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Mapping the landscape: a comprehensive bibliometric analysis of immunotherapy advances in glioblastoma research

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Abstract

Background Glioblastoma (GBM) is the most aggressive primary brain tumor in adults, with a poor prognosis largely due to its immunosuppressive microenvironment. Immunotherapy offers a promising approach by targeting this barrier to anti-tumor immunity. Despite growing research interest, an overview of the field's development is still lacking. This study uses bibliometric analysis to map trends and key advances in GBM immunotherapy research from 2005 to 2024.

Methods A systematic bibliometric search was performed in the Web of Science Core Collection from 2005 to 2024, using a predefined search strategy combining terms related to "glioblastoma" and "immunotherapy". Only peer-reviewed articles and reviews in English were included. Bibliometric analysis was conducted using VOSviewer, CiteSpace, and Scimago Graphica to visualize research trends and collaboration networks.

Results From 2005 to 2024, a total of 2064 publications on GBM immunotherapy were identified, with China and the United States as the leading contributors. Co-citation analysis highlighted Roger Stupp as the most influential author, while *Frontiers in Oncology* was the most prolific journal. Keyword burst analysis revealed increasing clinical interest in nivolumab and chemotherapy, with neoadjuvant immunotherapy emerging as a promising research direction.

Conclusions The analysis of 2,064 publications on GBM immunotherapy highlights a high level of collaborative effort aimed at advancing novel therapeutic approaches. The findings emphasize the importance of the tumor microenvironment and suggest that future efforts should focus on overcoming immune suppression and developing targeted combination therapies. This study provides a useful reference for guiding research and improving immunotherapy strategies in GBM.

1 Introduction

Glioblastoma (GBM), classified as a WHO grade IV astrocytoma, is the most aggressive and frequently diagnosed primary malignant brain tumor in adults [1–3]. It accounts for approximately 45–50% of all malignant central nervous system tumors, with an annual



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incidence of about 3–4 cases per 100,000 individuals [4, 5]. GBM predominantly affects older adults, with a median age at diagnosis of 64 years, and exhibits a male predominance [6, 7]. Despite advances in multimodal therapies, including maximal safe surgical resection, adjuvant radiotherapy, and temozolomide-based chemotherapy, the prognosis remains poor, with a median overall survival of less than 15 months [8, 9]. The presence of extensive intratumoral heterogeneity, a highly infiltrative growth pattern, and resistance to apoptosis collectively contribute to the challenges in achieving complete tumor eradication and preventing recurrence.

The tumor microenvironment (TME) plays a central role in GBM pathogenesis and therapeutic resistance [10]. This dynamic and complex niche is composed of various cellular and non-cellular components, including tumor cells, immune cells (such as tumor-associated macrophages, microglia, T lymphocytes, and myeloid-derived suppressor cells), endothelial cells, fibroblasts, extracellular matrix (ECM) proteins, and a wide array of cytokines, chemokines, and growth factors [11–13]. The GBM TME is characterized by profound immunosuppression, which allows tumor cells to evade immune surveillance. Immune checkpoint molecules, including PD-1/PD-L1 and CTLA-4, are frequently overexpressed, leading to T cell exhaustion and functional impairment [14–16]. Additionally, the recruitment of immunosuppressive cells such as regulatory T cells (Tregs) and myeloid-derived suppressor cells (MDSCs) further dampens anti-tumor immunity, creating a major barrier to effective immunotherapy [17].

Immunotherapy has emerged as a promising alternative to conventional treatment modalities, offering several unique advantages [18]. Unlike surgery, radiation, or chemotherapy, which primarily target tumor cells directly, immunotherapy seeks to harness and amplify the host immune system to recognize and eliminate cancerous cells [19]. Approaches such as immune checkpoint inhibitors (ICIs), adoptive T cell therapies (e.g., CAR-T), and therapeutic vaccines have shown encouraging results in preclinical models and early-phase clinical trials [17]. Notably, neoadjuvant immunotherapy—administered prior to definitive treatment—has demonstrated potential to modulate the TME, enhance T cell infiltration, and improve responses to subsequent therapies. However, clinical trials in GBM have yielded mixed outcomes, with only a small subset of patients showing durable responses [20, 21]. This highlights the need for a deeper understanding of the complex interactions within the TME and the identification of novel, high-specificity therapeutic targets that can overcome immunosuppressive barriers.

Given the growing body of literature on GBM and immunotherapy, there is a pressing need to synthesize and analyze research trends to guide future investigations. Bibliometric analysis is a powerful tool that enables the visualization of scientific output, collaboration networks, and emerging research hotspots [22]. By quantitatively analyzing publication trends, citation patterns, and keyword evolution, this method provides insights into the development of a research field and helps identify gaps and opportunities.

Therefore, this study performs a comprehensive bibliometric analysis of GBM and immunotherapy research from 2005 to 2024. Utilizing tools such as CiteSpace and VOSviewer, we map the global research landscape, identify key research themes, and predict future trends in this field. Our objective is to provide a structured overview of the progression of immunotherapy in GBM, highlight underexplored areas, and inform the direction of future research and clinical strategies.

