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Review Article

Assessing the Current Landscape and Future Directions of Digital Denture Technology

Ravinder S. Saini[1] Muhammad Sohail Zafar[2,3,4,5] Necdet Adanir[6]
Mario Alberto Alarcón-Sánchez[7] Artak Heboyan[8,9]

[1] Department of Dental Technology, COAMS, King Khalid University, Abha, Saudi Arabia
[2] Department of Clinical Sciences, College of Dentistry, Ajman, United Arab Emirates
[3] Centre of Medical and Bio-allied Health Sciences Research, Ajman University, Ajman, United Arab Emirates
[4] School of Dentistry, University of Jordan, Amman, Jordan
[5] Department of Dental Materials, Islamic International Dental College, Riphah International University, Islamabad, Pakistan
[6] Department of Restorative Dentistry, College of Dentistry, King Faisal University, Al Ahsa, Saudi Arabia
[7] Biomedical Science, Faculty of Chemical-Biological Sciences, Autonomous University of Guerrero, Guerrero, Mexico
[8] Department of Research Analytics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India
[9] Department of Prosthodontics, Faculty of Stomatology, Yerevan State Medical University after Mkhitar Heratsi, Yerevan, Armenia

Address for correspondence Artak Heboyan, PhD, Department of Prosthodontics, Faculty of Stomatology, Yerevan State Medical University after Mkhitar Heratsi, Str. Koryun 2, Yerevan 0025, Armenia (e-mail: heboyan.artak@gmail.com).

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Abstract

Digital dentures are removable dental prostheses fabricated using computer-aided design/computer-aided manufacturing (CAD/CAM) technology. This study aimed to explore the trends in digital dentures. A comprehensive four-phase search and selection strategy was framed.

Dimensions and Lens.org databases were used. Boolean operators were used to combine keywords.

The most significant growth occurred by 2021, with 71 publications and 984 citations. Egypt had the highest publication rankings, with 46 total publications (TP) and 45 total citations (TC). The University of Geneva played a significant role in contributing to 16 TP and 491 TC. *Egyptian Dental Journal* ranked at the top. The group with four authors had an even higher number of authorships, with a total of 60. The top four keywords were CAD/CAM, 3D printing, CAD-CAM, complete denture, and digital dentistry. The Glossary of Prosthodontic Terms, Ninth Edition, was referenced 614 times and had the highest average number of citations (75.2). The top three writers had strong relationships with the three sources and preferred to publish using four keywords. The 11-author group, cluster 6, had the highest level of network cooperation.

In conclusion, research on digital dentures has grown in terms of number of articles and citations.

Keywords
- digital denture
- bibliometric trends
- CAD-CAM
- 3D printing
- complete dentures

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Introduction

The field of dentistry has undergone a revolutionary transformation since the introduction of digital dentistry. One of the significant advancements in this field is the utilization of computer-aided design and computer-aided manufacturing (CAD/CAM) technology to create digital dentures.[1] These dentures are removable dental prostheses fabricated through the precise process of CAD/CAM technology.[2] Comparing digital dentures to traditional dentures provides a number of benefits, including greater retention, better appearance, and less labor.[3]

Analyzing current trends and the state of research on digital denture technology is essential as it continues to develop. Using bibliometric analysis, researchers can find significant authors, preeminent institutions, and hot themes by quantitatively evaluating scientific publications in a certain area. The goal of this bibliometric research is to examine the trends in the literature on digital dentures, concentrating on how fully removable dental prostheses are made using CAD/CAM technology. By providing an overview of the present state of digital complete denture technology, this study puts the research from a larger perspective and emphasizes its significance.[4] This study also discusses the clinical outcomes,[5] reviews the latest trends in digital dentistry,[6] and revisits complete denture aesthetics in the digital age.[7] This study's analysis of the literature on digital dentures intends to shed light on the status of this field's research and highlight potential directions for further investigation.

The goal of this bibliometric study was to examine the trends in the literature on digital dentures, with an emphasis on how full removable dental prostheses are made using CAD/CAM technology.[8] This study attempts to shed light on the current status of this field's research and highlight potential directions for further investigation. The importance of this study rests in the fact that CAD/CAM technologies have enabled the creation of digital dentures, revolutionizing the field of dentistry. Comparing digital dentures to traditional ones provides a number of benefits, including greater retention, better appearance, and less labor.[9] This study may contribute to the development of digital denture technology and enhance patient outcomes by identifying knowledge gaps and potential topics for future research via an analysis of the literature on the subject.

Several bibliometric analyses have focused on the status of research on digital dentures.[10–12] These studies employed bibliometric analysis to assess the features of literature pertaining to dental research and education, as well as trends in the publication of antibacterial dental adhesive literature. The results of these studies have shed light on the development of and other distinctive changes in dentistry, offering perceptions on how the field's overall body of knowledge changes over time. In relation to digital dentures, research on the clinical use of CAD/CAM and three-dimensional (3D) printed dentures came to the conclusion that the primary benefits of digital dentures were time-saving, record creation, and production of a clinically acceptable denture.[2,13,14] However, divergent theories have been proposed on this subject. For instance, research on the aesthetics of full dentures in the digital era has discovered that biometric measures have become clearer over the last 60 years, acting as the foundation for both analog and digital denture aesthetics.[12] In addition, a bibliometric study of artificial intelligence (AI) in dentistry has indicated the field's frontiers and research trends.[11]

While there is evidence to support the overall benefits of digital dentures, there are also opposing theories and areas that need further study. To improve digital denture technology and enhance patient outcomes, bibliometric analysis may be used to discover knowledge gaps and potential research topics.

The main goal of this research was to conduct a bibliometric examination of the development and changes in the area of digital dentures. Digital dentures were made possible using CAD/CAM technology,[15,16] which revolutionized the dental industry. In order to expand digital denture technology and enhance patient outcomes, the study intends to identify knowledge gaps and potential research topics. The goal of this research was to obtain insights into how the field of dentistry as a whole is changing over time and how to advance digital denture technology to benefit patients. This goal can be accomplished by reviewing the literature on digital dentures.[17,18] The key finding is that there are data demonstrating the benefits of digital dentures, but there are also conflicting ideas and areas that require further study. To improve digital denture technology and enhance patient outcomes, bibliometric analysis may be used to discover knowledge gaps and potential research topics.

Methods

The Dimensions database's digital denture literature is indexed, and the bibliometric analysis examines the publishing patterns of that literature. While bibliometric analysis is a statistical tool for examining publishing trends, patterns, and the extent of published academic work, the Dimensions database is acknowledged as a legitimate and trustworthy indexing and abstracting database on a worldwide scale.

Search Strategy

This bibliometric analysis focused on the Dimensions database because it is comprehensive and easy to use, which is acceptable for the scope of this study. The present database provides wider coverage to international, peer-reviewed journals between the years 2013 and 2023 providing a better extent of analysis as compared to other databases like Scopus or Web of Science. In the first round, we searched for international peer-reviewed journals and came up with 1,206 journals. To control the appropriateness and the quality of the collection, a more sophisticated search strategy was applied. This strategy was achieved from a detailed categorization of the keywords that were used during the preliminary searches to make sure that all necessary studies were done. After applying rigorous inclusion and exclusion

criteria, 331 articles that were highly relevant were found eligible for further bibliometric analysis.

Inclusion and Exclusion Criteria

The inclusion criteria for this study were as follows:

- Studies examining digital dentures including research on CAD/CAM, 3D printing, and other types of digital technologies relevant to denture fabrication.
- Clinical trials, observational studies, case reports, literature reviews, systematic reviews, or meta-analyses that are focused on digital dentures.
- Studies that assess the outcomes of digital dentures, including aspects such as fit, accuracy, aesthetics, patient satisfaction, complications, and clinical performance.
- Studies published in peer-reviewed journals.
- To facilitate appropriate interpretation and comprehension, studies written in English, Spanish, French, or German were consulted. Translators were also available for these languages.

