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A Bibliometric Analysis of Removable Partial Denture-related Research in Dentistry

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ABSTRACT

The objective of this study was to characterise articles published in removable partial denture (RPD) research from 1948 to 2022 to identify the most influential journals, publications, authors, and core research areas using bibliometric analysis. The Scopus database was used to retrieve publications with titles containing the truncated search term (“removable partial denture*” OR “removable prosthodontics*”). Data analysis and visualisation were done using Microsoft Excel, Biblioshiny software and VOSviewer. A total of 2,484 articles were analysed from 1948 till 2022, representing an annual growth rate of 4.9%. The *Journal of Prosthodontic Research* demonstrated the highest average normal citation rate, with productive authors with highest citations being from Japan. From 1948 to 1999, most in-vitro and clinical research focused on the basic concept of RPD using cobalt-chromium as a framework before shifting to titanium in 2000. RPD research after 2012 focuses on new technology and non-metal-based frameworks as an alternative to metal-based frameworks. Wakabayashi and Fueki were the most prominent researchers, according to a three-field plot analysis, with the *Journal of Prosthetic Dentistry*, *Journal of Oral Rehabilitation*, and *Journal of Prosthodontic Research* among the authors’ preferred journals. “CAD/CAM” and “3D printing” were identified as emerging themes in year 2020 to 2022, while “selective laser melting” was the trending keyword in 2017 to 2019. Research on “oral health and quality of life” has been identified as core research area in RPD-related research. RPD research on digital dentistry and new framework materials is anticipated to increase in the future with the incorporation of research on quality of life.

Keywords: *Bibliometrics; citation analysis; removable prosthodontics; removable partial dentures*

INTRODUCTION

Bibliometric analysis is a statistical mathematical technique that enables quantitative evaluation of information and

knowledge, links the impact and growth of a journal, identifies influential authors, recognises important research areas, and explores contemporary concepts in a particular field (Donthu *et al.*, 2021; Daryakenari &

Batooli, 2022). It has been studied extensively in other dental specialties and sub-topics, including endodontics (Adnan & Ullah, 2018; Yilmaz *et al.*, 2019; Nagendrababu *et al.*, 2022), periodontology (Ahmad *et al.*, 2020), orthodontics (Primo *et al.*, 2014), oral and maxillofacial surgery (Aslam-Pervez & Lubek, 2018) and paediatric dentistry (Poletto & Faraco, 2010). However, most prosthodontic bibliometric studies found in the literature focus on the analysis and evaluation of certain respective journals (Alhajj *et al.*, 2022; 2023) or the most cited articles in the prosthodontic field as a whole (Praveen *et al.*, 2020).

Bibliometric analysis can be used as a quantitative indicator to measure a researcher's productivity or as a performance indicator to help measure the quality of the journal or the researcher. It can also serve as a structural indicator, establishing a link and analysing trends in an individual's or field of study's area, identifying appropriate sources to publish in, and potential research collaborators (Joshi, 2014; Donthu *et al.*, 2021). By identifying the pattern of publication authorship and citation through time within a study area, it helps to provide an insight into the dynamics of the research. Further analysis can be performed using the quantitative measures obtained by extracting keywords from the articles to quantify evolving areas of future research needs, where allocation of research funds can be distributed more efficiently (Joshi, 2014). A recent bibliometric study from the *Journal of Prosthetic Dentistry* identified experimental and clinical studies on patients and dental materials as being among the top 10 emerging keywords (Alhajj *et al.*, 2023). Similarly, the *Journal of Prosthodontic Research* indicated the same trends with new dental materials (zirconia) and technologies (computer-aided design/computer-aided manufacturing [CAD/CAM]) were among the top 10 keywords of interest among the researchers (Alhajj *et al.*, 2022).

According to the top 100 cited publications in prosthodontic journals, the predominant area of prosthodontic research was dental

implants, followed by composite resins and ceramics, while *Journal of Prosthetic Dentistry* remained the most influential journal among the researchers (Praveen *et al.*, 2020). Numerous studies on removable partial dentures (RPDs) have been conducted, taking into account the availability of new, improved, biocompatible materials and the development of digital technologies (Tamimi *et al.*, 2020; Cagna *et al.*, 2022). However, despite the adoption of these new technologies, RPDs-related research is relatively low in number, with a lack of clinical trial data on RPDs-related research available (Campbell *et al.*, 2017). As no RPDs-related bibliometric analysis is found in the literature, this review can inform clinicians and researchers about the evolutionary dynamics, prolific researchers, influential journals, and emerging research areas in this field.

MATERIALS AND METHODS

Bibliographic Search Strategy

A search was conducted within the Scopus database's core collection. Scopus was chosen because of its extensive thematic and broad coverage database of health sciences. On 10 January 2023, the search was conducted using the truncated search term ("removable partial denture*" OR "removable prosth*"") to locate original articles on RPD and its derivative forms. Data extraction for this study was conducted on a single day to allow for a consistent and comparable set of articles and citation counts. This is because data extraction on different days can lead to variations in citation counts between articles due to new articles being published and researchers continuing to cite existing literature (Chen *et al.*, 2020). The search was limited to the topic field (title, keywords, and abstract). The search results were narrowed down to only published articles, articles in the final stages of publication and in English. Titles, authors, year of publication, number of citations, sources, abstracts, different

keywords, and other reference information were transferred in a comma-separated values (CSV) UTF-8 (comma delimited) file format. The data was then saved in Microsoft Excel 1997–2003 Workbook files (Microsoft Corporation, USA) for data cleaning. Duplicate articles were removed. A manual revision of article titles was performed to ensure the accuracy and relevance of the articles included in the study. Abstracts were read for articles with insufficient information in the title. All records were manually refined and normalised to standardise terms and eliminate typographical, transcriptional, and/or indexing errors. The fields “author,” “journal,” “country of origin,” and “affiliation” had their data normalisation completed. All data pertaining to bibliographic and citation information, such as title, authors, year of publication, number of citations, sources, abstract different keywords, and other references information, were returned in a CSV UTF-8 (comma delimited) (Microsoft Corporation, United States) file format for data analysis. During citation analysis with the software VOSviewer, word derivatives were merged from thesaurus files. For example, “removable partial dentures,” “partial denture*,” and “rpd” were merged as “removable partial denture.”

Data Analysis

A descriptive analysis of the variables was performed using Microsoft Excel software (Microsoft Corporation, United States). The growth of scientific productivity among authors, country, and journals was evaluated, along with the frequency with which various keywords appear. Analysis and visualisation of large networks were performed using statistical analysis software either using Biblioshiny software (RStudio Desktop, Boston, MA) or VOSviewer (Version 1.6.18).

