Original Research Article

DIGITAL HEALTH

DIGITAL HEALTH
Volume 10: 1–18

DOI: 10.1177/20552076241260837
journals.sagepub.com/home/dhj

Sage

Text mining analysis of scientific literature on digital intraoral scanners in dentistry: Bibliometric analysis

Ravinder S Saini[1], Abdulkhaliq Ali F Alshadidi[1], Jaismeen Rakhra[2], Lujain Ibrahim N Aldosari[3], Saeed Awod Bin Hassan[4], Syed Altafuddin Quadri[1], V.N.V Madhav[5], Anna Avetisyan[6] and Artak Heboyan[7,8]

Abstract

Objective: This study aimed to provide valuable insights into the current research status and gaps in digital intraoral scanner literature in dentistry.

Methodology: Scopus Search Query TITLE-ABS-KEY (intraoral AND scanners AND (dentistry OR digital AND dentistry)). The search query used in Scopus for the bibliometric analysis was "TITLE-ABS-KEY (intraoral AND scanners AND (dentistry OR digital AND dentistry))." This query indicates that the analysis focused on documents in which the title, abstract, or keywords contained the terms "intraoral," "scanners," and either "dentistry" or "digital dentistry."

Results: The analysis covers a timespan from 1998 to 2023 and includes 331 documents sourced from 136 publications. The annual growth rate of research in this field is reported to be 15.9%, indicating a steady increase over time. Among the top sources, the "Journal of Esthetic and Restorative Dentistry" and the "Journal of Prosthetic Dentistry" have the highest number of articles, indicating their significance in the field. Some notable authors and their corresponding statistics include WÖSTMANN B, with 15 articles and a fractionalized value of 3.16, and SCHLENZ MA, with 14 articles and a fractionalized value of 2.91. The United States has the highest number of articles, indicating a significant presence in research publications. Germany closely follows this, demonstrating a notable contribution to the scientific community.

Conclusions: This bibliometric analysis of intraoral scanners used in dentistry provided valuable insights into the current state of research and scholarly publications in this field. This analysis sheds light on the trends, patterns, and advancements in the use of these scanners in dental practice.

Keywords

Digital, technology, connected devices, digital health, imaging

Submission date: 22 September 2023; Acceptance date: 20 May 2024

[1]Department of Dental Technology, COAMS, King Khalid University, Abha, Saudi Arabia
[2]Leadership in Healthcare (Canada), Langley, Canada
[3]Department of Prosthodontics, College of Dentistry, King Khalid University, Abha, Saudi Arabia
[4]Department of Restorative Dental Sciences, College of Dentistry, King Khalid University, Abha, Saudi Arabia
[5]Department of Prosthodontics, YCMM & RDF's Dental College and Hospital, Ahmednagar, India
[6]Department of Therapeutic Stomatology, Faculty of Stomatology, Yerevan State Medical University after Mkhitar Heratsi, Yerevan, Armenia
[7]Department of Research Analytics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India
[8]Department of Prosthodontics, Faculty of Stomatology, Yerevan State Medical University after Mkhitar Heratsi, Yerevan, Armenia

Corresponding author:
Artak Heboyan, Department of Prosthodontics, Faculty of Stomatology, Yerevan State Medical University after Mkhitar Heratsi, Str. Koryun 2, Yerevan 0025, Armenia.
Email: heboyan.artak@gmail.com

Introduction

Background

One of the important innovations in modern dentistry is the use of intraoral scanners for impression capture, replacing traditional impression techniques. These impressions play a vital role when it comes to the preparation and presentation of dental items to be made, ensuring the accuracy and correct form of items like crowns, bridges and dentures. The intraoral scanners act as small, handheld electronic devices that rely on optical technology (either from a structured light source, or with a type of laser that can detect finely detailed edges or textures) to produce a digitized, three-dimensional (3D) model of both teeth and soft tissues.[1–4] The elimination of traditional impression materials, such as alginate or polyvinyl siloxane, not only streamlines the process but also enhances patient comfort by reducing the discomfort associated with conventional impressions. These digital impressions serve various dental applications, including restorative dentistry, orthodontics, and implantology.[5–8] However, the most significant benefit of the new scanners is that they deliver highly accurate and detailed digital models of the oral anatomy, by which dentists can carry out precise measurements, facilitate better treatment planning, and enhance clinical outcomes. That dental information can be manipulated and analyzed on a computer facilitates diagnosis and the simulation of treatment as well as improved communications between the multidisciplinary team and the patient.[9,10]

Managing tooth shade is a significant challenge in esthetic dentistry, particularly for anterior restorations. Accurate shade assessment, combined with tailored treatment strategies and effective communication, is crucial.[11] Intraoral scanners are also used for the fabrication of appliances for obstructive sleep apnea.[12] Moreover intraoral scanners are used to fabricate temporary prosthesis.[13–15] In addition to increased accuracy and patient comfort, intraoral scanners have significantly improved clinical workflows in dental practices. Traditional methods for creating physical impressions involve multiple steps, including pouring the impression material, waiting for it to be set, and shipping it to a dental laboratory. This process is time consuming and prone to errors. In contrast, intraoral scanners provide immediate digital impressions that can be sent electronically to the laboratory, thereby saving time and reducing the risk of inaccuracies.[16]

Intraoral scanners offer increased accuracy in auricular impression acquisition compared to traditional hydrocolloid techniques, reducing tissue shape distortion[17] This method reduces both clinical and laboratory time compared to conventional workflows, offering a more efficient alternative for the fabrication of auricular prostheses.[18] The role of intraoral scanners is also important for the virtual design of high-quality retentive attachment inserts for overdentures, potentially reducing the need for maintenance visits and the frequency of changing bar attachment.[19]

Based on the imaging principles main type of intraoral scanners are 3D Video, Confocal local laser scan, red laser 680 nm, while LED (itero Element), Ultrafast optical sectioning TM, confocal laser scan (Trios 3), 3D in motion, video, active wavefront sampling (True Definition) and continuous filming, triangulation, white LED (Cerec Omnicam AC).

Another advantage of intraoral scanners is their ability to digitally store and retrieve patient data. This eliminates the need for the physical storage of bulky and fragile dental models. Instead, digital records can be easily archived, shared, and accessed as needed. This digital storage also enhances communication between dental professionals, allowing for efficient collaboration and consultation irrespective of geographical location.[5]

Although intraoral scanners have numerous advantages, it is important to acknowledge their limitations. First, the cost of purchasing and maintaining these devices can be a barrier to some dental practices, especially for smaller ones. In addition, the learning curve associated with intraoral scanners can be steep, requiring additional training and practice for dentists and dental technicians. Moreover, certain clinical scenarios, such as deep subgingival areas or excessive salivation, may pose challenges to accurate scanning.[16,20–22]

Nevertheless, the adoption of intraoral scanners has increased continuously in the dental industry. Their benefits in terms of accuracy, patient comfort, and improved workflow make them attractive tools for dental professionals. As technology continues to advance, it is likely that these devices will become more prevalent in dental practice, further enhancing the quality of patient care.

Although their use is limited, their benefits have made them increasingly popular tools in the dental industry. With further advancements in technology, intraoral scanners are expected to continue to play a pivotal role in modern dentistry. Consequently, there is a growing body of scientific literature on intraoral scanners in dentistry. However, given the expansive volume of publications, identifying key research themes and trends is challenging.

Rationale

Bibliometrics is a powerful tool and with the analysis of the scientific literature on intraoral scanners, we aimed to understand the current and emerging research topics, growth trends and possible future research directions. Leveraging the knowledge of text mining methods, such as keyword overlap analysis and topic modeling, helps uncover concealed patterns in the literature, narrowing down the possible areas of research gaps for future exploration.[23] Specifically, our aims were to find dominant research trajectories, reveal emerging topics, assess the

global distribution of research trends for intraoral scans, and identify research lacunae in the existing dental literature on intraoral scanners. Our ultimate goal was to provide a comprehensive guideline for understanding the current research development in this area and understanding the direction of future research.

Research gaps

There are still areas that need thorough research, such as validating the accuracy and precision of intraoral scanners against traditional methods and verifying the efficiency of the scanners in different clinical scenarios, as well as standardizing the methods of evaluation, the quality of the images under conditions that are challenging to clinical practice, and the limitations of intraoral scanners in restoring complex implant cases.[1,9] This is particular important for increasing the chance of full adoption of this new technology (in two ways), improving the efficiency of these technologies in dental practice, as well as for assisting practitioners in making informed choices for the types and brand of scanners to be used in their practices

Objectives

These include conducting a comprehensive literature review of intraoral scanners in dentistry; applying text mining methods (e.g. keyword frequency; co-occurrence; and topic modeling) to identify dominant fields of research; clustering results to identify emerging subfields; visualizing the keyword network to show research hot topics and relations; a time-series analysis to illustrate the long-term research development; comparing global research outputs; and analyzing the impact of intraoral scanning on dentistry and providing guidance for future studies.

Methodology

The Scopus search query "TITLE-ABS-KEY (intraoral AND scanners AND (dentistry OR digital AND dentistry))" was used for bibliometric analysis. This query targeted documents with relevant content regarding the intersection of intraoral scanners with dentistry, particularly digital dentistry. By employing specific keywords and logical operators (AND, OR), the analysis aimed to gather research articles, books, conference papers, and other literature focusing on the use of intraoral scanners within the realm of dentistry, emphasizing the digital aspects of dental practice. This precise search approach ensured compilation of highly pertinent documents for this study.

Data selection and extraction

The articles were selected using a procedural screening process. Articles that did not meet the eligibility criteria were omitted based on an assessment of their titles and abstracts. Two reviewers (MI and AK) examined the research titles and abstracts separately, followed by the full texts of all papers that fulfilled the eligibility criteria. Thereafter, the reviewers' perspectives were discussed to reach a consensus. All discrepancies and concerns were addressed by a third independent reviewer (MK) and resolved accordingly. Data from the included studies were systematically extracted and checked for consistency. A total of 331 documents were selected for bibliometric analysis.

Data management

Information on the number of annual publications, research types, and other relevant data were extracted from the sample data. Microsoft Excel was used to analyze all information from the recruited sources. The collected bibliometric data were analyzed using Microsoft Excel 2021 and VOSviewer version 1.6.18. Microsoft Excel was used to conduct the performance analysis of the obtained articles. To work on visualization and bibliometric construction, VOSviewer software version 1.6.17 was used, and to clean the data.

Results and analysis

The bibliometric analysis conducted on the topic of "Intraoral Scanners and Digital Dentistry" provides valuable insights into the research landscape.