Exclusion Criteria

- Studies that do not specifically address digital dentures or related technologies.
- Studies that focused solely on traditional denture fabrication techniques without digital components.
- Animal studies, in vitro studies, or studies conducted on nonhuman subjects.
- Editorial articles, opinion pieces, conference abstracts, or non-peer-reviewed sources.
- Studies that are not accessible in full text, as they may lack sufficient data for thorough analysis, which could potentially compromise the study's comprehensiveness.
- References to studies published in languages other than English, Spanish, French, or German were excluded if translation resources were available.

Methodology of Segregating Collected Articles

To gather data for the bibliometric analysis, a comprehensive search and selection process was implemented. As outlined in ►**Fig. 1**, this method comprises four stages. To retrieve relevant literature from the Dimensions database, a query was developed that incorporated relevant keywords. Boolean operators were employed to combine keywords and refine the search results. The keywords used in the query included "digital denture" OR "CAD/CAM denture" OR "3D-printed denture" OR "digital prosthodontics" OR "denture fabrication techniques."

In the first round of the search, we identified a total of 1,206 articles from international peer-reviewed journals. For the studies addressing the digital denture technology, a

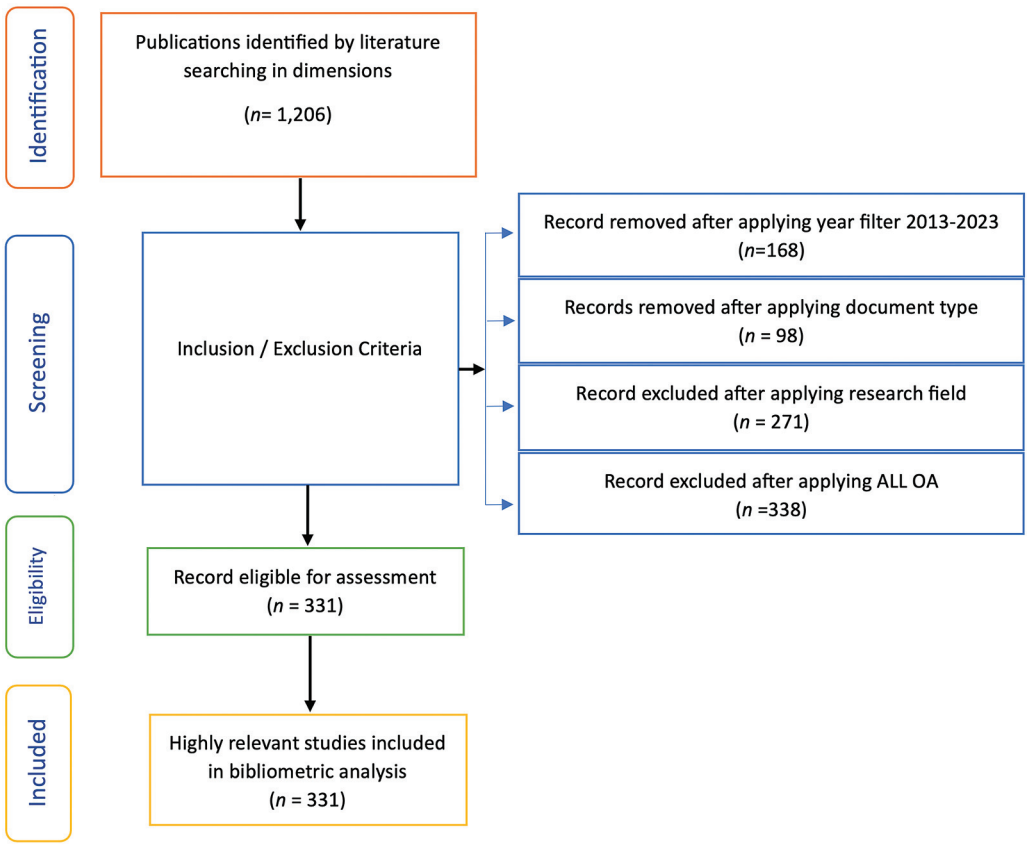

Fig. 1 Data extraction and filtering from the digital denture publications are shown in a four-phase flow diagram.

number of quality control mechanisms were put in place. In the first filtering step, we applied the inclusion and exclusion criteria based on the publication years 2013 to 2023, which led to the exclusion of 168 studies, leaving us with 1,038 studies. This step was crucial to making sure that the chosen articles were within the set time frame and more importantly reflected the most recent researches. Then, the document type (clinical trials, observational studies, case reports, literature reviews, systematic reviews, or meta-analyses) were examined, excluding articles that did not conform to the research criteria, such as conference papers and editorials. This resulted into the exclusion of 98 studies, leaving the dataset with 940 records. Thereafter, the research field was assessed, and articles irrelevant to the topical focus on the use of digital denture technology were eliminated. In this step, 271 studies were eliminated and 669 articles remained. As the last step in the filtering process, we used all articles available through open access (ALL-OA) criterion which was directed to the open access articles in order to guarantee the validity of the data collected. This step resulted in the removal of 338 studies, leaving us with the final dataset of 331 articles. Every stage of this sequence was carefully carried out in order to reduce the sample of the data, making sure that the end sample was relevant with what was being researched on currently in the region.

Data Analysis

The studied data were collected from the Dimensions and Lens.org databases, two of the major repositories of connected research content that include only top-notch academic publications. The free software package VOSviewer, which also includes information on research clusters, current interests, and new subject fads, was used to generate and illustrate bibliometric networks. Scholarly books or journals, search terms, authors, localities, research groups, or other inclusion criteria were all included in the bibliometric networks. A network can be built using citations, scientific co-authorship, co-occurrence, co-citation, and bibliographic links. Finally, data from 331[1,14–333] pertinent recordings of digital dentures were analyzed and visualized using VOSViewer, R studio, and Citespace tools.

Terms Used in Data Analysis

Similar to other studies, a few abbreviations are used in this article for data analysis in various columns of tables, such as TP for total publications, TC for total citations, TLS for total link strength, CY for citations per year, IF for impact factor, and Q for quartile category.

Results

Examination of the General Expansion Pattern

►**Fig. 2** presents the results in a more visual manner the emerging trends within central denture oral appliance literature that took place within the last decade and even more at the turn of the century. It further shows a course involving an upward trend consisting of the number of new cited and published articles on this field of study over time. There was an upward trend in the number of articles published in 2013. This began with two articles without any citation, but by 2014 there were four publications with two citations each, indicating that modest attention had been gained. The situation improved within the year in 2015 where seven articles were published with six citations. However, in the year 2016 there was a more visible growth as the same seven publications received 26 citations, suggesting perhaps a gradual acceptance of digital dental dentures in the wider field of digital dentistry. There was an even more progressive growth in the year 2017 with 18 publications resulting in 56 citations, demonstrating that the year could have been the inception point for this area of study and its growth. This growth was sustained in the year 2018, with the number of publications increasing to 21 and their citation growing to 157, indicating the rapid development of digital dental devices. In 2019, this trend took an even sharper increase, with 35 publications having been cited 280 times, further

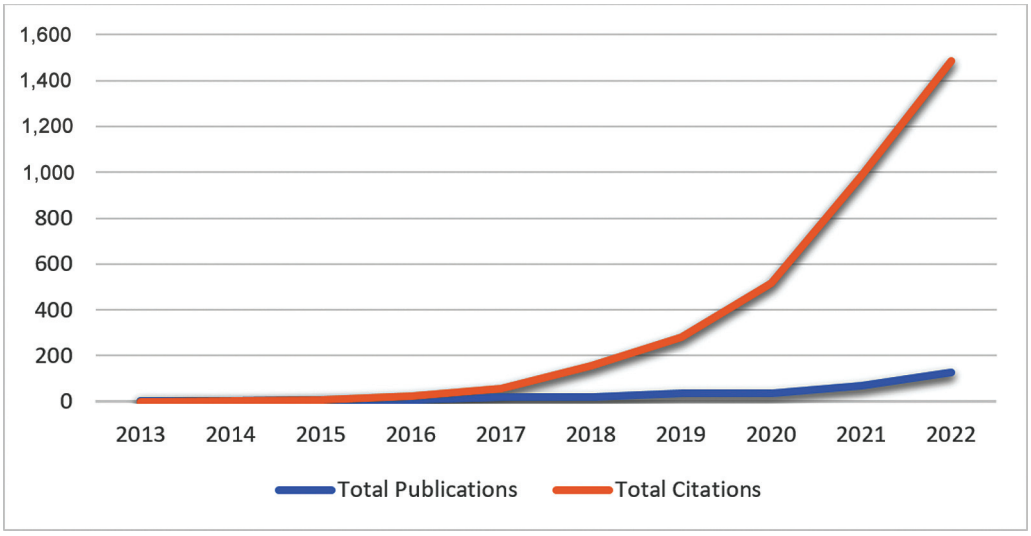

Fig. 2 Publishing and citation trends in digital denture literature.

