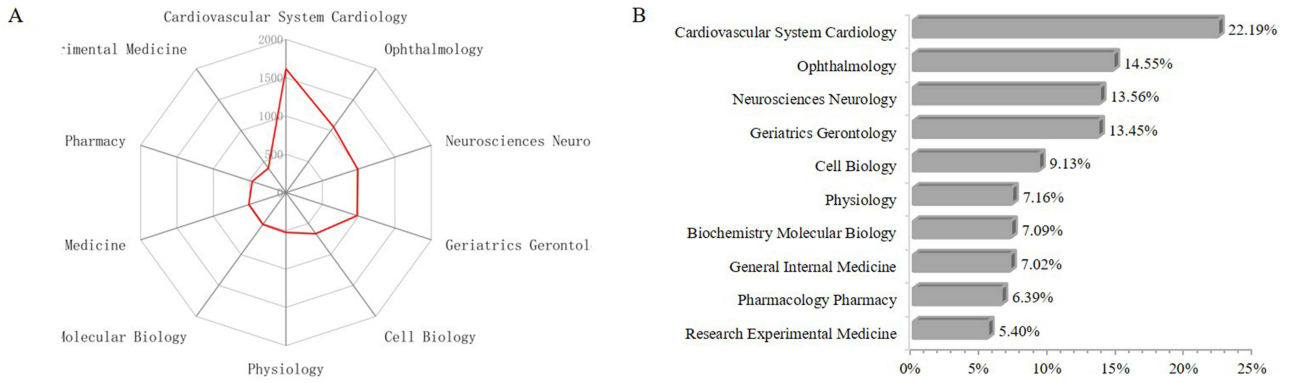

Figure 5 Visualization of the vascular aging research field in the last decade (**A**) Radar chart of the distribution areas of vascular aging; (**B**) chart of the percentage of the number of publications in different areas of vascular aging.

terms extracted from the articles were used as cluster markers. The association of age-related macular degeneration, aging, arterial stiffness, and oxidative stress with VA will become an extremely important research topic. We hypothesize that these subfields will continue to produce a lot of scholarship to better explore VA for a long time to come. Finally, the citation burst analysis was used to filter out the 20 studies that wanted the strongest citation bursts. The timeline features red and green lines, where red indicates periods of high citation bursts and green represents periods of low citation bursts. Notably, the article written by Martin et al had the highest intensity of citation bursts.

Keywords

Through the keyword co-occurrence network, "aging", "oxidative stress", "arterial stiffness", "hypertension", "inflammation", "atherosclerosis", and "Alzheimer's disease" were the most frequent keywords. Keyword citation burst detection effectively highlights emerging research trends and future academic hotspots in a specific field. Among the top 10 keywords with the highest citation explosion rate in the past 10 years, "reactive protein" was the most popular among peers. In addition, "neovascular age-related macular degeneration", "calcification", "stem cells" and "endothelial cell" will become new research hotspots in 2024 (Figure 7).

Table 6 Top 10 Co-Cited References

Rank	First Author	Year	Journal	Co-Citations	DOI
1	Ungvari Z	2018	Circ Res	159	10.1161/CIRCRESAHA.118.311378
2	Schmidt-Erfurth U	2014	Ophthalmology	146	10.1016/j.ophtha.2013.08.011
3	Maguire MG	2016	Ophthalmology	125	10.1016/j.ophtha.2016.03.045
4	Dugel PU	2020	Ophthalmology	111	10.1016/j.ophtha.2019.04.017
5	Schmidt-Erfurth U	2014	Brit J Ophthalmol	108	10.1136/bjophthalmol-2014-305702
6	Donato AJ	2018	J Mol Cell Cardiol	104	10.1161/CIRCRESAHA.118.312563
7	Holz FG	2015	Brit J Ophthalmol	101	10.1136/bjophthalmol-2014-305327
8	Donato AJ	2015	J Mol Cell Cardiol	93	10.1016/j.yjmcc.2015.01.021
9	Grunwald JE	2014	Ophthalmology	90	10.1016/j.ophtha.2013.08.015
10	Mitchell P	2018	Lancet	80	10.1016/s0140-6736(18)31550–2