RESULTS

Following the refinement criteria, the search yielded 3,681 articles. A total of 1,195 articles were excluded after data cleaning, leaving 2,486 documents from 146 journals to be analysed. Reasons for exclusion include articles focusing either on restoration of endodontically treated teeth, post and core, fixed dental prosthesis, implant or removable complete denture (without any comparison to RPD) and duplication of articles. Overall, the number of publications on RPD fluctuated throughout the years 1948 to 2022 (Fig. 1) with an annual growth rate of 4.9%. The graph demonstrated the highest number of publications recorded in the year 2014 ($n = 101$) with 1,472 citations. The key information from RPDs-related research is summarised in Table 1.

Authors, Contributing Countries and Institutions

A total of 5,262 authors contributed to the included articles, an average of 3.32 authors per article. Wakabayashi was the most prolific author (37 articles), and Fueki received the most citations (734 citations). Fueki, Baba, Brudvik and Allen are researchers that appeared on both lists (the most productive and most cited authors), indicating that they were the most productive and significant researchers in RPDs. Author profiles of the most productive authors and the most cited authors are reported in Table 2. From 1948 to 2011, the majority of international collaborations were centred in the United States. However, the trends of collaboration changed in 2012 onward, with more countries involved in RPDs-related research (Fig. 2). Nonetheless, the United States continues to have the most documents and citations (Table 3). The distribution of highly productive countries matched that of institutions as displayed in Table 4 with Tokyo Medical and Dental University contributed the most documents in the RPDs-related research.

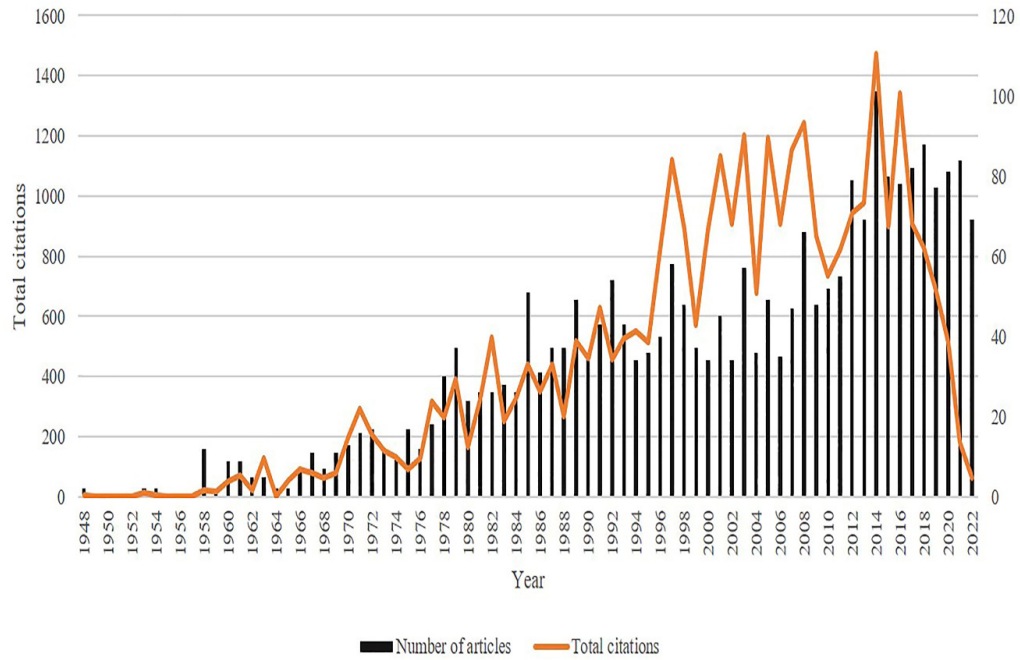


Fig. 1 The total number of citations versus the number publications on RPDs-related research from year 1948 to 2022.

Table 1 Principal information of RPDs-related research from the year 1948 to 2022

Main information	
Timespan	1948:2022
Sources (journals, books, etc.)	146
Documents	2,484
Annual growth rate (%)	4.9
Document average age	21.8
Average citations per doc	13.63
References	38,302
Document contents	
Keywords plus (ID)	3,185
Author's keywords	2,321
Authors	
Authors	5,262
Authors of single-authored documents	378
Authors collaboration	
Single-authored documents	482
Co-authors per documents	3.32
International co-authorships (%)	10.46
Document types	
Article	2,346
Review	139

Table 2 Author profile articles of most productive (with at least 18 articles) and most cited authors in RPDs-related research

Authors	The most productive authors			The most cited author			
	H-index	Affiliation/country	Number of articles	Author	H-index	Affiliation/country	Number of citations
Wakabayashi, Noriyuki	26	Graduate School of Medical and Dental Sciences, Japan	37	Fueki, Kenji	21	Graduate School of Medical and Dental Sciences, Japan	734
Fueki, Kenji	21	Graduate School of Medical and Dental Sciences, Japan	36	Käyser, Arnold F.	31	Radboud Universiteit, Nijmegen, Netherlands	685
Maeda, Yoshionobu	35	Osaka University, Japan	26	Witter, John A	31	University of Michigan, Ann Arbor, United States	659
Brudvik, James S.	18	University of Washington, United State	22	Bergman, Bo	11	Umeå Universitet, Sweden	587
Baba, Kazuyoshi	32	Showa University, Japan	20	Baba, Kazuyoshi	32	Showa University, Japan	558
Ohkubo, Chikahiro	25	Tsurumi University School of Dental Medicine, Japan	20	Brudvik, James S	18	University of Washington, United State	498
Ohyama, Takashi	26	Tokyo Dental College, Japan	20	Igarashi, Yoshimasa	22	Osaka Dental University, Japan	449
Sato, Yuuji	23	Showa University, Japan	20	Giampaolo, Eunice Teresinha	28	Universidade Estadual Paulista, Sao Paulo, Brazil	441
Allen, Patrick Finbarr	39	National University of Singapore, Singapore	18	Allen, Patrick Finbarr	39	National University of Singapore, Singapore	428
Wöstmann, Bernd	25	Justus-Liebig-Universität Gießen, German	18	Ohkubo, Chikahiro	25	Tsurumi University School of Dental Medicine, Japan	428
Kern, Matthias	65	Christian-Albrechts-Universität zu Kiel, Germany	18				
Lynch, Christopher D.	28	Cork University Dental School and Hospital, Ireland	18				

