



Review article

Visualization of transcatheter aortic valve implantation from the perspective of bibliometric analysis

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ABSTRACT

Transcatheter aortic valve implantation (TAVI) was originally devised as a treatment for patients with aortic stenosis (AS). It has since emerged as a beneficial alternative to surgical aortic valve replacement (SAVR), extending its reach to a broader array of patients. Our objective was to illustrate the developmental trends and focus areas in TAVI research. We sourced a total of 11,480 research papers on TAVI, published between 1994 and 2022, from the Web of Science Core Collection (WoSCC) database. We conducted a bibliometric analysis of these publications, generating cooperation maps, performing co-citation analysis of journals and references, and carrying out a cluster analysis of keywords. Our findings indicate that TAVI research grapples with numerous clinical challenges. We created knowledge maps that highlight contributing countries/institutions, authors, journals with high publication and citation rates, and notable references in this domain. North America and Europe have been at the forefront of research within the TAVI field. The institutions and authors from these regions exert significant influence in this area of study. Beginning in 2009, China has progressively expanded its research on TAVI over the past two decades. We anticipate that future research will increasingly focus on three key areas: implementation scope, lifelong management, outcomes and predicting the risk of TAVI. Research on TAVI is flourishing. Cooperation among different countries and institutions in this field must be strengthened in the future, especially for developing countries.

1. Introduction

Transcatheter aortic valve implantation (TAVI), also known as transcatheter aortic valve replacement (TAVR), was first developed in 2002 as a treatment for aortic stenosis (AS) [1], a prevalent heart valve disorder especially in North America and Western Europe [2, 3]. Historically, surgical aortic valve replacement (SAVR) has been the primary recommended treatment for AS [4–6]. However, not all AS patients are suitable candidates for surgery due to factors such as advanced age, frailty, and significant comorbid conditions [7].

Consequently, TAVI quickly became the standard of care for patients with AS who were at prohibitive surgical risk, and is now the

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preferred treatment for many intermediate and high-risk elderly patients [8,9]. TAVI, when compared to SAVR, is associated with a reduction in all-cause mortality and stroke up to 2 years, regardless of baseline surgical risk [10]. Presently, TAVI has evolved to become a valuable alternative to SAVR in an ever-expanding patient population, including low-risk patients with AS and aortic valve incompetence [11].

The recent upswing in TAVI implementation has led to a significant increase in related publications. This makes it essential for researchers to identify the most active areas of TAVI research and to track changes in research focus over time. Bibliometric analysis, a technique employing qualitative and quantitative analysis, has become a widely used tool for exploring knowledge structures and development trends [12,13]. Novel bibliometric software systems, VOSviewer and CiteSpace, provide researchers with efficient means to evaluate the distribution of countries, institutions, authors, and journals within a specific research field, as well as to understand the focus and developmental trends in that field [14,15]. Despite their application across diverse disciplines to develop guidelines, evaluate research hotspots, and explore research trends, few studies have examined the trends and hot topics in TAVI via relevant publications, aside from three studies that performed citation analyses based solely on the top 100 most cited articles recently [16–18].

With this study, based on the bibliometric analysis of publications from the Web of Science Core Collection (WoSCC) database, we aim to: (i) identify enduring challenges and research hotspots in TAVI; (ii) reveal the research trend of TAVI over the past decade; (iii) construct a knowledge graph with VOSviewer and CiteSpace in this field; and (iv) provide valuable insights for future related research.

2. Materials and methods

2.1. Data sources and searches

We conducted a search of records pertinent to TAVI in the WoSCC database. The search strategy employed was: Topic = (“Transcatheter Aortic Valve Implantation” OR “Transcatheter Aortic Valve Replacement”). The types of literature included were limited to articles and reviews. There were no constraints on language. All retrieval and data extraction procedures were completed on April 23rd, 2023. The acquired records were stored as plain text files under the name ‘download_txt’.

2.2. Data analysis

The documents procured from the WoSCC database were imported into CiteSpace 6.1. R2 and VOSviewer 1.6.18. Visualization analysis of countries/regions and institutions, co-citation analysis of references, and detection of burst keywords were carried out using CiteSpace 6.1. R2. Visualization analysis of authors and co-cited authors, co-citation analysis of journals, and clustering analysis of keywords were accomplished using VOSviewer 1.6.18. The Bibliometrix R Package software was employed to represent source dynamics and topics dynamics, while ArcGIS 10.8 was utilized to illustrate the global distribution of publications.