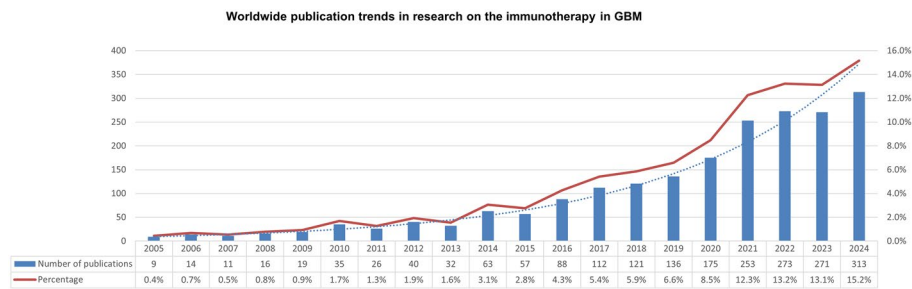


Fig. 1 Process of obtaining data

Table 1 Selection criteria for the study

Category	Specific standard requirements
Research database	Web of Science core collection
Citation index	All
Searching period	2005–2024
Language	“English”
Searching topic	(“glioblastoma” OR “GBM”) and (“immunotherapy” OR “immune checkpoint”).
Document types	“Article” OR “Review Article”
Subject categories	All
Data extraction	Export with full records and cited references in plain text format
Search results	2064

2 Methods

2.1 Data collection

Web of Science Core Collection is a citation-type database, containing citation information in addition to literature abstracts, unlike PubMed, which is typically an abstract-type database. It is true that Scopus and WOS cover mainly natural sciences, engineering, and biomedical research, but Scopus is superior to WOS when it comes to covering aspects of the social sciences and humanities. It is, however, WOS that is most commonly used for statistical analysis [23–25]. There is a possibility that WOS does not include all relevant publications, leading to bibliometric studies being omitted [26]. In addition to its ability to identify reviews or articles that meet specific criteria, it also contains a vast body of scientific literature across a broad range of subject areas [27]. The restrictions are as follows: Topic = (“glioblastoma” OR “GBM”) and (“immunotherapy” OR “immune checkpoint”). The search spanned from 2005 to 2024. Then we used End-Note to identify and remove duplicate references. A total of 2064 results were found, containing articles and reviews. A total of 2064 English-language articles were exported after screening. This figure illustrates how to screen the resulting table and export the data (Fig. 1; Table 1).

2.2 Data analysis and visualization

To analyze and visualize research trends in glioblastoma (GBM) immunotherapy, we used several bibliometric tools, including VOSviewer (1.6.20.0), CiteSpace (6.3.1.0), Scimago Graphica (1.0.42.0), and Microsoft Excel 2021. Each of these tools offers unique functionalities that, when used in combination, provide a multi-dimensional understanding of research trends, collaborative networks, and emerging topics. VOSviewer is a commonly used tool for constructing maps of scientific domains based on co-occurrence and citation patterns. It supports the visualization of research outputs across multiple dimensions, such as countries, academic institutions, authors, journals, and

keywords. The software can generate various types of graphical outputs, including network maps, overlay visualizations, and density views, which help in identifying major thematic clusters and developmental trends in a given research area. In this study, network visualization was the primary mode employed, where individual nodes correspond to entities like authors, organizations, or terms, and the links between them represent either collaborative or conceptual associations. The size of each node reflects the frequency or prominence of the corresponding element, while the thickness of the connecting lines indicates the strength of the relationship or co-citation intensity. CiteSpace, a Java-based visualization application, is especially effective in identifying key knowledge shifts and emerging research trends. It achieves this through the analysis of citation bursts and co-citation networks, allowing for the tracking of a field's intellectual evolution over time. By highlighting pivotal references and influential publications, CiteSpace helps reveal the foundational works that have shaped the progression of a topic. Additionally, it can detect “burst” terms—keywords that have seen a sharp rise in scholarly interest—making it a valuable tool for uncovering novel and rapidly developing research themes. Scimago Graphica was utilized to further analyze and visualize the distribution of publications and journal impact across different academic disciplines. This provided a clearer understanding of the academic reach and subject-specific trends in glioblastoma (GBM) immunotherapy research. To assess the distribution of scientific productivity among authors in the selected literature, we applied Lotka's Law, a fundamental principle in bibliometrics that describes the frequency distribution of author output in a given field. The law is mathematically expressed as: ($f(n)$ = the number of authors who have published n papers; n = the number of papers published by a group of authors; C = a normalization constant representing the number of authors who have published one paper; a = an empirical exponent, typically close to 2 in most scientific disciplines.)

$$f(n) = \frac{C}{n^a}$$

3 Results

3.1 World publication trends

The Web of Science database contains 2064 publications on immunotherapy research in glioblastoma (GBM) from 2005 to 2024, including 1252 original articles and 812 review papers. A time-series graph is provided to demonstrate the evolution of publication trends over this period (Fig. 2). Between 2005 and 2009, more than 20 documents were published annually. From 2010 to 2016, the number of publications fluctuated around 60 per year. After 2017, there was a notable increase, with over 100 publications appearing each year. A preliminary analysis indicates that the number of publications in this field rises steadily within a certain range, with notable variations occurring every five to 6 years. Notably, more than half (53.8%) of the total 2064 publications were released in just the past four years, highlighting a recent surge in research activity.

