Original Article

Current landscape and future trends in salivary gland oncology research—a bibliometric evaluation

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Background: The salivary glands are susceptible to both endogenous and exogenous influences, potentially resulting in the development of oncology. With the wide application of various technologies, research in this area has experienced rapid growth. Therefore, researchers must identify and characterize the current research hot topics to grasp the forefront of developments in the dynamic field of salivary gland oncology. The objective of this study was to thoroughly assess the current status and identify potential future research directions in salivary gland oncology.

Methods: The relevant salivary gland oncology dataset was obtained from the Web of Science Core Collection (WOSCC) database. Subsequently, VoSviewer and CiteSpace were employed for further evaluation.

Results: A total of 9,695 manuscripts were extracted and downloaded from the WOSCC database. Our findings revealed a substantial surge in research volume over the past 12 years. The researchers' analysis revealed that Abbas Agami showed unparalleled dedication, with over 180 publications, and that RH Spiro had the highest cocitation count, confirming its status as a key figure in the field. The detection of bursts in secretory carcinoma and the integration of artificial intelligence in salivary oncology have attracted increasing interest. Notably, there is a discernible trend towards increased research engagement in the study of salivary gland malignancies.

Conclusions: This study not only evaluated the current research landscape in salivary gland oncology but also anticipates future trends. These insights could contribute to the advancement of knowledge and policymaking in salivary gland oncology.

Keywords: Salivary gland oncology; bibliometric analysis; research hotspots; research trends; sociometric analysis

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Introduction

The salivary glands play a fundamental role in saliva synthesis and secretion and are a key element in maintaining the physiological environment in the oral cavity. The salivary glands are susceptible to a multitude of internal and external factors that can predispose them to tumour formation (1,2). Pathologically, salivary gland tumours (SGTs) are categorized into three primary groups: benign and malignant epithelial tumours and mesenchymal tumours (2). Although the majority of SGTs are benign, malignant SGTs constitute a small proportion of head and neck oncological diseases, approximately 5%. Within this subset,

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the malignancy rates vary, with those of the parotid gland ranging from 15% to 35%, those of the submandibular gland ranging from 45%, and those of the sublingual glands ranging from 70% to 90%. Furthermore, malignant salivary tumours are predominant in cases involving the minor salivary glands, which are located on the floor of the mouth, the upper palate, the retromolar region, the tongue, and the lips (3). These conditions can lead to severe consequences, including facial paralysis, lung metastasis, and, in extreme cases, death (4,5).

Salivary gland oncology research traces back to the early 1900s when researchers primarily reported medical cases. During this period, fine needle sampling became a notable diagnostic technique (6,7). Simultaneously, researchers were actively involved in establishing surgical considerations and diagnostic standards for SGTs (8). The World Health Organization (WHO) released the initial edition of the histological classification in 1972. This classification divides SGTs into three categories: unclassified tumours, epithelial tumours, and nonepithelial tumours (9). This guideline was in effect for the subsequent two decades. Following further refinement and supplementation, the second edition of the WHO guidelines, published in 1992, incorporated 31 pathologies of SGT (10). In the early 2000s, there was a growing trend in exploring the expression or immunoreactivity of specific biomarkers in malignant SGTs, leading to the reclassification of salivary gland cancer (11). Owing to technological limitations, studies have primarily relied on single pathological or radiological methods, leading to a lack of detailed exploration into the mutual interactions involved in the mechanism of salivary gland cancer.

Through in-depth exploration in salivary gland oncology, the seemingly challenging mission of establishing guidelines for salivary gland oncology in the 1990s became tangible, leading scientists to recognize the genetic alterations associated with SGT. In 2017, the WHO introduced a new edition of the SGT classification system, providing a new perspective on salivary gland classification by emphasizing genetic alterations in SGTs for the first time (12).

The integration of various technologies, such as artificial intelligence, experimental devices, and methods, has driven a significant surge in studies and prompted revisions of the classification of SGTs in recent years (5,13-16). Currently, deep learning methods have recently been employed to differentiate and classify malignant and benign tumours in salivary gland oncology studies (14,17). Nonetheless, single-cell sequencing has been used to trace the tumorigenesis process in salivary gland oncology (18). The integration of these technologies and discoveries has contributed to a surge in the volume of scientific research manuscripts in salivary gland oncology.

In an era of information explosion, it is easy to access big data generated by the vast amount of research. Therefore, there is a need for effective tools to grasp and identify research hotspots and frontiers to comprehensively understand the current state and future research trends in salivary gland oncology.

Bibliometric analysis has become an established scientific specialty and a crucial component of research methodology, providing both qualitative and quantitative insights into scientific publications. VOSviewer is a widely utilized tool for bibliometric analysis and excels in generating knowledge maps through large-scale graphics. This software facilitates the analysis of manuscripts based on keyword occurrences, cocitations, references, authors, etc. It is a valuable tool

Highlight box

Key findings

- This manuscript offers an overview of the current state of research in salivary gland oncology.
- Salivary gland malignancies, target gene therapies, and radiotherapies emerge as hotspots in this field.
- Secretory carcinoma and the integration of artificial intelligence techniques in salivary gland oncology research are potential upcoming research trends in this area.

What is known and what is new?

- The number of studies on salivary gland oncology has significantly increased, benefiting from the wealth of big data available in today's information-rich environment. This abundance of research data is instrumental in gaining a overview of the current status and projecting future trends in salivary gland oncology.
- Our manuscript integrated VOSviewer and CiteSpace to navigate through the intricate research landscape of salivary gland oncology. By identifying crucial biomarkers and exploring emerging trends, we aim to provide a comprehensive picture of the field's current trajectory and potential future developments.

What is the implication, and what should change now?

- The findings of this study provide valuable insights into the status and future directions of salivary gland oncology research. Clinicians can use this knowledge to enhance diagnostic and treatment strategies for salivary gland malignancies, particularly focusing on areas with heightened research interest such as adenoid cystic carcinoma and secretory carcinoma. Moreover, the emerging trend of integrating artificial intelligence into salivary oncology research presents promising opportunities for developing innovative diagnostic tools and personalized treatment approaches.

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for comprehending fundamental information in specific research areas. To detect and predict future trends in the area of salivary gland oncology, we used CiteSpace V for our analysis. Developed by Chaomei Chen, CiteSpace is software that can assist in analysing different manuscripts at multiple latitudes, including using keywords to cluster and timelines to analyse research (19-23). In addition, researchers could use this software to explore research trends in certain research fields via burst detection.

To the best of our knowledge, this study represents an inaugural bibliometric evaluation in the field of salivary gland oncology. In this manuscript, we integrated VOSviewer and CiteSpace to unravel the current landscape of research and highlight important biomarkers in salivary gland oncology, all while peering into the horizon to anticipate and depict future trends in this dynamic field.

Methods

Search strategy

The Web of Science Core Collection (WOSCC) database served as the primary source for data collection. The search formula for this study was as follows: "(TS=parotid OR salivary gland OR submandibular gland OR sublingual gland) AND TS= (tumor* OR cancer* OR onco*)".

The study was limited to manuscripts published in English within the timeframe of 2012–2023. Only original articles were included in our bibliometric analysis. To minimize potential bias due to database updates, the literature search process was conducted within a single day on January 6th, 2024. Since the data for this research were obtained from the WOSCC database, ethical approval was not required for this study.

Statistical analysis

VOSviewer was utilized for co-occurrence analysis, while CiteSpace was applied for cocitation analysis, keyword clustering, and burst detection.