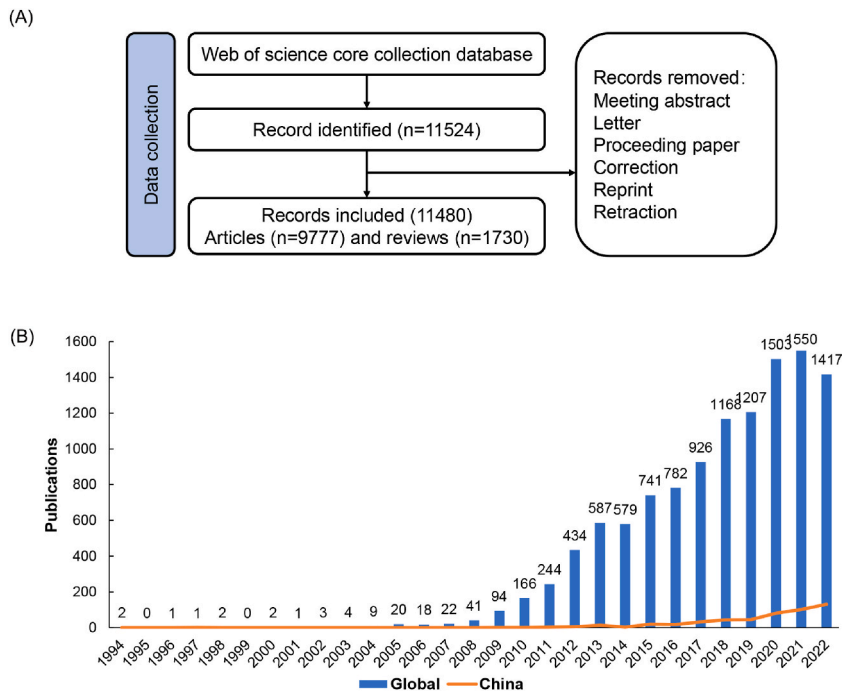


Fig. 1. Diagram depicting literature selection process and trends in publication growth from 2007 to 2022. (A) Diagram depicting literature selection process; (B) Trends in publication growth from 2007 to 2022.

3. Results

3.1. Annual publication outputs

As demonstrated in the retrieval process diagram (Fig. 1A), there were 11,480 publications concerning transcatheter aortic valve implantation available up to December 31, 2022. Of these, 9777 articles, representing 85.17 % of the total, were followed by 1730 reviews (15.07 %). The dynamic change in publication volume over the last decade mirrors the overall developmental trend in this field. As shown in Fig. 1B, there has been steady growth in publication output from 1994 to 2022, though the annual growth has been modest and even showed a decrease in 2014 and 2022. However, TAVI research commenced relatively late in China, and the number of publications remains limited.

3.2. Contributions by countries/regions and institutions

Over the past decade, 738 countries/regions have successively conducted research on TAVI, and Fig. 2A showed the top 99 countries/regions. The United States in North America leads the pack with 4226 publications, followed by Europe's Germany and Italy with 2097 and 1391 articles, respectively (Table 1). These three countries account for over half of the worldwide publications. France and the United Kingdom in Europe, as well as Canada in North America, have also contributed more than 900 articles each, making