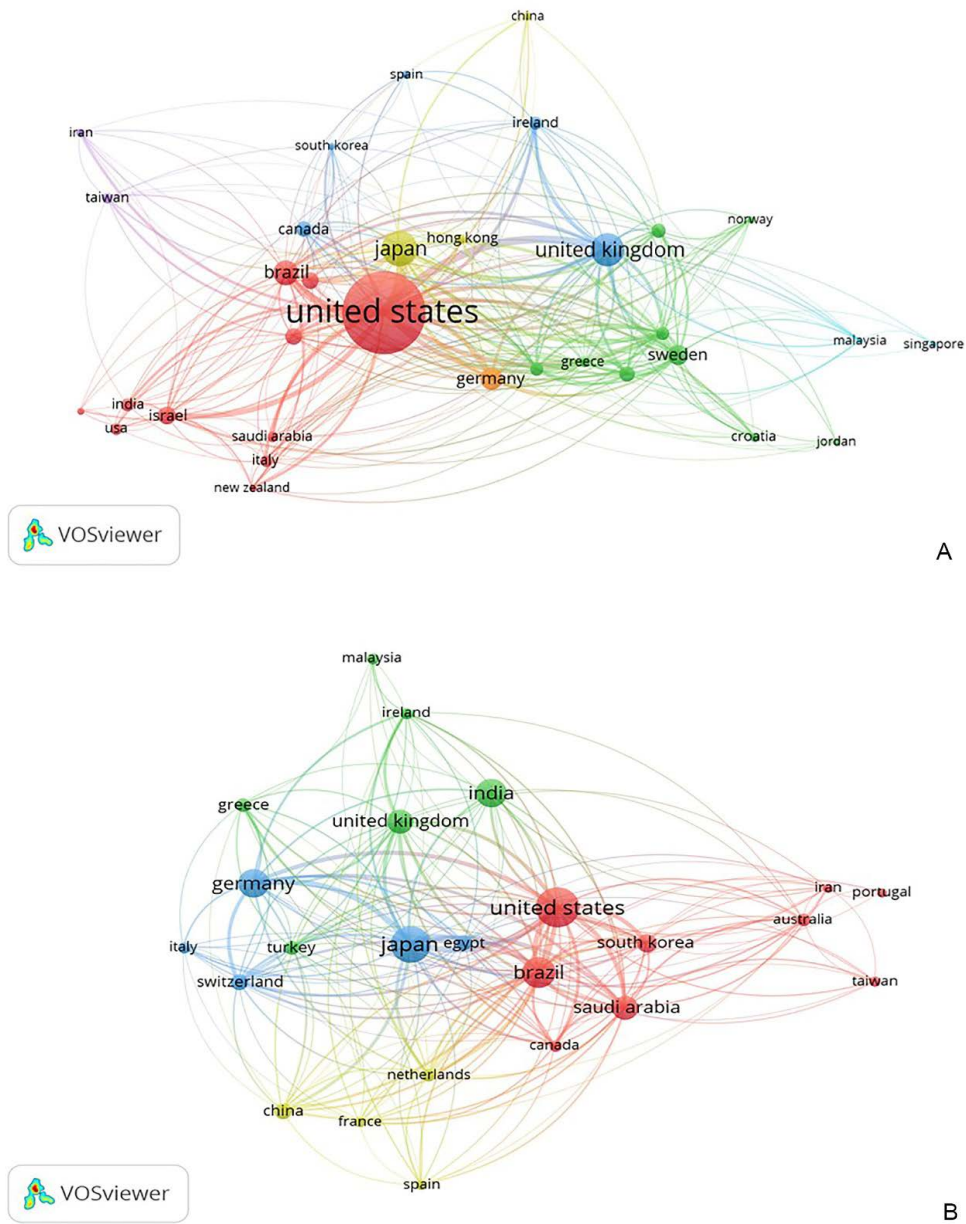


Fig. 2 The collaboration network between countries based on the year (A) from year 1948 to 2011, (B) from year 2012 to 2022. The bubble size indicates the number of documents published. The bigger bubbles indicated more documents published from the country. Link length indicates the closeness of collaboration.

Table 3 Number of documents and number of citations in between the top five countries in the year 1948 to 2011 and the year 2012 to 2022

Country	1948 to 2011		Country	2012 to 2022	
	Number of documents	Number of citations		Number of documents	Number of citations
United States	616	8,408	United States	146	1,745
Japan	123	2,857	Japan	127	1,316
United Kingdom	110	2,191	Brazil	88	904
Brazil	64	1,388	Germany	78	922
Germany	51	1,727	India	78	368

Table 4 Top 10 contributing institutions in the year 1948 to 2022

Institution	Country	Number of articles	Number of citations	Citations per article
Tokyo Medical and Dental University	Japan	37	816	22.05
University of California	United States	29	514	17.72
University of Washington	United States	24	492	20.50
University College Cork	Ireland	20	420	21.00
University of Michigan	United States	17	279	16.41
Osaka University	Japan	15	157	10.46
Tsurumi University	Japan	14	237	16.92
University of Zagreb	Croatia	11	413	37.54
The University of Iowa	United States	11	168	15.27
Tohoku University	Japan	10	113	11.3

Citations

Twenty-six publications were cited more than 100 times based on Scopus citations, ranging from 101 to 383 citations. Table 5 shows the top 10 most cited articles in RPDs-related research based on study characteristics. Most of the highly cited papers are review papers. “Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics (2016)” was the most highly cited article with the highest average citation (AC) per year of 22.47 (Najeeb *et al.*, 2016). AC is defined as the average number of citations received by the documents published by an author, a source, an organisation, or a country (van Eck & Waltman, 2018). Three articles

(“A new visible light-cured resin system applied to removable prosthodontics” (AC = 10.8); “Accuracy of CAD/CAM systems for removable partial denture framework fabrication: A systematic review” (AC = 9.64); and “A 5-year longitudinal study of cantilevered fixed partial dentures compared with removable partial dentures in a geriatric population” (AC = 9.35) received the highest AC apart from the most cited article (Ogle *et al.*, 1986; Budtz-Jørgensen & Isidor, 1990; Pereira *et al.*, 2021). The article titled “Changes caused by a mandibular removable partial denture opposing a maxillary complete denture” is considered one of the “classical papers” by the journal (Kelly, 1972).