Literature gaps

Insufficient research exists on comprehensive comparative accuracy studies to evaluate intraoral scanners against traditional impression techniques, thus limiting insights into their efficacy across different clinical scenarios. Further investigations are required to validate the clinical utility of digital impressions, understand user training needs, optimize workflow integration, and enhance error reduction during intraoral scanning. Additionally, exploring patient perspectives, satisfaction, and preferences with intraoral scans compared to traditional impressions could provide valuable insights into dental care practices. Long-term studies assessing the durability, accuracy, and performance of restorations created from digital impressions are crucial for establishing the clinical reliability and sustainability of intraoral scanning technologies in dentistry.

Analysis of literature

The analysis of 331 documents from 1998 to 2023 revealed a 15.9% annual growth rate in intraoral scanners and digital dentistry research. This growing body of work, sourced from 136 publications, reflects a focus on recent research trends, with an average document age of 3.28 years. Each document received an average of 14.08 citations, indicating a moderate impact

Table 1. Main information about data.

Description	Results
Main information	
Timespan	1998:2023
Sources (journals, books, etc.)	136
Documents	331
Annual growth rate, %	15.9
Document average age	3.28
Average citations per doc	14.08
References	10,070
Document contents	
Keywords plus	1403
Author's keywords	747
Authors	
Authors	1201
Authors of single-authored docs	20
Authors collaboration	
Single-authored docs	21
Co-authors per doc	4.7
International co-authorships, %	22.05
Document types	
Article	262
Book chapter	5
Conference paper	23
Conference review	2
Editorial	3
Letter	2
Note	1
Review	33

Table 2. Annual scientific production.

Year	Articles	Year	Articles
1998	1	2011	2
1999	0	2012	2
2000	0	2013	8
2001	1	2014	7
2002	0	2015	8
2003	0	2016	8
2004	0	2017	17
2005	0	2018	25
2006	0	2019	31
2007	1	2020	55
2008	0	2021	49
2009	1	2022	74
2010	1	2023	40 (ongoing)

within the research community. With 10,070 references cited, the analysis provides a broad and in-depth exploration of the relevant literature. This study uncovered 1403 distinct keywords and 747 unique author keywords, shedding light on specific research areas and themes. Involving 1201 authors, collaborative efforts are evident, with an average of 4.7 co-authors per document and 22.05% of collaborations being international. Document types ranged from articles to reviews, showcasing the diverse scholarly output in this field. This bibliometric analysis provides a comprehensive picture of research trends and collaboration patterns while offering valuable insights for further exploration in intraoral scanners and digital dentistry (Table 1).

Annual scientific production

Annual scientific production in the field of intraoral scanners and digital dentistry gradually increased from 1998 to 2010, with a low number of articles published during that period. However, starting in 2011, there was noticeable growth in research output, with the number of publications ranging from two to eight per year. The year 2017 marked a significant increase, with 17 articles being published,

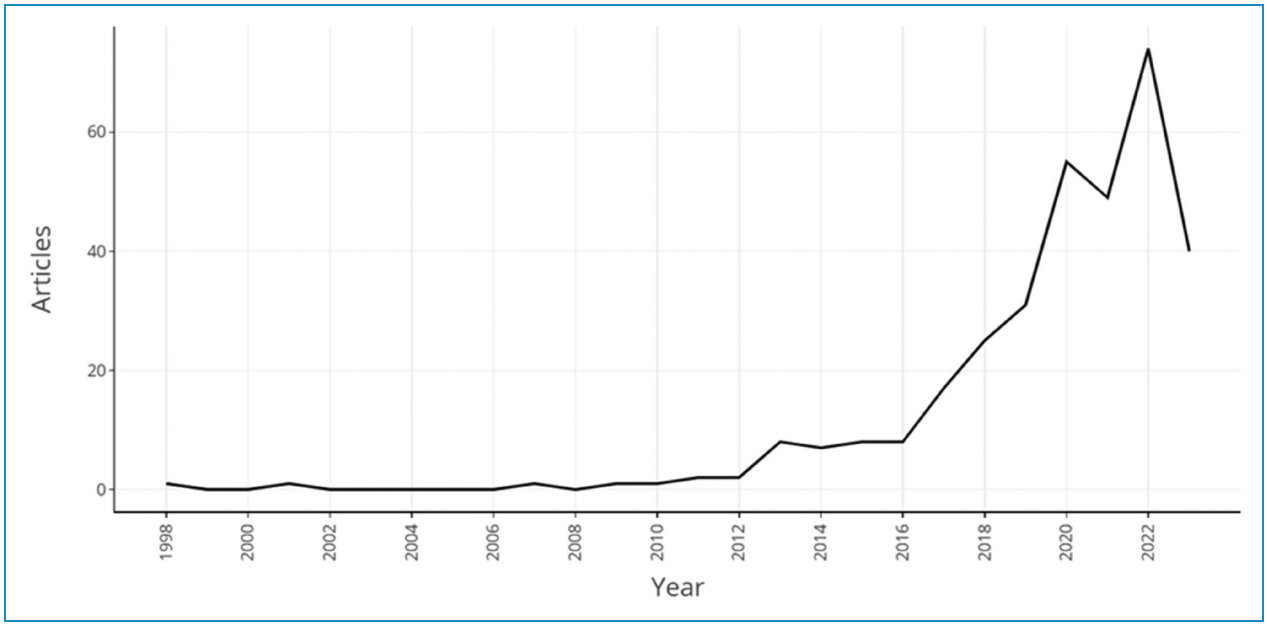

Figure 1. Annual scientific production.

indicating a growing interest in the topic. From 2018 to 2022, there was a consistent increase in annual scientific production, reaching a peak of 74 articles by 2022. However, the number of articles published in 2023 has decreased to 40 compared to the previous year (Table 2 and Figure 1). These findings suggest a growing research interest in the intersection of intraoral scanners and digital dentistry, driven by advancements in technology and emerging trends in dental practice.

Average citations per year

The figurative analysis of citation impact during different years from 1998 to 2023 is illustrated in the figure below. During early years, visibility was very less therefore most of the articles have an average of 0 citations per year and only 1 article had some citations per year which depicts no impact on the community in the initial stage. However, in late years there was a huge difference in citation rates. It means that these articles have a greater impact on the community. For example, in 2007 there was a sudden increase in citations as compared to previous years which is an average of 1.41 citations per year for 17 years and this trend continued with a very high amount of visibility in coming years such as in 2010, 1 article had an average of 4.86 citations per year for 14 years and this means that their visibility increased in the domain. Furthermore, some years had different citation averages for different articles such as in 2013 and 2014 which means that in these years, scholarly impact and quality of the research were enhanced and improved which is good for research (Figure 2 and Table 3).

Analyzing the list of most relevant sources

Examining the leading sources shows that this area of scholarly output has a high focus on dentistry and oral health. The journals 'Journal of Esthetic and Restorative Dentistry' and 'Journal of Prosthetic Dentistry' contribute to 7.94% and 6.23% of articles in the field, respectively. Other important sources contributing to Dentistry and Oral Health articles include 'Applied Sciences (Switzerland)' which contributes 2.29%, 'International Journal of Computerized Dentistry' contributing 1.63% and 'BMC Oral Health' contributing 1.14%. This focus on publication in highly specialized sources points to researchers' preference for publications in established fields that are well-cited and well-received by their community of scholars. This means that, because of their leading position, the citation patterns of the sources are influencing the citation trends of articles in the field (Figures 3 and 4).

Bradford's Law is a statistical pattern that describes the distribution of sources in a bibliographic database. According to Bradford's law, the number of articles published in a field is distributed in a core and multiple zones, with each zone containing fewer articles than the previous zone. The core sources of Bradford's law are those that contribute the most to the field. In the given list, the core sources based on Bradford's law are as follows.

Zone 1:

1. Journal of Esthetic and Restorative Dentistry
2. Journal of Prosthetic Dentistry
3. Applied Sciences (Switzerland)
4. International Journal of Computerized Dentistry
5. BMC Oral Health

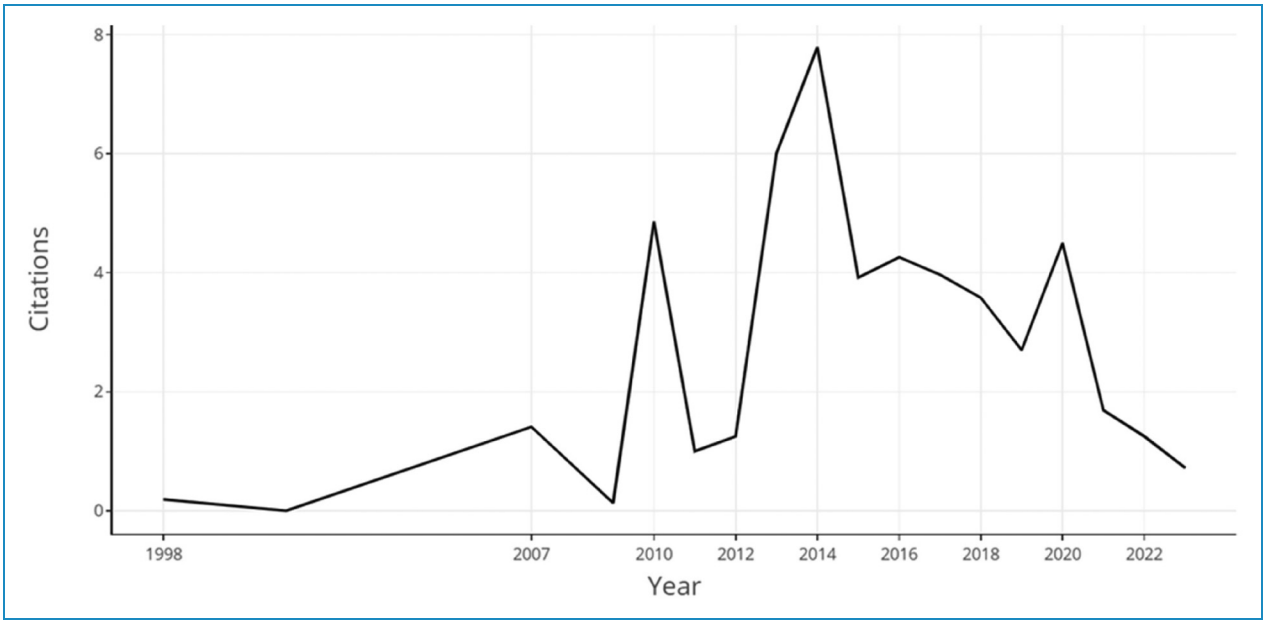

Figure 2. Average citations per year.

Zone 2:

1. International Journal of Environmental Research and Public Health
2. Journal of Dental Sciences
3. Journal of Dentistry
4. Journal of Prosthodontics
5. PLoS ONE

These core sources are the most influential and contribute to a significant number of articles in their respective zones according to Bradford's law.