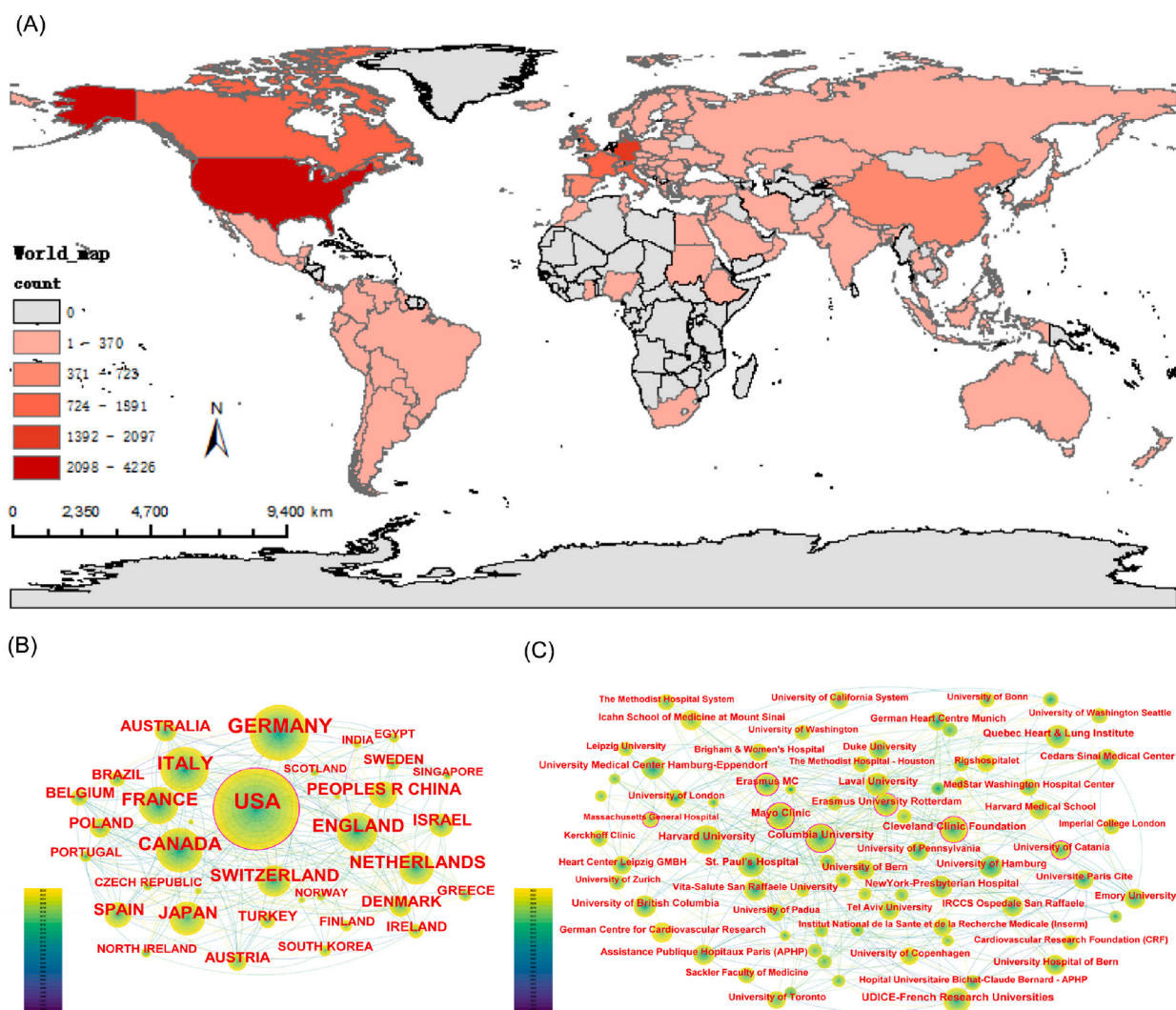


Fig. 2. Illustrates collaboration among countries/regions and institutions within the transcatheter aortic valve implantation field. (A) Geographical heat map of publications. (B) Network demonstrating co-occurrence among countries/regions. The lines connecting the circles signify collaboration, while circles with purple borders denote countries of high centrality. (C) Network highlighting co-occurrence among institutions. Lines connecting circles depict collaboration, and circles with purple borders denote institutions of high centrality.

significant literature contributions in this area. However, since 1994, there have been less than 30 publications in most countries, and some regions have yet to contribute to this field (Fig. 2A).

In the CiteSpace diagram, circles represent countries/regions, with larger circles indicating more publications (Fig. 2B). Lines between circles signify cooperation between these regions. Purple-rimmed circles represent countries with high centrality, emphasizing their importance in the network [15]. The United States ranks first in the total number of publications and first in centrality, and cooperation has been established in many regions (high centrality). But Italy and Germany, despite being the second and third highest in publication volume, shows relatively low centrality. This could be attributed to different academic cultures across countries.

Over the past decade, more than 31,690 institutions have conducted TAVI research (Fig. 2C). Harvard University leads with 540 publications, closely followed by Columbia University (520), UDICE-French Research Universities (500), and the Cleveland Clinic Foundation (490), which have all significantly contributed to TAVI research (Table 1). Of the top ten institutions, five are located in the United States. Regarding institutional cooperation, we found that institutions with higher centrality (denoted by purple-rimmed circles) are primarily in Europe and America, such as the UDICE-French Research Universities and Columbia University.

3.3. Authors and Co-cited authors

Over the years, a total of 35,745 authors have contributed to TAVI research. The connectivity among the top 100 most productive authors is presented in Fig. 3. As per Fig. 3A, their collaborations can be segmented into 8 clusters. When combined with the overlay visualization of the year (Fig. 3B), the light blue, dark blue, green, coffee, red, orange and yellow clusters in Fig. 3A were mainly active before 2018, and the purple cluster in Fig. 3A was mainly active after 2018. Table S1 lists the top 10 most productive authors. Webb, John G from Cardiovascular Center Frankfurt, Germany, has the highest number of publications (304), followed by Leon, Martin B from New York Presbyterian Hospital, USA, and Rodes-Cabau, Josep from Humanitas Research Hospital IRCCS, Italy, with 285 and 283 publications, respectively.

The co-citation relationship is displayed in the cluster diagram (Fig. 3C), and their influence in the field is shown in the density map (Fig. 3D). The top 10 co-cited authors are also listed in Table S1, with Leon, Martin B. from the New York Presbyterian Hospital leading with the most co-citations (6980), followed by Smith Cr. from the University of Florida in the USA and Kappetein Ap. from Erasmus University Rotterdam in the Netherlands with 3378 and 3044 co-citations, respectively.

3.4. Journal and Co-cited journals

A total of 814 journals have published studies on TAVI, and the top ten are shown in Table S2. Journal of Catheterization and Cardiovascular Interventions is the most productive journal with 885 articles (7.71 %), followed by American Journal of Cardiology (557, 4.85 %) and JACC-Cardiovascular Interventions (463, 4.03 %). Among the top ten journals, seven are based in the United States. Five journals have an impact factor greater than 5, including JACC-Cardiovascular Interventions (11.075), Eurointervention (7.728), Journal of the American College of Cardiology (27.206), Annals of Thoracic Surgery (5.113), and Journal of Thoracic and Cardiovascular Surgery (6.439).