First, we used software to analyse the origin of the research in salivary oncology. Then, to understand the research focus of the scientists in salivary gland oncology, keyword clustering was employed to highlight the themes among the most frequently cocited authors.

Next, for keyword and reference analysis, we integrated VOSviewer and CiteSpace for a more comprehensive analysis. Through keyword clustering among the most cocited authors, we attempted to gain insights into the current research in this area. Next, by categorizing the most cocited references into different clusters by their research keywords, we generated a timeline visualization and depicted the change in each cluster over time.

Finally, burst detection was utilized to identify the keywords and references that experienced citation bursts, offering valuable insights into the upcoming research frontiers in this field. *Figure 1* shows the workflow of this study.

Results

Annual distribution of publication output

The data collected from WOSCC were uploaded to CiteSpace for intelligent data cleaning. We found 9,695 original articles concentrating on salivary gland oncology from 2012 to 2023. As illustrated in *Figure 2*, fewer publications focused on salivary gland oncology from 2012 to 2018, with an aggregate number of approximately 500 manuscripts annually. However, from 2019 to 2023, there was a noticeable increase in publications within the field of salivary gland oncology. This increase in volume indicates that the years from 2021 to 2023 potentially witnessed notable advancements in salivary gland oncological research.

Contributing countries and journals

To gain a comprehensive understanding of research manuscripts in salivary gland oncology, we then examined the countries and journals that contributed significantly to this field.

As illustrated in *Figure 3A*, the United States, China, and Japan have emerged as the primary contributors in this domain, collectively accounting for nearly 50% of the total research manuscripts in salivary gland oncology. It is also noteworthy that the United States, England, Canada, and France exhibit relatively higher centrality in their research endeavors, suggesting that they may have made noteworthy discoveries and advancements in the field of salivary gland oncology.

According to *Figure 3B*, spanning from 2012 to 2023, the journals *Head and Neck*, *Oral Surgery Oral Medicine Oral Pathology Oral Radiology*, and *European Archives of Oto-Rhino-Laryngology* have collectively published over 500 manuscripts on salivary gland oncology. These journals are identified as the top three sources contributing to research in this field.

Moreover, we also found that from 2021 to 2023, the

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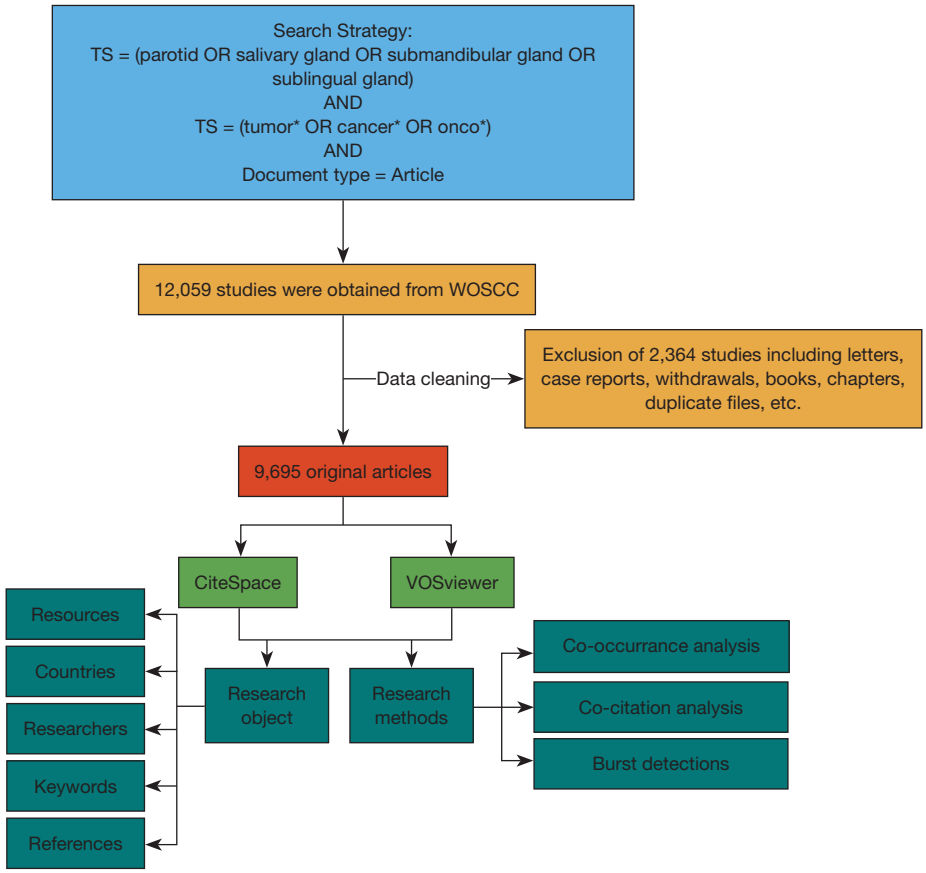

Figure 1 The workflow of this study. TS, topic search; WOSCC, Web of Science Core Collection.

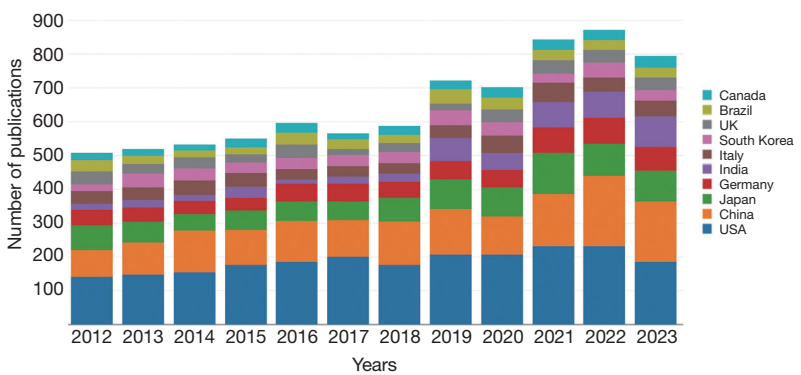

Figure 2 The initial phase of the last 12 years [2012–2018] witnessed limited growth in the quantity of original articles in salivary gland oncology research. However, a significant surge in research output occurred in 2019, continuing to thrive in 2021 and 2022. Nevertheless, there was a decline in the number of manuscripts in 2023.

number of publications on salivary gland oncology in cancer, *Frontiers in Oncology*, and *Head & Neck Pathology* increased, which may also indicate that salivary gland oncology has gained increased attention in these journals. Furthermore, an observed increase in the volume of citations related to salivary gland oncology research is noted in journals such as *Cancers*, *Frontiers in Oncology*, and *Head & Neck Pathology* from 2021 to 2023. This increase suggests that there may be

