Original Article

The literature on digital technologies for removable dental prostheses: A two-decade bibliometric analysis

Min-Hsun Hsu [a], Yu-Chao Chang [a,b*]

[a] *School of Dentistry, Chung Shan Medical University, Taichung, Taiwan*
[b] *Department of Dentistry, Chung Shan Medical University Hospital, Taichung, Taiwan*

Abstract *Background/Purpose:* The advent of digital technologies has significantly transformed the current dentistry, particularly in the fabrication of removable dental prostheses. A bibliometric analysis of literature may provide a direction of research hotspots and future trends in this field.

Materials and methods: Data were retrieved from Web of Science database for the analysis of literature on digital technologies for removable dental prostheses. Microsoft Excel was used for the descriptive statistics. VOSviewer was deployed for the analysis of published articles.

Results: A total of 457 published documents were identified from 2004 to 2023. The most frequently published article type was original article (n = 262, 57.33%). The number of annual publications and citations significantly increased from 2004 to 2023, respectively (*P* for trend <0.001). In addition, the significant increased number of publications and citations pre year affected by COVID-19 pandemic were noted (*P* < 0.002). Most articles were published in Journal of Prosthetic Dentistry (n = 141, 30.85%). The computer-aided design (CAD)/computer-aided manufacturing (CAM) and 3D printing technique were the frequent emphasized keywords in digital technologies for removable dental prostheses.

Conclusion: This bibliometric analysis revealed a growing research interest and technological progress in digital technologies for removable dental prostheses during past two decades. The enhancement of accuracy by CAD/CAM and 3D printing suggests a promising future for the application of these technologies in dental practice.

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* Corresponding author. School of Dentistry, Chung Shan Medical University, 110, Sec.1, Chien-Kuo N. Rd., Taichung, 40201, Taiwan.
   E-mail address: cyc@csmu.edu.tw (Y.-C. Chang).

Introduction

Current dentistry has undergone a remarkable change due to the introduction of digital technologies which have revolutionized multiple aspects of dental practice and education.[1] Digital dentistry, a key part of this innovation, incorporates various technologies such as digital impressions, computer-aided design (CAD), and computer-aided manufacturing (CAM). These advanced digital technologies facilitate the creation of dental prostheses with more precise properties and superior esthetic appeal to improve clinical outcomes as well as patients' satisfaction.[2,3] Traditionally, the fabrication of removable dentures was a meticulous, manual process, well-established skill, and abundant experience of dentists and dental technicians. The use of intraoral scanners can quickly capture the dental arches without the need for conventional impression materials.[4] CAD/CAM technology has improved the design and the fabrication of dentures with accuracy and even esthetic.[5] Moreover, digital denture records could provide an invaluable resource for future reference and adjustment.

Bibliometric analysis offers a systematic approach to review and interpret the extant literature for providing insights into the development, growth, and impact of research within a specific field.[6–8] Until now, numerous studies have delved into digital dentistry concerning the removable prostheses. As far as we know, no bibliometric analysis was performed in this research field. Our study conducted an extensive bibliometric review of literature including article citations, countries of origin, journals, most-cited papers, and key terms. In addition, the prevailing research trends and key areas of focus were also evaluated. The goal of this analysis is to furnish researchers with a clear and objective overview of the current research landscape in this field. This may offer the foundational reference for future intensive studies.

Material and methods

We conducted research on digital dentistry and removable prostheses by using the world's largest and most comprehensive database Web of Science (WoS) (Clarivate Analytics, Philadelphia, PA, USA). In this study, WoS database was searched from the establishment date up to December 31, 2023. The search was with the application of "digital dentistry OR removable prostheses OR complete dentures OR partial dentures, OR overdenture" in dental, scientific, or multidisciplinary journals. The terms related to fixed partial dentures and other fixed dental prostheses were excluded. Repeated publications were identified by article title, list of authors, and the authors' affiliations. In addition, only original article, review article, case report, and short communication written in English were included. The exclusion criteria for article types were the conference abstracts or meeting abstracts, editorial materials, proceeding papers, letters, books or book chapters, news items, corrections, and retracted publications. Our goal is to explore research related to digital dentistry and removable prostheses, so any irrelevant articles were carefully reviewed through title, abstract, and main text. If there was any disagreement about the article type, a consensus was resolved after discussion by two authors. All extracted data were transferred into Microsoft Excel (Microsoft, Redmond, WA, USA) for descriptive bibliometric analysis. The flowchart was illustrated in Fig. 1.