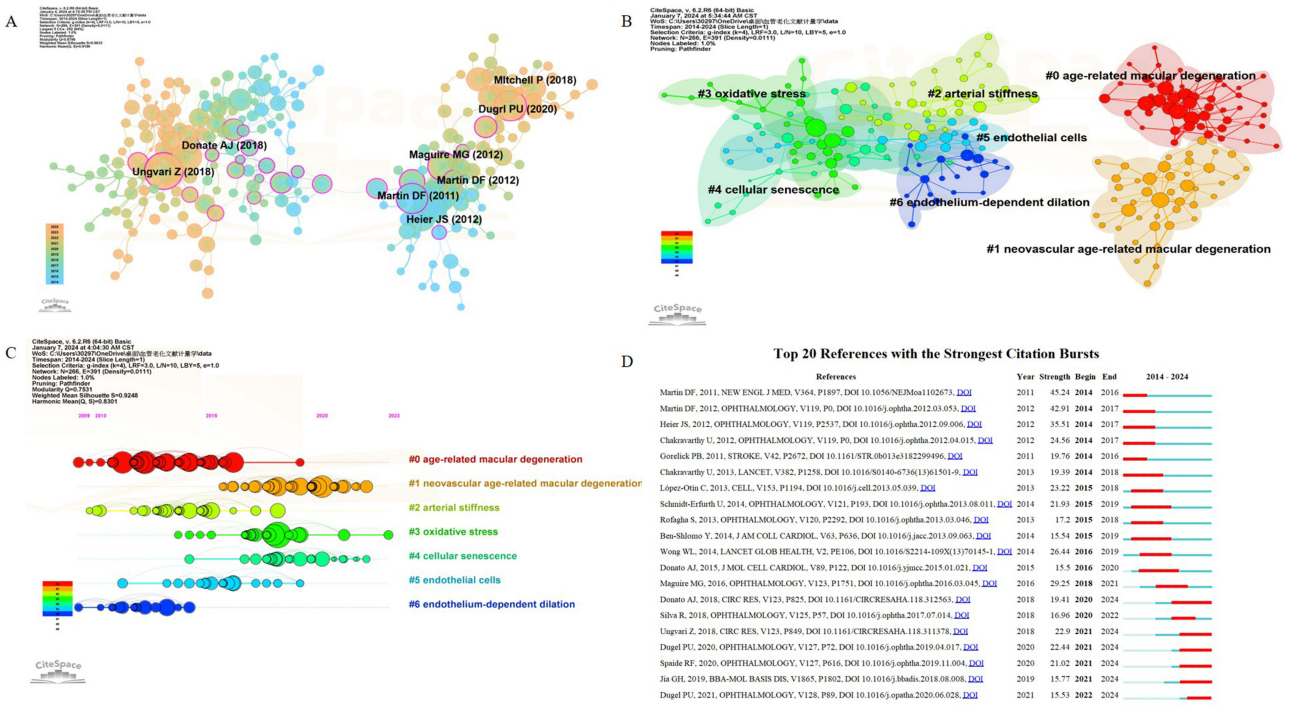

Figure 6 Visual analysis of co-cited references (**A**) citation network of co-cited references; (**B**) cluster analysis of co-cited references; (**C**) timeline distribution of the seven clusters; (**D**) top 20 references with the highest citation bursts.