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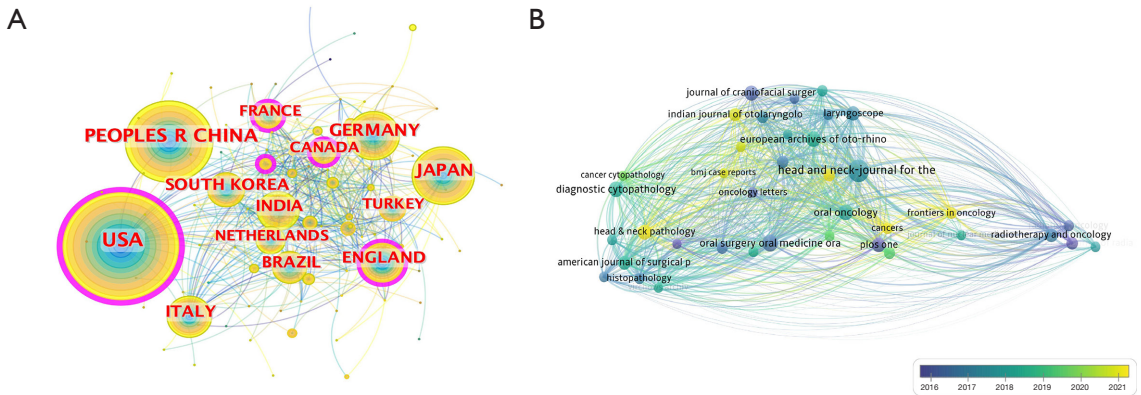

Figure 3 Countries and journals devoted to salivary gland oncology. (A) Top 13 contributing countries: each node represents a country, with node size indicating the quantity of manuscripts. The highlighted outlines signify the centrality of each country, reflecting its significance in the field. Links between nodes depict cooperative relationships. (B) Contributing journals: each node represents a journal, with sizes indicating the quantity of publications in salivary gland oncology. Links denote manuscript citations, and color indicates the year of citation.

an increasing focus on salivary gland oncology within these journals.

Analysis by researchers

Analysis of active researchers

Among the active researchers, as depicted in *Figure 4A*, Abbas Agami, Justin A. Bishop and Skalova Alena have emerged as the 3 most productive researchers in salivary gland oncological studies. These researchers have been dedicated to this field and have published more than 180 manuscripts during the last 12 years. Furthermore, our findings indicate that Abbas Agami, also known as the hub node, has relatively high centrality, indicating active collaboration with other researchers in this domain.

To reveal the specific research areas of the most productive ones, we utilized keyword clustering in CiteSpace for further evaluation. According to *Figure 4B*, the research topics in this area can be categorized into 13 clusters. The most substantial clusters included #RET, #Parotid tumor, and #Parotid gland. Moreover, we observed that researchers in this field focused on radiotherapy and proton therapy (clusters #5 and #8) within the domain of salivary gland oncology.

Cocited author analysis

According to the small H parameter, when two authors or publications are cited together, their research focus may be the same. According to the keyword clustering, CiteSpace was then applied to construct a knowledge map of cocited authors. This map aids in a more comprehensive understanding of researchers' focuses and the commonalities among the most cocited authors in the field of salivary gland oncology.

RH Spiro holds the top position with 699 citations, followed by Raja R. Seethala [643] and Skalova Alena [577]. In *Figure 4C*, through keyword clustering, nodes representing the most cocited authors are grouped into Cluster #0, Xerostomia, and Cluster #1, Survival. This grouping may suggest potential research foci within the field, shedding light on the shared interests of researchers in salivary gland oncology.

Keyword analysis

Next, to analyse hotspots in salivary gland oncology, VOSviewer and CiteSpace were integrated for keyword analysis, with a focus on generating significant results by excluding redundant and negligible keywords. Using VOSviewer, we produced a network visualization based on keyword occurrences, as shown in *Figure 5A*. Each node represents an article keyword in this area, and their sizes show the frequency of the keywords mentioned. In *Figure 5A*, we can see that researchers in this area are concentrating on "adenoid cystic carcinoma", which is undoubtedly the landmark node in keyword clustering.

CiteSpace was then employed to generate a clustering map for cocited keywords, revealing that the research topics in this area can be categorized into 9 clusters, as shown in *Figure 5B*. Notably, cluster 0 salivary adenoid cystic carcinoma appears to be common, underscoring its predominant role in salivary gland cancer research.

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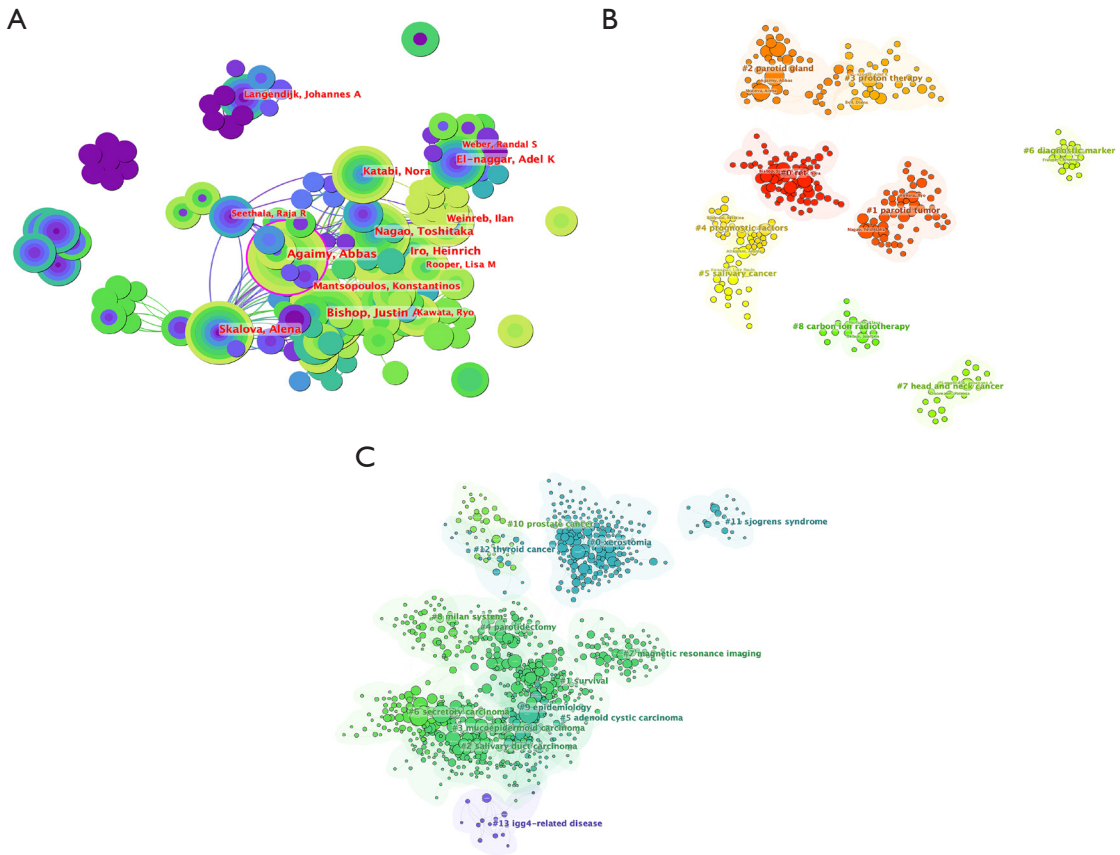

Figure 4 Active researchers and research focus of top co-cited researchers. (A) The diagram illustrates the most prolific researchers in salivary gland oncology. Each node represents a scientist, with node sizes denoting the number of publications. The highlighted circle around Abbas Agami emphasizes his significant centrality in this domain. Links between nodes signify collaboration among researchers. (B) Keywords clustering has revealed the hotspots among the most productive authors. (C) Through keyword clustering, we have identified the research focus among the most co-cited authors. Shared keywords have grouped two researchers into the same cluster. (C) 14 clusters, with cluster #0 being the largest, indicating that the top co-cited authors primarily focus on xerostomia in this field.