The number of publications, journals, citation counts, countries, and keywords were recorded in Microsoft Excel for further analysis. The annual number of publications and citations per year was examined by P for trend test. Manne-Whitney U test was used to evaluate the effects of COVID-19 pandemic on publications and citations per year. The results were presented by median with interquartile range. The significance level set at $P < 0.05$. Moreover, a metric analysis instrument VOSviewer version 1.6.20 (Leiden University, Leiden, Netherlands) was use for the display of visualized results. It is widely used in bibliometric research for visualizing knowledge graphs based on data collected through literature analysis.[9]

Results

A total of 457 articles met the search criteria were included from 2004 to 2023 (Fig. 2). The most frequently published article type was original article (n = 262, 57.33%), followed by case report (n = 155, 33.92%), review article (n = 37, 8.09%), and short communication (n = 3, 0.66%). The annual publication number significantly increased from 2004 to 2023 (P for trend <0.001). In addition, the number of citations was also demonstrated an upward tendency. The peak was illustrated in 2023 with 2017 total citations in 90 articles of digital technology for removable dental prostheses.

In addition, COVID-19 outbreak in 2020 was taken considered for the influence of digital technologies for removable dental prostheses. There were 170 articles with 1671 total citations published from 2001 to 2019. However, there were up to 287 articles published with 6166 total citations during the pandemic-affected period from 2020 to 2023. This indicated a notable increased number and citations of digital technologies for removable dental prostheses publications affected by COVID-19 pandemic. As shown in Table 1, P value of 0.002 was obtained from Manne-Whitney U test which indicated the significant increased publications and citations pre year affected by COVID-19 pandemic, respectively.

The calculation of country origin based on institutional address of the corresponding author is illustrated in Table 2. The United State of America ranked as the top 1 country with 128 publications (28.01%) in digital technologies for removable dental prostheses, followed by Japan (n = 67, 14.66%). The results also revealed that Germany, Italy, and Switzerland acted as the leadership in European.

The top five journals with the most published articles related to digital technologies for removable dental prostheses are presented in Table 3. *Journal of Prosthetic Dentistry*, with an impact factor of 4.3 in 2023 edition, published the highest number of articles up to 141 publications (30.85%).