3.2 International contributions by countries and institutions analyses

Publications originated from 54 countries and 1297 institutions. In terms of document count, China and the United States dominated the top ten most productive countries, followed by several European nations. The United States led with 462 publications, followed by China ($n = 264$), Germany ($n = 69$), Italy ($n = 53$), and Iran ($n = 34$), with each

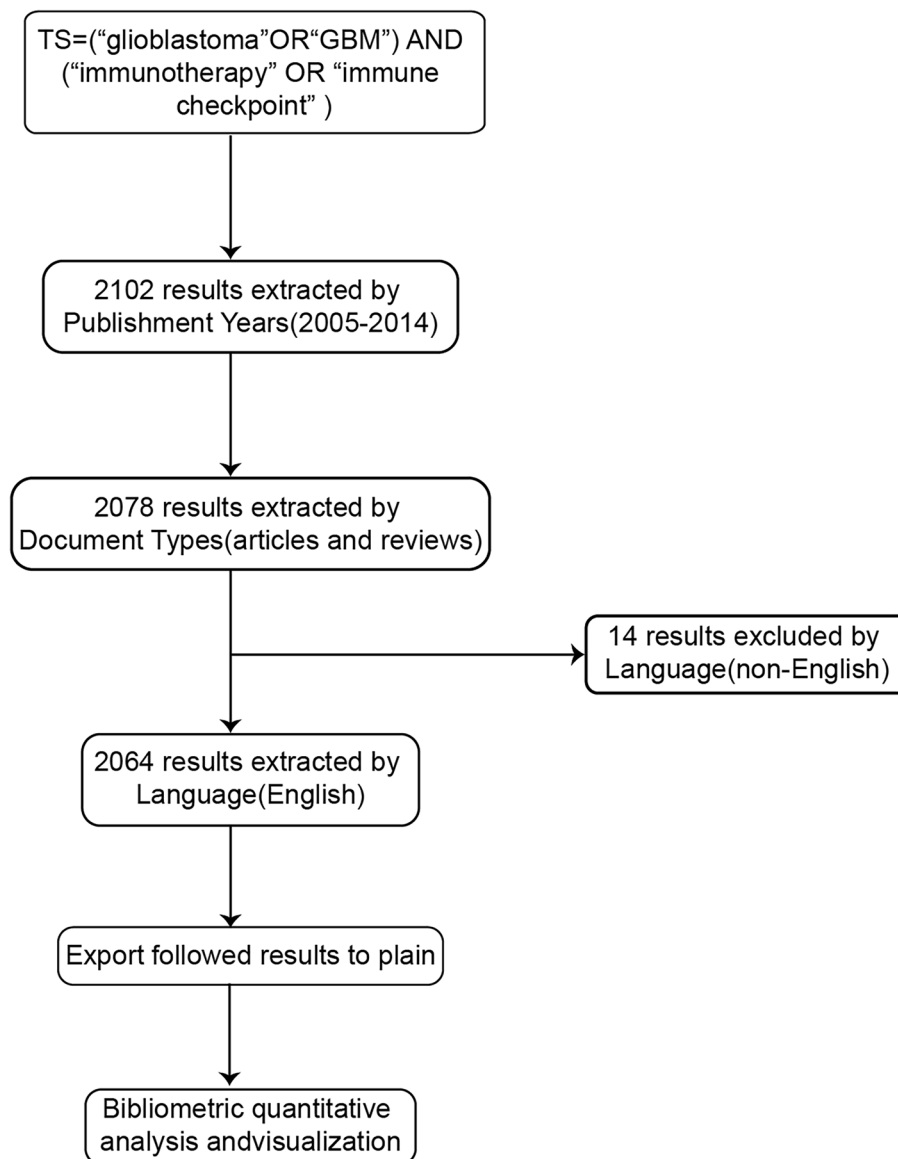


Fig. 2 Worldwide publication trends in research on the immunotherapy in GBM

country contributing at least 30 documents. Publications from the United States are not only more numerous but also of higher quality, as evidenced by their higher average citation count (66.37 citations per article). In contrast, China's average citation rate was notably lower than that of Western countries, with a total of 7,531 citations for its publications compared to 3,712 for the second-highest Western country. Western countries such as Switzerland (78.66), Canada (66.92), the United Kingdom (60.37), and Australia (54.90) all exhibited higher average citation rates per article (Fig. 3a). Evidence suggests that the quality of research articles published in Asia may require further development, whereas European countries tend to produce more advanced and influential studies in this field, contributing significantly to the global body of knowledge. This discrepancy may be attributed to differences in national funding availability and the absence of universal screening programs for glioblastoma in certain regions. To visualize the collaborative linkages and intersections among these countries, a linking circle diagram has been