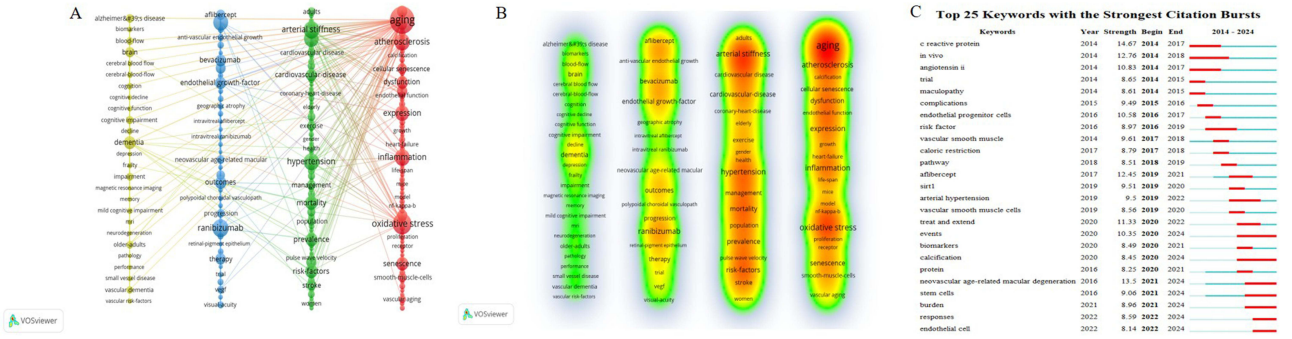

Figure 7 Keywords and burst words analysis (**A**) keyword network map; (**B**) keyword density map; (**C**) top 10 keywords with the most explosive citations. The number of citations of the top 10 ranked institutions; (**C**) cluster analysis of the number of publications of the top 10 ranked institutions.

Discussion

Main Results

This study utilizes visualization software to analyze research trends and hotspots in VA publications from 2014 to 2024. Annual publications in this field have increased over this decade, with an annual growth rate of 34.51%, and research in this field can be expected to continue to grow, with a significant increase in publications and quotations in future years. An analysis of the annual citation counts revealed that articles published closer to the data collection date received fewer

average citations. This trend may be explained by the rapid increase in newer publications, while citations to these articles remain significantly lower.

The quantity and quality of published papers in a research field are key indicators for assessing the scientific research levels of countries, institutions, and authors. A thorough analysis of countries, institutions, and authors can help identify where the strongest scientific research is found. The United States produces the most research papers and has the highest citation rate. This can be explained by several factors. For example, the US has the most institutions and authors, the highest number of citations, and the most cited references. Despite having the second-highest number of publications, China has fewer cited articles. This may be because, in recent years, Chinese research collaborations have occurred mainly at home, where research conditions are poor. China has recently implemented policies to enhance scientific research, suggesting that the quality and level of research in the country will improve in the future. In addition, Tarantini S from the United States is the most prolific writer, often collaborating with Csiszar A and Ungvari Z from the same organization, and his institution, the University of Oklahoma System, is the most productive. In addition, his group focuses on cerebrovascular changes in aging mice with the pathogenesis and pathophysiologic alterations of VA.[9–11]

As researchers explore studies from multiple disciplinary areas, new pathogenic mechanisms as well as diagnostic strategies continue to advance, and this field of research establishes disciplinary boundaries and developmental directions in the process of integration. This study found that the disciplinary areas related to VA are concentrated in the areas of cardiovascular system cardiology, ophthalmology, neurology, and geriatrics, which points to a major future direction of research and development in VA. Journals are a key medium for disseminating academic literature. *Retina-The Journal of Retinal and Vitreous Diseases*is the leading journal with the largest number of published articles in this field, and VA-related ophthalmology research can be submitted to this journal. Furthermore, academic journals with high co-citation rankings serve as reliable reference sources for our manuscripts. The analysis indicates that the journal with the highest number of co-citations is *Circulation. Circulation* is one of the top journals in cardiovascular academia, hence the importance of VA research. Current research is focused on basic and clinical medicine, while further expansion of the field is needed to advance its development.