Table 5 Articles information on 10 most cited articles in research in RPD-related research

Article information	Authors	Total citation (Scopus)	Average citation per year
Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. <i>Journal of Prosthodontic Research</i> , 2016 (Review)	Najeeb S., Zafar M.S., Khurshid Z., Siddiqui F.	383	22.47
Advancements in CAD/CAM technology: Options for practical implementation. <i>Journal of Prosthodontic Research</i> , 2016 (Review)	Alghazzawi T.F.	243	14.34
Titanium for prosthodontic applications: A review of the literature. <i>Quintessence International</i> , 1996 (Review)	Wang R.R., Fenton A.	238	11.72
Caries, periodontal and prosthetic findings in patients with removable partial dentures: A ten-year longitudinal study. <i>Journal of Prosthetic Dentistry</i> , 1982 (Clinical study)	Bergman B., Hugoson A., Olsson CO.	174	8.51
Functional units, chewing, swallowing, and food avoidance among the elderly. <i>Journal of Prosthetic Dentistry</i> , 1997 (Cross-sectional study)	Hildebrandt G.H., Dominguez B.L., Schork M.A., Loesche W.J.	171	8.85
A review of the shortened dental arch concept focusing on the work by the Käyser/Nijmegen group. <i>Journal of Oral Rehabilitation</i> , 2006 (Review)	Kanno T., Carlsson G.E.	153	5.89
Future needs for fixed and removable partial dentures in the United States. <i>Journal of Prosthetic Dentistry</i> , 2002 (Review)	Douglass C.W., Watson A.J.	146	5.46
Changes caused by a mandibular removable partial denture opposing a maxillary complete denture. <i>Journal of Prosthetic Dentistry</i> , 1972 (Review)	Kelly E.	144	11.76
Use of CAD/CAM technology to fabricate a removable partial denture framework. <i>Journal of Prosthetic Dentistry</i> , 2006 (Case report)	Williams R.J., Bibb R., Eggbeer D., Collis J.	142	5.47
The shortened dental arch concept and its implications for oral health care. <i>Journal of Prosthetic Dentistry</i> , 1999 (Review)	Witter D.J., Van Palenstein Helderma W.H., Creugers N.H.J., Käyser A.F.	132	8.56

Journal's Publication

Table 6 shows the top 10 contributing journals in RPDs-related research based on the year. The *Journal of Prosthetic Dentistry* published the most articles in RPDs-related research in all years (1948 to 2022) with 751 documents, which received 10,415 citations, followed by the *Journal of Prosthodontics* with 166 documents and 1,949 citations. For the years 2012 to 2022, the *Journal of Prosthetic Dentistry*, *Journal of Prosthodontics*, and *Journal of Prosthodontic Research* were

the most contributing journals among those for RPDs-related research. The *Journal of Prosthodontic Research* received the highest average normal citation (ANC) (2.1022). ANC is defined as the average normalised number of citations, that is, the average normalised number of citations received by the documents published by an author, a source, an organisation, or a country. Fig. 3 depicts the total number of articles published in the top 10 journals by the year of publication.

Table 6 Top 10 contributing journals in the RPDs-related research based on year

Journal	194 to 2011		2012 to 2022		All year 1948 to 2022	
	Number of documents	Average normal citation	Number of documents	Average normal citation	Number of documents	Average normal citation
<i>Journal of Prosthetic Dentistry</i>	653	1.0525	98	1.2697	751	1.0860
<i>Journal of Oral Rehabilitation</i>	120	1.7344	92	1.0938	166	0.9577
<i>International Journal of Prosthodontics</i>	87	1.3507	57	2.1022	162	1.5956
<i>Quintessence International</i>	84	0.5815	55	0.8271	142	1.1479
<i>Journal of Prosthodontics</i>	74	0.7885	42	1.1992	89	0.5722
<i>Dental Clinics of North America</i>	53	0.4531	28	1.1779	66	1.9302
<i>General Dentistry</i>	35	0.1872	28	1.3651	58	0.5545
<i>British Dental Journal</i>	29	0.6806	21	0.9592	56	1.3644
<i>Journal of Dentistry</i>	28	1.3638	19	0.4456	48	0.1703
<i>Journal of The American Dental Association</i>	28	0.5743	18	0.636	47	0.6635

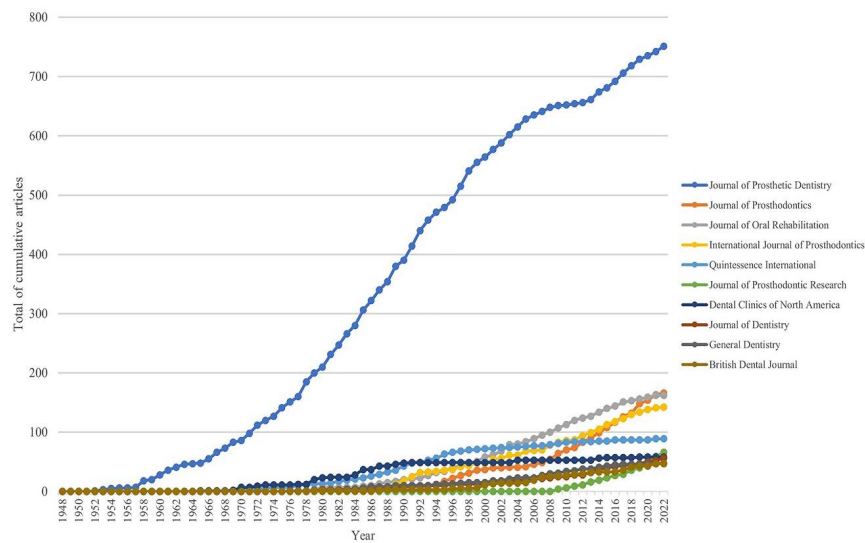


Fig. 3 The total cumulative number of articles published according to the top 10 journals by year of publications.

Three-field Plot Analysis: The Relationship among Authors, Journals and Countries

A three-field plot analysis was performed using Biblioshiny software (RStudio Desktop, Boston, MA) to classify key authors and journals associated with the keywords. Relationships between the top 10 key journals, 10 authors, and 10 keywords were summarised by a Sankey plot (three-fields plot) shown in Fig. 4. For both figures, all the top 10 authors published research that consisted of the “removable partial denture” keywords. “Shorten dental arch” and “CAD/CAM” were the most frequently used keywords by researchers throughout the year, while “CAD/CAM” and “quality of life” were the top keywords used by authors in RPD research in 2012 and beyond. The majority of top authors who conducted and published research were from Japan, with Wakabayashi and Fueki being the most prominent researchers in RPDs-related research. The *Journal of Oral Rehabilitation* is among the authors’ preferred journals, apart from the *Journal of Prosthetic Dentistry* and *Journal of Prosthodontic Research* (Fig. 4A). The shift in publishing trend was noticed in the years 2012 to 2022, with the

Journal of Oral Rehabilitation and the *Journal of Prosthodontic Research* being among the chosen journals among the authors (Fig. 4B).