Table 1 Top nine countries on trends in digital denture literature

Position	Country	TP	TC	TLS
1	South Korea	30	183	80
2	Switzerland	29	865	219
3	United States	29	445	83
4	Saudi Arabia	28	297	101
5	Japan	25	178	71
6	Germany	17	193	53
7	Italy	15	635	56
8	China	14	96	42
9	Turkey	10	93	37

proving this topic's increasing importance in the dental world. The upward trend continued in the year 2020 as there were 38 publications and a remarkable increase in citations to 517, most probably owing to further technological changes and digitization of dental practices. It was in the year 2021 that the most remarkable growth occurred as the number of publications rose to 71 and the number of citations to a whopping 984, an indicator that digital dental technologies were becoming the norm and more attention was being directed toward this field of research. The trend continued in 2022, with a total of 128 publications and 1,485 citations, indicating the consistent and increasing focus on digital dental dentures in the arena of development in global digital dentistry. Such extraordinary increases in the production of literature and the number of citations can be explained against broader phenomena like the trends in digital dentistry itself and technological progress including CAD/CAM systems, 3D printing, etc. These advances in technology not only enhanced the demand for research but also facilitated more practical use of the researches. In the case of digital dentures, especially, more scholarly works were produced, leading to more citations.

Top Countries and Organizations for Trends in Digital Denture Literature

As indicated in ►**Table 1**, the most successful nations and entities in the digital denture literature are in terms of TP, TC, and TLS at the global level. For the top 10 most productive countries, the criteria chosen were based on the minimum number of documents in a country (3) and the minimum number of citations in a country (1). Of the 53 countries, 25 met this criteria. South Korea came in the first place with 30 TP, 183 TC, and a TLS of 80. With 29 TP and an amazing 865 TC, Switzerland took the second place with a TLS of 219 points. With 29 TP, 445 TC, and a TLS of 83, the United States tied with Switzerland in terms of TP.

With 28 TP and 297 TC, Saudi Arabia came in the fourth place, behind the United States, with a TLS of 101. With 25 TP and 178 TC, Japan earned a TLS of 71. Germany obtained 17 TP, 193 TC, and 53 TLS. Italy had a TLS of 56, a remarkable TC of 635, and a TP of 15, compared with China's 14 TP and 96 TC, which resulted in a TLS of 42. Finally, Turkey earned a TLS of 37 and the ninth place with 10 TP and 93 TC.

Similarly, as indicated in ►**Table 2**, the top 10 most productive organizations were based on the minimum

Table 2 Top 10 institution on trends in digital denture literature

Position	Institution	TP	TC	TLS
1	University of Geneva	16	491	222
2	University of Bern	15	516	164
3	University of Zurich	15	368	171
4	King Saud university	13	147	46
5	Tokyo Medical and Dental University	9	108	38
6	Peking University	8	71	34
7	Al Azhar University	7	2	13
8	Cairo University	7	6	1
9	Dankook University	7	31	13
10	University Hospital of Geneva	7	299	135

Abbreviations: TC, total citations; TLS, total link strength; TP, total publications.

Table 3 Top 10 journals in digital denture literature

Journal	Country	TP	TC	TLS	Publisher	IF	Q
The Journal of Advanced Prosthodontics	South Korea	20	247	53	The Korean Academy of prosthodontics	1.989	1
Journal of Prosthetic Dentistry	United States	17	878	69	Mosby Inc.	4.148	1
Applied Sciences	Switzerland	15	34	13	MDPI AG	2.838	2
BMC Oral Health	UK	15	585	50	BioMed Central Ltd.	3.747	1
Journal of Dentistry	The Netherlands	15	149	44	Elsevier BV	4.991	1
Dental Materials Journal	Japan	9	131	28	Japanese Society for Dental Materials and Devices	5.687	1
International Journal of Dentistry	United States	9	231	11	Hindawi Limited	0.5	2
Journal of Prosthodontic Research	Japan	9	75	20	Japan Prosthodontic Society	4.338	1

Abbreviations: IF, impact factor; Q, quartile category; TC, total citations; TLS, total link strength; TP, total publication.

number of documents of an organization (3) and the minimum number of citations of an organization (1). Of the 277 organizations, 45 met this threshold. A substantial contribution came from the University of Geneva, which provided 16 (TP), 491 (TC), and 222 (TLS).

A substantial donation came from the University of Bern in the form of 15 TP, 516 TC, and 164 TLS. The University of Zurich made a large contribution, providing 15 TP, 368 TC, and 171 TLG. With 13 TP, 147 TC, and 46 TLS, King Saud University stood out. Tokyo Medical and Dental University made considerable contributions with 9 TP, 108 TC, and 38 TLS. Peking University stood out at the sixth place with 8 TP, 71 TC, and 34 TLS. Al Azhar University made a large contribution by providing 7 TP, 2 TC, and 13 TLS. Significant contributions came from Cairo University, including 7 TP, 6 TC, and 1 TLS contributions. Dankook University played a significant role by contributing 7 TP, 31 TC, and 13 TLS. With 7 organizations, 299 TP, and 135 TC, the University Hospital of Geneva made considerable contributions.

Journals with Significant Impact

►**Table 3** lists the top eight journals with the highest impact on the literature on digital dental dentures excluding *Egyptian Dental Journal* and *The Journal of Korean Academy of Prosthodontics*. The criteria were based on the source's minimum number of documents (5) and the minimum number of citations (5) and only journals included in Web of Science for the top eight most highly influential journals. Twenty articles were published by *The Journal of Advanced Prosthodontics*, with TC of 247 and TLS of 53. Similarly, *The Journal of Prosthetic Dentistry* produced a total of 17 articles, with TC and TLS of 878 and 69, respectively. With a TC of 34 and a TLS of 13, the journal *Applied Sciences* published a total of 15 articles, whereas *BMC Oral Health* produced 15 articles with TC of 585 and TLS of 50. Among others, *Journal of Dentistry* published 15 articles, with TC of 149 and TLS of 44; *Dental Materials Journal* published 9 articles, with TC of 131 and TLS of 28; *International Journal of Dentistry* published 9 articles, with TC of 231 and TLS of 11; and, finally, *Journal of Prosthodontic Research* published 9 articles, with TC of 75 and TLS of 20. These results provide information about the publication and citation impact of each journal. Journal tend to be more important in the dentistry area. The more articles a journal publishes and the more citations it receives, the higher its TLS. In terms of publications and citations, *The Journal of Advanced Prosthodontics* and *The Journal of Prosthetic Dentistry* were the top two journals in the top eight.