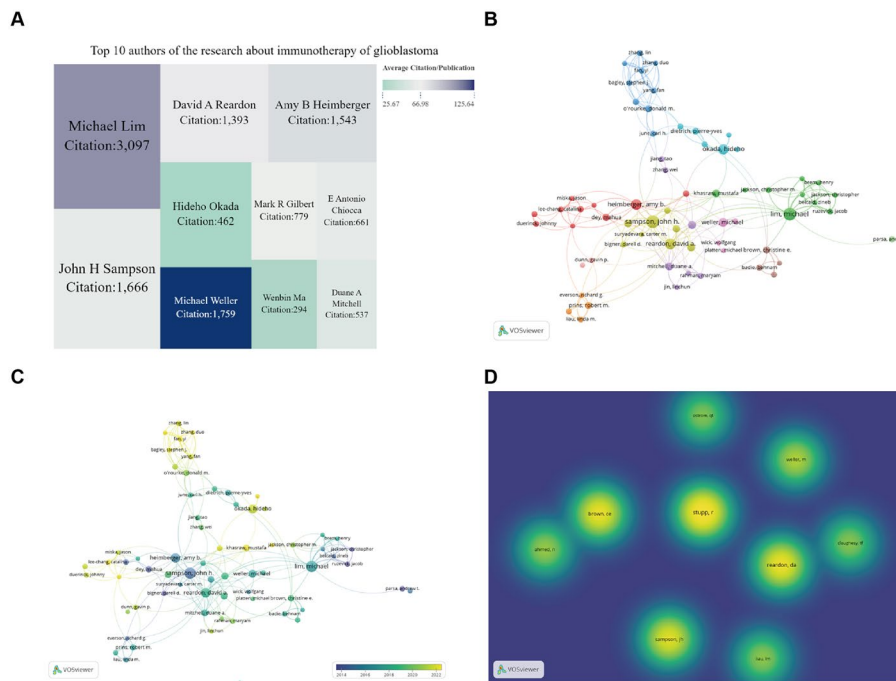


Fig. 3 International contributions by countries and institutions analyses **A**, the graph of publications and citations is presented. **A** darker board color indicates a higher average citation rate. **B**, Illustrates the interaction strength among all 53 countries through SCImago Graphica. The degree of international collaboration is shown by the size of the circles (reflecting the number of publications) and the connecting lines (indicating cooperation). **C**, The overlap map in shows the timeline of each country using VOSviewer. The size of the nodes stands for the number of publications, the lines between nodes signify collaborations, and the color shades represent the years when the country carried out relevant research publications. **D**, The trend chart in depicts the top ten institutions globally that are engaged in research on GBM immunotherapy. The size of the circles in this chart represents the number of documents

provided. (Fig. 3b). The visual map demonstrates that the United States occupies a central position, showing strong interconnections with China, which highlights the substantial contributions of both nations to advancements in this field. Furthermore, the United States is noted for its extensive collaborations, especially with China, Canada, Germany, and Switzerland. (Fig. 3c). Capital Medical University has undertaken the majority of research studies in this field, while Duke University stands out for having received the highest number of citations for its contributions. (Fig. 3d).

3.3 Author and co-cited author analyses

A total of 5,755 authors contributed to the 1,274 immunotherapy-related publications on glioblastoma, among which 27 were identified as core authors with seven or more publications. The most productive authors were Michael Lim ($n = 29$), John H. Sampson ($n = 28$), and Amy B. Heimberger ($n = 20$). Based on citation analysis, Michael Lim's 29 publications accumulated 3,097 citations, yielding an average of 73.7 citations per article. Notably, Behnam Badie achieved the highest average citation rate, with 2,265 citations from only seven publications (Fig. 4a), highlighting the significant academic impact of his work in this field (Fig. 4a). Using VOSviewer, we mapped the co-authorship network among authors with at least seven publications, identifying six clusters and 52 interconnections. The network structure highlights John H. Sampson and David A. Reardon as central figures, with a prominent collaborative link between them. (Fig. 4b). It should

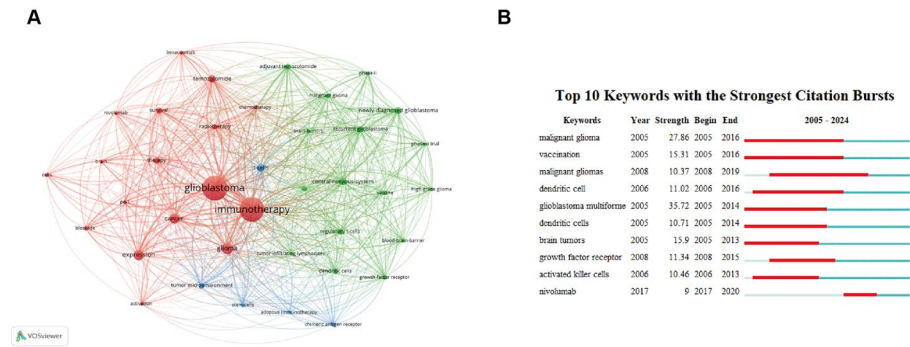


Fig. 4 presents analyses of authors and co-cited authors in the realm of GBM immunotherapy. **A**, the number of documents and citations of authors are depicted. The network map in part **B** and the overlay map in part **C** display the interactions among authors. The size of the nodes corresponds to the number of publications an author has. The lines connecting the nodes denote mutual collaboration, while the color shades represent the time when the authors published their relevant research. **D**, the density map illustrates the interactions of co-cited authors. Darker colors signify a greater number of citations. Additionally, the size and distribution of the circles indicate the extent of collaboration between authors