The influence of journals in a research field depends on the number of citations. The co-citation analysis was performed using VOSviewer (Fig. 4A). The size of nodes represents the number of citations, and the lines between nodes indicate the co-citation relationship. The colors in the cluster analysis differentiate between general medical periodicals (green) and heart research-specific academic journals (red). Journal of the American College of Cardiology, based in the United States, is the most influential journal with 40,067 citations, indicating its authority in the field of transcatheter aortic valve implantation. Among the top ten co-cited journals, five have an impact factor greater than 10 and belong to Q1, showcasing the high quality of TAVI-related articles and the

Table 1

Top 10 productive countries and institutions regarding the research on transcatheter aortic valve implantation.

rank	country	Publication [#]	centrality	ACI	h-index	institution	Publication [#]	centrality	ACI	h-index
1	USA	4226 (36.81)	0.15	16.36	150	Harvard University (USA)	540 (4.70)	0.03	40.32	81
2	Germany	2097 (18.27)	0.04	26.75	115	Columbia University (USA)	520 (4.53)	0.11	29.65	77
3	Italy	1391 (12.12)	0.08	24.58	81	UDICE-French Research Universities (France)	500 (4.36)	0.07	–	–
4	Canada	1288 (11.22)	0.10	60.45	136	Cleveland Clinic Foundation (USA)	490 (4.27)	0.13	15.37	28
5	England	1167 (10.17)	0.10	41.17	94	St.Paul's Hospital (USA)	453 (3.95)	0.10	31.21	197
6	France	937 (8.16)	0.08	39.54	99	Mayo Clinic (USA)	453 (3.95)	0.22	19.53	36
7	Netherlands	764 (6.66)	0.06	40.29	89	Laval University (Canada)	386 (3.36)	0.02	25.27	41
8	Japan	723 (6.30)	0.04	9.01	42	Quebec Heart & Lung Institute (Canada)	378 (3.29)	0.04	30.44	128
9	Switzerland	704 (6.13)	0.02	29.42	79	University of British Columbia (Canada)	373 (3.25)	0.02	11.13	91
10	China	496 (4.32)	0.02	0.77	14	University of Hambury (Germany)	359 (3.13)	0.01	91	1

ACI, average citations per item; UK, United Kingdom; USA, the United States of America; NA, not applicable.

[#] Expressed as number (proportion).

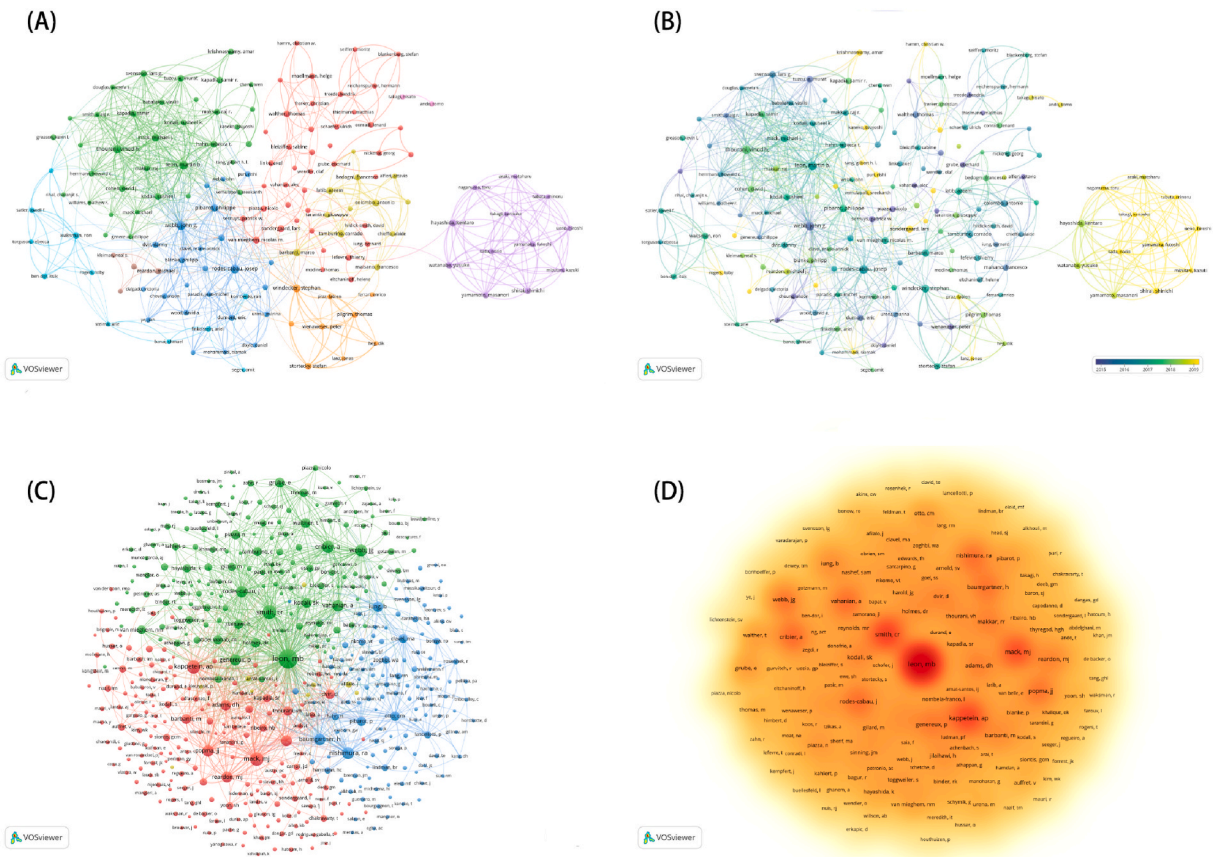


Fig. 3. Depicts collaboration among authors and co-cited authors within the field of transcatheter aortic valve implantation. (A) Network demonstrating collaboration among authors. (B) Time-overlay map of the collaboration network among authors. Purple denotes earlier keywords, whereas yellow signifies recent keywords. (C) Network illustrating cooperation among co-cited authors. (D) Density visualization of co-cited authors. Keywords with higher weights are closer to the color red.

academic significance of this research (Table S3).