The data provided showcase the publication trends of the 5 dental journals over a span of 26 years. Notably, the Journal of Esthetic and Restorative Dentistry and Journal of Prosthetic Dentistry have demonstrated consistent growth in publications, with the former reaching a peak of 20 publications by 2023. Applied Sciences (Switzerland) has exhibited a slow start, but its publication output has steadily increased, reaching 14 publications in 2023. The International Journal of Computerized Dentistry maintained a relatively stable publication rate, while BMC Oral Health showed a gradual increase before stabilizing at around to 7 to 9 publications per year since 2020 (Figure 5). These trends suggest growing interest and research activity in the respective dental fields covered by these journals.

Most relevant authors

Figure 6 shows the authors, number of articles they have written, and fractionalized value of their articles. Some notable authors and their corresponding statistics include WÖSTMANN B with 15 articles and a fractionalized value of 3.16, SCHLENZ MA with 14 articles and a fractionalized value of 2.91, SCHMIDT A with 12 articles and a fractionalized value of 2.58, TURKYILMAZ I with 10 articles and a fractionalized value of 2.37, and REVILLA-LEÓN M with 8 articles and a fractionalized value of 1.95 (Figure 6). These values represent the relative contribution of each author's article to the overall body of the work.

The analysis of author productivity through Lotka's law demonstrates a power law distribution in the distribution of authors based on the number of documents written. Of the total authors analyzed, 82.2% authored only one document, whereas 12.4% authored two documents. The proportion of authors decreased as the number of documents increased, showing a pattern consistent with Lotka's law. For instance, only 3.2% of the authors had written three documents, with diminishing proportions for higher document counts (Figure 7).This trend validates Lotka's law, indicating that a small group of highly productive authors generates the majority of publications, whereas most authors have fewer contributions. The data underscores the unequal distribution of scholarly output among authors, emphasizing the impact of a select group on the overall publication landscape.[24,25]

Most relevant affiliations

The compiled data provides a varied representation of universities, hospitals, and research institutions worldwide and their corresponding article counts. The list, arranged by article numbers from highest to lowest, showcases prolific research outputs by institutions like "Justus Liebig University" with 51 articles, "Semmelweis University" with 41 articles, and

Table 3. Average citations per year.

Year	Mean TC per article	N	Mean TC per year	Citable years
1998	5	1	0.19	26
2001	0	1	0	23
2007	24	1	1.41	17
2009	2	1	0.13	15
2010	68	1	4.86	14
2011	13	2	1	13
2012	15	2	1.25	12
2013	66.12	8	6.01	11
2014	77.86	7	7.79	10
2015	35.25	8	3.92	9
2016	34.12	8	4.26	8
2017	27.76	17	3.97	7
2018	21.48	25	3.58	6
2019	13.48	31	2.7	5
2020	17.98	55	4.5	4
2021	5.08	49	1.69	3
2022	2.49	74	1.25	2
2023	0.72	40	0.72	1

TC: total citation count.

"Sapienza University of Rome" with 23 articles. Notable contributions are also seen from "Seoul National University" and "Shandong First Medical University," each with 22 articles, along with the "Medical University of South Carolina" with 21 articles (Figure 8).

Analyzing the research output trends of four key affiliations—Seoul National University, Sapienza University of Rome, Justus Liebig University, and Semmelweis University—reveals compelling patterns. Seoul National University did not publish articles until 2017. Since then, there has been a steady increase, with 22 articles published by 2022. Similarly, Sapienza University of Rome exhibited no articles until 2017, gradually increasing to 23 articles in both 2022 and 2023. Justus Liebig University saw a significant increase from 10 articles in 2020 to 51 articles in 2023, indicating a notable surge in research productivity. Semmelweis University had six articles in 2021, escalating to 41 articles by 2022. These findings illustrate consistent growth in research output for these institutions, reflecting their intensified commitment to scholarly endeavors and notable contributions to academic publishing (Figure 9).

Corresponding author's countries

The data on the corresponding authors' countries revealed interesting patterns in scientific research affiliations. The United States has the highest number of articles, indicating a significant presence in research publications. Germany closely follows this, demonstrating a notable contribution to the scientific community. Italy and Korea have a considerable number of publications, reflecting their active involvement in research. Switzerland and Spain exhibited moderate representation, with Switzerland showing a higher occurrence of multiple corresponding authors. Other countries, such as India, Japan, and Brazil, have single corresponding authors for all their articles, while China and Hungary have a mix of single and multiple corresponding authors. The dataset encompasses a wide range of countries, emphasizing the global nature of scientific collaboration (Figure 10). It is important to interpret these findings within the context of a specific dataset because they may not necessarily reflect the overall distribution of the corresponding authors' countries in scientific research.

The production of scientific articles varies across countries and evolves over time, thus reflecting their research contributions. The United States has consistently maintained a high level of scientific output, with a steady increase from 1998 to 2023, reaching a peak of 270 articles in the most recent year. Germany has also demonstrated a notable growth trend, with a significant rise in production since 2011, culminating in 179 articles by 2023. South Korea's scientific production has also experienced steady growth with a notable surge in recent years, reaching 110 articles by 2023. Spain's research output has shown consistent progress, increasing from 3 articles in 2013 to 75 articles in 2023. Italy, although starting with limited production, has exhibited remarkable growth, with 172 articles by 2023, emphasizing its strong presence in the scientific community. These trends highlight the dynamic nature of scientific research across countries and continuous efforts made to advance knowledge and innovation (Figure 11).

Most cited countries

The list of the most cited countries provides insight into the impact and influence of scientific research. Italy ranks first with a total citation count (TC) of 821, with an average of 29.3 citations per article. The United States closely follows a TC of 693, with an average of 16.1 citations per article. Switzerland stands out, with a high average of 46.5 citations per article, contributing to its TC of 604.

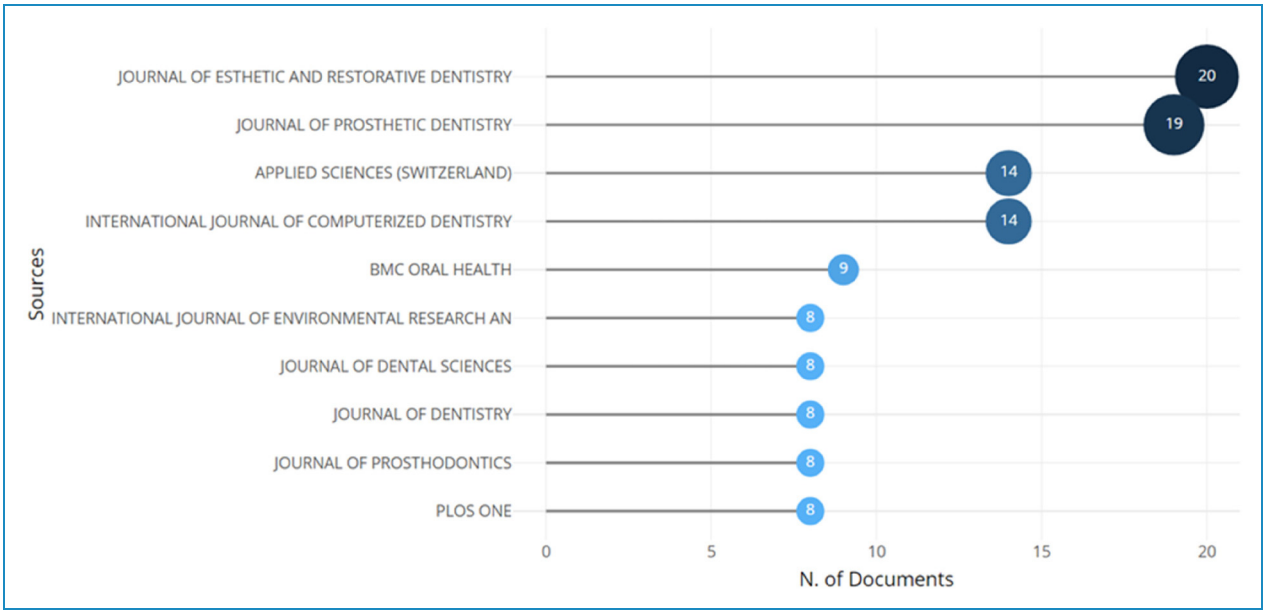

Figure 3. Most relevant sources.

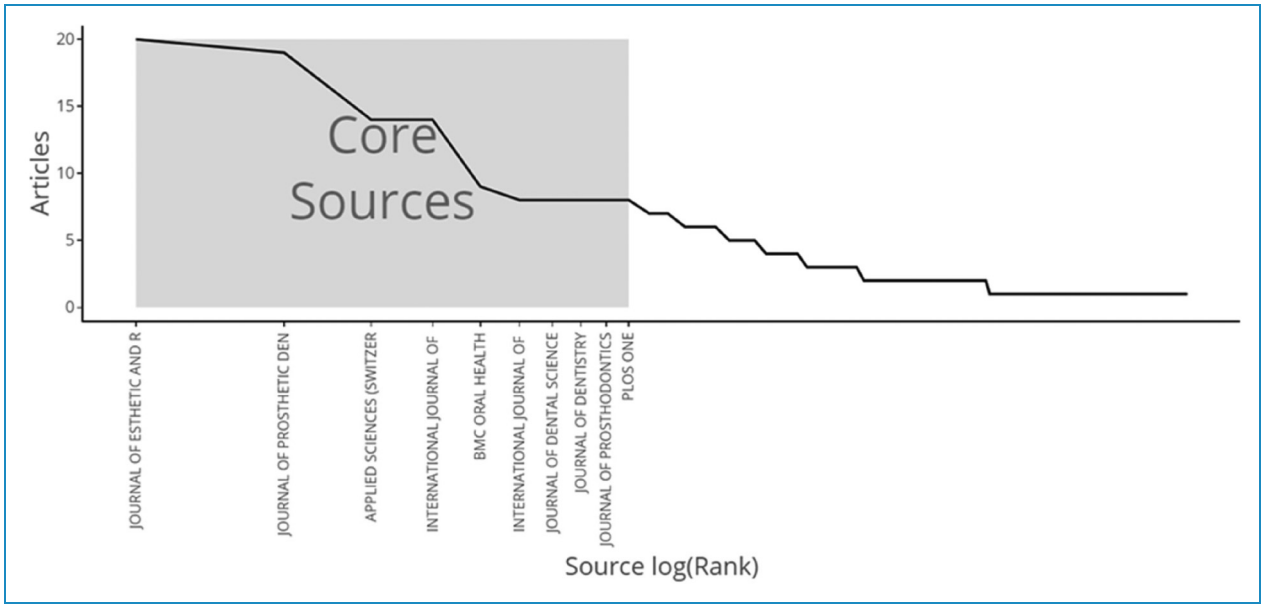

Figure 4. Core sources by Bradford's law.