Keywords

For visual content analysis of the relationship between the most frequently used keywords, VOSviewer software (version 1.6.18) was used. Fig. 5 depicts the number of occurrences in different time periods based on the author’s keywords: (A) from years 1948 to 1999 and (B) from years 2000 to 2022. Only 306 keywords were analysed from 1948 to 1999, with most themes focusing on understanding the material and basic principles of RPD, with keywords such as “stress”, “retention”, “dental material”, and “oral health” frequently used. The keywords were divided into eleven clusters from 2000 to 2011, with the trending keywords primarily being “quality of life”, “shortened dental arch”, “implant”, and “finite element analysis”. “CAD/CAM” and “3-D printing” were among the growing bubbles identified between 2012 and 2022. To determine trends of keywords with greater influence, the period 2017 to 2022 was divided into two 2-year

periods, with the top 10 recurring terms identified as high-impact terms in each period based on the AC and ANC scores (Table 7). The terms “removable partial denture” and “removable full denture” were omitted from the summary because they were commonly used in RPD research. The

new technology in RPD fabrication was identified as an emerging theme in recent years with the terms “CAD/CAM” (ANC = 1.78) and “3-D printing” (ANC = 1.33), while “selective laser melting” was the trending keyword from 2017 to 2019 with an ANC of 2.91.

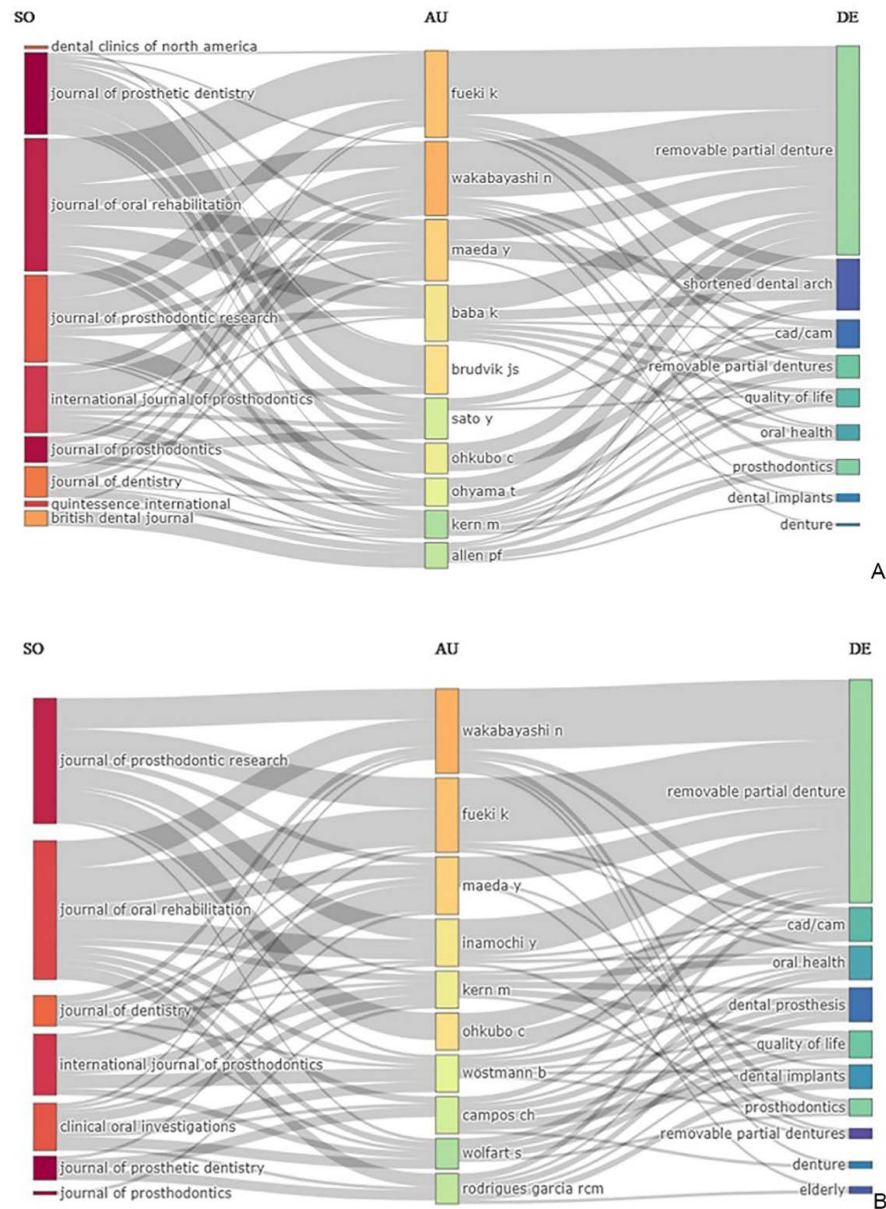


Fig. 4 The three-field plot analysis of 10 journals, 10 authors, and 10 keywords. The relationship between journal, authors, and keywords in the (A) entire period (1948 to 2022) and (B) for the period (2012 to 2022). Each column represents data field (left most column – journal; middle – authors, and right most column – keywords). The lines’ thickness and width stand of the grey arrow proportionally represents the strength of associations between the three fields, while the rectangle’s dimensions represent the normalised number of articles between two fields.