The dual-map overlay of journals presents the relationship between the journals and their cited counterparts. Different colored paths represent different citation relationships [19]. As seen in Fig. 4B, two main paths, marked in green, indicates that articles published in “Molecular, Biology, Genetics” and “Health, Nursing, Medicine” journals (right) are generally cited in “Medicine, Medical, Clinical” journals (left). Fig. S1 presents the source dynamics, showcasing the cumulative and annual occurrences of the 10 journals with the largest number of publications in this field.

3.5. Co-cited references

We analyzed a total of 83,852 co-cited references, and the co-citation network is presented in Fig. 5A. The top 10 are listed in Table S4. The article titled “2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines” in the JACC-Cardiovascular Interventions (11.075), holds the most central role in the co-citation network with a co-citation count of 5666 [20]. Half of the top 10 co-cited articles were published in the New England Journal of Medicine (176.082), which is considered one of the most prestigious peer-reviewed medical journals. As for the themes of these highly co-cited references, comparisons and developments of surgical methods along with their postoperative results are the most prevalent topics. These topics are also of significant interest in post-operative care and research. We further conducted co-citation cluster analyses, resulting in the division of references into 9 clusters exhibiting active co-citation relationships (Fig. 5B).

3.6. Keyword analysis

The keyword analysis provides insight into current research topics in the TAVI field, including prevalent themes and future trends. The most frequently occurring keywords are visualized in a density plot in Fig. 5C. The keywords “replacement”, “stenosis”, and “transcatheter aortic valve implantation” top the list with occurrences of 4,020, 3938, and 3545 times, respectively. We’ve also