Authorship Pattern

►**Fig. 3** highlights authorship patterns in the existing literature on digital denture technology, focusing on authors who meet the minimum threshold of 3 publications and 1 citation. Out of a total of 1239 authors in the dataset, only 38 meet these criteria, demonstrating that a relatively small group of researchers are making significant contributions to the field. The data provide valuable insights into the number of publications, authorships, and citations, illustrating the extent of participation and the influence of individual researchers within this academic domain.

The researcher, "Srinivasan, Murali," stands out with 14 publications and 486 citations, signaling active participation in academic initiatives and potentially holding a leadership role in co-authored projects. The concentration of authorship might suggest that certain authors hold leadership roles in emerging research clusters, potentially influencing the direction of trends within their disciplines. However, this raises concerns about the diversity within these networks and whether other researchers have equal opportunities to participate at the same level.

The second researcher, "Müller, Frauke," with 11 publications and 442 citations, also demonstrates significant engagement in intellectual activity. While they have fewer publications than "Srinivasan, Murali," the high citation count indicates substantial influence and recognition in the field. "Schimmel, Martin," the third researcher, has 10 publications and 417 citations, which further underscores their impact on the field. The high number of citations relative to publications suggests that their work is likely foundational and influential in shaping future directions in digital denture technology. Collaboration is a key aspect for authors such as "Abduo, Jaafar," with 5 publications and 237 citations, and "Kalberer, Nicole," with 6 publications and 197

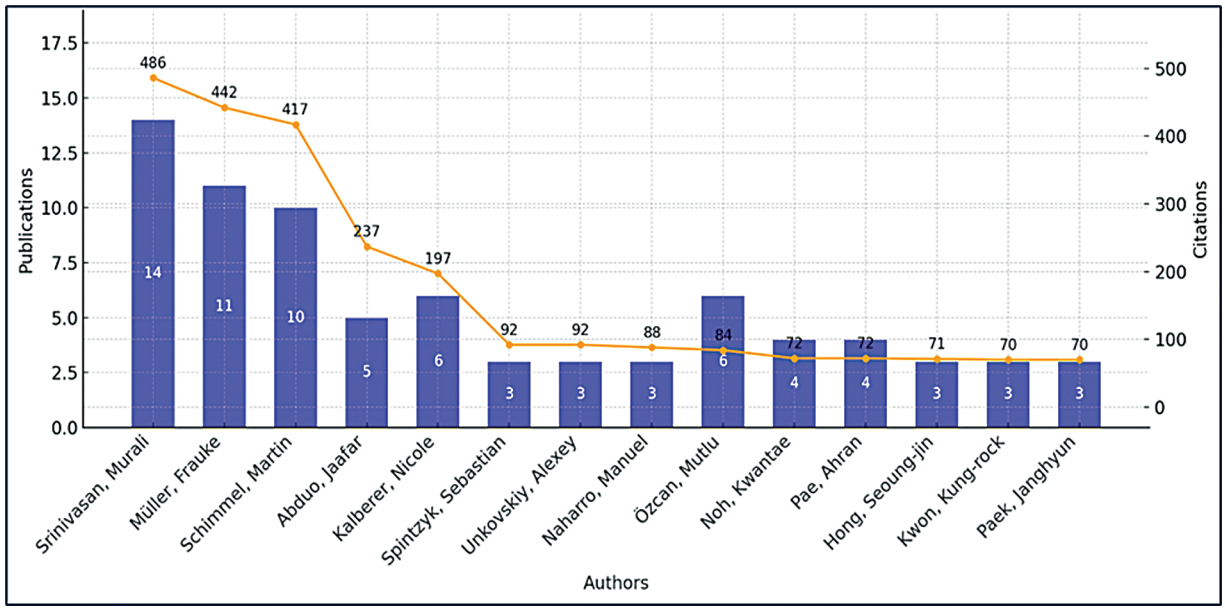

Fig. 3 Authorship pattern.

citations. These figures indicate a trend of high academic productivity through collaborative networks. However, the concentration of authorship in a small group of researchers brings up questions about whether this centralization limits broader collaboration opportunities, especially on an international scale. Notably, "Noh, Kwantae," with 6 publications and 84 citations, shows that even individuals with fewer publications can gain considerable prominence. This highlights the fact that impactful contributions are not necessarily tied to the sheer number of publications but rather the significance and relevance of the research. From "Unkovskiy, Alexey" to "Paek, Janghyun," the remaining authors have fewer publications and citations, indicating a more peripheral position in the academic landscape of digital denture technology. This may suggest less involvement in key research clusters or a lack of collaboration, which could limit their influence and visibility in the field.

To summarize, this dataset evidences various degrees of authorship, publications, and citations of researchers, but there appears to be a certain level of centralization of power within certain areas. It raises important issues: Are there other factors that may explain the limited engagement of scholars, especially in the international context, and do the current ways of engagement prevent development and innovations in the field? Further discussing these issues would help develop ways of enhancing more active inclusion of many people in the academic life.

Authors' Keyword Analyses on Trends in Digital Denture

The results of keyword analysis of the literature on digital dental dentures are shown in ►**Fig. 4**. Out of a total of 508 writers' terms, 94 satisfy this requirement, consisting of 11 clusters, and have a minimum of 2 occurrences. Clusters are organized based on the connection strength and occurrence, and each hue denotes a different cluster. Therefore, the association between link strength, incidence, and bubble size may be determined. The top four keywords in terms of overall link strength were CAD/CAM (link strength of 62), 3D printing (link strength of 56), CAD-CAM (link strength of 48), full denture (link strength of 32), and digital dentistry (link strength of 26). Among 11 clusters, 1 included 13 items (AI, complete denture, dental implants, dental impression techniques, digital denture, digital workflow, edentulous jaw, education, immediate loading, mastication, patient satisfaction, perception, and prosthodontics). Cluster 2 included 11 items (acrylic resin, CAD/CAM, denture base resin, dentures, digital dentures, flexural strength, implant overdentures, implants, overdenture, rapid prototyping, and 3D printing). Similarly moving from top to down, cluster 3 included 10 items, cluster 4 included 9 items, cluster 5 included 9 items, cluster 6 included 8 items, cluster 7 included 8 items, cluster 8 included 8 items, cluster 9 included 7 items, cluster 10 included 7 items, and cluster 11 included only 3 items (dental education, digital dentistry, and intraoral scanner).

Thematic Evolution Map of Author Keywords

The thematic evolution of keywords over the last 10 years shows a clear shift in the digital denture research streams. Stereophotogrammetry, polymethyl methacrylate, removable partial dentures, CAD, dental materials, complete dentures, and dental implant–related keywords disappeared by 2021 as shown in ►**Fig. 5**. The results show that 3D printing, additive manufacturing, digital dentistry, systematic review, dentistry, digital technology, and CAD/CA are hot topics in 2022. Additionally, CAD/CAM, digital technology, accuracy, and PEEK were important keywords throughout the 10 years (2013–2022).