Additionally, we also noticed a significant number of manuscripts focusing on the salivary gland in relation to other types of cancer, such as thyroid cancer and prostate cancer. Through further exploration, we revealed substantial correlations between treatment methods for these diseases and salivary gland carcinomas (SGCs), which has attracted the attention of researchers in salivary gland oncology.

Furthermore, keywords related to the mechanisms of salivary gland oncology, such as "pathway" and "protein", were identified in Cluster #0. This cluster encompasses crucial research studies, including one by Praktiknjo *et al.*, who utilized epitope profiling and single-cell transcriptome techniques to investigate tumorigenesis mechanisms in salivary gland squamous cell carcinoma (18). Nonetheless, Weinreb *et al.* identified the *PRKD1* *p.Glu710Asp* hotspot mutation as a driver of polymorphous low-grade adenocarcinoma (24). Furthermore, Wang *et al.* applied simvastatin with a miR-21 inhibitor to prevent lung metastasis in salivary adenoid cystic carcinoma, which may suggest a new treatment target for distant metastasis in patients with malignant salivary diseases (25).

In terms of burst detection, as illustrated in *Figure 5C*, the term "secretory carcinoma" stands out as the keyword with the most significant number of citation bursts. This term can be divided into two distinct phases. In the initial phase, Skalova *et al.* first reported secretory carcinoma in the salivary glands (26). However, the number of studies on this disease has increased over the past several years. However, burst detection of secretory carcinoma did not occur until 2019. This surge in citations indicates a

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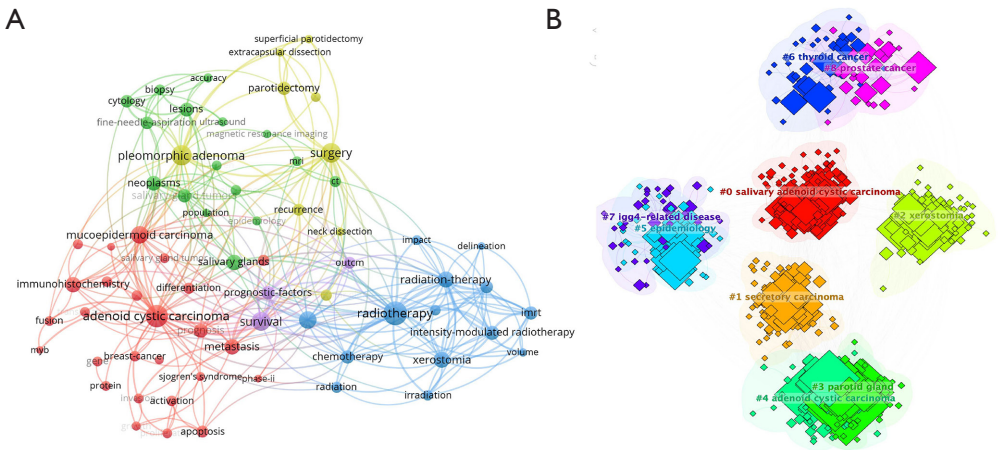

C

Top 10 keywords with the strongest citation bursts

Keywords	Year	Strength	Begin	End	2012–2023
Salivary gland function	2012	10.9	**2012**	2015	
Stage nasopharyngeal carcinoma	2012	10.51	**2012**	2013	
Epithelial cells	2012	10.02	**2012**	2015	
Locally advanced head	2012	9.13	**2012**	2016	
Epithelial mesenchymal transition	2015	10.13	**2015**	2018	
Secretory carcinoma	2019	13.45	**2019**	2023	
Deep learning	2020	12.56	**2020**	2023	
Machine learning	2021	11.5	**2021**	2023	
Recurrent	2015	10.21	**2021**	2023	
Oxidative stress	2014	9.61	**2021**	2023	

Figure 5 Keywords analysis. (A) Most occurrences of article keywords in salivary gland oncology: each node represents an article keyword, and nodes sharing a close relationship are color-coded similarly. Links indicate the co-occurrences of the keywords in the same manuscript. (B) Keyword clustering of the most-cited keywords: our findings emphasize that salivary adenoid carcinoma is a significant hotspot in salivary gland oncology. (C) Top 10 keywords under citation bursts [2012–2023]: burst strength reflects the number of sudden surges of research manuscripts related to each keyword. The bar indicates the time interval between these surges.

significant increase in interest or relevance within the field of salivary gland oncology.

Likewise, "machine learning" and "deep learning" have also undergone citation bursts in recent years, which may signify the importance of applying artificial intelligence in diagnosis, treatment and prognosis in salivary gland oncology.

In general, a citation burst signifies a period marked by a sudden increase in citations for a specific keyword, indicating a noteworthy surge in interest or relevance within the field of salivary gland oncology. Consequently, the keywords observed in burst detection not only underscore the current significance of these topics, such as secretory carcinoma and artificial intelligence but also imply a potential focal point for future researchers in salivary gland oncology.

Reference analysis

When composing manuscripts, researchers often cite numerous references related to their research direction. When two references were cited together, they shared the same focus on the topic of research. In our study, 1,175 references were selected from WOSCC, which may provide insights into research hotspots over time and potential future research fronts in this area. *Table 1* shows the top 10 references with the highest frequencies of cociting. Among them, a manuscript composed of El-Naggar [2017], which has been cited more than 130 times, has gained the most popularity (12). Researchers have delineated the diagnostic

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Table 1 The top 10 co-cited references in salivary gland oncology

Rank	Title	Author	NOC
1	World Health Organization Classification of Head and Neck Tumours	El-Naggar *et al*.	138
2	Update from the 4th Edition of the World Health Organization Classification of Head and Neck Tumours: Tumors of the Salivary Gland	Seethala *et al*.	118
3	Parotid-sparing intensity modulated versus conventional radiotherapy in head and neck cancer (PARSPORT): a phase 3 multicentre randomised controlled trial	Nutting *et al*.	107
4	Adenoid cystic carcinoma of the head and neck - An update	Coca-Pelaz *et al*.	81
5	Management of Salivary Gland Malignancy: ASCO Guideline	Geiger *et al*.	68
6	Radiotherapy dose-volume effects on salivary gland function	Deasy *et al*.	64
7	Phase II Trial of Trastuzumab and Docetaxel in Patients With Human Epidermal Growth Factor Receptor 2-Positive Salivary Duct Carcinoma	Hideki Takahashi *et al*.	63
8	The Role of Molecular Testing in the Differential Diagnosis of Salivary Gland Carcinomas	Skálová *et al*.	63
9	A prospective phase II study of combined androgen blockade in patients with androgen receptor-positive metastatic or locally advanced unresectable salivary gland carcinoma	Fushimi *et al*.	60
10	Pembrolizumab for the Treatment of Advanced Salivary Gland Carcinoma Findings of the Phase 1b KEYNOTE-028 Study	Cohen *et al*.	59

NOC, number of citations.

criteria and pathological features in salivary gland oncology. Meanwhile, this study introduced the genetic alterations associated with SGT. Building on the research foundation laid by El-Naggar *et al.*, a manuscript by Seethala *et al.* [2017] further explored common translocations and gene fusions in SGT, accumulating over 100 citations in studies related to salivary gland oncology (27). In summary, this research introduced an international standard and offered a guide for designing studies and evaluating responses to therapies for salivary oncologists. Moreover, this manuscript has provided a complement to the classification in salivary gland oncology.