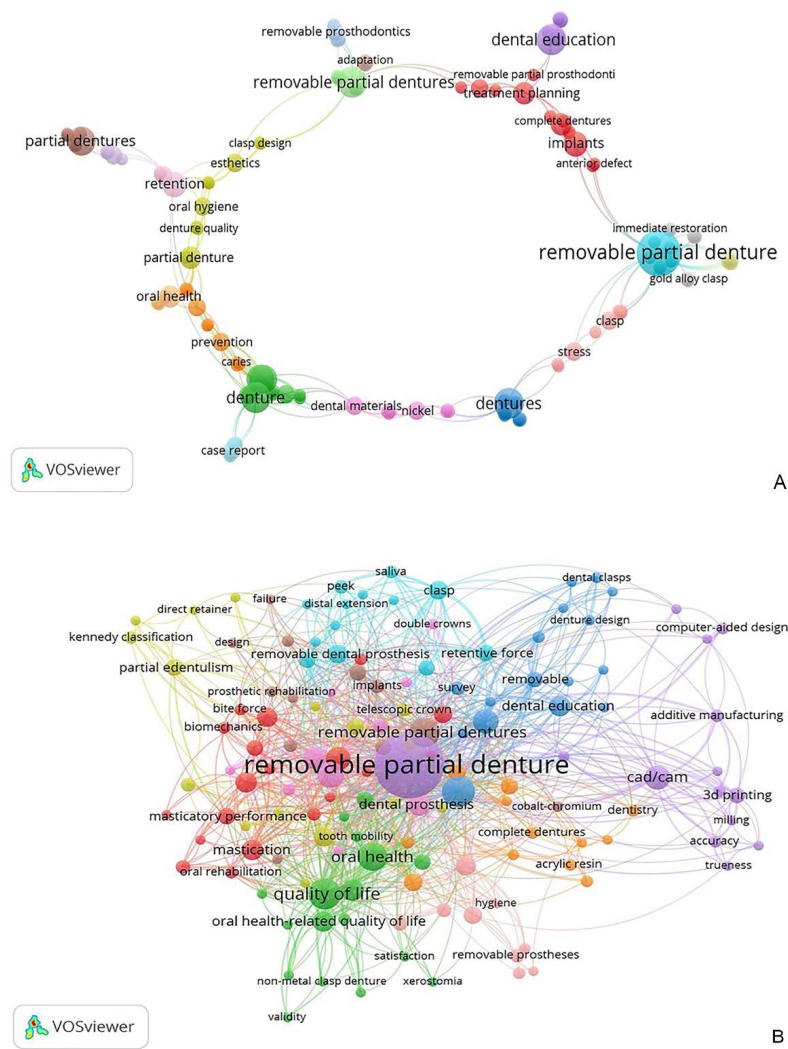


Fig. 5 The number of occurrences based on the authors keywords (A) from the year 1948 to 1999; (B) from the year 2000 to 2022. Each keyword illustrated by the bubble size and label of the circle indicates weightage of the item as frequency of term in the publications based on the published year.

Table 7 Two-year periodic average citation (AC) and average normalised citation (ANC) scores of high-impact keywords from 2017 to 2022

Keywords (Year 2017 to 2019)	AC	ANC	Keywords (Year 2020 to 2022)	AC	ANC
Selective laser melting	26.0	2.91	CAD/CAM	7.29	1.78
3-D printing	25.5	2.74	3-D printing	6.46	1.33
Partially edentulous	23.6	2.54	Non-metal clasp	6.40	1.48
Complete denture	20.0	2.12	Patient-reported outcome	5.80	3.66
CAD/CAM	18.2	1.97	Clasp	5.46	1.48
Double crown	18.0	1.83	Complete denture	4.15	1.19
PEEK	18.0	2.02	Finite element analysis	4.00	0.75
Periodontal disease	16.0	1.66	Patient’s satisfaction	4.00	2.79
Complication	15.0	1.50	Implant	3.89	2.17
Oral health-related quality of life	14.5	1.38	PEEK	3.81	1.23

Core Research Areas

Term co-occurrence networks are used to identify and analyse the distribution and evolution of the core study subjects in RPDs-related research. Based on the time period selected, the co-occurrence network distribution density will reflect how “hot” or “cold” a research topic is. Fig. 6 depicts the density distribution of the keyword co-occurrence network for the time periods (A) 1948 to 2022; and (B) 2012 to 2022. According to the map, there were four major areas of core research: (1) Oral health and quality of life; (2) Research in association with dental implant; (3) Shortened dental arch; and (4) Digital technologies. Both time periods reveal “oral health and quality of life” as the primary core research topic. For the past 10 years, the emphasis has been on secondary research core topics associated with dental implants. The topic of new technologies in RPD fabrication (CAD/CAM, 3-D printing, additive technology) has grown, while the topic of “shorten dental arch” has weakened slightly.

DISCUSSION

This study aims to characterise the dynamics of RPDs research in terms of prominent researchers, collaborating countries and institutions, principal journals, and emerging research areas using bibliometric analysis. This bibliometric analysis revealed that the annual research output in RPDs-related research is relatively low when compared to

other areas of dental research, with an annual growth rate of 4.9% between 1948 and 2022. With an average annual growth rate of 25%, implant dentistry had the greatest increase in average annual growth rate, followed by restorative dentistry (9%), endodontics (9%), oral surgery (6%) and orthodontics (6%) (Yang *et al.*, 2001). Further analysis of RPDs-related research output from 2012 to 2022 revealed a 1.34% decrease in annual growth rate, most likely due to researchers’ focus shifting to other prosthodontic topics such as fixed, implant, or maxillofacial prosthodontics. The top 10 most cited RPDs-related articles (as listed in Table 5) received between 132 and 383 citations, eight of which being review articles. This total number of citations however, is significantly lower than the total number of citations in prosthodontic research related to dental implants, fixed prosthodontics, dental materials, or temporomandibular joint (between 343 and 2,368) (Praveen *et al.*, 2020). A publication is considered a classic if it has been cited more than 400 times, but in some fields with fewer researchers, 100 citations may suffice (Garfield, 2022). For example, the *Journal of Prosthetic Dentistry* considers the article “Changes caused by a mandibular removable partial denture opposing a maxillary complete denture” as a “classical paper” despite receiving only 144 citations in Scopus (Kelly, 1972). Other articles in the field of dentistry such as periodontics received between 117 and 1,069 citations (Ahmad *et al.*, 2020) while endodontics received between 246 and 2,115 citations (Yilmaz *et al.*, 2019).