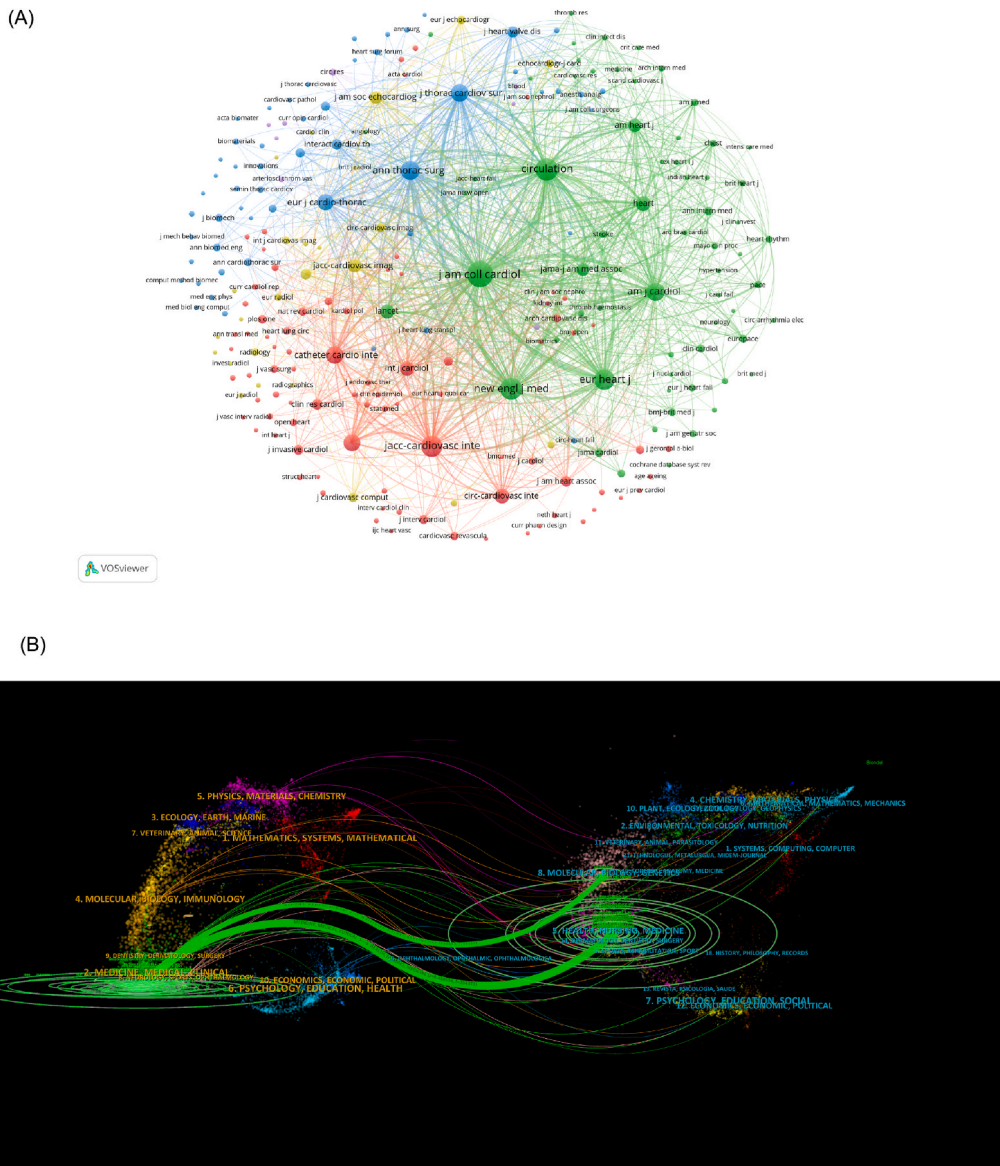


Fig. 4. Presents journal analyses within the transcatheter aortic valve implantation field. (A) VOSviewer network visualization map of journal citations. (B) Dual-map overlay of journals. Journals citing articles are on the left, while journals of initially published co-cited articles are on the right.

established a co-occurrence network of high-frequency keywords, visualized through clustering analysis (Fig. 5D). The clusters can be categorized into four domains: 1) Imaging examination (the yellow cluster includes “aortic stenosis”, “regurgitation”, “computer-tomography”, and “echocardiography”); 2) Implementation studies of TAVI in high-risk aortic stenosis patients (the blue cluster includes “high-risk patients”, “replacement”, “stenosis”, “surgery”, and “risk”); 3) Outcomes of TAVI (the red cluster includes “elderly patients”, “mortality”, “heart failure”, “therapy”, and “society”); 4) Predicting the risk of transcatheter heart valve implantation (the green cluster includes “implantation”, “impact”, “predictors”, “meta-analysis”).

In addition, we’ve used color coding to visualize the average year of keyword appearance in Fig. 5E, where blue represents earlier keywords, and yellow symbolizes recent ones. This representation allows for a clear observation of research trend shifts. The top 25 keywords with the most significant citation bursts are identified in Fig. 5F, indicating a rapid surge in specific research topics during certain periods. Keywords like “prosthesis” (142.96, 2004–2014), “transcatheter implantation” (44.68, 2004–2011), “stenosis” (40.58, 2006–2012), “surgery” (25.4, 2006–2012), “experience” (35.90, 2007–2013) highlight that in the early stages (from 2002 to 2014), as an emerging technique with relatively low invasiveness, how to learn and improve TAVI experience, as well as the therapeutic effects of TAVI compared to established traditional surgical treatments became two major matters of great concern. More recent keywords, such as “TAVR” (43, 2021–2023), “conduction disturbance” (25.77, 2020–2023), and “case report” (24.18, 2020–2023), suggest that