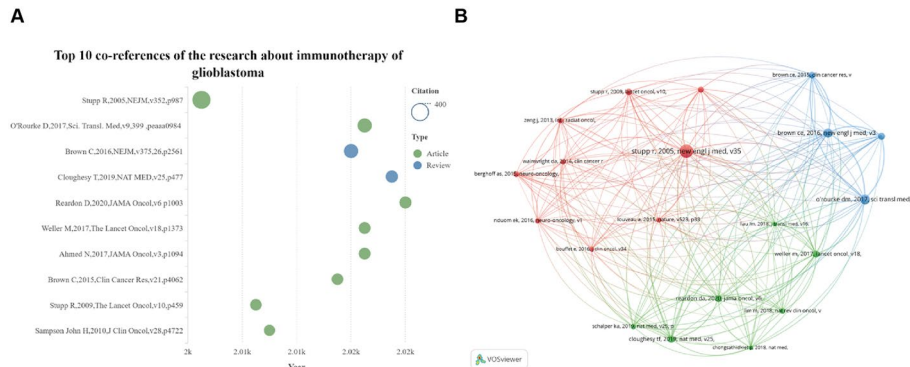


Fig. 5 Journal and co-cited journal analysis **A**, These are the top ten journals. **B**, The overlay map presents the timely interaction of journals. **C**, The top ten co - cited journals. **D**, The network map depicts the interaction of co-cited journals

be noted, however, that their study covers only the period from 2015 to 2018, and as such, may not capture the most up-to-date trends or advancements in this rapidly evolving field. (Fig. 4c). The field encompasses 27,628 co-cited authors, which were filtered to retain those with ≥ 40 co-citations. Roger Stupp ($n = 786$) and David A. Reardon ($n = 629$) emerged as the most co-cited authors, reflecting their prominent contributions to this area of research. (Fig. 4d).

3.4 Journal and co-cited journal analysis

A total of 2,064 publications on immunotherapy for glioblastoma (GBM) were identified. The top three journals publishing this research were Frontiers in Oncology ($n = 59$), Cancers ($n = 49$), and Frontiers in Immunology ($n = 40$). In terms of impact factor, Frontiers in Immunology (IF = 5.9) had the highest, followed by Cancers (IF = 4.4). With respect to journal impact factors, Frontiers in Immunology (IF = 5.9) ranked highest, followed by Frontiers in Oncology (IF = 3.3), indicating a higher relative influence of the former in the field of immunology research (Fig. 5a). The correlation visualization among 63 journals with at least four publications revealed that Frontiers in Oncology has the strongest co-occurrence relationship with Journal of Neuro-Oncology and Cancers (Fig. 5b). Based

on the time-series data, it is evident that the Journal for Immunotherapy of Cancer has emerged as a key publication venue for the latest studies in this area (Fig. 5b). Among the 3,929 co-cited journals, two were cited more than 4,000 times: Neuro-Oncology (4,464 citations) and Clinical Cancer Research (4,443 citations). Among the top 10 co-cited journals, Nature (IF = 48.5) and Cell (IF = 42.5) had the highest impact factors, indicating their significant influence in the field (Fig. 5c). Three distinct clusters are observable in the co-citation network based on 33 journals with a minimum of 300 citations. Positive co-citation relationships were found between Frontiers in Immunology and Journal of Neuro-Oncology, Cancers, and Neuro-Oncology (Fig. 5d).

3.5 Analysis of commonly cited references

Over the past two decades, a total of 40,617 co-cited references have been identified in the field of glioblastoma (GBM) immunotherapy research. The most frequently cited article is “Radiotherapy plus concomitant and adjuvant temozolomide for glioblastoma” by Roger Stupp, which has received 329 citations. This study, published in The New England Journal of Medicine (IF = 78.5), is the most cited and leads the list [28]. Additionally, two other references with ≥ 200 citations are “A Single Dose of Peripherally Infused EGFR VIII-Directed CAR T Cells Mediates Antigen Loss and Induces Adaptive Resistance in Patients with Recurrent Glioblastoma” ($n = 241$) by Donald M. O’Rourke, published in Science Translational Medicine, and “Regression of Glioblastoma after Chimeric Antigen Receptor T-Cell Therapy” ($n = 237$) by Christine E. Brown, published in The New England Journal of Medicine [29, 30]. Furthermore, the graph illustrates that the majority of highly cited studies were published between 2011 and 2016 (Fig. 6a). References with ≥ 90 citations were visualized using VOSviewer to explore co-citation relationships. The visualization reveals that the study “Radiotherapy plus Concomitant