Germany, with a TC of 465 and an average of 11.9 citations per article, demonstrated its significant research impact. Korea also shows a strong presence, with a TC of 383 and an average of 15.3 citations per article. The Netherlands exhibits a remarkable average of 101.5 citations per article, contributing to its TC of 203. Sweden follows closely, with an average of 90 citations per article and TC of 180. Japan has a TC of 174, with an average of 17.4 citations per article. Spain, Brazil, and India also appear on the list with lower citation counts but provide valuable contributions to the scientific literature (Figure 12). It is important to note that citation counts are not the sole measure of research quality or impact; other factors such as the field of study, publication venue, and research discipline should also be considered.

These findings offer valuable insights into the most influential research in various fields. The two most cited papers are "ENDER A, 2013, J PROSTHET DENT" with

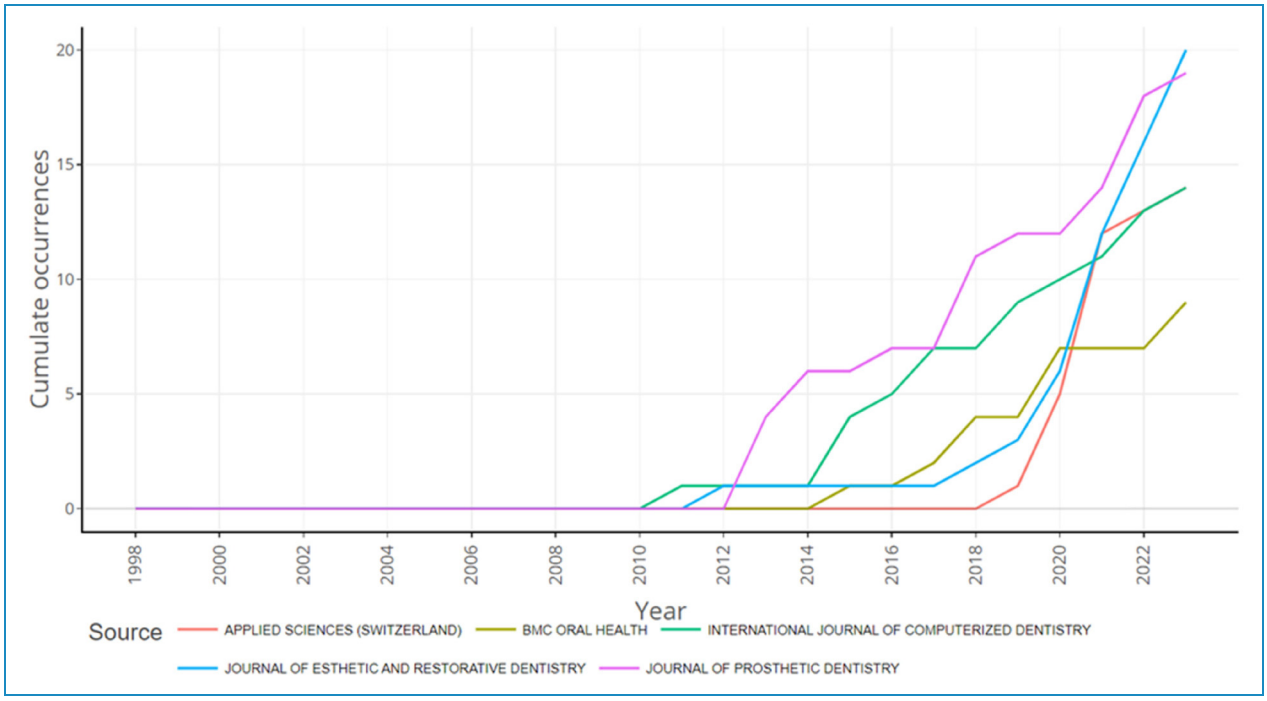

Figure 5. Sources' production over time.

a total of 380 citations and "MANGANO F, 2017, BMC ORAL HEALTH" with 308 citations. These studies have received significant attention within their respective domains and have demonstrated their impact on the research community. Several trends and themes have emerged among the most cited papers. Most studies have focused on dental prostheses and oral health, suggesting the importance of these areas in the field of dentistry. For example, papers such as "ANDRIESSEN FS, 2014, J PROSTHET DENT," "NEDELCU RG, 2014, J PROSTHET DENT," and "MIZUMOTO RM, 2018, J PROSTHET DENT" explore different aspects of prosthodontics and have received significant citations. Another prominent theme is the application of advanced technologies to dentistry. Papers such as "LOGOZZO S, 2014, OPT LASERS ENG-a" and "ZIMMERMANN M, 2015, INT J COMPUT DENT-a" discuss the use of lasers and computer-aided technologies in dental treatments. These findings highlight the growing interest in incorporating innovative approaches into dental practice. Furthermore, some articles have focused on specific topics within the broader field of dentistry. For instance, "ANH J-W, 2016, KOREAN J ORTHOD" explores orthodontic practices, while "BLATZ MB, 2019, DENT CLIN NORTH AM" delves into esthetic dentistry. These papers indicate the diversity of research interests within dentistry and the importance of specialized knowledge. In addition, it is interesting to note that certain papers have consistently high citation rates over time. For example, "ENDER A, 2013, J PROSTHET DENT" not only has 380 citations, but also maintains an average of 34.55 citations per year, indicating its continued relevance and impact in the field (Figure 13). These findings highlight the influential papers in dentistry and oral health research. High citation counts reflect the significance of these studies and their contributions to advancing knowledge and practice in the field. Further exploration of these studies and their specific findings will provide valuable insights for researchers, practitioners, and policymakers in the dental community.

The analysis revealed that "intraoral scanner" and "digital dentistry" were the most common terms, appearing 110 and 105 times, respectively. Other prominent terms included "cad/cam," "digital impression," "accuracy," and "dentistry," with 38, 38, 34, and 31 occurrences. These words highlight the focus on intraoral scanners, digital dentistry, Computer Aided Manufacturing/Computer Aided Design (CAD/CAM) systems, digital impressions, and procedural accuracy in dentistry. Specific areas, such as prosthodontics, orthodontics, dental implants, and esthetic dentistry, were also identified. The prevalence of these terms strongly emphasizes the integration of digital technology across various dental fields (Figure 14).

The word cloud analysis reveals a focus on dentistry, with prominent terms like "dental impression," "CAD," and "three-dimensional imaging," indicating a strong emphasis on technology integration in dental practices. Additionally, word clouds highlight the importance of 3D imaging techniques in dentistry. Terms such as "three-dimensional

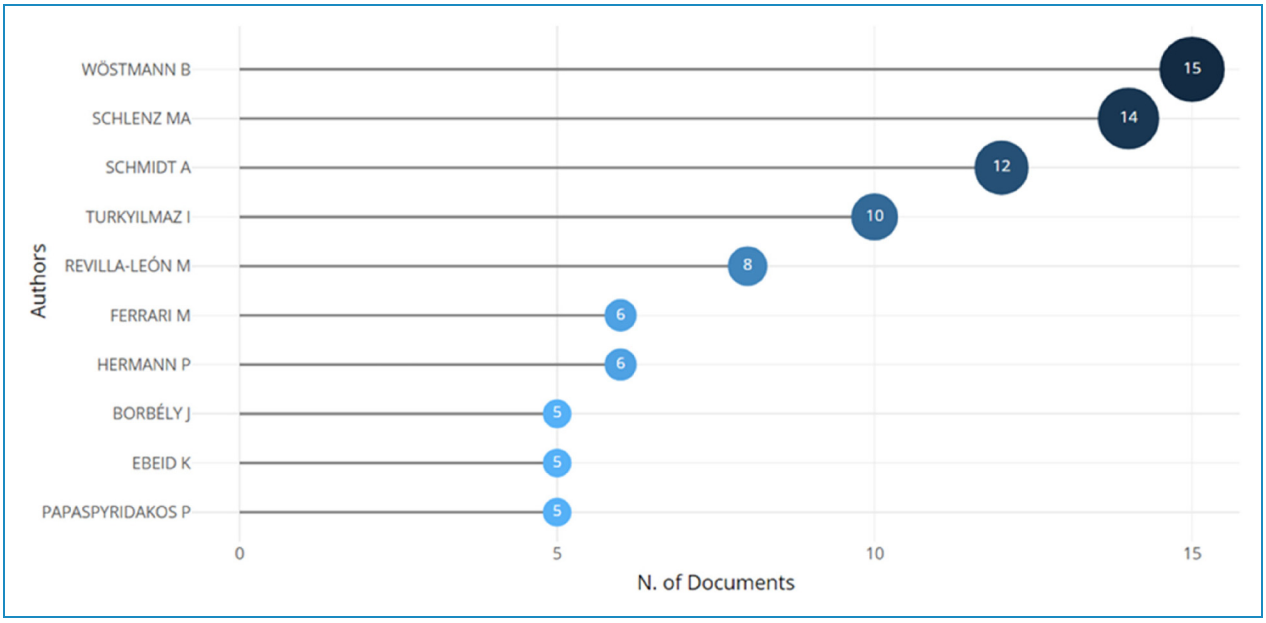

Figure 6. Most relevant authors.

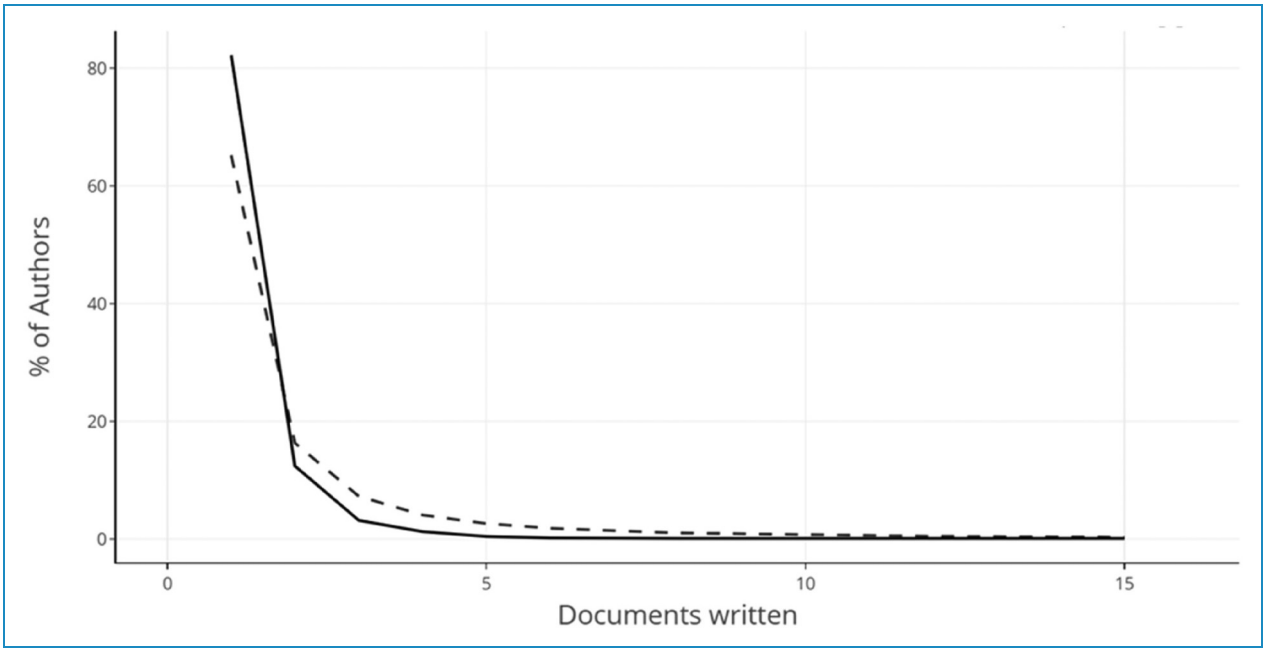

Figure 7. Author productivity through Lotka's law.