Highly Cited Articles on Digital Denture

The top 10 articles on digital dentures with the highest citations are shown in ►**Table 4**. The citations and years

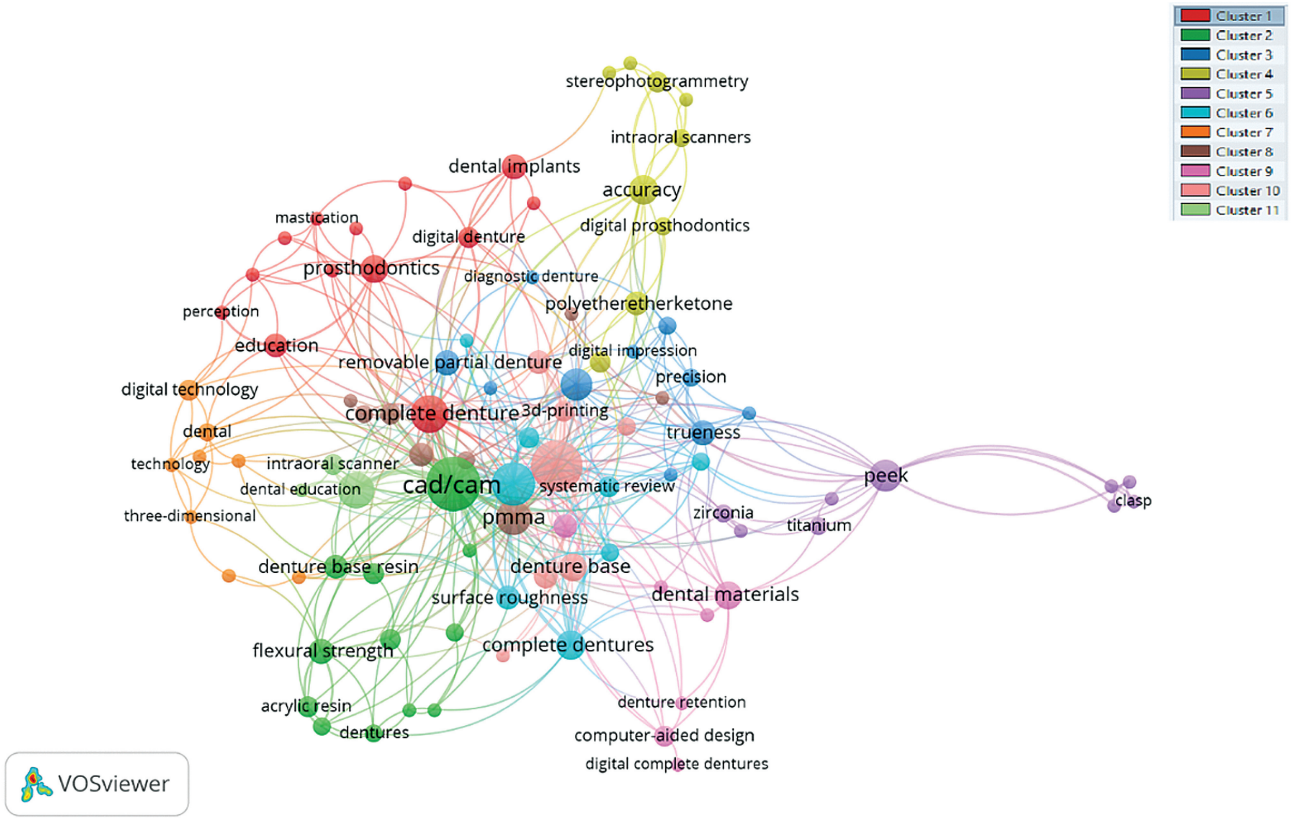

Fig. 4 Author–keyword relationship network.

for the top 10 highly referenced publications varied from a maximum of 614 to a minimum of 80 citations from 2013 to 2022. The Glossary of Prosthodontic Terms, Ninth Edition, topped the list of the 10 most cited articles with 614 citations and the highest average citation rate (75.2), followed by an article by Abduo et al titled "Trends in computer-aided manufacturing in prosthodontics: a review of the available streams," with 203 citations and a lower average citation rate (24.8).

Relationships between Three Factors (Keywords, Authors, and Sources)

►**Fig. 6** shows a three-factor analysis of the relationships among sources (on the right), authors (in the middle), and keywords (on the left), illuminating the field's publication preferences and partnerships. Notably, *Journal of Dentistry*, *The Journal of Prosthetic Dentistry*, and *The Journal of Advanced Prosthodontics* all show tight working relationships with three particular authors: Srinivasan M., Schimmel M.,

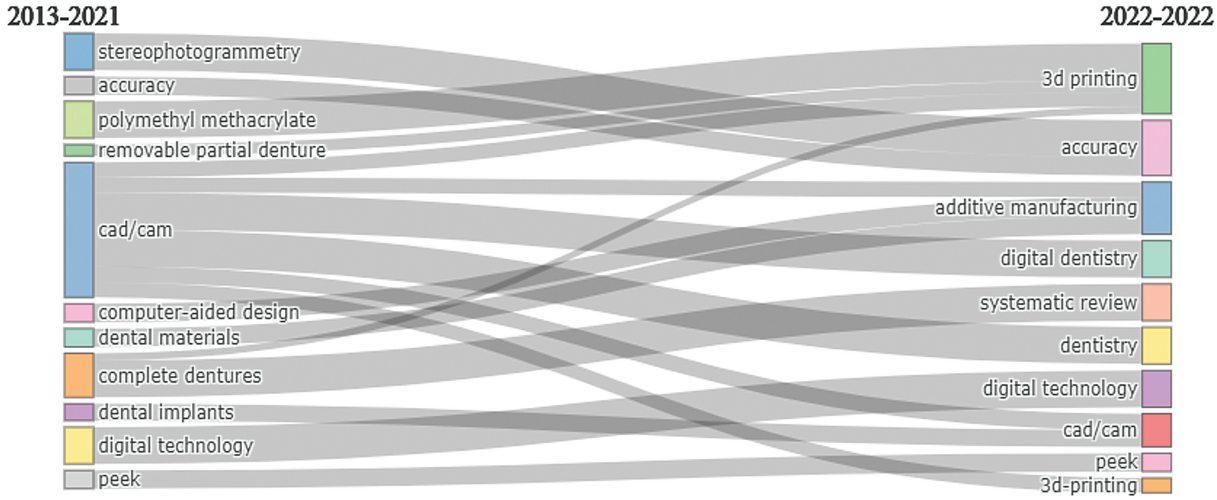

Fig. 5 Thematic evolution map of author–keywords.

Table 4 Top 10 highly cited articles on digital denture

Title	Authors	Journal	TC	C/Y	Year
The Glossary of Prosthodontic Terms, Ninth Edition	Anonymous[328]	*Journal of Prosthetic Dentistry*	614	75.2	2017
Trends in computer-aided manufacturing in prosthodontics: a review of the available streams	Abduo et al[317]	*International Journal of Dentistry*	203	24.8	2014
The complete digital workflow in fixed prosthodontics: a systematic review	Joda et al[336]	*BMC Oral Health*	202	24.7	2017
Current status on lithium disilicate and zirconia: a narrative review	Zarone et al[256]	*BMC Oral Health*	144	17.6	2019
CAD-CAM milled versus rapidly prototyped (3D-printed) complete dentures: an in vitro evaluation of trueness	Kalberer et al[44]	*Journal of Prosthetic Dentistry*	125	15.3	2019
3D printing-encompassing the facets of dentistry	Oberoi et al[224]	*Frontiers in Bioengineering and Biotechnology*	115	14.1	2018
3D and 4D printing in dentistry and maxillofacial surgery: Printing techniques, materials, and applications	Khorsandi et al[70]	*Acta Biomaterialia*	112	13.7	2021
Do CAD/CAM dentures really release less monomer than conventional dentures?	Steinmassl et al[36]	*Clinical Oral Investigations*	92	11.3	2017
CAD/CAM produces dentures with improved fit	Steinmassl et al[33]	*Clinical Oral Investigations*	87	10.6	2018
CAD/CAM milled complete removable dental prostheses: an in vitro evaluation of biocompatibility, mechanical properties, and surface roughness	Srinivasan et al[80]	*Dental Materials Journal*	80	9.8	2018

Abbreviations: C/Y, citation per year; TC, total citations.

and Muller F. These writers have a propensity to submit their writings to these specific periodicals. Additionally, the data show that these writers use four particular terms in their writing. These key phrases include "completed dentures," "CAD-CAM," "CAD/CAM," and "dental materials." This implies that these writers are particularly interested in or are knowledgeable about these subjects and regularly include them in their studies. The results of this research illustrate the publication trends and cooperative networks in the digital denture literature. It contributes to a better