According to the keywords of the cocited manuscript, timeline zone view clustering showed that the cocited manuscripts could be categorized into 15 clusters. We list the top 10 clusters in *Figure 6A*. Each node in the figure represents an original article, and the cocited manuscripts were clustered together when a significant number of articles with shared keywords cited them. Cluster #0, which centers around salivary duct carcinoma, emerged as the largest and most recent cluster, providing valuable insight into future research trends in the domain of SGT.

By exploring cluster #0, we traced several noteworthy manuscripts. In a 2018 study, Fushimi *et al.* conducted a phase II clinical trial involving patients with androgen receptor-positive SGC. Their findings suggest that combined androgen blockade offers comparable efficacy with reduced toxicity compared to conventional chemotherapy (28). Additionally, a study conducted by Arolt in 2020 revealed that elevated expression of lymphocyte activation gene 3 (*LAG3*) is correlated with reduced event-free survival in adenoid cystic carcinoma patients. This study also highlighted for the first time the potential of *LAG3* as a target therapy for SGC (29).

In terms of citation burst detection, as shown in *Figure 6B*, we discovered that before 2022, there is no unified therapeutic consensus for salivary gland malignancies. To address this gap, Geiger *et al.* analysed 293 studies related to salivary gland malignancies and proposed guidelines on surgical diagnostic and therapeutic procedures for this disease (30). Notably, this manuscript has recently experienced a citation burst, registering the highest strength of 32.76. Meanwhile, the manuscripts authored by El-Naggar [2017] and Seethala [2017], which have gained significant popularity, are also undergoing a citation burst. This phenomenon may underscore the sustained and increasing interest in these pivotal works within the research community.

Discussion

As the key components involved in synthesizing, modifying and secreting saliva, the salivary glands are crucial for sustaining the physiological environment (31) of the mouth.

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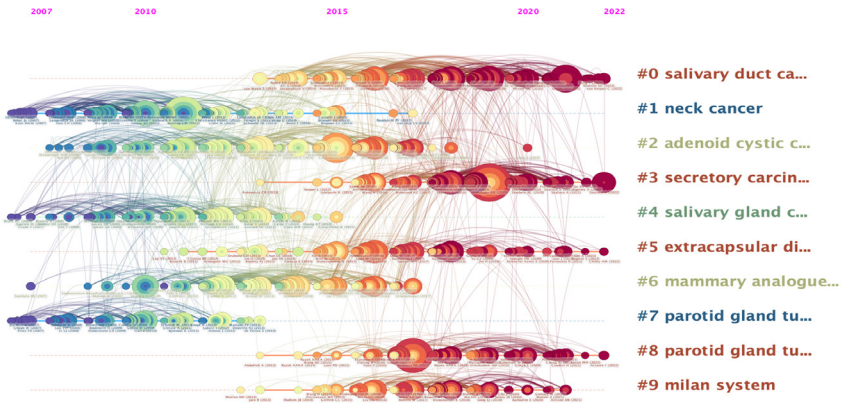

B

Top 20 references with the strongest citation bursts

References	Year	Strength	Begin	End	2012–2023
Nutting CM, 2011, LANCET ONCOL, V12, P127, DOI 10.1016/S1470-2045(10)70290-4, DOI	2011	40.39	2012	2016	
Deasy JO, 2010, INT J RADIAT ONCOL, V76, PS58, DOI 10.1016/j.ijrobp.2009.06.090, DOI	2010	29.09	2012	2015	
SkalovaA, 2010, AM J SURG PATHOL, V34, P599, DOI 10.1097/PAS.0b013e3181d9efcc, DOI	2010	24.97	2012	2015	
Tian Z, 2010, INT J ORALMAX SURG, V39, P235, DOI 10.1016/j.jom.2009.10.016, DOI	2010	20.87	2012	2015	
Laurie SA, 2011, LANCET ONCOL, V12, P815, DOI 10.1016/S1470-2045(10)70245-X, DOI	2011	16.88	2012	2016	
Connor A, 2012, AM J SURG PATHOL, V36, P27, DOI 10.1097/PAS.0b013e318231542a, DOI	2012	19.46	2013	2017	
West RB, 2011, AM J SURG PATHOL, V35, P92, DOI 10.1097/PAS.0b013e3182002777, DOI	2011	18.73	2013	2016	
Brill LB, 2011, MODERN PATHOL, V24, P1169, DOI 10.1038/modpathol.2011.86, DOI	2011	18.29	2013	2016	
Chiosea SI, 2012, HISTOPATHOLOGY, V61, P387, DOI 10.1111/j.1365-2559.2012.04232.x, DOI	2012	16.57	2013	2017	
Ellington CL, 2012, CANCER-AM CANCER SOC, V118, P4444, DOI 10.1002/cncr.27408, DOI	2012	16.57	2013	2017	
Jaspers HCJ, 2011, JCLIN ONCOL, V29, PE473, DOI 10.1200/ICO.2010.32.8351, DOI	2011	16.54	2013	2016	
Ho AS, 2013, NAT GENET, V45, P791, DOI 10.1038/ng .2643, DOI	2013	20.61	2014	2018	
Stephens PJ, 2013, JCLIN INVEST, V123, P2965, DOI 10.1172/JCI67201, DOI	2013	16.4	2014	2018	
Coca-Pelaz A, 2015, ORAL ONCOL, V51, P652, DOI 10.1016/j.oraloncology.2015.04.005, DOI	2015	23.37	2017	2020	
El-Naggar AK, 2019, WHO CLASSIFICATION H, V1, PO	2019	26.49	2019	2023	
Seethala RR, 2017, HEAD NECK PATHOL, V11, P55, DOI 10.1007/s12105-017-0795-0, DOI	2017	22.61	2018	2023	
Dalin MG, 2016, CLIN CANCER RES, V22, P4623, DOI 10.1158/1078-0432.CCR-16-0637, DOI	2016	16.83	2018	2020	
Liu CC, 2016, OTOLARYNG HEAD NECK, V154, P9, DOI 10.1177/0194599815607841, DOI	2016	16.59	2019	2021	
Geiger JL, 2021, JCLIN ONCOL, V39, P1909, DOI 10.1200/JCO.21.00449, DOI	2021	32.76	2022	2023	
Pfister DG, 2020, J NATL COMPR CANC NE, V18, P873, DOI 10.6004/jnccn.2020.0031, DOI	2020	16.8	2022	2023	

Figure 6 Reference analysis. (A) Timeline view of the most cited references in salivary gland oncology. Each node represents a manuscript, with keyword clustering dividing the most cocited references into 15 clusters. The traversing link between the nodes depicts the cocitation timeline. The 10 largest clusters are shown in (A). (B) Top 20 references with the strongest citation bursts [2012–2023]: identifies references with the most notable and sudden increases in citations during the specified time frame.

They contribute significantly to oral health. SGTs are rare among neoplasms in humans, with epithelial-origin salivary tumors being the most common. According to our research, there are currently more than 30,000 manuscripts in the WOSCC, and the earliest ones date back to the 1900s. Researchers have focused primarily on exploring anatomical structures and identifying the pathology of salivary gland diseases. Concurrently, there is a significant body of literature concentrating on surgical considerations in salivary gland oncology. In some salivary gland cancers, several risks have been identified; however, the etiology and pathology of SGTs are poorly understood. Recently, the rapid growth of scientific inquiry in oncological research has been propelled by the application of sequencing technologies and artificial intelligence. The number of manuscripts from 2012 to 2023 alone accounted for more than one-third of the entire database.