imaging," "imaging three-dimensional," and "diagnostic imaging" suggest a focus on advanced imaging technologies, such as cone beam computed tomography (CBCT) and intraoral scanners. These techniques provide detailed and accurate representations of dental structures, enabling better diagnosis, treatment planning, and evaluation of dental conditions.[26,27] Terms related to specific procedures, materials, and demographic factors highlight a comprehensive exploration of dental research themes. The presence of research methodologies and article types underscores the scientific nature of the analyzed texts, emphasizing evidence-based practices in dentistry. Overall, the word cloud offers a condensed yet insightful summary of key concepts in dental literature, showcasing the impact of technology, procedural focus, and demographic considerations within the dataset (Figure 15).

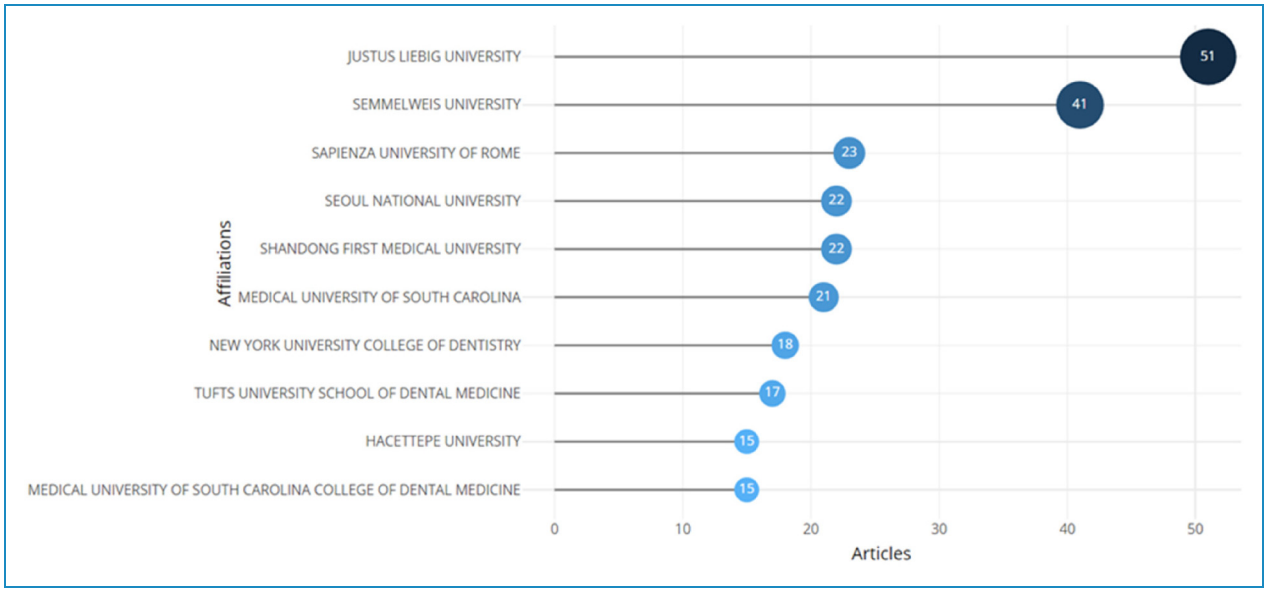

Figure 8. Most relevant affiliations.

Trend topics

Most trending topics are shown in Figure 16.

Photography, Dental. The frequency of this topic gradually increased from 2009 to 2017, suggesting a growing focus on dental photography techniques and their application in digital dentistry.

Methodology. The frequency of this topic has remained relatively consistent over the years, indicating continued emphasis on research methods and approaches in the field of digital dentistry.

Computer interface. The frequency of this topic peaked in 2013 and then gradually declined. This trend suggests a focus on the development and utilization of computer interfaces for dental applications, potentially followed by a shift towards other technological advancements.

Tooth prosthesis. The frequency of this topic peak around 2013 to 2014 and then declined. This trend reflects a period of significant interest in tooth-prosthesis design and implant-supported dental prostheses.

Image analysis. The frequency of this topic will gradually increase from 2013 to 2022, indicating an ongoing focus on the analysis of dental images by using digital techniques and algorithms.

Titanium. The frequency of this topic peak around 2013 to 2014 and then gradually declined. This trend suggests a period of interest in the use of titanium in dental implants and prostheses.

Patient care planning. The frequency of this topic consistently increased from 2013 to 2018, highlighting the growing importance of comprehensive care planning in digital dentistry to enhance patient outcomes.

Equipment design. The frequency of this topic steadily increased from 2012 to 2018, indicating a continuous focus on the design and development of dental equipment, particularly in the context of digital dentistry.

Temporomandibular joint. The frequency of this topic shows a relatively steady pattern, with a slight increase from 2015 to 2022. This trend suggests ongoing research and interest in the temporomandibular joint and its relationship with digital dentistry. Only a few examples of trends are observed in the data provided. The frequencies and years associated with each topic provided insights into the evolving focus areas within the fields of intraoral scanners and digital dentistry, reflecting the dynamic nature of research, technology, and patient care in this domain (Figure 16).

Co-occurrence network

The co-occurrence network provided insights into the relationships between the different terms in the context of intraoral scanners and digital dentistry (Figure 17). The key observations are as follows.

Intraoral scanner and digital dentistry. These two terms were closely clustered in the network, indicating their strong

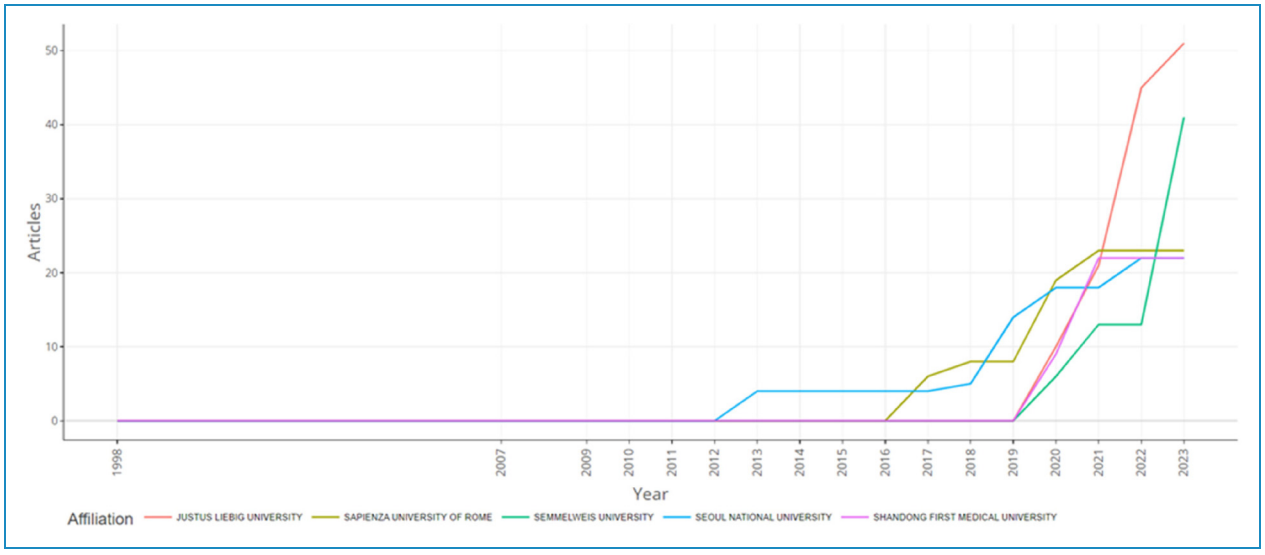

Figure 9. Affiliations' production over time.

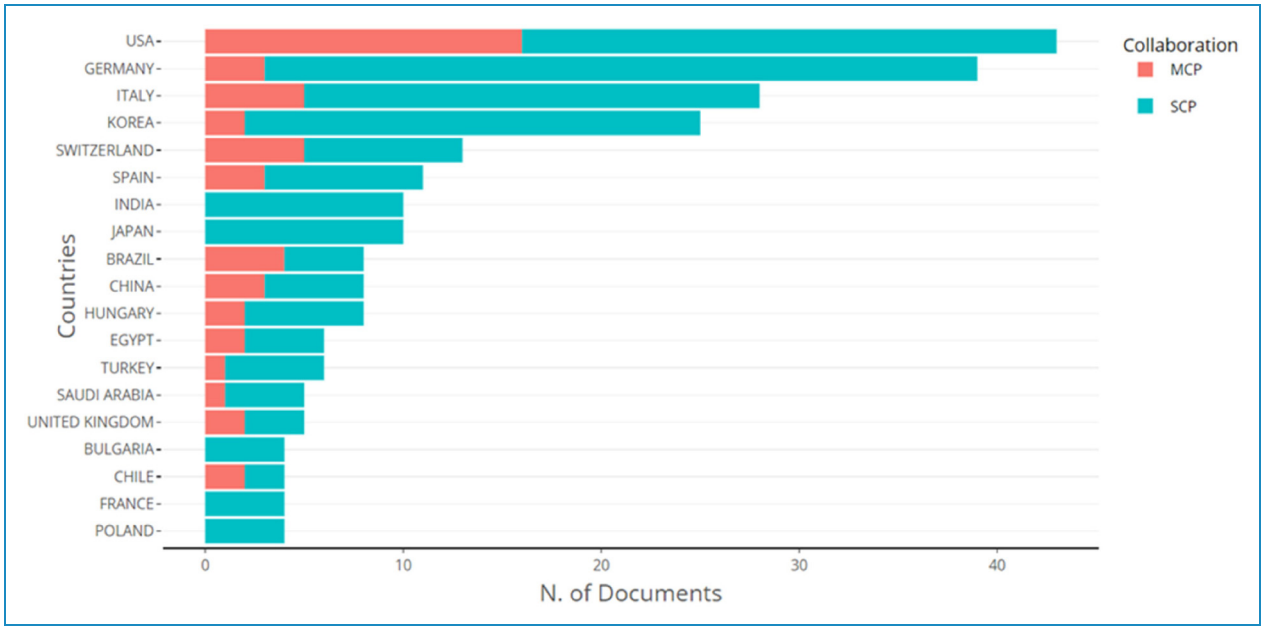

Figure 10. Corresponding author's countries.

association and relevance within the field. They have high betweenness centrality and closeness, suggesting their significance as the central nodes in the network. Additionally, they have relatively high PageRank values, indicating their importance in terms of the information flow within the network.