Research Hotspots in VA

According to a cluster analysis of co-citations, researchers are particularly interested in age-related macular degeneration, atherosclerosis, and oxidative stress. Age is the strongest influence on macular degeneration, with almost all advanced macular degeneration pathology occurring in people over 60 years of age.[12] It has been found that the onset of age-related macular degeneration may be closely related to the mechanisms of choroidal capillary senescence.[13] Macular degeneration mainly affects the structure and function of the macular region of the retina, which is the most nutrient-rich and oxygen-supplying area of the retina. However, with age, the microcirculatory network and vascular system in the macula gradually deteriorate and become functionally impaired, leading to an inadequate supply of nutrients and oxygen, which accelerates the development of macular degeneration.[14] In addition, degradation of vascular endothelial cell function may also accelerate the process of macular degeneration due to aging damage to the macular vasculature and increased inflammatory response.[15] Therefore, effective control of VA and protection of the vascular system in the macula is important for the prevention and treatment of macular degeneration. Atherosclerosis is an early pathological manifestation of VA, as well as an indicator of early vascular damage and a predictor of cardiovascular disease (Cui et al, 2023; Han et al, 2024). Atherosclerosis is based on the structural changes of the arterial wall. Atherosclerosis is a characteristic feature of VA based on structural changes in the arterial wall. The characteristic impedance and forward wave amplitude of the aortic root increase in atherosclerosis, causing reflected waves to reach the heart earlier in systole, resulting in higher systolic and lower diastolic blood pressure, which in turn causes systolic hypertension and higher pulse pressure, both of which are associated with an increased expected risk of cardiovascular events.[7,16,17] In addition, atherosclerosis-induced VA and ischemic cerebrovascular disease should also be taken into account. VA is a multifaceted contributor to ischemic stroke, and VA-induced endothelial dysfunction and vascular remodelling increase susceptibility to and, at the same time, exacerbate the pathology of ischemic stroke (Liu et al, 2024). The meta-analysis showed that PWV was higher in patients with acute ischaemic stroke and that stroke patients with high PWV had an increased risk of adverse outcomes of approximately 46.2% and an increased risk of death of 12.7% (Nikolaos Kakaletsis et al, 2024;

N. Kakaletsis et al, 2024). Given the key role of atherosclerosis in the development of VA and related cardiovascular diseases, improving atherosclerosis is undoubtedly an important strategy to slow down the process of VA and reduce the risk of cardiovascular diseases. Therefore, we surmise that age-related macular degeneration and arteriosclerotic cardiovascular disease will all be future research hotspots for VA. The pathogenesis of VA is complex, and oxidative stress is one of its major etiologic factors.[18] Aging vessels produce excess reactive oxygen species, which impairs nitric oxide-mediated vasodilatory activity and promotes the formation of harmful peroxynitrite. Similarly, excess reactive oxygen species damage vascular endothelial cells, which leads to dysfunction and promotes the development of VA.[19] Therefore, amelioration of VA from the oxidative stress pathway becomes a hot topic for future mechanistic studies and drug development.

From the clustering of references and keywords and the timeline analysis of citation bursts, it appears that endothelial cells have recently attracted a great deal of attention. Vascular endothelial cells are a single layer of flattened cells located on the inner surface of blood vessels, attached to the basal layer of the endothelium. In addition to serving as a protective barrier between blood and the vessel wall, it plays important physiological roles in vascular homeostasis, maintenance of blood flow, regulation of vascular tone, pro-inflammatory responses, and neovascularization.[20] Senescent endothelial cells typically exhibit features such as flattened and enlarged morphology, decreased NO bioavailability, and secretion of large amounts of pro-inflammatory cytokines, which may contribute to the pathogenesis of VA by decreasing vessel density, increasing intima-media thickness and collagen deposition, decreasing elastin deposition, and dilating the lumen of the vasculature.[21,22] As a result of these physiological changes, decreased arterial elasticity leads to increased vascular stiffness and enhanced vascular inflammatory response, which in turn leads to impaired angiogenesis and vascular tone, further exacerbating VA (Bulbul et al, 2023; Rios et al, 2024; Vatner et al, 2021). Animal experiments have found that endothelial cell senescence can be reversed and endothelial cell function can be restored through stimulation of NO levels and lowering of blood pressure, which reduces the level of β-galactosidase in rats,[23] which suggests that improving endothelial cell function is a target of action for improving VA. In addition, genomics identified 2351 genes with differential expression in human umbilical vein endothelial cells in young and elderly populations, suggesting that endothelial cells are closely related to VA.[24] The Current studies on VA endothelial cells are mostly limited to oxidative stress and inflammatory responses, and their specific molecular mechanisms need to be further explored.