The analysis of contributing countries revealed that the United States has been a prominent contributor, publishing 2,588 original articles in the last 12 years, and we have listed the top 10 most cocited manuscripts in the United States in *Table 2*. Subsequently, in 2017, researchers in the US applied convolutional neural networks in head and neck oncology. By leveraging deep learning methods, they successfully segmented organs at risk of SGT on medical images (32). Moreover, researchers from the United States have significantly contributed to the development of multiple guidelines for treatment modalities and lymph

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Table 2 The top 10 popular research in the United States

Rank	Title	Author	NOC
1	Radiotherapy dose-volume effects on salivary gland function	Pfister *et al*.	476
2	Delineation of the neck node levels for head and neck tumors: A 2013 update. DAHANCA, EORTC, HKNPCSG, NCIC CTG, NCRI, RTOG, TROG consensus guidelines	Gregoire *et al*.	445
3	The global incidence of lip, oral cavity, and pharyngeal cancers by subsite in 2012	Shield *et al*.	438
4	Management of Salivary Gland Malignancy: ASCO Guideline	Miettinen *et al*.	438
5	NCCN Guidelines® Insights Head and Neck Cancers, Version 1.2018 Featured Updates to the NCCN Guidelines	Dimitrios Colevas *et al*.	373
6	The mutational landscape of adenoid cystic carcinoma	Ho *et al*.	334
7	Segmentation of organs-at-risks in head and neck CT images using convolutional neural networks	Ibragimov *et al*.	332
8	Transoral robotic surgery: A multicenter study to assess feasibility, safety, and surgical margins	Weinstein *et al*.	328
9	AnatomyNet: Deep learning for fast and fully automated whole-volume segmentation of head and neck anatomy	Zhu *et al*.	297
10	Oral Complications of Cancer and Cancer Therapy From Cancer Treatment to Survivorship	Epstein *et al*.	295

NOC, number of citations.

node delineation in salivary gland oncology (30,33,34). This underscores the significant and active contribution of the United States in the field of salivary gland oncology, positioning it as a dominant force in research and advancements in this area.

In terms of literature resource analysis, the period from 2012 to 2023 revealed that the journal *Head and Neck* stands out as the largest contributing journal in the field of salivary gland oncology. Following Bradford's law, we have also identified the following journals as core publications in the field of salivary gland oncology: *Head and Neck*, *Oral Oncology*, *Laryngoscope*, *International Journal of Radiation Oncology Biology Physics*, *Cancer*, *American Journal of Surgical Pathology*, *Otolaryngology-Head and Neck Surgery*, *Journal of Clinical Oncology*, *Archives of Otolaryngology*, and *Head & Neck Pathology*. Moreover, recent studies in salivary gland oncology have demonstrated an increasing presence in journals such as *Cancers*, *Frontiers in Oncology*, and *Head & Neck Pathology*, indicating a growing interest and acceptance of research in these journals. This trend also suggests that these journals are becoming significant platforms for disseminating and advancing knowledge in the field of salivary gland oncology.

Next, to gain an overall understanding of the research focal points among the most productive and popular researchers, we utilized keyword clustering. Significantly, our findings indicate that the most productive research points revolve around the topics related to the rearranged during transfection (*RET*) gene fusion, malignant salivary cancer and radiotherapy. On the other hand, when examining the most cocited authors, Cluster #Xerostomia and #Survival were the most common, which may suggest that a significant portion of researchers in salivary gland oncology pay close attention to research related to these topics.

In bibliometric analysis, keyword and reference analyses are efficient tools for revealing current hot topics and research trends in the scientific field. In *Figure 5*, the most frequent keywords can be categorized into four parts, indicating that the field's hotspot comprises four well-studied aspects. Each part is centered around a core term: "adenoid cystic carcinoma", "pleomorphic adenoma", "radiotherapy", and "surgery". Further keyword clustering highlights the ongoing significance of adenoid cystic carcinoma, underscoring its central role in salivary gland oncology research. Moreover, our cocited reference analysis indicates a notable emphasis on salivary duct carcinoma among researchers. However, the frequency of the keyword "salivary duct carcinoma" is relatively low, which may illustrate the growing demand for studies on this disease.

Based on the above findings, in addition to classic salivary gland tumors such as pleomorphic adenoma and adenoid cystic carcinoma, our research and keyword analysis highlighted several current hotspots in salivary gland oncology as follows:

(I) *RET*: SGC represents approximately 5% of head

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and neck malignancies and is characterized by resistance to cytotoxic chemotherapy and immune checkpoint inhibition therapy. Historically, treatment options were limited to surgery and radiotherapy, leading to poor outcomes due to the diverse clinical behaviors of these cancers. However, there has been a significant shift in the treatment landscape for SGC in recent years (35). Researchers have shown that *RET* gene fusion is prevalent in SGCs. Specifically, researchers have discovered *EVT6-RET* gene fusions in salivary duct carcinomas (36). Moreover, *RET* gene fusions, including *TRIM33-RET* and *NCOA4-RET*, have also been reported in other subtypes of salivary gland malignancies (37). The discovery of these gene fusions has advanced our understanding of the oncogenic mechanisms underlying salivary gland tumors and presents a promising treatment target for these cancers.

(II) Carbon ion radiotherapy and proton therapy: radical surgery remains the primary treatment modality for SGCs. However, the role of radiotherapy is crucial in the postoperative setting, particularly for managing inoperable malignancies and recurrent tumors (38). Given their proximity to normal organs and resistance to conventional radiotherapies, especially in cases of adenoid cystic carcinoma, SGCs present significant challenges for clinicians. Carbon ion radiotherapy and proton therapy have shown high efficacy and the potential to minimize harmful effects on surrounding organs. Notably, both techniques have demonstrated excellent outcomes in treating adenoid cystic carcinoma. Currently, clinicians are actively working to establish the optimal treatment approach for these tumors by integrating multiple radiotherapies, which may offer improved chances for patients (39,40).

(III) Xerostomia: this is the most significant and long-term complication for patients with salivary gland tumors undergoing radiotherapy and is characterized by the loss of salivary gland function. Researchers have shown that intensity-modulated radiotherapy has the greatest potential for preserving salivary gland function. Additionally, techniques such as salivary gland or stem cell transfer may serve as methods for supplementing fluid to the glands (41,42). However, effective strategies are still being sought to preserve salivary gland secretion function postradiotherapy.

(IV) IgG4-related diseases: IgG4-related diseases are characterized by $CD4^+$ and $CD8^+$ T-cell infiltration, along with elevated serum IgG4 levels, leading to sclerotic and fibrotic changes in affected organs (43). In the salivary gland region, these diseases often manifest as Mikulicz's disease and Küttner's tumor, presenting as painless bilateral swelling in the salivary glands. Co-occurrence of IgG4-related diseases with salivary gland malignancies has also been reported (44). However, distinguishing between salivary gland tumors and IgG4-related diseases is challenging due to their similar appearances, leading researchers in salivary gland oncology to focus on improving diagnostic methods. These efforts include biopsies, radiographic exams, DNA sequencing, and blood tests (45,46).

(V) Neurotrophic tyrosine receptor kinase (NTRK) and prostate-specific membrane antigen (PSMA): due to the approval of larotrectinib, an effective treatment for *NTRK* fusion cancers, significant progress has been made in managing cancers such as thyroid cancer, secretory carcinoma of the breast, and salivary glands (47-50). The assessment of *NTRK* fusion has now become a standard approach for managing these diseases. As a result, numerous manuscripts focusing on topics related to salivary gland oncology and thyroid cancers have emerged.