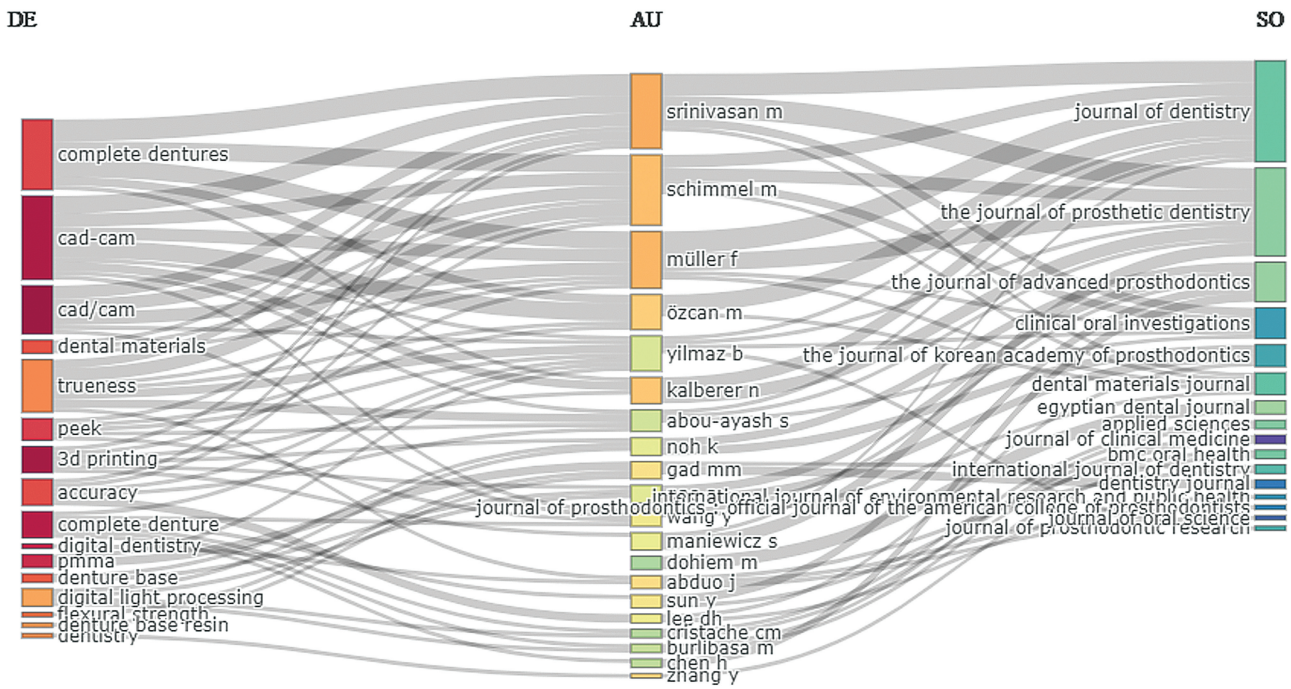

Fig. 6 Relationships between three factors (keywords, authors, and sources).

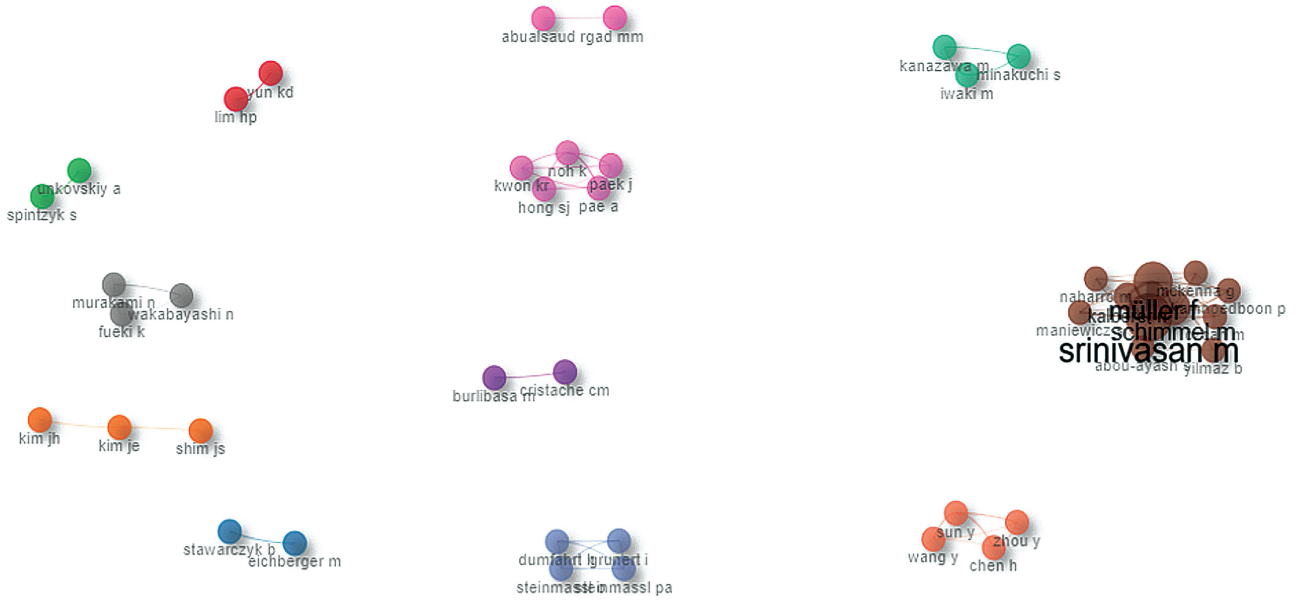

Fig. 7 Collaboration network of digital denture literature.

understanding of the research landscape and distribution of knowledge in the subject by offering insightful information about the relationships between authors, sources, and keywords.

Collaboration Network of Digital Denture Literature

►**Fig. 7** describes the collaboration network in the digital denture literature. The collaboration network of digital denture literature based on authors indicates the relationships and collaborations among authors in the field of digital dentures. By analyzing this network, we can gain insights into the patterns of collaboration and identify key contributors in this domain. Network analysis reveals that several authors have established strong collaborative ties with each other, forming 12 clusters or groups within the network. These clusters often represent collaboration within specific research teams, institutions, or geographic regions. Furthermore, the presence of influential authors or central nodes in the network suggests their significant contributions and leadership in the field of digital dentures, like Srinivasan M. and Müller F., and their significant contributions and leadership in the field of digital dentures with Schimmel M., Kalberer N., Özcan M., Maniewicz S., Yilmaz B., Abou-Ayash S., Kamnoedboon P., McKena G., and Naharro M. Overall, the collaboration network of digital denture literature based on authors provided a visual representation of the collaborative landscape in this field. It offers valuable insights into relationships, collaborations, and influential authors, enabling researchers, practitioners, and institutions to understand the current state of the field and to foster future collaborations to advance the domain of digital dentures. A total of 78 network collaboration entries were recorded by the authors. The first cluster contained two collaborations; the 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, and 12th had 2, 2, 2, 3, 11, 2, 3, 3, 4, 4, and 5 collaborations, respectively. The highest level of network collaboration was found in cluster 6. This collaboration was between 11 authors.

Citation Bursts of Digital Denture Literature

The strongest citation bursts for the top 16 references in the literature on digital dentures are shown in ►**Fig. 8**. These citation bursts increased between 2013 and 2022. The majority of the references had peak citation bursts between 2.00 and 6.00. However, although the citations in the second place had a strength of 8.7 expanded from 2013 to 2018, the citations at the top had the longest expanded length (2015–2020) and the strongest citation bursts (8.31). The citation of a piece of work published by Kattadiyil et al in 2015 had the largest citation burst (8.76), whereas the citation of a piece of work written by Lin et al had the weakest burst (2.82). Citation bursts are periods of intense citation activity around a certain study subject or publication in bibliometric analysis, and they signify the times when research on digital denture technology has received more attention, interest, and impact. The growth and significance of research in the area of digital dentures may be better understood by analyzing citation bursts. This might highlight notable turning points, scientific discoveries, or important writings that have had a major impact on the development and comprehension of digital denture technology. Citation spikes may occur for several reasons, including the adoption of ground-breaking methods or technologies, the release of important research articles, and the rise of fresh viewpoints or paradigms in the industry. They may denote the acceptance and acknowledgment of certain theories, strategies, or procedures by the scientific community as well as their effect on later research.