Deficiencies

In this study, we utilized bibliometric software to systematically illustrate the current state of research on VA. However, this study still has some limitations. Firstly, due to the limitations of current bibliometric software, we only analyzed data from the WOS Core Collection database, which may have resulted in the omission of some data available in other databases. (eg PubMed and Scopus databases). Secondly, only English-language articles and reviews were included in this study. Online publications, editorial material, conference papers, book chapters, and non-English articles were excluded. Finally, the current knowledge map of the field is provisional due to database and software updates. It will need to be updated in the future.

Conclusion

In summary, we have analysed the knowledge base, hotspots and future trends in VA over the past decade using VOSviewer, CiteSpace, pejack and Scimago Graphica. The literature on VA has grown rapidly in the United States and China over the last decade, highlighting the growing global interest in this field. Our study identifies recent research hotspots such as vascular endothelium and oxidative stress, suggesting that amelioration of VA from these pathways may become a hotspot for future mechanistic studies and drug development. In addition, age-related macular degeneration and atherosclerosis are major research topics that have attracted much attention; therefore, we hypothesise that macular degeneration and atherosclerotic cardiovascular diseases will be the main directions for future research on VA.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (Grant No. 82074509), the Chinese medicine clinical research integration platform construction project of Xiyuan Hospital (Grant No. XYZX0405-18) and