Digital impression and accuracy. These terms are also closely connected in the network, indicating their relationship and potentially shared focus on research and practice. They had moderate betweenness centrality and closeness scores, suggesting their importance in connecting the different parts of the network.

3D printing and tooth wear. These terms have a relatively weak connection with other nodes in the network. They had low betweenness centrality, suggesting that they did not play a significant role in connecting different parts of the network. However, their presence in the network indicates their relevance in intraoral scanners and digital dentistry.

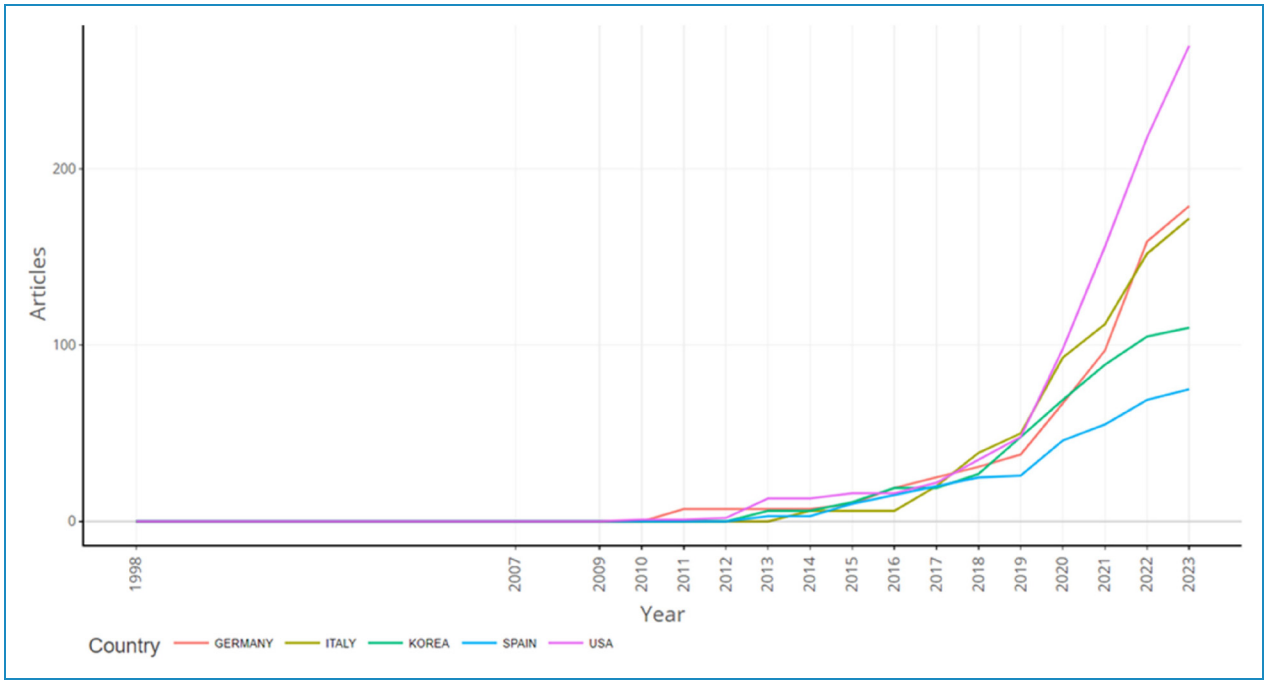

Figure 11. Countries' production over time.

CAD/CAM. This term forms a separate cluster in the network and has a high betweenness centrality and PageRank values. This suggests that CAD/CAM is a central and influential concept within the field with strong connections to other terms in the network.

Dental materials. This term also forms a separate cluster and has moderate betweenness centrality. This indicates the importance of dental materials in intraoral scanners and digital dentistry.

Dentistry. The term "dentistry" had the highest betweenness centrality in the network, indicating its critical role in connecting different parts of the network. It also has a relatively high PageRank value, suggesting its importance in the broader context of intraoral scanners and digital dentistry.

The co-occurrence network provides a visual representation of the relationships and the importance of different terms within the fields of intraoral scanners and digital dentistry. It highlights the central concepts, influential nodes, and clusters of related terms, offering insights into key areas of focus and research within this domain.

Discussion

Between 2018 and 2022, there was a notable and steady growth in the yearly scientific output, culminating in a pinnacle of 74 papers by the year 2022. Notably, the average number of citations per year exhibited a shifting pattern over time. While several years had greater mean values, the others had lower mean values. This observation suggests that there are fluctuations in the quantity and influence of research findings throughout various time periods.

The "Journal of Esthetic and Restorative Dentistry" and the "Journal of Prosthetic Dentistry" are prominent sources with a substantial volume of papers underscoring their notable influence within the profession. Additional noteworthy sources that provide substantial contributions to research production include "Applied Sciences (Switzerland)," "International Journal of Computerised Dentistry," and "BMC Oral Health." BMC Oral Health is particularly prominent in this regard. The Journal of Esthetic and Restorative Dentistry and the Journal of Prosthetic Dentistry have shown a steady increase in the number of published articles, with the former reaching its zenith of 20 publications by the year 2023.

Several prominent writers and their respective publication records were identified. Notably, author WÖSTMANN B has contributed to the academic community with a total of 15 articles. Similarly, author SCHLENZ MA made significant contributions to 14 articles, while author SCHMIDT A published 12 articles. These authors have demonstrated their dedication to scholarly research and have made valuable contributions to their respective fields.

"Justus Liebig University" has shown a notable level of research productivity, as seen by the astounding total of 51 papers associated with the institution. In recent years, Seoul National University has seen a notable upswing in research production, indicating a growing dedication to the dissemination of scholarly work.

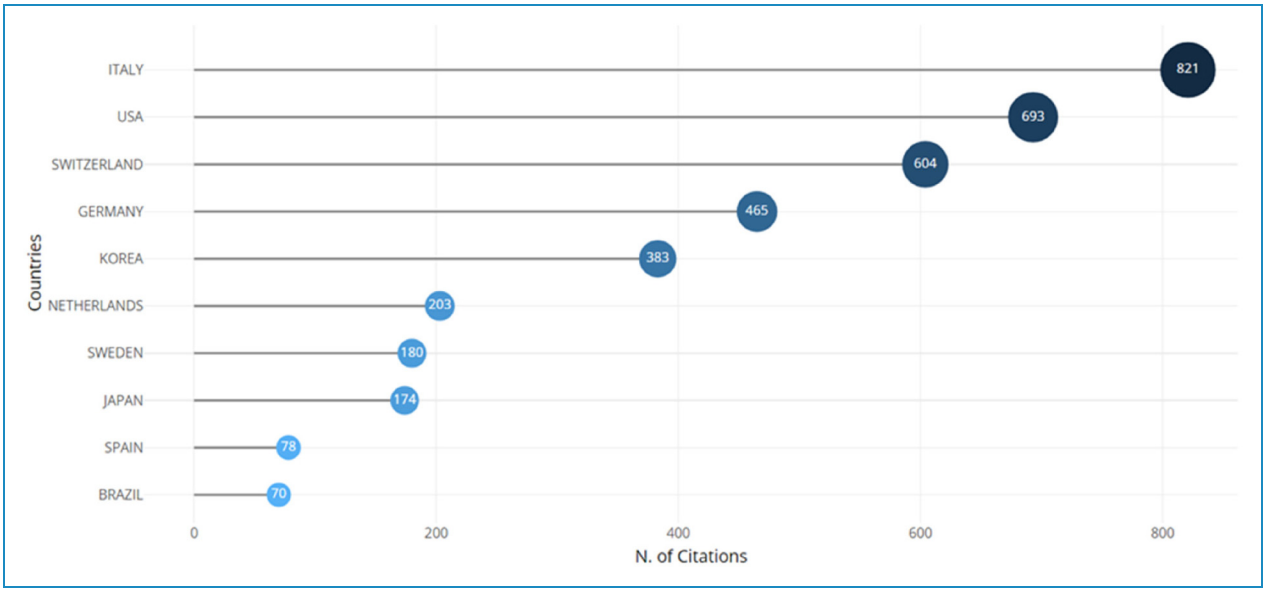

Figure 12. Most cited countries.

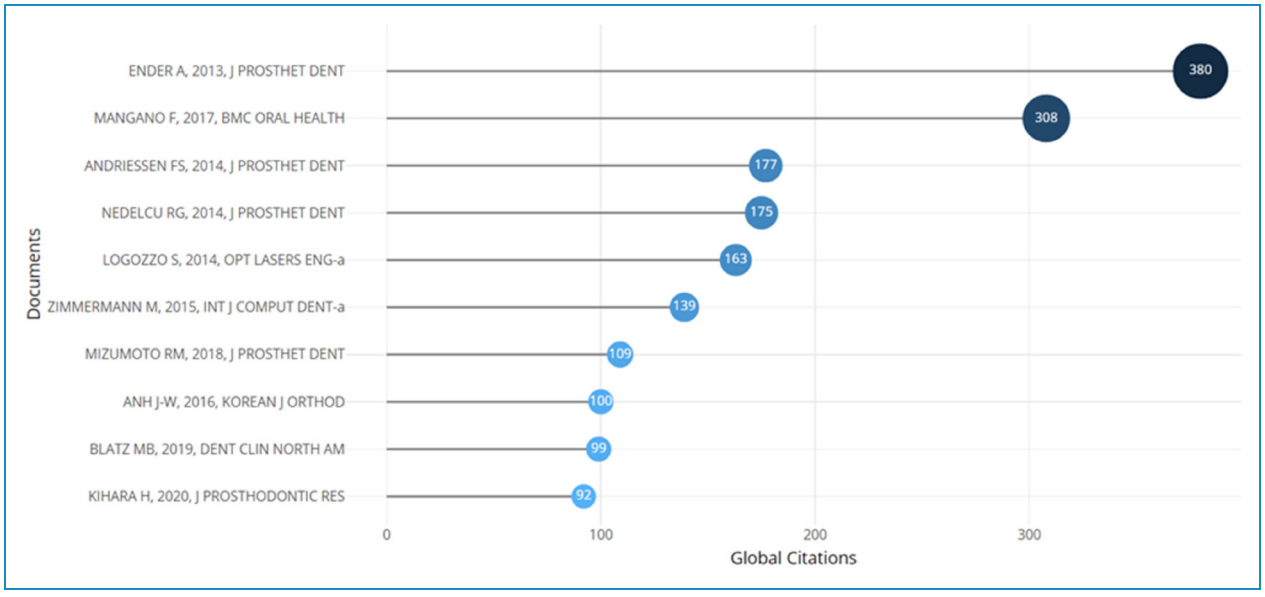

Figure 13. Most global cited documents.