The top 10 most cited articles in the field of digital technology in removable prostheses are listed in Table 4. These studies were primarily focus on the CAD/CAM research. The top one most cited article was reported by
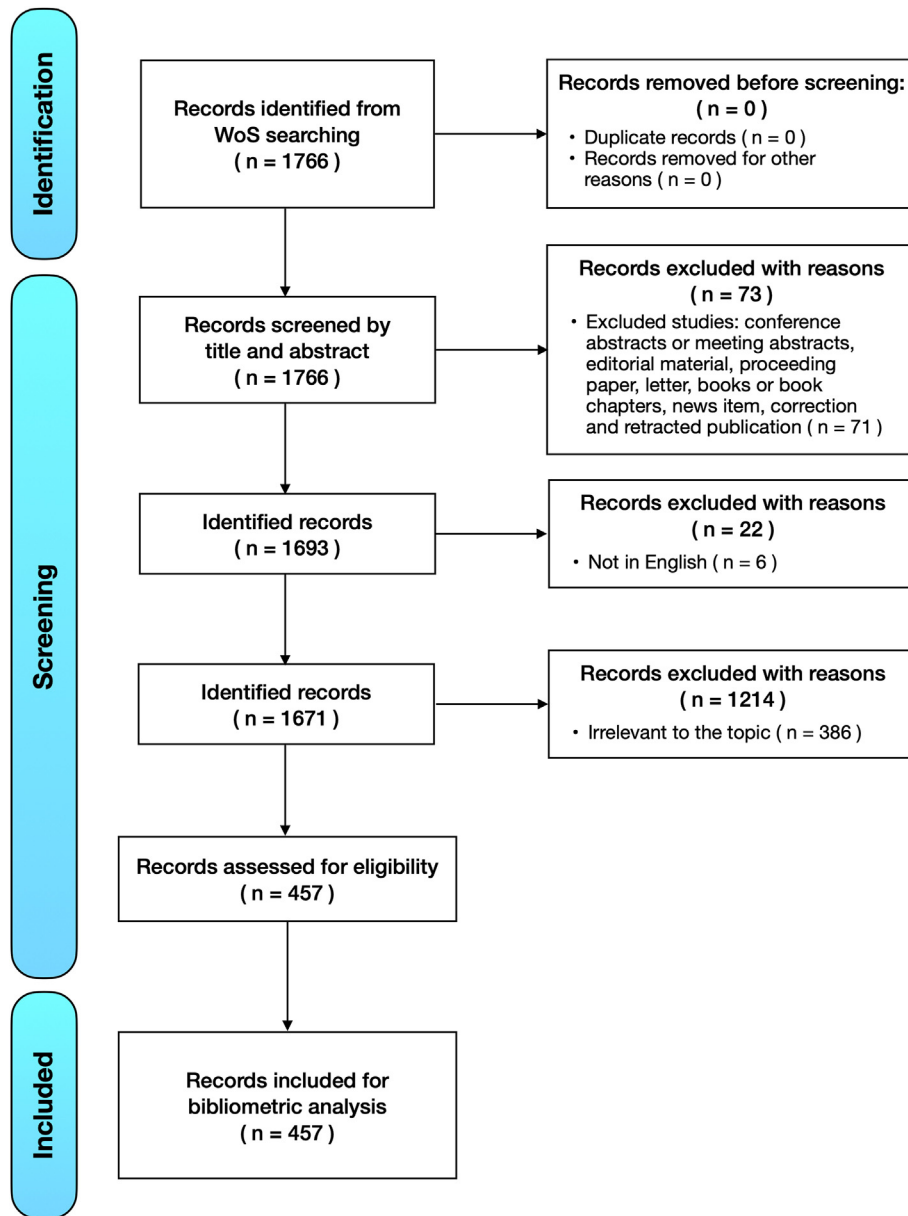
Figure 1 A flow diagram of the study search and identification with Web of Science.

Bidra et al.[10] who described the systematic review of the use of computer-aided technology in fabricating complete dentures.

The top 10 most average citations per year articles are listed in Table 5. The article type were five original articles, four review papers, and one case report. According to the article contents, most of them emphasized about the techniques of CAD/CAM and 3D printing.

Keyword analysis by VOSviewer was used to identify the prominent research themes in literature related to digital dentistry in removable prostheses (Fig. 3A). The predominant identified keywords in blue cluster are accuracy, fabrication, and removable partial denture. The top 3 key words in red cluster are CAD/CAM, technology, and complete denture. The green cluster included 3D printing, mechanical properties, and additive manufacturing.

The time overlay visualization of keyword is revealed in Fig. 3B. The color gradient at the bottom, ranging from blue to yellow, represents a timeline from 2019 to 2021. The terms 3D printing, additive manufacturing, mechanical properties, and CAD/CAM labelled with yellow color exhibited more prominent in recent years.