We also observed that the keyword "prostate cancer" appeared as the main cluster in the keyword analysis. *PSMA*, a transmembrane glycoprotein, is known to be overexpressed in prostate cancer. Recently, researchers have reported relatively high expression of this gene in the tumor parenchyma in salivary gland malignancies, particularly in adenoid cystic carcinomas and salivary duct carcinomas (51). Consequently, *PSMA* radioligand therapy for salivary gland malignancies has garnered increased amounts of attention from researchers (52,53). Studies related to other types of malignancies, including breast cancer, prostate cancer and thyroid cancer, have revealed new treatment options for salivary gland tumors.

Beyond that, burst detection is intended to find related references and keywords under citation bursts, implying a research trend in specific fields.

Interestingly, the keyword 'stage nasopharyngeal

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Table 3 The top 10 co-cited keywords in secretory carcinoma in salivary gland oncology

Rank	Keyword	NOC
1	Acinic cell carcinoma	73
2	Secretory carcinoma	73
3	Mammary analogue secretory carcinoma	60
4	Analog secretory carcinoma	53
5	Diagnosis	49
6	Adenoid cystic carcinoma	41
7	Fusion	34
8	Translocation	34
9	Mucoepidermoid carcinoma	29
10	Etv6 ntrk3 gene fusion	28

NOC, number of citations.

Table 4 The top 10 co-cited keywords in artificial intelligence in the salivary gland oncology

Rank	Keyword	NOC
1	Radiotherapy/radiation therapy	35
2	Computed tomography/CT/CT images	32
3	Parotid gland	12
4	Images	12
5	Auto segmentation	12
6	Delineation	11
7	Organs	11
8	Convolutional neural network	9
9	Classification	9
10	Diagnosis	8

NOC, number of citations.

carcinoma' experienced a citation burst from 2012–2013. Salivary gland nasopharyngeal cancers are rare and have received limited discussion in the literature. During that period, controversies arose regarding the staging and treatment of these diseases because of their diverse clinical manifestations and pathological appearance (54). In 2019, a comprehensive analysis of a large patient cohort with salivary gland nasopharyngeal carcinomas revealed a prognosis similar to that of patients with squamous cell carcinomas, and the prognosis of this disease was determined by various factors, including race, age and histological subtype (55).

Furthermore, we found that the keywords "secretory carcinoma", "machine learning", and "deep learning" are associated with citation bursts with the greatest strength. By conducting additional analysis of the manuscripts using CiteSpace and focusing on these keywords, we have summarized the prevalent biomarkers or topics in *Tables 3*,*4*. The information related to these keywords is as follows:

(I) Secretory carcinoma: this disease was initially described in 2010, with approximately 300 experimental manuscripts related to it in salivary gland oncology. However, burst detection of secretory carcinoma did not occur until 2019. Upon analysing manuscripts published in 2019 with this keyword, a study by Haller *et al.* had the most citations. This study explored the molecular pathogenesis of salivary gland acinic cell carcinoma, highlighting the influential role of NR4A3 upregulation in cell proliferation within this carcinoma (56). Similarly, in 2019, several studies focused on salivary gland acinic cell carcinoma and gene translocation (57). These outcomes potentially indicate an ongoing upswing in future studies centered around gene translocation in secretory carcinoma.

(II) Machine learning and deep learning: given that these are techniques within the domain of artificial intelligence, we added all three keywords—"machine learning", "deep learning", and "artificial intelligence"—with the previous search words for salivary oncology in WOSCC and analysed the related manuscripts in CiteSpace. Our investigation revealed that the use of artificial intelligence in salivary gland oncology began in 2013, with a consistent and steady increase in the number of manuscripts in this domain. To date, researchers have utilized artificial intelligence to assimilate data, integrating clinical records with medical images. Artificial intelligence remains the most extensively studied method in the context of diagnosis, classification, and prediction in salivary gland oncology (14,17,58-61). However, despite its prominence, the citation frequency for these keywords in the field is average. This could be attributed to the predominantly single-centered nature of most studies and the significant variability in the format of medical images, resulting in fewer citations across various works.

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Table 5 The top 10 universal guidelines/consensus and related studies under citation bursts in salivary oncology

Rank	References	Strength
1	Management of Salivary Gland Malignancy: ASCO Guideline	32.76
2	WHO classification (2019)	26.49
3	Update from the 4th Edition of the World Health Organization Classification of Head and Neck Tumours: Tumors of the Salivary Gland	22.61
4	Head and Neck Cancers, Version 2.2020, NCCN Clinical Practice Guidelines in Oncology	16.8
5	Minor salivary gland tumors of the head and neck—Memorial Sloan Kettering experience: Incidence and outcomes by site and histological type	9.97
6	Multiparametric Magnetic Resonance Imaging for the Diagnosis and Differential Diagnosis of Parotid Gland Tumors	9.28
7	Major and minor salivary gland tumours	9.11
8	Salivary Gland Malignancies	8.93
9	Salivary duct carcinoma: Updates in histology, cytology, molecular biology, and treatment	8.25
10	Who classification of head and neck tumours (2017)	8.1

(III) International standards and guidelines: according to burst detection in salivary gland oncology manuscripts, we observed a significant surge in citations for several international standards and guidelines (27,30). Likewise, in our analysis of the most frequently cocited manuscripts, guidelines and standards consistently emerged as top-ranking in terms of citation frequency, especially within the domain of salivary gland malignancies. This trend may be attributed to the lack of a unified consensus on the etiology and pathology of salivary gland cancer. Furthermore, the clinical symptoms and pathological features of SGTs exhibit considerable variation, posing challenges in diagnosis, classification, and treatment procedures in both research and clinical settings. The mission of establishing a unified guideline for SGT has long been a challenge, and it was not until 2017 that the WHO started to include gene alterations in SGT classifications. Thus, the need and challenge for developing more cohesive guidelines in this domain create an opportunity for more in-depth manuscripts focusing on tumor cell behaviors within SGTs, as well as for researchers to contribute meaningfully (27,30).

Furthermore, our analysis identified references that experienced a citation burst during the specified years. These references have been categorized into universal guidelines/consensus and related studies, clinical/experimental studies, studies in salivary gland malignancies, and studies focusing on gene biomarkers in salivary gland oncology. Among these categories, we selected the top ten references for each, which are listed in *Tables 5-8*.

Our study has several limitations. First, we focused on the WOSCC for data collection due to software requirements, thus, not all database were evaluated, which may limit the scope of scientific research analysed. Second, our findings provide only a snapshot of current salivary gland oncology, subject to ongoing updates. Third, despite our primary focus on original articles, the inclusion of some reviews or case report (categorized as articles in the Web of Science) was challenging to filter through the website and the software. Fourth, due to the software's topic search method, there are some pieces of manuscript related to other types of carcinomas and salivary gland was also included in this research. Lastly, due to the algorithm used in CiteSpace, there may be some misleading display of words in the results. For instance, in *Figure 6A*, the term "neck cancer" (#1) actually refers to head and neck cancer.