The United States has notable prominence in research publications, as evidenced by its largest number of papers. Germany exhibits strong adherence to this practice, thereby showcasing a noteworthy contribution to the scientific world. The United States has consistently shown a notable degree of scientific productivity, demonstrating a stable upward trajectory from 1998 to 2023, culminating in a pinnacle of 270 scholarly papers in recent years. Italy is positioned at the top of the rankings, with a TC of 821, accompanied by an average of 29.3 citations per article. The United States diligently adheres to a total citation count of 693, with an average of 16.1 citations per piece. Switzerland exhibits a notable distinction as it has a significantly elevated average of 46.5 citations per article, making a substantial contribution to its TC of 604.

Implications for intraoral scanner literature in dentistry

In dental research, intraoral scanning technology has garnered attention owing to its significant advantages. The integration of intraoral scanners has notably enhanced the

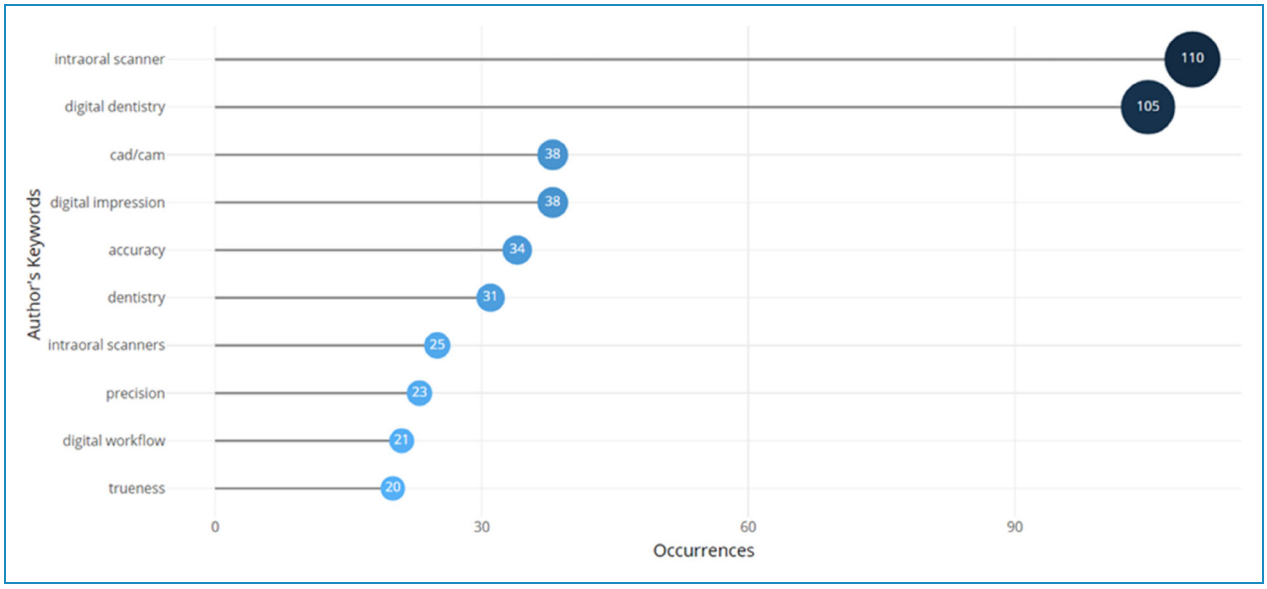

Figure 14. Most frequent words.

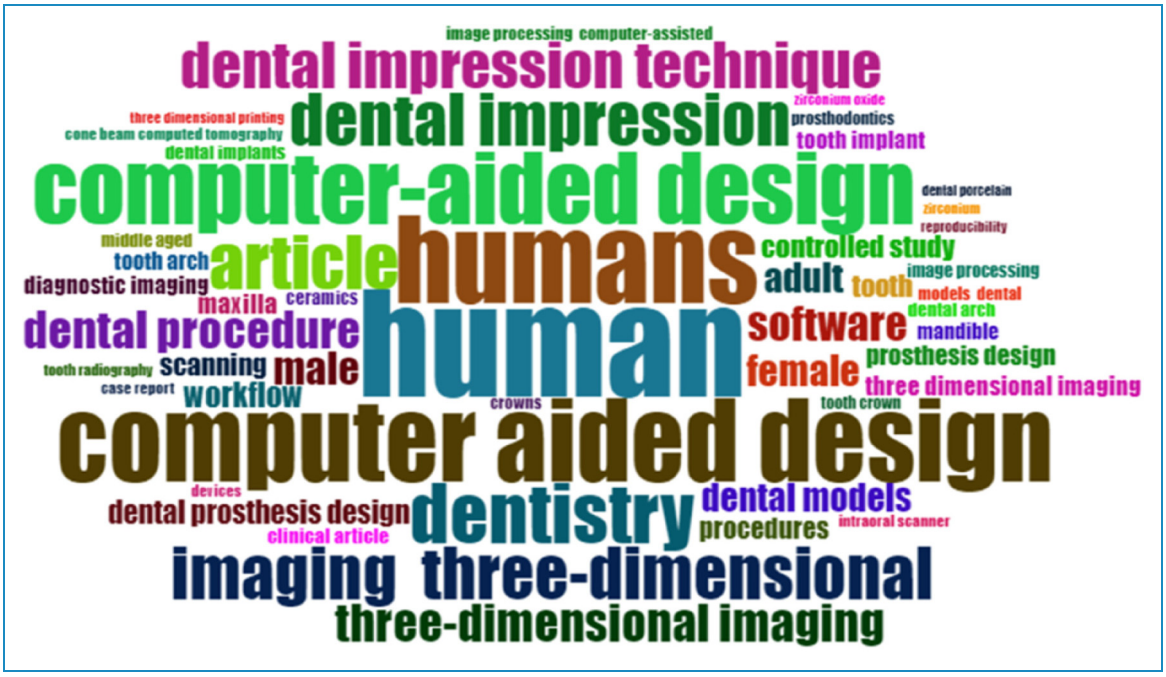

Figure 15. Word cloud.

precision and accuracy of dental impressions, reducing errors and improving treatment planning reliability[16]

Patients benefit from a more comfortable and efficient process using intraoral scanners, leading to higher satisfaction levels and enhanced perceptions of dental care.[1] By streamlining digital workflows and reducing the need for physical materials, intraoral scanners offer time-saving benefits and potential cost reductions, thereby showcasing their efficiency in practice.[28]Intraoral scanner technology paves the way for seamless sharing of digital impressions among dental professionals, promoting effective interdisciplinary treatment planning, and ultimately contributing to improved patient outcomes.[29]

Limitations of the Study

Bibliometric analysis can be influenced by various biases and limitations. Publication bias may lead to an under-

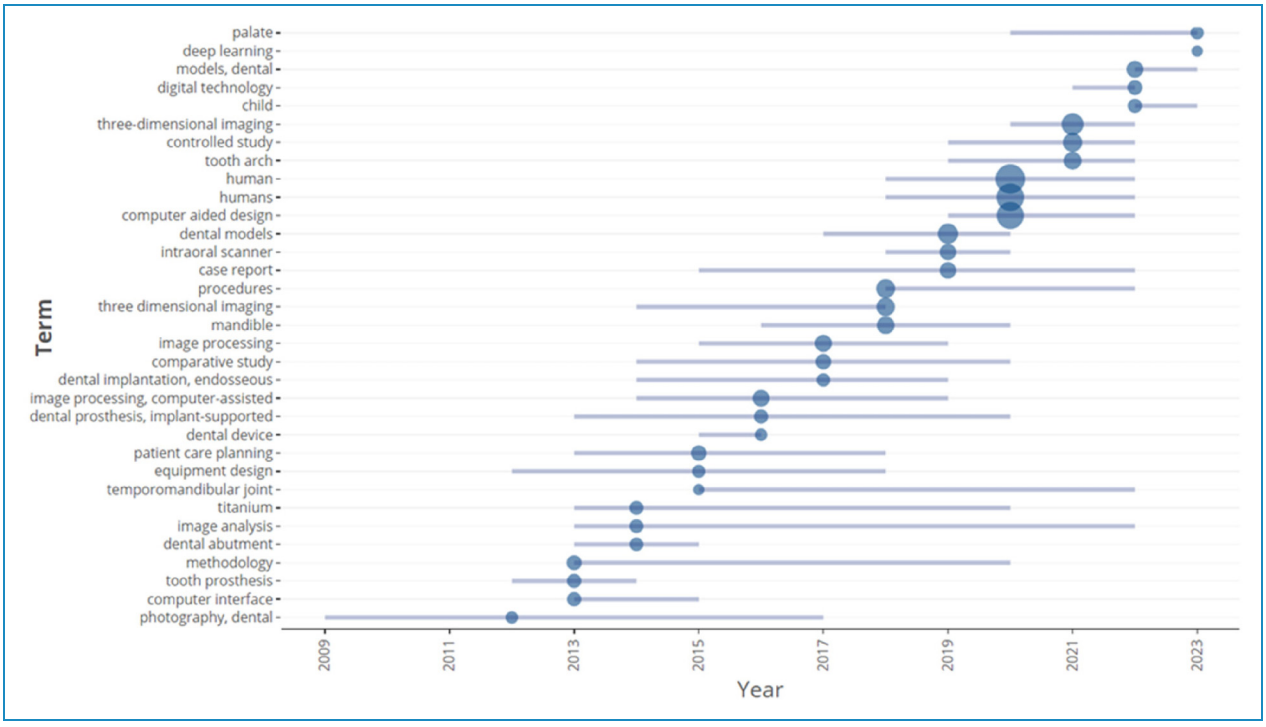

Figure 16. Trend topics.

representation of negative or nonsignificant findings. Language bias, particularly towards English publications, could restrict the inclusivity of the analysis. Limited timeframes and database selections may overlook valuable older studies and diverse sources of information. Additionally, focusing on peer-reviewed journal articles may neglect insights from other publication types such as conference proceedings or reports. Varying study quality and potential errors in data extraction can affect the reliability of the analysis. A narrow focus solely on intraoral scanners in dentistry may hinder a broader understanding of scanning technologies and their implications in the field.

Possible future research directions

There are several potential future research directions for the use of intraoral scanners in dentistry, which can further enhance their impact and utility.