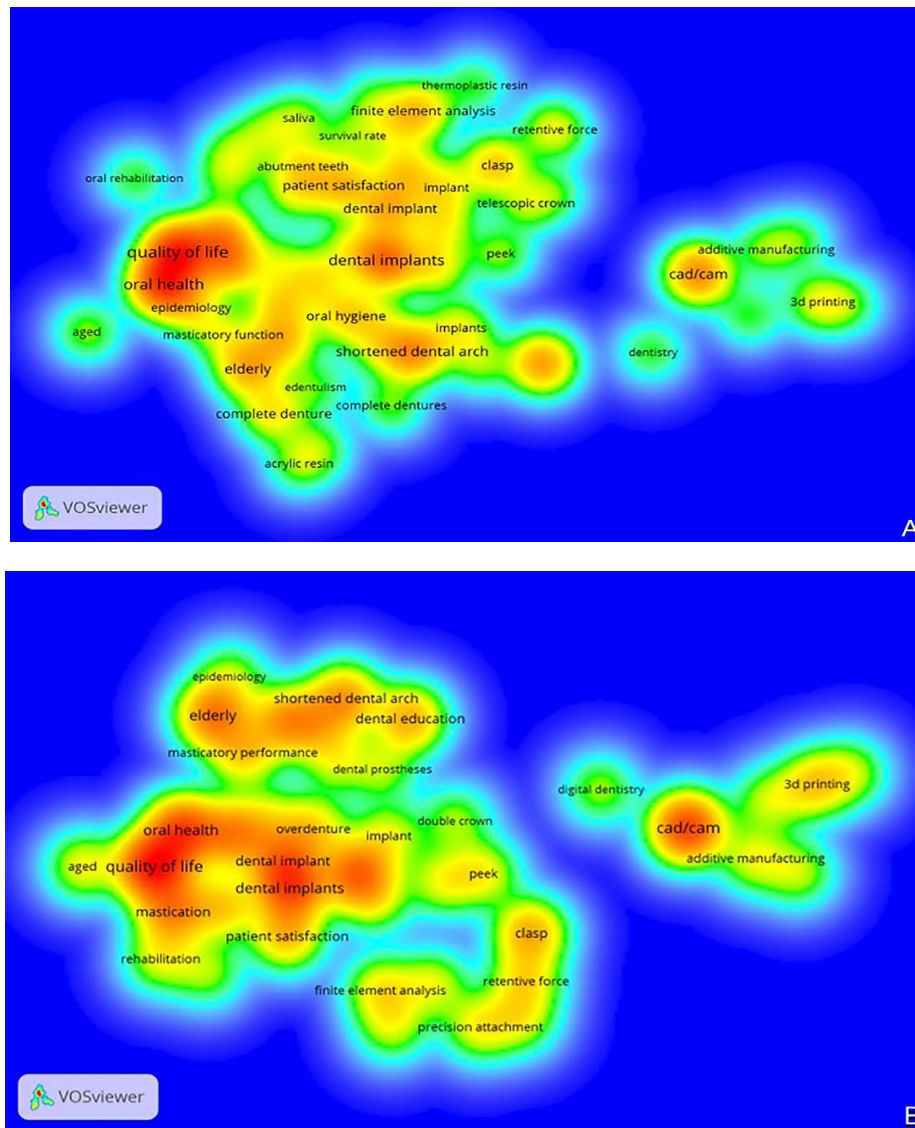


Fig. 6 The keyword co-occurrence network density distribution map showing the core research area for years (A) 1948 to 2022; and (B) 2012 to 2022. The high-density nodes (red) reflected the “hot” core research topic in RPD-related research.

Author impact can be measured either by the number of academic publications to solidify the subject’s foundation (as Wakabayashi) or the number of significant publications with lots of citations (as Feuki). Although the United States contributes to the most articles in RPDs research, our three-field plot analysis revealed that a recent trend has indicated more researchers from Japan have published in RPDs research as well as gained recognition in terms of citation. The *Journal of Prosthetic Dentistry* (SJR²⁰²¹ = 1.11, H-index = 136) remains the most influential journal, contributing the most to RPDs

research. Furthermore, while the *Journal of Prosthodontics* (SJR²⁰²¹ = 0.9, H-index = 67) contributed the second most documents in RPDs-related research, its citations were lower than those from the *Journal of Oral Rehabilitation* (SJR²⁰²¹ = 0.94, H-index = 98) and the *International Journal of Prosthodontics* (SJR²⁰²¹ = 0.59, H-index = 99). Further analysis using the three-plot analysis (Sankey diagram) revealed that apart from the *Journal of Prosthetic Dentistry*, the *Journal of Oral Rehabilitation* is also the preferred journal among the top researchers in RPDs for the past 10 years. The *Journal of Prosthodontic*

Research (SJR²⁰²¹ = 1.23, H-index = 44) demonstrated the highest average normal citation for RPDs-related research for the last 10 years, reflecting the increasing productivity of Japanese researchers in RPDs research.

The Trends in RPDs-related Research from 1948 until 2022

Before the year 2000, most studies were focused on the basic concepts of RPDs, such as treatment planning (Mills, 1960; Dunn, 1961; Steffel, 1962; Holmes, 1968), laboratory techniques and procedures (Bolouri *et al.*, 1975; Feit, 1999), denture biomechanics (Knowles, 1958; Levin, 1979) and denture design (Schmidt, 1953; Potter *et al.*, 1967; Bolouri, 1978; Becker *et al.*, 1994). Many *in vitro* studies evaluated different materials or denture designs in relation to the abutment teeth and surrounding oral mucosa (Robinson, 1970; Benson & Spolsky, 1979; Gomes *et al.*, 1981) as well as shorten dental arch concept (Witter *et al.*, 1989; 1991; 1999). The majority of studies conducted between 2000 to 2011 focused on either longitudinal, retrospective or oral health-related quality of life studies, which assessed difference between the RPDs-complete dentures (Celebić & Knezović-Zlatarić, 2003; Bae *et al.*, 2006), RPDs-fixed partial prosthesis (Tanaka *et al.*, 2009) and RPDs-implants (Smith *et al.*, 2009; Bortolini *et al.*, 2011). The physical and mechanical properties of titanium and cobalt-chromium as the new alternative materials for the RPD frameworks were also explored (Rodrigues *et al.*, 2002; 2010). A new method of assessing the stress distribution of the oral mucosa using finite element analysis was introduced in early 2000, to evaluate the effect of stress distribution on different components of the RPD (Sato *et al.*, 2001; Eto *et al.*, 2002; Muraki *et al.*, 2004). From the year 2012 onwards, the trends were on new technologies in RPD fabrication either using 3-dimensional printing (3-D printing), CAD/CAM, or laser sintering, and new materials