Top 16 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2013 - 2023
Bidra AS, 2013, JOURNAL OF PROSTHETIC DENTISTRY, V109, P361, DOI 10.1016/s0022-3913(13)60318-2, DOI	2013	6.82	2014	2018	
Goodacre CJ, 2012, JOURNAL OF PROSTHETIC DENTISTRY, V107, P34, DOI 10.1016/s0022-3913(12)60015-8, DOI	2012	5.8	2014	2017	
Kattadiyil MT, 2013, JOURNAL OF THE CALIFORNIA DENTAL ASSOCIATION, V41, P407	2013	8.76	2015	2018	
Inokoshi M, 2012, DENTAL MATERIALS JOURNAL, V31, P40, DOI 10.4012/dmj.2011-113, DOI	2012	3.6	2015	2017	
Kattadiyil MT, 2015, JOURNAL OF PROSTHETIC DENTISTRY, V114, P818, DOI 10.1016/j.prosdent.2015.08.001, DOI	2015	8.31	2016	2020	
Infante L, 2014, JOURNAL OF PROSTHETIC DENTISTRY, V111, P351, DOI 10.1016/j.prosdent.2013.10.014, DOI	2014	7.19	2016	2019	
Steinmassl P, 2016, CLINICAL ORAL INVESTIGATIONS, V21, P1697, DOI 10.1007/s00784-016-1961-6, DOI	2016	4.03	2017	2020	
Baba NZ, 2016, GENERAL DENTISTRY, V64, P23	2016	3.56	2017	2018	
Wimmer T, 2016, JOURNAL OF PROSTHETIC DENTISTRY, V115, P541, DOI 10.1016/j.prosdent.2015.10.016, DOI	2016	3.14	2017	2019	
Schwindling FS, 2016, JOURNAL OF PROSTHETIC DENTISTRY, V116, P756, DOI 10.1016/j.prosdent.2016.03.022, DOI	2016	2.91	2017	2018	
Bilgin MS, 2015, JOURNAL OF PROSTHODONTICS, V24, P576, DOI 10.1111/jopr.12302, DOI	2015	2.85	2017	2020	
Goodacre BJ, 2016, JOURNAL OF PROSTHETIC DENTISTRY, V116, P249, DOI 10.1016/j.prosdent.2016.02.017, DOI	2016	4.08	2018	2020	
Srinivasan M, 2016, CLINICAL ORAL INVESTIGATIONS, V21, P2007, DOI 10.1007/s00784-016-1989-7, DOI	2016	3.77	2018	2019	
Kattadiyil MT, 2017, JOURNAL OF PROSTHETIC DENTISTRY, V117, P721, DOI 10.1016/j.prosdent.2016.12.006, DOI	2017	3.31	2018	2020	
Pereyra NM, 2015, JOURNAL OF THE NEW JERSEY DENTAL ASSOCIATION, V86, P26	2015	3.31	2018	2020	
Lin W, 2018, JOURNAL OF PROSTHETIC DENTISTRY, V120, P331, DOI 10.1016/j.prosdent.2017.12.027, DOI	2018	2.82	2019	2020	

Fig. 8 Citation bursts of digital denture (2013–2022).

Discussion

Several methodologies, including bibliographic analyses, have been utilized to examine the mechanisms and operations of science. In our study, we conducted a qualitative assessment of scientific publications that resulted from research using different standards or queries, some of which are discussed in the following sections.

Evolutions of Publications and Citations

The bibliometric analysis in this research revealed that, whereas there were only two publications in 2013 with no citations, there were four publications with two citations in 2014. Starting in 2015, there was a steady rise that peaked in 2022, with 128 publications and 1,485 citations.

According to the search results, there has been an increase in the interest in digital denture technology. The body of knowledge on this subject has grown dramatically over time, with recent years seeing a noteworthy increase in publications and citations. The reviewed studies cover various aspects of digital denture technology, including clinical outcomes and costs,[4] clinical efficiency,[337] and recent developments for CAD/CAM-generated restorations.[338] Overall, these findings suggest that digital denture technology is an area of active research and development that is likely to continue growing in importance in the coming years.

Countries and Organizations with Notable Productivity and Citation Rates

The analysis of the literature on digital dentures indicates the existing countries and institutions of the world where progress in this area has been made. Egypt came first in the publishing ranking with a total number of publications of 46 (TP), a total number of citations of 45 (TC), and a high TLS of 89. This trend may be attributed to increasing willingness of Egypt to provide more funding for dental research in the region. Egypt's determination to enhance the technology of digital dentures is also supported by better collaboration of its schools with the industries. In the next place is South Korea on 30 TP, 183 TC, and TLS of 80. Such a rank of South Korea can be explained by its good position in such research fields because of good research infrastructure and policy, together with funding from both the government and private health innovation funders. It may be understood that the collaboration of universities with the industry and government has perhaps enhanced the contribution of South Korea in the field of digital denture literature as well. Of the various academic institutions, it is obvious that the University of Geneva has impressive numbers of TP (16), TC (491), and TLS (222), indicating strong knowledge and influence in the area. This level of contribution is very high and it may be because the university is oriented at leading research and participates actively in international research activities to generate more awareness and connectivity to the research field. In the same vein, the University of Bern in Switzerland also impressed with the figures of 15 TP, 516 TC, and 164 TLS in terms of contributions while providing its solid footing in the rankings. The third spot for Switzerland with 29 TP and a whopping 865 TC resulting in a TLS of 219 reflects the strong emphasis on research in the country, which could be attributed to substantial funding, well-equipped facilities, and activities for dental science excellence. Switzerland's achievement of 15 TP, 368 TC, and TLS of 171 further underscored the University of Zurich's role in perhaps enhancing the country's dominance in dental research over the years. However, other countries including the United States, Saudi Arabia, Japan, Germany, Italy, China, and Turkey were also active in the literature on digital dentures coming 4th to 10th. Their performance with respect to publications and citations can be explained by the availability of resources,

concentration on health care technologies, and the presence of strong research system in the countries. Out of the top institutions, positions were also secured by King Saud University, Tokyo Medical and Dental University, Peking University, Al-Azhar University, Cairo University, Dankook University, and University Hospital of Geneva, which due to their importance in the development of digital dentures are worthy of mention.

Finally, the efforts made by these countries and institutions are aimed at progressing the practice and research of digital dentures. The remarkable performance in publishing, the number of citations received, and total link power emphasizes the need for sufficient research infrastructure, investment, and teamwork for the digital denture industry on a global scale.

Highly Cited Papers

The Glossary of Prosthodontic Terms, being the most frequently cited article with a total of 614 citations, occupies the central position in The Journal of Prosthetic Dentistry and serves as an important pillar in prosthetic dentistry. It has a citation frequency of 75.2 per year and an impact factor of 4.148, placing it is clearly in the Q1 category. This glossary is more than a compilation of words. It is a huge attempt to propose as much as possible a unifying language for the field of prosthodontics. It provides clear definitions and explanations, so that professionals all over the world can express their ideas and methods in the text so that the readers, no matter where they are or what their expertise is, will be able to understand the content. It stands out because of its high number of citations, demonstrating that it has acted as a primary source for the development and provision of clear, uniform language within the discipline.[328]

Another important article is the article by Abduo et al entitled "Trends in computer-aided manufacturing in prosthodontics: a review of the available streams," which has been published in the *International Journal of Dentistry* in the year 2014. This article has been cited 203 times at the last count and averaged a citation rate of 24.8 per year since publication. The primary significance of this article is the exhaustive review of CAD/CAM techniques in prosthodontics. This particular instance pertains to additive and subtractive manufacturing. By looking very closely at the materials as well as the accuracy of the approaches, this research managed to become the foundation for other researchers and practitioners interested in the use of CAM in prosthodontics and is hence identified as a milestone in the digital revolution of dental industry.[317]

The article "The complete digital workflow in fixed prosthodontics: a systematic review" by Joda et al[336] ranks as the third most cited article with 202 citations out of the total 13 outlined in this article and its average CY is 24.7. This article is scored in its impact on an entirely new area, which aims to address the growing trend of digitalization in fixed prosthetic restoration. There have been many studies that report on the time taken for procedures involving digital tools bringing notable time reductions highlighting the case for all digital forms becoming the norm in this domain, making it a very famous and creative piece of work.