Discussion

In this study, a total 457 publications regarding digital technology in removable prostheses has been investigated and the research landscape were illustrated with visually map in this field. An increasing trend in the number of publications was evident over past two decades (year 2004−2023). The substantial contributions were mainly
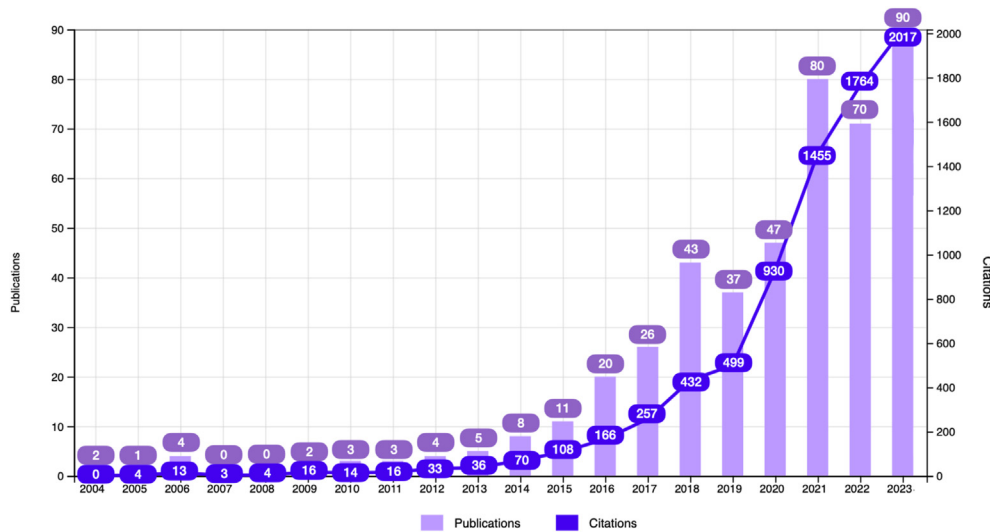
Figure 2 The annual publications and total citations of digital technologies for removable dental prostheses from 2004 to 2023.

Table 1 The effect of COVID-19 pandemic on publication and citation pre year analyzed by Manne-Whitney U test.

Period	2004 to 2019	2020 to 2023	P value
	Median (IQR)	Median (IQR)	
Publication/year	4 (2−17.75)	75 (52.75 −87.5)	0.002
Citations/year	24.5 (6.25 −151.5)	1609.5 (1061.25 −1953.75)	0.002

IQR: interquartile range.

Table 2 The top ten country distribution of publications on digital technologies for removable dental prostheses.

Country	Publications	Percentage
United States	128	28.01 %
Japan	67	14.66 %
Mainland China	57	12.47 %
South Korea	57	12.47 %
Saudi Arabia	39	8.53 %
Germany	27	5.91 %
Italy	21	4.60 %
Switzerland	20	4.38 %
Brazil	16	3.50 %
Egypt	14	3.06 %

Table 3 The top five journals listed by the number of publications on digital technologies for removable dental prostheses.

Journal	Impact factor	Publisher	Publications
Journal of Prosthetic Dentistry	4.3	Elsevier	141
Journal of Prosthodontics	3.4	Wiley-Blackwell	68
Journal of Prosthodontic Research	3.2	Elsevier	27
International Journal of Prosthodontics	2.1	Quintessence	20
Materials	3.1	MDPI	12

from United States as well as East Asia countries. In addition, Germany, Italy, and Switzerland acted as the leadership in European. This may be the famous innovated digital dental equipment suppliers located in the above countries. For example, the earliest commercial complete denture system with two-visit concept was established in US.[11] These automated technologies can reduce the need for skilled manual work. Both the particular knowledge and new skills are required for dental professionals, researchers, educators. In addition, the implementation of digital dentistry can promote environmental sustainability via waste reduction, energy conservation, and pollution prevention to achieve eco-friendly dentistry.[12,13] However, the real reason is still necessary to be investigated.

Our results demonstrated a statistically significant difference in the number of published papers and citations affected by COVID-19 pandemic. The reasons may be partly explained by the increased awareness of public health safety issues which have been driven in dental healthcare and education. Digital impression was reported to replace the traditional impressions for the reduction of virus contamination possibility.[14] Digital workflow may allow for the faster and more efficient removable denture fabrication.[15] Decreased appointment duration mean the less exposure risk of COVID-19 for patients and dental professionals. In addition, digital technology was also gained the popularity with the use of educational electronic platforms, haptic virtual reality simulation technology, and teledentistry.[16−19]

In this study, the most frequent keywords appeared were CAD/CAM and accuracy, respectively. Duret et al.[20]

Table 4 Top 10 most cited articles.