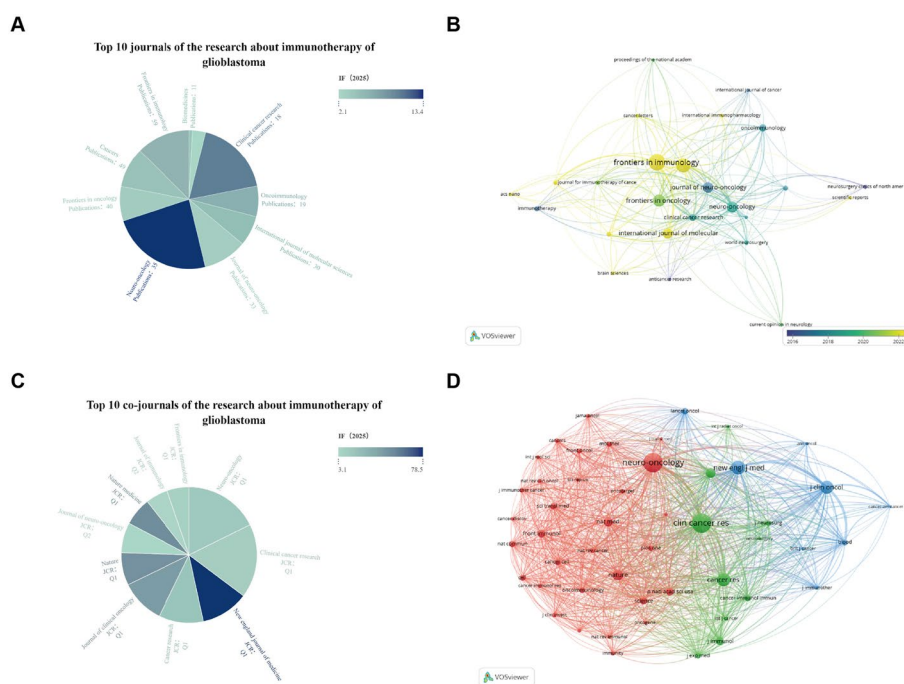


Fig. 6 Analysis of commonly cited references **A**, The top ten co-cited references within the domain of GBM immunotherapy. The magnitude of the circle is proportional to the citation count, and its placement indicates the year of publication. **B**, This illustrates the interplay among the co-cited references

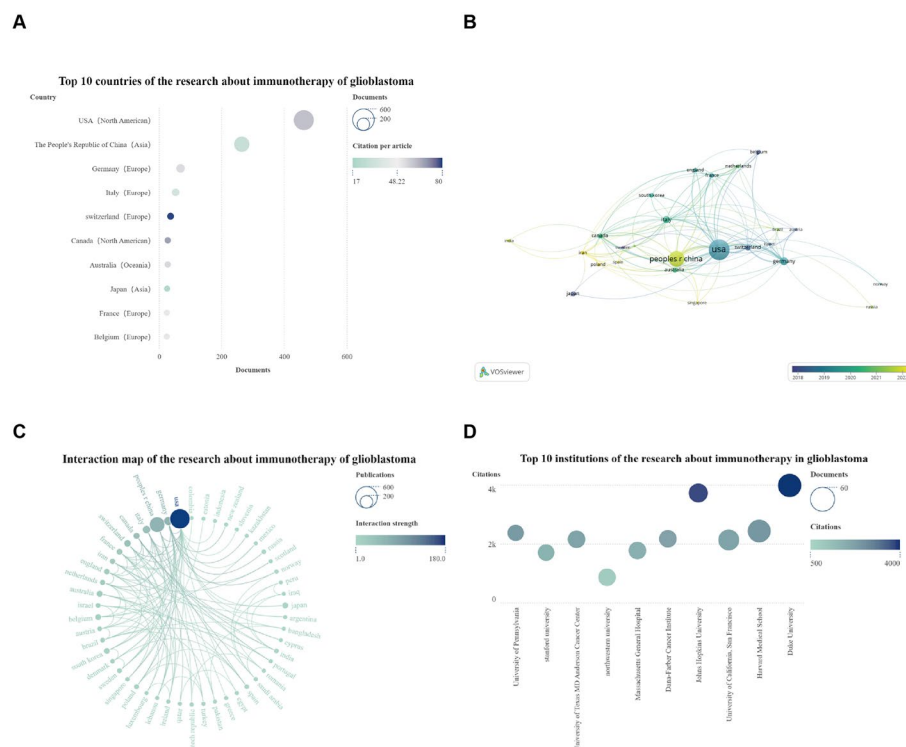


Fig. 7 Keyword analysis. **A**, The network map of keywords in the field of GBM immunotherapy. **B**, The outbreak graph of keywords in the field of GBM immunotherapy. The red color stands for the frequency of word occurrence. Meanwhile, the length of the nodes indicates both the importance and the time persistence

and Adjuvant Temozolomide for Glioblastoma” by Roger Stupp showed a positive co-citation relationship with “Regression of Glioblastoma after Chimeric Antigen Receptor T-Cell Therapy” ($n = 237$) by Christine E. Brown (Fig. 6b).