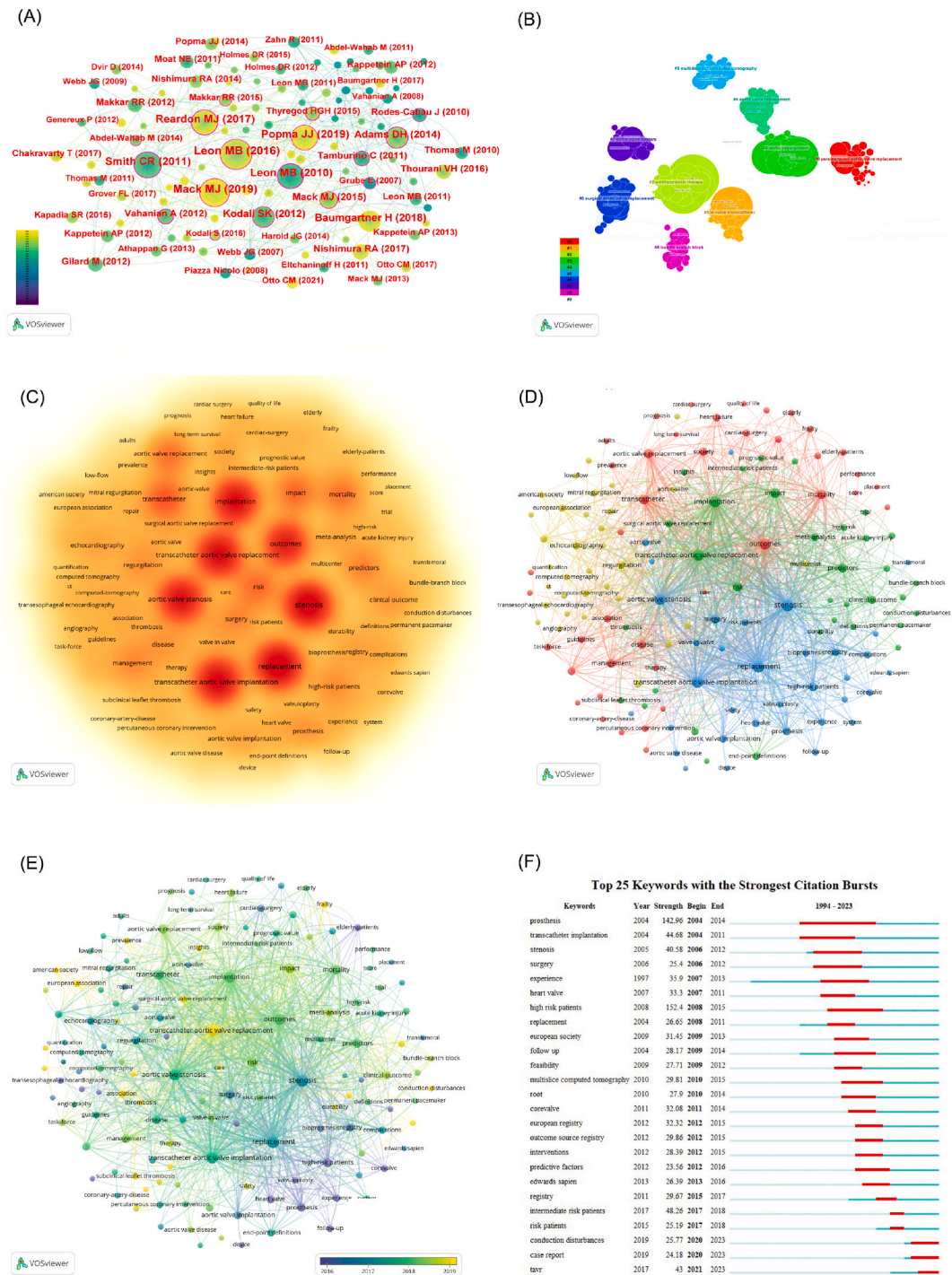


Fig. 5. Demonstrates reference analyses and keyword analyses within the field of transcatheter aortic valve implantation. (A) Co-citation networks of references. Lines connecting circles illustrate collaboration, and circles with purple borders signify references with high centrality. (B) Cluster diagrams of references. (C) Density visualization. The color of the keyword is closer to red with higher keyword weight. (D) Cluster visualization. (E) Overlay visualization. Purple signifies earlier keywords, while yellow represents recent keywords. (F) Top 10 keywords with the most significant citation bursts.

with the proven efficacy and familiarity with the technique, there is now more concern about the adverse complications associated with TAVR and the expansion of its indications.

We've also performed a per-year analysis of topic dynamics to further observe the transformation of research hotspots, as shown in

Fig. S2. From 2005 to 2013, terms such as “transluminal implantation”, “percutaneous implantation”, and “valve prosthesis” suggest that the primary focus was on the specific methods and procedures of transcatheter heart valve procedures. From 2014 to 2018, terms like “elderly-patients”, “high-risk patients”, “mortality”, “implantation”, “transcatheter” indicate that research was primarily concentrated on the scope and outcome of application of TAVI. From 2019 to 2022, terms such as “outcome”, “conduction disturbances”, “coronary access”, “impact”, and “randomized evaluation” suggest that recent research has been primarily focused on the evaluation of the adverse effect of TAVI, like coronary artery obstruction and cardiac conduction disorders.

4. Discussion

Our study offers a current, comprehensive analysis of the focus areas and developmental trends in TAVI research over the past several years. Utilizing VOSviewer and CiteSpace, we have visualized the knowledge structure that encapsulates the relationships among relevant countries, institutions, authors, keywords, and references. We employed various bibliometric analysis methods within these two innovative bibliometric software systems, thereby laying a foundation for future research in this domain.

4.1. Countries, institutions and authors

Analysing the distribution of countries, institutions, and authors, North America and Europe unequivocally emerge as leaders in TAVI research. The USA spearheads the field in terms of the volume of publications and possesses the highest centrality. Eight of the top ten most productive institutions are in North America, including the USA and Canada, with the remaining two located in Europe. These leading institutions are positioned near the core of each cluster in the co-authorship map, demonstrating their pivotal role in shaping research trends in this field.

Among the top ten most productive authors, six are from Europe (four from Italy, one from Germany, and one from Switzerland), while the remaining four are from North America (three from the USA and one from Canada). The three most prolific authors—John G. Webb, Martin B. Leon and Josep Rodes-Cabau—are also among the top ten most frequently co-cited authors. Most co-cited authors hail from North America and Europe as well. In this field, collaborations between countries, institutions, and authors are predominantly within North America and Europe. These areas’ high prevalence and early initiation of TAVI research have shaped the current trends. AS is estimated to have a prevalence of 7.6 million among adults over 75 years of age in North America and Europe, according to a 2013 meta-analysis [21]. Given the aging population, its prevalence is expected to increase in the future.

Japan and China are the only two Asian countries ranking highly in terms of TAVI-related publications. Although China’s publications began in 2009, it has shown robust growth over the past two decades. This trend may be closely associated with China’s economic growth and increased national health awareness. As TAVI research gains more global attention and international collaborations increase, we expect further progress. We propose that research institutions, particularly those in developing countries, should dismantle academic barriers and foster communication to advance TAVI research and development.