Rank	Title	Type	Journal	Total citations	Average citations per year
1	Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives.	Review	J Prosthet Dent 2013; 109:361—6.	220	20.0
2	Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques.	Original article	J Prosthet Dent 2016; 116:249—56.	172	21.50
3	Assessing the feasibility and accuracy of digitizing edentulous jaws.	Original article	J Am Dent Assoc 2013; 144:914—20.	162	14.73
4	CAD/CAM fabricated complete dentures: concepts and clinical methods of obtaining required morphological data.	Case report	J Prosthet Dent 2012; 107:34—46.	155	12.92
5	Fabricating complete dentures with CAD/CAM technology.	Case report	J Prosthet Dent 2014; 111:351—5.	155	15.50
6	Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting.	Original article	J Prosthet Dent 2015; 114:818—25.	147	16.33
7	The use of a modified poly-ether-ether-ketone (PEEK) as an alternative framework material for removable dental prostheses. a clinical report.	Case report	J Prosthodont 2016; 25:580—4.	139	17.38
8	Use of CAD/CAM technology to fabricate a removable partial denture framework.	Case report	J Prosthet Dent 2006; 96:96—9.	138	7.67
9	Trial of a CAD/CAM system for fabricating complete dentures.	Case report	Dent Mater J 2011; 30:93—6.	115	8.85
10	Evaluation of a complete denture trial method applying rapid prototyping.	Original article	Dent Mater J 2012; 31:40—6.	104	8.67

who were the pioneers to introduce CAD/CAM technology into clinical dentistry for fixed restorations in early 1970s. However, our results revealed that the development of digital technique for removable prostheses was just established during past two decades. The possible reasons may be explained as following. First, there are numerous steps involved in recording, transferring, and assessing before creating removable dentures as compared to fixed restorations. These will affect the esthetic and functional alignment with patient's occlusion and chewing. Today, CAD/CAM technique can create more accuracy and durable complete dentures with subtractive or additive manufacturing. With the advancements in open technologies such as optical scanners, design software, and manufacturing equipment, dental professionals now have more options beyond the current commercial systems, especial in complete denture fabrication. However, the main gap for removable partial dentures is the framework fabrication. Nowadays, direct additive manufacturing technique selective laser melting and new material poly-etheretherketone are begin to apply in framework fabrication.[11,21,22]

Second, the use of intraoral scanner in clinical digital process can easily achieve the accuracy and validation on

Table 5 The top 10 most cited articles based on the average citations pre year.

Rank	Title	Type	Journal	Total citations	Average citations per year
1	A comparison of the surface and mechanical properties of 3D printable denture-base resin material and conventional polymethylmethacrylate (PMMA).	Original article	J Prosthodont 2023; 32:40—8.	29	29.00
2	Comparison of mechanical properties of 3D-printed, CAD/CAM, and conventional denture base materials.	Original article	J Prosthodont 2020; 29:524—8	98	24.50
3	Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques.	Original article	J Prosthet Dent 2016; 116:249—56.	172	21.50
4	Accuracy of digital complete dentures: A systematic review of in vitro studies.	Review	J Prosthet Dent 2021; 125:249—56.	61	20.33
5	Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives.	Review	J Prosthet Dent 2013; 109:361—6.	220	20.00
6	3D printed complete removable dental prostheses: a narrative review.	Review	BMC Oral Health 2020; 20:343.	76	19.00
7	CAD/CAM complete denture systems and physical properties: a review of the literature.	Review	J Prosthodont 2021; 30:113—24.	54	18.00
8	The use of a modified poly-ether-ether-ketone (PEEK) as an alternative framework material for removable dental prostheses. a clinical report.	Case report	J Prosthodont 2016; 25:580—4.	139	17.38
9	Effect of printing direction on the accuracy of 3D-printed dentures using stereolithography technology.	Original article	Materials 2020; 13:3405.	69	17.25
10	A comparison of the surface properties of CAD/CAM and conventional polymethylmethacrylate (PMMA).	Original article	J Prosthodont 2019; 28:452—7.	86	17.20

the actual morphology of edentulous ridge.[23] It plays an initial critical step in current digital workflow. Alternatively, intraoral scanner could apply in the prediction of customized shape of denture by capturing the changes in mucosa. Recent study has supported that the use of intraoral scanner could improve the accuracy and adequate fit compared to the conventional impression techniques.[24]