3.6 Keyword analysis

Keywords represent the core content of a paper, and their co-occurrence can indicate prevailing research trends and focal areas within a specific domain [31]. Using VOSviewer, a total of 1,124 documents were analyzed to construct a network visualization of keyword co-occurrences. The results identified 3,604 unique keywords, of which 44 occurring at least 40 times were selected for visualization (Fig. 7a). Keywords such as “immunotherapy,” “glioblastoma,” and “glioma” are commonly used in the field, reflecting core research topics. The keyword co-occurrence map reveals three major research clusters, colored red, green, and blue, each representing a distinct thematic direction. The red cluster represents research focused on therapeutic approaches for glioblastoma, encompassing terms such as temozolomide, radiotherapy, nivolumab, immunosuppression, and nivolumab. The blue cluster centers on “T cells” and includes keywords such as growth factor receptor, dendritic cell, stem cell, and chimeric antigen receptor, underscoring research focused on T-cell biology and its role in glioblastoma immunotherapy. The green cluster, in contrast, emphasizes the tumor aspect of glioblastoma research, incorporating terms such as brain tumor and high-grade glioma, which highlight the classification and clinical features of malignant brain tumors. Recent years have witnessed an increasing focus on optimizing T-cell therapies and immune checkpoint inhibition strategies. A keyword burst reflects a sudden increase in citation frequency for a

specific term during a defined time period. The analysis reveals a notable shift toward immunotherapies, particularly exemplified by the rising prominence of nivolumab. The following research hotspots are expected to remain central to the development of glioblastoma (GBM) immunotherapy beyond 2017 (Fig. 7b).

4 Discussion

The bibliometric analysis revealed the current landscape, emerging trends, and key research hotspots in glioblastoma immunotherapy, offering valuable insights for future therapeutic development. This study analyzed 2,064 publications related to immunotherapy research in glioblastoma, retrieved from the Web of Science (WoS) database between 2005 and 2024. A notable increase in publication output has been observed since 2016, reflecting growing global interest and accelerated research activity in this field.

GBM immunotherapy is challenged by tumor heterogeneity, an immunosuppressive microenvironment, and multiple immune evasion mechanisms, among other factors. Glioblastoma cells frequently downregulate antigen-presenting molecules, secrete immunosuppressive factors such as TGF- β and IL-10, and express immune checkpoint proteins like PD-L1, all of which impair immune recognition and T-cell function [32]. These mechanisms, combined with the tumor's genetic and phenotypic diversity, lead to variable responses to immunotherapy and highlight the need for personalized treatment strategies based on molecular subtypes or antigen profiles. Moreover, the presence of immunosuppressive cells such as MDSCs, TAMs, and Tregs further limits local immune activation [33]. Overcoming these barriers may require novel approaches that target immune checkpoints, reprogram the tumor microenvironment, or enhance antigen presentation to restore effective anti-tumor immunity. Designing effective clinical trials for GBM immunotherapies is complicated by heterogeneous patient populations, lack of predictive biomarkers, and non-standardized endpoints. Incorporating biomarker-driven stratification, real-world evidence, and adaptive trial designs could improve trial efficiency and increase the likelihood of identifying effective therapies.

Over the past two decades, bibliometric analyses have shown that the United States has made the most significant academic contributions to the field of glioblastoma research, with all of the top ten institutions being based there. This dominance may be attributed, in part, to the relatively high incidence of glioblastoma in the U.S., where the disease is epidemiologically prevalent [34]. China ranks as the second-largest contributor, with Sichuan University leading national efforts and holding the 11th position globally. European countries, such as Germany and the United Kingdom, have also made substantial contributions to the field. This phenomenon may be due to differences in regulatory frameworks and funding between developed and less developed countries, which could restrict innovative research and development in immunotherapy.

Among the top ten journals in the field, *Frontiers in Immunology* published the highest number of articles, with over 50 papers, followed by *Cancers*, which published more than 40. Each of the remaining journals contributed more than 20 publications. Frequently cited journals include *Frontiers in Oncology*, *Neuro-Oncology*, and *The Journal of Neuro-Oncology*. These specialized journals appear prominently in both the most productive and co-cited journal lists, underscoring their significant influence in glioblastoma immunotherapy research. This publication pattern reflects the growing academic

interest and substantial advancements in the field, spanning from basic immunology to clinical applications.

Four main categories of immunotherapies have emerged as promising approaches for glioma treatment: immune checkpoint inhibitors (ICIs), chimeric antigen receptor T (CAR-T) cell therapy, therapeutic vaccines, and oncolytic virotherapy [35]. ICIs target immune checkpoints like PD-1/PD-L1 to enhance anti-tumor immunity in GBM. Despite promising mechanisms, their efficacy is limited by immunosuppression, low mutational burden, and heterogeneity. Research now focuses on biomarkers and combination therapies to improve outcomes [36]. Chimeric antigen receptor T (CAR-T) cell therapy has been investigated in glioblastoma (GBM), with targets including tumor surface molecules such as epidermal growth factor receptor variant III (EGFRvIII), interleukin-13 receptor alpha 2 (IL13R α 2), and human epidermal growth factor receptor 2 (HER2) [37]. Oncolytic virotherapy, an emerging therapeutic strategy for glioblastoma (GBM), has garnered increasing attention in recent years. The conditional approval of G47 Δ in Japan marks a significant milestone and highlights the potential for further advancements in immunotherapy for GBM [38]. Therapeutic vaccines are a promising approach for glioblastoma (GBM), aiming to stimulate the immune system to target tumor-associated antigens (TAAs) or tumor-specific antigens (TSAs) [39]. Different types of vaccines, such as peptide-based vaccines and dendritic cell (DC) vaccines, have been explored in GBM treatment. While combination therapies—such as immunotherapy with chemotherapy, radiation, or targeted agents—hold promise, identifying optimal regimens that maximize efficacy while minimizing toxicity remains a challenge.