4.2. Journals and articles

Heart research-specific academic journals, such as the Journal of Catheterization and Cardiovascular Interventions, American Journal of Cardiology, and Jacc-Cardiovascular Interventions, were among the most productive publications. However, comprehensive medical periodicals like the Journal of the American College of Cardiology, The New England Journal of Medicine, and Circulation demonstrated a broader influence through increased citation rates. Understanding the impact factor of these journals is integral to assessing the quality and significance of the published articles. Typically, journals with higher impact factors tend to publish research of superior quality, which consequently garners more citations. The top 10 most-cited publications in the TAVI field all originate from these journals.

4.3. Research focuses and frontiers

Keywords encapsulate the central topics and core content of publications. Through keyword co-occurrence analysis, we can gain insights into the distribution and development of various research focuses within a specific field. We performed a keyword cluster analysis based on co-occurrence, leading to the formation of four distinct clusters. By combining cluster analysis and time-zone analysis, we were able to identify three main research focuses and frontiers in this field. These are detailed below:

The first domain involves the expansion of TAVI implementation to a broader spectrum of patients. As per the 2017 guidelines, TAVI was established as the standard of care for patients with severe AS at prohibitive surgical risk, an equivalent choice for those with severe AS at high surgical risk, and an optional choice for patients with severe AS at intermediate surgical risk [5]. Given its minimally invasive nature and rapid recovery time, TAVI is being considered for a wider spectrum of patients, including those with low to intermediate surgical risk AS and those with aortic regurgitation. Nevertheless, there is still a lack of clear conclusions regarding the comparative prognosis of young, low-surgical-risk patients undergoing SAVR versus TAVI. Evaluating the benefits and risks of implementing TAVI in these patient groups is a significant focus, especially considering the potential increase in TAVI use among young, low-surgical-risk patients. Research that explores which subgroups of patients might benefit from TAVI is extremely valuable [22,23].

The second domain pertains to the lifelong management of patients undergoing TAVI. Historically, studies have predominantly involved patients at high to very high surgical risk with shorter life expectancies. As TAVI is extended to younger patients with lower

surgical risks and longer anticipated lifespans, strategies for valve lifelong management are also becoming a focal point of research within this field. Surgical outcomes are no longer the sole objective, immediate quality of life benefits, risks of complications, coronary access, valve durability, and the patient's expected longevity are increasingly gaining attention. In particular, the durability of bio-prosthetic valves remains an unresolved issue, and the appropriateness of multiple surgeries is questionable. The decision-making in young patients requires careful consideration [24,25].

The third domain is outcomes and predicting the risk of TAVI. Multiple randomized clinical trials have indicated that TAVI is either non-inferior or superior to SAVR for short- and mid-term outcomes among older patients with a shorter life expectancy [26,27]. However, the limited data on long-term clinical outcomes and the durability of transcatheter heart valves have raised concerns regarding the expansion of TAVI to patients with longer life expectancies. Recent randomized clinical trials have shown that TAVI is non-inferior to SAVR in terms of risk for all-cause mortality or disabling stroke in low-risk surgical patients, and even superior when considering valve-related re-hospitalization [28,29]. Several factors can influence clinical outcomes after TAVI, such as anti-coagulation and antiplatelet therapy [30,31], anesthesia strategy and valve type [32], and postoperative exercise training [33].

5. Limitations

This study possesses several limitations. Firstly, to ensure uniform quality of publications and standardized data collection, we limited our bibliometric analysis to the WoSCC. As a result, studies from other databases like Scopus, PubMed, MEDLINE, or Google Scholar were not included, due to their lack of detailed reference data. This may have resulted in the omission of some publications exclusive to these other databases. Secondly, although no restrictions were placed on the language of publications, potential language bias may exist. The majority of publications in the WoSCC are in English, which could have skewed our analysis. Thirdly, we may have inadvertently overlooked certain authors or institutions. The presence of special characters in their names could pose challenges for applications to recognize them accurately. Moving forward, we aim to address these limitations by exploring novel bibliometric methodologies in future studies.

6. Conclusions

We employed VOSviewer and CiteSpace to conduct a bibliometric visualization analysis of TAVI-related publications. This is an advanced instance of these tools being utilized to examine publications on TAVI. Our findings reveal that North America and Europe have been at the forefront of research within the TAVI field. The institutions and authors from these regions exert significant influence in this area of study. Beginning in 2009, China has progressively expanded its research on TAVI over the past two decades. We anticipate that future research will increasingly focus on three key areas: implementation scope, lifelong management, outcomes and predicting the risk of TAVI.

Data availability

The data that support the findings of this study are available upon request from the corresponding author.

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Ethics declarations

The author(s) declare(s) that there is no ethical implication as the data was from public databases.

CRediT authorship contribution statement

Wei Fang: Writing – original draft, Visualization, Software. **Xiaojie Yuan:** Writing – original draft, Visualization, Formal analysis. **Jianqiang Hu:** Supervision, Methodology. **Wenshuai Ma:** Supervision, Methodology. **He Ren:** Supervision, Methodology. **Yuemei Wang:** Visualization, Data curation. **Haijia Zhou:** Writing – review & editing, Validation. **Yan Li:** Writing – review & editing, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Yan Li reports financial support was provided by National Natural Science Foundation of China. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2024.e33061>.

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