To the best of authors' knowledge, this is the first bibliometric analysis of published articles on digital technologies for removable dental prostheses from 2004 to 2023. By searching the WoS databank, a comprehensive list of articles, journals, and countries were clearly compiled to gain an insight into the history and the development of digital technologies over time. The identification of citation
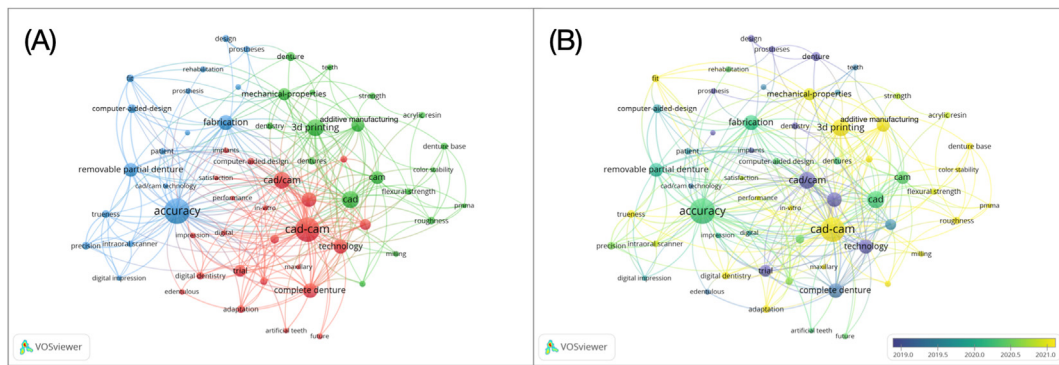
Figure 3 Bibliometric analysis of themes by VOSviewer. (A) Three clusters shown in map for the distribution of themes. (B) Network map of the trend topics according to the keywords used from 2019 to 2021. Indicator shows the current publications from purple to yellow. More studies focused on cad/cam, accuracy, and complete denture have been published recently. The size of the circles represents the frequency of appearance as the keywords. The distance between the two circles indicates their correlation.

and average citation pre year may facilitate the understanding of the advancement of digital technologies. This may identify the emerging themes and future directions. The most cited articles could reflect the important topics of scientific, education, and clinical dentistry. Taken together, this study could offer the important values of digital technologies for removable dental prostheses to enhance the efficiency of digital workflows and the accuracy of removable prostheses.

However, some limitations in this study should be addressed. First, only one database WoS was assessed. Therefore, the generalizability of the results may be dependent on the database extracted. Future studies need to consider the other databases, such as Scopus, PubMed, and MEDLINE to solve the potential selection biases from the single database. Second, only publications written in English were included. Some academic achievements written in other languages may not be captured. Third, the country of article was based on institutional address of the corresponding author listed in the article. Therefore, only those institutions and countries could be recognized where the author was employed or where the article was written. Fourth, self-citations and author citations of particular articles or journals were not analyzed. Thus, the presence of bias or quality of evidence in selected articles may not be ignore in this bibliometric analysis. Finally, the most recent articles that were accepted but not published before December 31, 2023 were not included. This would lead the total number of relevant papers is expected to be lower.

Despite the limitations, this bibliometric analysis revealed the ascendancy of digital technologies such as CAD/CAM and intraoral scanner. It also demonstrates a transition toward accuracy and total solution by digital technologies for removable dental prostheses. Furthermore, it delineates a pathway for future digital technology research to enhance the quality and efficacy of removable prosthodontic treatments.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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