First, exploring the integration of artificial intelligence (AI) and machine learning algorithms with intraoral scanners could revolutionize their capabilities.[30] Research could focus on developing algorithms that can automate tasks such as tooth segmentation, shade matching, and restoration design, thereby improving efficiency and accuracy.

Second, investigating the use of intraoral scanners in novel applications such as orthodontics and endodontics could expand their scope. Research should explore how intraoral scanners can aid in the assessment of tooth movement during orthodontic treatment or assist in precise canal measurements during root canal procedures.[3,20]

In addition, evaluating the long-term performance and durability of restorations fabricated from digital impressions obtained using intraoral scanners could provide valuable information. Comparative studies against traditional impression techniques could help to identify any potential advantages or limitations specific to the use of intraoral scanners.[2]

Furthermore, considering patient-oriented outcomes and studying the impact of intraoral scanners on patient satisfaction and treatment acceptance are crucial. Exploring patients' perceptions, experiences, and preferences when scanned with intraoral scanners compared to traditional methods can provide valuable insights for improving patient care.[2]

Finally, research on the integration of intraoral scanners with other digital technologies, such as 3D printing and virtual reality, could open new avenues for advanced treatment planning and personalized dental care[1]

Overall, these future research directions have the potential to further optimize the use of intraoral scanners in dentistry, enhance their efficiency, expand their applications, and ultimately improve patient outcomes.

Conclusion

In conclusion, bibliometric analysis of intraoral scanners showed important trends and advancements in dentistry.

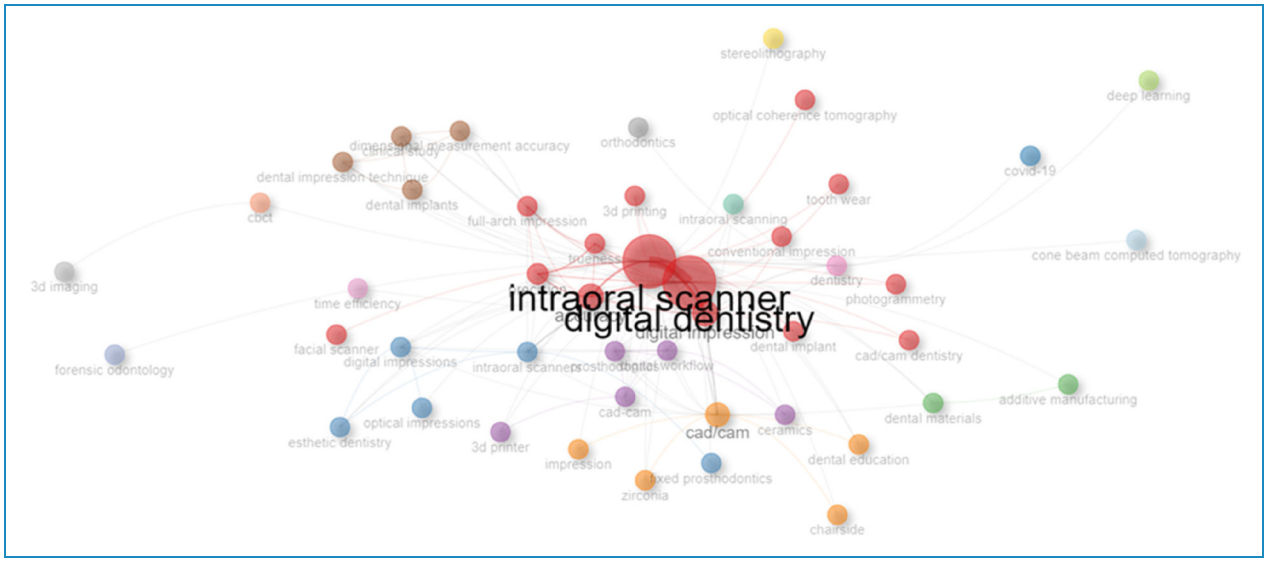

Figure 17. Co-occurrence network.

It is noted that there is limited number of original articles in this field of study, which could be attributed to publication bias and language restrictions. Despite that, the advantage of scanners and the importance in impressions, patient care and smooth and efficient workflow was highlighted. Improvement in collaboration and productivity were also noted. There are recommendations for improving the future analysis, such as expanding the search strategy, refining the quality analysis and more appropriate statistical technique. This will give readers, dentist, researchers and industries an advantage in knowing the field completely and make evidence-based new discovery.

Author contributions: RS and VNVM were involved in conceptualization and methodology; RS, VNVM, and AK in data curation and formal analysis; RS and AO in investigation and resources; RS and JR in original draft preparation; AH, JR, SH, and AA in writing, reviewing, and editing; AK, AH, and AA in supervision and project administration; and AK in funding acquisition.

Data availability statement: The data is available upon genuine request.

Declaration of conflicting interests: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding: The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through large group Research Project under grant number RGP2/452/44.

Guarantor: RS

ORCID iD: Artak Heboyan https://orcid.org/0000-0001-8329-3205

References

1. Mangano F, Gandolfi A, Luongo G, et al. Intraoral scanners in dentistry: a review of the current literature. *BMC Oral Health* 2017; 17: 149.
2. Tomita Y, Uechi J, Konno M, et al. Accuracy of digital models generated by conventional impression/plaster-model methods and intraoral scanning. *Dent Mater J* 2018; 37: 628–633.
3. Winkler J and Gkantidis N. Trueness and precision of intraoral scanners in the maxillary dental arch: an in vivo analysis. *Sci Rep* 2020; 10: 1172.
4. Gupta S, Patil N, Solanki J, et al. Oral implant imaging: a review. *Malays J Med Sci* 2015; 22: 7.
5. Chiu A, Chen Y-W, Hayashi J, et al. Accuracy of CAD/CAM digital impressions with different intraoral scanner parameters. *Sensors (Basel)* 2020; 20(4): 1157. doi: 10.3390/s20041157
6. Hamalian TA, Nasr E and Chidiac JJ. Impression materials in fixed prosthodontics: influence of choice on clinical procedure. *J Prosthodont* 2011; 20: 153–160.
7. Ainoosah S, Farghal AE, Alzemei MS, et al. Comparative analysis of different types of occlusal splints for the management of sleep bruxism: a systematic review. *BMC Oral Health* 2024; 24: 29.
8. Heboyan A and Bennardo F. New biomaterials for modern dentistry. *BMC Oral Health* 2023; 23: 817.
9. Zhang F, Suh KJ and Lee KM. Validity of intraoral scans compared with plaster models: an in-vivo comparison of dental measurements and 3D surface analysis. *PLoS ONE* 2016; 11: e0157713.
10. Motel C, Kirchner E, Adler W, et al. Impact of different scan bodies and scan strategies on the accuracy of digital implant impressions assessed with an intraoral scanner: an in vitro study. *J Prosthodont* 2020; 29: 309–314.

11. Vohra M and Shenoy A. In vitro evaluation of accuracy and reliability of tooth shade selection using different digital instruments. *Cureus* 2024; 16: e52363.
12. Fagundes NCF, Minervini G, Furio Alonso B, et al. Patient-reported outcomes while managing obstructive sleep apnea with oral appliances: a scoping review. *J Evid Based Dent Pract* 2023; 23(1s): 101786.
13. Shenoy A, Maiti S, Nallaswamy D, et al. An in vitro comparison of the marginal fit of provisional crowns using the virtual tooth preparation workflow against the traditional technique. *J Indian Prosthodont Soc* 2023; 23: 391–397.
14. Saini RS, Gurumurthy V, Quadri SA, et al. The flexural strength of 3D-printed provisional restorations fabricated with different resins: a systematic review and meta-analysis. *BMC Oral Health* 2024; 24: 66.
15. Heboyan A, Zafar MS, Rokaya D, et al. Insights and advancements in biomaterials for prosthodontics and implant dentistry. *Molecules* 2022; 27: 5116.
16. Ender A and Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. *J Prosthet Dent* 2013; 109: 121–128.
17. Dohiem MM, Emam NS, Abdallah MF, et al. Accuracy of digital auricular impression using intraoral scanner versus conventional impression technique for ear rehabilitation: a controlled clinical trial. *J Plast Reconstr Aesthet Surg* 2022; 75: 4254–4263.
18. Abdelaziz MS and Tella E. Digital designing of a 3D-printed stackable ear mold for auricular rehabilitation: a technical note. *Int J Prosthodont* 2023; 36: 637–641.
19. Abdelaziz MS and Tella E. Digital fabrication of polyetheretherketone retentive bar attachment inserts as overdenture maintenance: A dental technique. *J Prosthet Dent* 2022: S0022-3913(22)00275-X. doi: 10.1016/j.prosdent.2022.04.019
20. Christopoulou I, Kaklamanos EG, Makrygiannakis MA, et al. Intraoral scanners in orthodontics: a critical review. *Int J Environ Res Public Health* 2022; 19(3): 1407. doi: 10.3390/ijerph19031407
21. Róth I, Hermann P, Vitai V, et al. Comparison of the learning curve of intraoral scanning with two different intraoral scanners based on scanning time. *BMC Oral Health* 2023; 23: 267.
22. Elbashti M, Molinero-Mourelle P, Aggarwal H, et al. Feasibility and accuracy of using intraoral scanners to digitize maxillectomy defects for prosthetic rehabilitation: a systematic review. *Int J Maxillofacial Prosthet* 2022; 5: 3–9.
23. Smink WAC, Fox J-P, Tjong Kim Sang E, et al. Understanding therapeutic change process research through multilevel modeling and text mining. *Front Psychol* 2019; 10: 1186.
24. Snaith BA. An evaluation of author productivity in international radiography journals 2004–2011. *J Med Radiat Sci* 2013; 60: 93–99.
25. Adigwe I. Lotka's law and productivity patterns of authors in biomedical science in Nigeria on HIV/AIDS: a bibliometric approach. *Electron Lib* 2016; 34: 789–807.
26. Bornstein MM, Horner K and Jacobs R. Use of cone beam computed tomography in implant dentistry: current concepts, indications and limitations for clinical practice and research. *Periodontol* 2017; 73: 51–72.
27. Lee D-G, Son K and Lee k-b. Comparison of the accuracy of intraoral scanners based on the type of tooth preparation for a single crown. *Appl Sci* 2021; 11: 1–10.
28. Sawase T and Kuroshima S. The current clinical relevancy of intraoral scanners in implant dentistry. *Dent Mater J* 2020; 39: 57–61.
29. García-Gil I, Cortés-Bretón-Brinkmann J, Jiménez-García J, et al. Precision and practical usefulness of intraoral scanners in implant dentistry: a systematic literature review. *J Clin Exp Dent* 2020; 12: e784–e793.
30. Alshadidi AAF, Alshahrani AA, Aldosari LIN, et al. Investigation on the application of artificial intelligence in prosthodontics. *Appl Sci* 2023; 13: 5004.