involving non-metal thermoplastic materials (Muhsin *et al.*, 2018; Lee & Kwon, 2019; Pelletier *et al.*, 2022; Refai *et al.*, 2022). This digital technology attracts more research as it improves time efficiency, has lower technique sensitivity, and results in fewer human errors as compared to conventional laboratory procedures (Akl & Stendahl, 2022). The emerging of non-metal thermoplastic materials as an RPD frameworks in 2014 caused the Japanese Prosthodontic Society to publish two position papers discussing the properties and clinical guidelines in response to a request from the Japanese Social Insurance and Dental Service Problem Committee (Fueki *et al.*, 2014a; 2014b). The majority of denture design principles are based on cobalt-chromium properties. While non-metal thermoplastic RPD do not adhere to the standard principle of RPD design, they may cause detrimental effects to the periodontal tissues of abutment teeth and the residual ridge. Recently, PEEK has become another material of interest with superior physical and mechanical properties to be used as an RPD frameworks, fixed partial prosthesis, and implant-supported fixed dental prostheses. A review paper on PEEK was identified as the most highly cited article with the highest AC per year, indicating a high interest in that topic (Najeeb *et al.*, 2016). Apart from clinical case reports (Harb *et al.*, 2019; Ichikawa *et al.*, 2019), many *in vitro* researches were conducted to evaluate the properties and suitability of the material to be used as the direct retainer and framework in relation to the best design principles for each component (Muhsin *et al.*, 2018; El-Baz *et al.*, 2020; El Mekawy & Elgamal, 2021; Guo *et al.*, 2022). Few studies have incorporated the finite element analysis to assess the mechanical properties and stress distribution of this new material. The results showed that PEEK offered superior flexibility and a lower elastic modulus than traditional metal clasps, making it a promising alternative to traditional metal clasps (Chen *et al.*, 2019; Peng *et al.*, 2020; Lyu *et al.*, 2023).

Future Direction of RPDs-related Research

The new emerging themes identified in RPDs-related research within the two-year period (2020 to 2022) were CAD/CAM, 3-D printing and non-metal clasps highlighting the new research interest among researchers. All mentioned themes received an average normalised citation score above 1, indicating the high-impact terms introduced in previous years. Future research is expected to focus on the various techniques for fabricating RPD frameworks, which include either additive manufacturing (laser sintering/3-D printing) or subtractive manufacturing (CAD/CAM) using various materials such as polyamide, PEEK, polyethylene glycol, and aryl-ketone polymers. As technology evolves rapidly, it is anticipated that new upgraded user-friendly CAD software and further improvement of CAD/CAM systems will help to improve the accuracy and adaptability of the framework fabricated. As a result, high-quality RPDs that can be effectively designed and made to meet the specific needs of the patient can be produced.

Research on non-metal high-performance polymers is still low, despite the fact that they have been used for many years in a wide range of industries, including aerospace, automotive, electronics, and healthcare (Najeeb *et al.*, 2016; Papathanasiou *et al.*, 2020). The growth of new polymers presents a chance to reassess the fundamental partial denture design principles, which are largely based on the characteristics of cobalt-chromium. Future research should highlight the need for more well-controlled randomised clinical research to validate the experimental study done in the laboratory (Muhsin *et al.*, 2018; El-Baz *et al.*, 2020; El Mekawy & Elgamal, 2021; Guo *et al.*, 2022), as currently it is suggested that high-performance polymers are best used as interim prostheses as long-term evidence of their function and its effect on the tooth and periodontal structures is still lacking (Ahmed *et al.*, 2021). Research on oral health and quality of life was found to be the primary core research area in RPDs-related

research for the past 10 years apart from research in association with dental implant and new technologies in the fabrication of RPD. Furthermore, based on the higher AC rate analysis of the terms “patient-reported outcome” and “patient satisfaction,” it is expected that “patient-oriented” research will be prioritised in the future and remains important as a predictor of treatment success (Haraldstad *et al.*, 2019).

Although the annual research output of RPDs is relatively low, it remains a relevant treatment option, particularly for restoring long-span edentulous areas and achieving aesthetic results through the replacement of hard and soft tissue. RPDs play a crucial role in addressing the specific needs of individuals with limited resources or financial constraints, enabling them to access appropriate dental care and attain satisfactory aesthetic outcomes (Campbell *et al.*, 2017). Over the years, RPDs research has been significantly influenced by advancements in materials, technologies, and patient demands. Initially, the focus of RPDs research was primarily on the fundamental concepts and functional aspects, mainly using metal-based materials. This involved the development of more efficient designs to enhance the biomechanical properties of dentures (Gomes *et al.*, 1981; El Mekawy & Elgamal, 2021; Guo *et al.*, 2022). As the field progressed, researchers expanded their investigations to include the impact of RPDs on abutment teeth and surrounding oral tissues, incorporating clinical studies and studies related to oral health-related quality of life. In recent years, the evolution of RPDs-related research has focussed on investigating patient-centred outcomes such as patient satisfaction, quality of life, and psychological well-being, while utilising a broader spectrum of materials and capitalising on technological manufacturing advances (Mohamed & Rasha, 2019; Ali *et al.*, 2020). This shift towards patient-centred research has resulted in a more holistic approach, considering not only the technical aspects but also the overall well-being of patients wearing RPDs. Notably,

recent RPDs research has witnessed the increasing utilisation of polymer-based frameworks, such as PEEK, as materials for RPD frameworks, incorporating new technologies like 3D printing and CAD/CAM (Mohamed & Rasha, 2019; Ali *et al.*, 2020).

Implications to the RPDs-related Research

With a greater emphasis on patient-centred outcomes, RPDs-related research has shifted from solely technical and functional considerations to a more complete approach. However, due to the diverse features of the new materials on the market, assessing their biomechanical properties remains critical. Incorporating the numerical simulation method of finite element analysis would be extremely beneficial in analysing the behaviour of an RPD under varied loads and boundary conditions. Aside from that, current research will continue to focus on new RPDs materials and technologies, with the goal of enhancing the design in respect to the qualities of the materials available and suggesting the best RPD clinical protocols. Integration of novel materials and digital dentistry will enable more precise and efficient manufacture of RPDs, which is expected to improve treatment outcomes and overall RPD success.

This bibliometric analysis has several inherent limitations. First, data was extracted exclusively from the Scopus database, but the Scopus database provides wider coverage (20% more data) than the Web of Science database (Patil *et al.*, 2020). Second, for articles published prior to the year 2000, the analysis of the occurrence of keywords for the research only captured 306 keywords, necessitating manual identification of the paper based on its title. This is because the older article lacks sufficient keyword information or provides no keywords at all.

CONCLUSION

Within the limitations of our study, the following conclusions were drawn. The output and citations of RPDs-related research are relatively lower compared to other topics and fields in dentistry. The *Journal of Prosthetic Dentistry* is the most contributing journal in RPDs-related research, but from 2012 onward, the *Journal of Prosthodontic Research* received the highest annual citation rate compared to other journals. The most productive and highly cited authors are from the Tokyo Medical and Dental University. Most highly-cited publications in RPDs-related research are review articles. RPDs research on digital dentistry and thermoplastic materials as alternative frameworks is anticipated to increase in the future and research on the quality of health-related issues will remain significant in RPDs-related research.

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