Zarone et al's[256] article "Current status on lithium disilicate and zirconia: a narrative review," published in 2019 in *BMC Oral Health*, ranked fifth with 144 scholarly work citation average, which has been 17.6 yearly over the period from 2019 to 2022. This review is significance because it provides an in-depth analysis of lithium disilicate and zirconia, materials that have improved modern prosthetic dentistry. The article has garnered significant interest, particularly among individuals seeking to understand the benefits of these metal-free ceramics. Their superior technical and aesthetic characteristics helped facilitate their rapid adoption by professionals.

Kalberer et al's research work entitled "CAD-CAM milled versus rapidly prototyped (3D-printed) complete dentures: an in vitro evaluation of trueness" appeared in *The Journal of Prosthetic Dentistry* in 2019.[44] This article has received 125 citations and has an average number of citations of approximately 15.3 a year. This article evaluated biomechanical and clinical outcomes of digital denture manufacturing techniques, which are crucial for clinicians and researchers to evaluate the possibilities of these approaches.

Since 2014, there has been growing worldwide research activity in the field of digital dentures, with Egypt (46), South Korea (30), Switzerland (29), the United States (29), Saudi Arabia (28), and Japan (25) high up in the rankings. Germany, Italy, China, and Turkey are also giving a worthy input. In particular, the prolific Murali Srinivasan, author of 14 of the most cited articles in this domain, is evidence of the increasing focus in this area of research. Spanning multiple subjects, Srinivasan's work includes 86% lithium disilicate and zirconia used in digital dentures, and the comparison of several approaches for the denture manufacturing process within a total of 486 citations. Many of the articles that provide this level of principles are therefore very likely to be highly cited in the future.

Preferred Journals

Regarding their impact on publications and citations, two journals stand out as the most significant. Due to the publishing of a sizable number of articles (24), which have amassed a respectable number of citations (16), *Egyptian Dental Journal* has a commendable TLS of 31. Similarly, *The Journal of Advanced Prosthodontics* published 20 articles, which were referenced by 247 authors, earning a higher TLS score of 53. On this list of the top 10 journals, *The Journal of Prosthetic Dentistry* is another important journal. It has a TLS of 69, 17 publications, and a significant number of citations (878). *BMC Oral Health* and *Journal of Dentistry* contained 15 articles each with 585 and 149 citations, respectively, indicating that they have a large impact on both publication and citations. The results suggest that the number of articles published, total number of citations, and total number of citations per article are all indicators of the importance of a journal in the field of digital dental dentures. A greater degree of impact is often attributed to journals that publish more articles and receive more citations. Owing to their impact and influence in the literature related to digital dental dentures, *Egyptian Dental Journal* and *The Journal of Advanced Prosthodontics* have become significant publications.

Commonly Used and New or Emerging Keywords (2013–2021, 2022–2022)

The results showed that the trend of publications in this field was influenced by keywords. Researchers might find publications on digital dentures using the most popular keywords. A three-factor analysis was employed to investigate the relationship between keywords , authors and sources. This research attempted to learn more about which writers like to publish using certain keywords and specific sources. Based on the research conducted, it was noted that three prominent authors, namely Srinivasan M.,[47] Schimmel M.,[43] and Muller F.,[236] had a strong association linked to three resources: *Journal of Dentistry*, *The Journal of Prosthetic Dentistry*, and *The Journal of Advanced Prosthodontics*. The four preferred keywords of these authors were CAD-CAM, dental materials, completed dentures, and CAD/CAM. While these terms are frequently repeated, they are somewhat general in nature. Keywords related to digital dentures, including 3D-printed denture base resin, acrylate resins, and acrylic denture base, have received less attention. Highly cited articles were associated with the Egyptian Dental Association, the Korean Academy of Prosthodontics, Mosby Inc., and MDPI AG–based digital dentures. In a thematic evaluation of these articles, four significant keywords were identified: "CAD/CAM," "digital technology," "accuracy," and "PEEK." Consequently, the utilization of CAD/CAM technology in digital dentures has gained substantial interest.[107,273,283,288] Innovative technologies such as CAD/CAM and AI that drive digital dentistry make dental care safer, quicker, and more client oriented than ever before since it produces less pollution.[339] It is essential for the dentistry profession to acknowledge the need for sustainable practices, waste reduction, and oral health promotion even in light of COVID-19-related challenges that have surged.[340] In summary, it can be said that the sky is the limit when it comes to the incorporation of the CAD/CAM system and AI in terms of their application within dentistry, while at the same time enhancing the practices of dental care to be more environment friendly. Such considerations on the acceptance of the technologies being discussed here, especially with recent world woes, should be taken into account.

Limitations and Future Research Directions

There are few limitations of this study. These include the following:

- *Possible omission of important studies*: Despite efforts to include relevant keywords, there is a chance that some significant studies may have been missed during the literature search.
- *Limited databases included*: Only article data in the Dimensions and lens.org database were utilized.
- *Exclusion of certain publication types*: This study did not include meetings, case reports, letters, abstracts, biographies, or editorials.

Despite these drawbacks, work on digital dentures offers opportunities for further study and advancement. In order to identify research gaps and get fresh perspectives on this topic, this study also identified important articles, authors, and journals. Considering the results of the bibliometric study, the potential research areas are as follows:

- Targeted research on digital dentures.
- Comparative studies between developed and developing countries to provide valuable insights into variations and similarities in antibacterial adhesive research.
- Future research should consider using more comprehensive and diverse demographic variables to enhance our understanding of digital dentures in different populations.

Conclusions

- In terms of articles and citations, research on digital dentures has grown significantly, with 2021 witnessing the greatest jump.
- Egypt had the highest publishing output with 46 publications and 45 citations.
- With 16 articles and 491 citations, the University of Geneva has made a substantial contribution to the field of digital dentures.
- In terms of digital denture research, *Egyptian Dental Journal* held the top spot.
- With a total of 60 authorships, a group of four writers had the most authorships.
- CAD/CAM, 3D printing, full dentures, and digital dentistry were the top four search terms used for digital dentures.
- The subject progression of keywords over the last 10 years revealed a noticeable movement in the area of digital denture study concentration.
- With 614 citations and an average citation score of 75.2, the ninth edition of The Glossary of Prosthodontic Terms was the most frequently cited study.
- The top three authors showed a commitment to three sources and a preference for utilizing four particular keywords when they were published.
- Cluster 6, with 11 authors, demonstrated the highest network interactions.
- Overall, the results show that both the number of articles and the number of citations of research on digital dentures have increased dramatically.

Authors' Contributions

M.S.Z. and N.A. developed the concept and methodology. R.S.S. was responsible for data curation and formal analysis. R.S.S. and M.A.A-S. were responsible for investigation and resources. Original draft preparation was done by R.S.S., A.H., and M.A.A-S. Writing, reviewing, and editing were done by M.S.Z. and N.A. Supervision and project administration were done by R.S.S. and A.H. The guarantor of the study was R.S.S.

Data Availability Statement

The data are available upon genuine request from the corresponding author.

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Conflict of Interest
None declared.

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