Generally, to understand the current state and explore future research trends in salivary oncology, we used bibliometric methods to evaluate and analyse 9,695 original research articles. To our knowledge, our research represents the first comprehensive bibliometric study focusing specifically on salivary gland oncology. In an era characterized by information explosion, bibliometric analysis offers researchers a new method to grasp the most important and influential studies. By integrating CiteSpace and VOSviewer, we attempted to conduct a series of

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Table 6 Top 10 clinical/experimental studies under citation bursts in salivary oncology

Rank	References	Strength
1	Phase II Trial of Trastuzumab and Docetaxel in Patients With Human Epidermal Growth Factor Receptor 2–Positive Salivary Duct Carcinoma	16.01
2	Salivary gland pleomorphic adenoma in the Netherlands: A nationwide observational study of primary tumor incidence, malignant transformation, recurrence, and risk factors for recurrence	13.87
3	Pembrolizumab for the Treatment of Advanced Salivary Gland Carcinoma: Findings of the Phase 1b KEYNOTE-028 Study	11.76
4	Enhancer hijacking activates oncogenic transcription factor NR4A3 in acinic cell carcinomas of the salivary glands	11.42
5	Molecular Profiling of Mammary Analog Secretory Carcinoma Revealed a Subset of Tumors Harboring a Novel ETV6-RET Translocation	11.37
6	A prospective phase II study of combined androgen blockade in patients with androgen receptor-positive metastatic or locally advanced unresectable salivary gland carcinoma	11.13
7	Entrectinib in patients with advanced or metastatic NTRK fusion-positive solid tumours: integrated analysis of three phase 1–2 trials	10.66
8	Phase II Study of Lenvatinib in Patients With Progressive, Recurrent or Metastatic Adenoid Cystic Carcinoma	10.65
9	Efficacy of Larotrectinib in TRK Fusion–Positive Cancers in Adults and Children	10.3
10	Salivary Secretory Carcinoma With a Novel ETV6-MET Fusion Expanding the Molecular Spectrum of a Recently Described Entity	9.47

Table 7 The top 10 studies with citation bursts in salivary gland malignancies

Rank	References	Strength
1	Phase II Trial of Trastuzumab and Docetaxel in Patients With Human Epidermal Growth Factor Receptor 2–Positive Salivary Duct Carcinoma	16.01
2	Pembrolizumab for the Treatment of Advanced Salivary Gland Carcinoma Findings of the Phase 1b KEYNOTE-028 Study	11.76
3	Enhancer hijacking activates oncogenic transcription factor NR4A3 in acinic cell carcinomas of the salivary glands	11.42
4	Molecular Profiling of Mammary Analog Secretory Carcinoma Revealed a Subset of Tumors Harboring a Novel ETV6-RET Translocation	11.37
5	A prospective phase II study of combined androgen blockade in patients with androgen receptor-positive metastatic or locally advanced unresectable salivary gland carcinoma	11.13
6	Phase II Study of Lenvatinib in Patients With Progressive, Recurrent or Metastatic Adenoid Cystic Carcinoma	10.65
7	Efficacy of Larotrectinib in TRK Fusion–Positive Cancers in Adults and Children	10.3
8	Microsecretory Adenocarcinoma: A Novel Salivary Gland Tumor Characterized by a Recurrent MEF2C-SS18 Fusion	9.97
9	Nuclear NR4A3 Immunostaining Is a Specific and Sensitive Novel Marker for Acinic Cell Carcinoma of the Salivary Glands	9.97
10	Expanding the Molecular Spectrum of Secretory Carcinoma of Salivary Glands With a Novel VIM-RET Fusion	9.97

There are three manuscripts experiencing citation bursts that have equal strength.

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Table 8 The top 10 studies on gene biomarkers with citation bursts in salivary gland oncology

Rank	References	Strength
1	Enhancer hijacking activates oncogenic transcription factor NR4A3 in acinic cell carcinomas of the salivary glands	11.42
2	Molecular Profiling of Mammary Analog Secretory Carcinoma Revealed a Subset of Tumors Harboring a Novel ETV6-RET Translocation	11.37
3	Entrectinib in patients with advanced or metastatic NTRK fusion-positive solid tumours: integrated analysis of three phase 1–2 trials	10.66
4	Efficacy of Larotrectinib in TRK Fusion–Positive Cancers in Adults and Children	10.3
5	Microsecretory Adenocarcinoma: A Novel Salivary Gland Tumor Characterized by a Recurrent MEF2C-SS18 Fusion	9.97
6	Nuclear NR4A3 Immunostaining Is a Specific and Sensitive Novel Marker for Acinic Cell Carcinoma of the Salivary Glands	9.97
7	Expanding the Molecular Spectrum of Secretory Carcinoma of Salivary Glands With a Novel VIM-RET Fusion	9.97
8	Molecular Profiling of Salivary Gland Intraductal Carcinoma Revealed a Subset of Tumors Harboring NCOA4-RET and Novel TRIM27-RET Fusions	9.73
9	Salivary Secretory Carcinoma With a Novel ETV6-MET Fusion Expanding the Molecular Spectrum of a Recently Described Entity	9.47
10	NCOA4-RET and TRIM27-RET Are Characteristic Gene Fusions in Salivary Intraductal Carcinoma, Including Invasive and Metastatic Tumors: Is “Intraductal” Correct?	9.23

bibliometric analyses to offer a general view of and research trends in this area.

Conclusions

In an era characterized by information explosion, bibliometric analysis offers researchers a new method to grasp the most important and influential studies. By employing various bibliometric analysis tools, we scrutinized 9,695 original research articles published between 2012 and 2023 in salivary gland oncology, aiming to present a comprehensive view and identify research trends in this domain.

Our research indicates that salivary gland malignancies currently dominate the field of salivary oncology research and will remain the primary research focus in this field. Researchers are actively investigating promising treatment targets for these malignancies, with a particular focus on gene fusion detection. Notably, RET gene fusions have emerged as a key area of interest in salivary gland malignancies. Additionally, studies on various cancers, such as breast cancer, prostate cancer, and thyroid cancer, have revealed new treatment options for salivary gland tumors. For instance, *NTRK* fusions and *PSMA*, previously studied in thyroid, breast, and prostate cancers, have recently gained attention in the context of salivary gland malignancies.

While radical surgery remains the primary treatment for SGCs, ongoing efforts are directed towards carbon ion radiotherapy and proton therapy. These modalities have demonstrated increased efficacy and reduced toxicity to nearby organs, showing outstanding treatment outcomes in managing adenoid cystic carcinomas and addressing inoperable or recurrent malignancies (39,40). Consequently, radiotherapy has gained popularity in salivary gland oncology. However, the application of radiotherapies in salivary gland oncology and other malignancies has also raised concerns regarding complications, particularly xerostomia, which remains a significant research focus in the field.

A correct diagnosis is paramount for the prognosis of patients with salivary gland cancer. With diverse clinical and pathological manifestations, the classification and diagnosis of SGTs have posed challenges for researchers in this field. The call for establishing more cohesive guidelines presents researchers with an opportunity to explore deeper into tumor cell behaviors within SGTs, thereby contributing to the advancement of clinical practice and research in this domain.

On the other hand, the application of artificial intelligence has mainly concentrated on the diagnosis and classification of SGCs (62,63). However, the number of studies in this area remains relatively low at this time.

With the progress in artificial intelligence, there is potential to use artificial intelligence algorithms to schedule

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treatment for patients with salivary gland cancer. These algorithms can identify, classify, and detect gene fusions or alterations, aiding in the development of optimal treatment plans that may include surgery, radiotherapy, and other therapies, either individually or in combination, tailored to each patient's needs.

In summary, this study represents the first comprehensive bibliometric analysis focused on salivary gland oncology. Our findings provide valuable insights into emerging trends and areas for future investigations in this field. We believe that this study will significantly benefit scientific researchers and clinical oncologists by enhancing their understanding of salivary gland oncology and contributing to the discipline's further development and policymaking.

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