Among the leading researchers in the field, Michael Lim, John H. Sampson, and Amy B. Heimberger exhibit higher average citations per publication, reflecting the significant impact and influence of their work. Their research primarily focuses on targeting the PD-1/PD-L1 axis, with the goal of reversing T-cell exhaustion and restoring anti-tumor immune function. In clinical research, immunotherapies aimed at modulating the tumor microenvironment (TME) have emerged as a major focus in recent years, highlighting a strategic shift toward overcoming immunosuppressive barriers to enhance therapeutic efficacy in glioblastoma [40]. Keyword analysis highlights nivolumab, chemotherapy, tumor recurrence, and T cells as central topics in current glioblastoma immunotherapy research. Nivolumab is administered either as a monotherapy or in combination with chemotherapy. Furthermore, these researchers have explored emerging CAR-T cell therapies, which, although still in early investigative stages for glioblastoma (GBM), have demonstrated significant advancements in hematological malignancies and certain solid tumors [41]. The emergence of innovative immunotherapies has expanded the therapeutic landscape for glioblastoma (GBM), with these approaches becoming increasingly integrated into the clinical management of the disease.

Improving therapeutic outcomes in glioblastoma (GBM) requires addressing a range of persistent challenges. Access to cutting-edge treatments remains unequal, with significant disparities driven by geographic location, healthcare infrastructure, and socioeconomic status—highlighting the urgent need to ensure equitable delivery of advances across diverse patient populations. Given the aggressive nature of GBM, achieving durable anti-tumor responses is critical; therefore, the long-term safety profiles of novel immunotherapies, particularly emerging agents such as CAR-T cells, must be rigorously evaluated to prevent delayed or chronic toxicities. Despite encouraging results in

preclinical models, many immunotherapies fail to translate into clinical success, largely due to interspecies differences in immune system architecture, tumor biology, and response dynamics. Enhancing preclinical accuracy through more representative models—such as patient-derived xenografts (PDX) and organoid systems—could help bridge this translational gap. Meanwhile, transformative technologies including CAR-T cell therapy, personalized neoantigen vaccines, and oncolytic virotherapy are reshaping the treatment landscape, yet their widespread adoption faces hurdles in manufacturing scalability, patient selection, and integration into standard care pathways. Overcoming these multifaceted challenges will be essential to realizing the full potential of next-generation immunotherapies in GBM.

This study has several limitations that should be considered. First, the data were sourced from a single database (Web of Science), which may have excluded relevant publications indexed in other platforms, potentially affecting the comprehensiveness of the analysis. Second, the inclusion of only English-language publications could introduce language bias and limit the representation of global research efforts. To ensure dataset accuracy, incomplete publications from 2025 were excluded; however, this may have hindered our ability to capture emerging trends, assess real-time citation impacts, and analyze evolving collaboration patterns. We plan to update the dataset in the next phase to incorporate all 2025 publications once full data become available. Additionally, the evaluation of study quality was based primarily on author visibility and citation frequency, which may not fully reflect methodological rigor or scientific depth. Future studies would benefit from applying standardized quality assessment tools to enable a more comprehensive and objective evaluation of GBM immunotherapy research. Notably, our analysis revealed that most studies focused on clinical investigations of neoadjuvant immunotherapy, either alone or in combination with other treatments, while fewer studies delved into the specific immune mechanisms and molecular targets involved in GBM immunotherapy, highlighting a need for more mechanistic and translational research in this area.

5 Conclusions

A bibliometric analysis of 2,064 publications on glioblastoma (GBM) immunotherapy reveals key insights into research progress, emerging themes, and evolving trends in the field. Advances in biomedical technologies and a deeper understanding of immune mechanisms have propelled novel therapeutic strategies—particularly neoadjuvant immunotherapy—into the spotlight. Among these, nivolumab and CAR-T cell therapy have demonstrated considerable efficacy, both as monotherapies and in combination with other treatment modalities. While immunotherapeutic approaches hold great promise for GBM, their clinical application is still constrained by several major challenges. These include the blood-brain barrier (BBB), the immunosuppressive tumor microenvironment (TME), tumor heterogeneity, and the presence of therapy-resistant glioma stem cells. Addressing these barriers will be critical to unlocking the full potential of immunotherapy in GBM management.

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Author contributions

Wei Li wrote the main manuscript text; Ruimin Guo and Rongrong Zhang prepared Formal analysis and Data curation; YuXin Wang, Ruijie Cao and Yunzhi Liu is responsible for Project administration and Investigation, Guojia Wu and

Runzhe Cheng is responsible for formal analysis. Dong Wang is responsible for Methodology, Investigation and Funding acquisition. All authors reviewed the manuscript.

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Data availability

All data generated or analysed during this study are included in this published article.

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate Review and/or approval by an ethics committee as well as informed consent was not required for this study because this article only used existing data from published studies and did not involve any direct experimentation/studies on living beings.

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