the Special research project on the inheritance of experience of famous and old Chinese medicine of Xiyuan Hospital (Grant No. XYZX0101-23). We also would like to express our sincere gratitude to Jiangang Liu for his valuable comments, which have greatly improved this paper.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Jani B, Rajkumar C. Ageing and vascular ageing. *Postgrad Med J*. 2006;82(968):357–362. doi:10.1136/pgmj.2005.036053
2. Climie RE, Alastruey J, Mayer CC, et al. Vascular ageing: moving from bench towards bedside. *Eur J Prev Cardiol*. 2023;30(11):1101–1117. doi:10.1093/eurjpc/zwad028
3. Ben-Shlomo Y, Spears M, Boustred C, et al. Aortic pulse wave velocity improves cardiovascular event prediction: an individual participant meta-analysis of prospective observational data from 17,635 subjects. *J Am Coll Cardiol*. 2014;63(7):636–646. doi:10.1016/j.jacc.2013.09.063
4. Sehestedt T, Jeppesen J, Hansen TW, et al. Risk prediction is improved by adding markers of subclinical organ damage to SCORE. *Eur Heart J*. 2010;31(7):883–891. doi:10.1093/eurheartj/ehp546
5. Li A, Yan J, Zhao Y, et al. Vascular aging: assessment and intervention. *Clin Interv Aging*. 2023;18:1373–1395. doi:10.2147/CIA.S423373
6. Mistriotis P, Andreadis ST. Vascular aging: molecular mechanisms and potential treatments for vascular rejuvenation. *Ageing Res Rev*. 2017;37:94–116. doi:10.1016/j.arr.2017.05.006
7. Vatner SF, Zhang J, Vyzas C, Mishra K, Graham RM, Vatner DE. Vascular stiffness in aging and disease. *Front Physiol*. 2021;12:762437. doi:10.3389/fphys.2021.762437
8. Chen C, Dubin R, Kim MC. Emerging trends and new developments in regenerative medicine: a scientometric update (2000 - 2014). *Expert Opin Biol Ther*. 2014;14(9):1295–1317. doi:10.1517/14712598.2014.920813
9. Ungvari Z, Tarantini S, Donato AJ, Galvan V, Csiszar A. Mechanisms of vascular aging. *Circ Res*. 2018;123(7):849–867. doi:10.1161/CIRCRESAHA.118.311378
10. Ungvari Z, Tarantini S, Sorond F, Merkely B, Csiszar A. Mechanisms of vascular aging, a geroscience perspective: JACC focus seminar. *J Am Coll Cardiol*. 2020;75(8):931–941. doi:10.1016/j.jacc.2019.11.061
11. Ungvari Z, Tarantini S, Kiss T, et al. Endothelial dysfunction and angiogenesis impairment in the ageing vasculature. *Nat Rev Cardiol*. 2018;15(9):555–565. doi:10.1038/s41569-018-0030-z
12. Mitchell P, Liew G, Gopinath B, Wong TY. Age-related macular degeneration. *Lancet Lond Engl*. 2018;392(10153):1147–1159. doi:10.1016/S0140-6736(18)31550-2
13. Al-Zamil WM, Yassin SA. Recent developments in age-related macular degeneration: a review. *Clin Interv Aging*. 2017;12:1313–1330. doi:10.2147/CIA.S143508
14. Uemura A, Fruttiger M, D'Amore PA, et al. VEGFR1 signaling in retinal angiogenesis and microinflammation. *Prog Retin Eye Res*. 2021;84:100954. doi:10.1016/j.preteyeres.2021.100954
15. Zhao B, Zhu L, Ye M, et al. Oxidative stress and epigenetics in ocular vascular aging: an updated review. *Mol Med*. 2023;29(1):28. doi:10.1186/s10020-023-00624-7
16. Antza C, Doundoulakis I, Akrivos E, et al. Estimated arterial stiffness and prediction of vascular aging: the rising of a new era. *Curr Pharm Des*. 2021;27(16):1871–1877. doi:10.2174/1381612826666200728150637
17. Oliveira AC, Cunha PMGM, de O Vitorino PV, et al. Vascular Aging and Arterial Stiffness. *Arq Bras Cardiol*. 2022;119(4):604–615. doi:10.36660/abc.20210708
18. El Assar M, Angulo J, Rodríguez-Mañas L. Oxidative stress and vascular inflammation in aging. *Free Radic Biol Med*. 2013;65:380–401. doi:10.1016/j.freeradbiomed.2013.07.003
19. Koutsaliaris IK, Moschonas IC, Pechlivani LM, Tsouka AN, Tselepis AD. Inflammation, oxidative stress, vascular aging and atherosclerotic ischemic stroke. *Curr Med Chem*. 2022;29(34):5496–5509. doi:10.2174/0929867328666210921161711
20. Hwang HJ, Kim N, Herman AB, Gorospe M, Lee JS. Factors and pathways modulating endothelial cell senescence in vascular aging. *Int J Mol Sci*. 2022;23(17):10135. doi:10.3390/ijms231710135
21. Jia G, Aroor AR, Jia C, Sowers JR. Endothelial cell senescence in aging-related vascular dysfunction. *Biochim Biophys Acta Mol Basis Dis*. 2019;1865(7):1802–1809. doi:10.1016/j.bbadis.2018.08.008
22. Jia G, Aroor AR, DeMarco VG, Martinez-Lemus LA, Meininger GA, Sowers JR. Vascular stiffness in insulin resistance and obesity. *Front Physiol*. 2015;6:231. doi:10.3389/fphys.2015.00231
23. Ramirez-Sanchez I, Mansour C, Navarrete-Yañez V, et al. (-)-Epicatechin induced reversal of endothelial cell aging and improved vascular function: underlying mechanisms. *Food Funct*. 2018;9(9):4802–4813. doi:10.1039/c8fo00483h
24. Mun GI, Lee SJ, An SM, Kim IK, Boo YC. Differential gene expression in young and senescent endothelial cells under static and laminar shear stress conditions. *Free Radic Biol Med*. 2009;47(3):291–299. doi:10.1016/j.freeradbiomed.2009.04.032