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A bibliometric analysis of 3D printing in endodontics

Bibliometrijska analiza 3D štampanja u endodonciji

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Abstract

Background/Aim. In recent years, owing to the development of the three-dimensional (3D) printing method, managing complex clinical cases and educational and standardized experimental models has become possible, with a sharp increase in publications from 2018. The aim of this study was to reveal the bibliometric analysis and trends of the studies published in the field of the use of 3D printing in endodontics in the last 10 years. **Methods.** Studies published between 2014 and 2023 were accessed in the Web of Science Core Collection database, and the data obtained were examined with bibliometric analysis in terms of countries, journals, publication years, publication numbers, publication types, topic tendencies, and citation analysis. **Results.** A total of 128 papers were included in the study. The retrieved papers received an average of 13.59% of citations *per* publication. The first three countries with the highest number of publications were the People's Republic of China, the United States of America (USA), and Germany. At the same time, the first three countries with the highest number of citations were Germany, Switzerland, and USA. In the co-authorship analyses, it can be seen that the highest total link strength is between Germany and Switzerland, while the USA is the country with the highest number of co-authorships. The top five keywords with the highest total link strength were "3D printing", "guided endodontics", "endodontics", "root canal treatments", and cone-beam computed tomography or "CBCT". **Conclusion.** To our knowledge, this study is the first bibliometric analysis of worldwide research on the use of 3D printing in the endodontic field. Such analyses need to be conducted regularly to closely monitor the development of this research field.

Key words:
bibliometrics; cone-beam computed tomography; database; endodontics; printing, three-dimensional.

Apstrakt

Uvod/Cilj. Poslednjih godina, zahvaljujući razvoju metode trodimenzionalnog (3D) štampanja, postalo je moguće rešavanje složenih kliničkim slučajeva i primena edukativnh i standardizovanh eksperimentalnih modela, uz nagli porast publikacija od 2018. godine. Cilj ove studije bio je da prikaže bibliometrijsku analizu i trendove istraživanja objavljenih u oblasti upotrebe 3D štampe u endodonciji u poslednjih 10 godina. **Metode.** Studijama objavljenim između 2014. i 2023. godine pristupalo se u bazi podataka *Web of Science Core Collection*, a dobijeni podaci ispitani su bibliometrijskom analizom u pogledu zemalja, časopisa, godina izdavanja, broja publikacija, tipova publikacija, tendencija tema i analize citata. **Rezultati.** U studiju je bilo uključeno ukupno 128 radova. Preuzeti radovi su u proseku dobili 13,59% citata po publikaciji. Prve tri zemlje sa najvećim brojem publikacija bile su Narodna Republika Kina, Sjedinjene Američke Države (SAD) i Nemačka. Istovremeno, prve tri zemlje sa najvećim brojem citata bile su Nemačka, Švajcarska i SAD. Najveća ukupna snaga povezanosti koautora pokazana je između Nemačke i Švajcarske, dok je SAD država sa najvećim brojem koautorstava. Top pet ključnih reči sa najvećom ukupnom snagom povezanosti bile su "3D štampanje", "vodjena endodoncija", "endodoncija", tretmani kanala korena i kompjuterizovana tomografija konusnog zraka (*cone-beam computed tomography* – "CBCT"). **Zaključak.** Prema našim saznanjima, ova studija je prva bibliometrijska analiza svetskih istraživanja o upotrebi 3D štampe u endodontskoj oblasti. Takve analize treba redovno sprovoditi kako bi se pomno pratio razvoj ove istraživačke oblasti.

Ključne reči:
bibliometrija; tomografija, kompjuterizovana, konusna; baze podataka; endodoncija; štampanje, trodimenzionalno.

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Introduction

Three-dimensional (3D) printing technology in dentistry is used, along with treatment planning and surgical guidance, to produce dental models for orthognathic surgery, implant surgery, oral and maxillofacial surgery, orthodontics, and prosthetic appliances [1]. Using 3D printing, high-resolution models can be produced from resin with an automatic production process and layered on top of each other, with a resolution of 16–32 μm for each layer. Rapid prototyping of natural teeth is very promising and has particular potential for inclusion in endodontic education. In addition, it allows the standardization of important samples in laboratory studies such as root canal instrumentation, filling, and retreatment [2].

Working on models obtained by 3D printing in endodontics is of great importance in terms of preclinical education and gaining experience for clinicians by working with replicas of teeth in different variations. In literature, the 3D guided endodontics technique has been studied increasingly in different clinical situations and indications (access cavity preparation, calcified canals, endodontic surgery, fiber post removal, teeth with developmental anomalies, and/or complicated root canal formation) [3–6].

Bibliometric methods or analysis are now considered a field of scientific expertise and, in many fields, have become an integral part of research evaluation methodology. Visualizing a specific field or subject in a certain systematic way and analyzing the relationship between authors or publications can be called bibliometric mapping or scientific mapping [7]. When explaining the relationship between bibliometric analysis and citations, scientific mapping comes to the fore. Scientific mapping and bibliometric analyses that enable us to recognize the relevant field have reached a high-quality stage. Advanced bibliometric analyses are seen as an indispensable element in the evaluation of research [8].

The aim of this study was to reveal the bibliometric analysis and trends of the studies published in the field of the use of 3D printing in endodontics in the last 10 years. In this way, it aims to increase the awareness of the authors and subjects that make up the discipline and how to direct the studies of the researchers in this field against the increasing number of papers.

Methods

Data collection tools and process

A search was made on January 1, 2024, on the Web of Science (WoS) Core Collection (WoSCC) database, using keywords “3D printing, root canal”, “3D printing, endodontics”, “replica, root canal”, and “replica, endodontics”. The data obtained were examined with bibliometric analysis in terms of countries, journals, publication years, publication numbers, publication types, subject tendencies, citation analysis, as well as the universities that supported the research.

When the keywords are entered as a subject in the WoSCC database, publications containing the words in the title, abstract, and keywords are scanned and ranked. With this screening, 128 studies published between 2014 and 2023 were accessed and analyzed.

Bibliometric analysis and mapping

Some of the data obtained as a result of the research were arranged in tabular form and expressed as percentages and frequencies. The findings of the research were analyzed using the descriptive analysis technique. Density and network maps were used with the help of the bibliometric mapping program VOSviewer 1.6.18, one of the software programs developed for bibliometric purposes [9].

Results

Main information of the collection

In the search, a total of 128 publications were reached, with the keywords specified in the last ten years. General information on the publications is presented in Table 1.

Table 1

General information of the publications

Publications	number (%)
Document type	
article	113 (88.28)
review article	13 (10.15)
proceeding paper	5 (3.90)
early access	41 (32.03)
Web of Science Categories	
Dentistry Oral Surgery Medicine	95 (74.21)
Materials Science Multidisciplinary	10 (7.81)
Education Scientific Disciplines	7 (5.46)
Materials Science Biomaterials	7 (5.46)
Physics Applied	7 (5.46)
Web of Science Index	
Science Citation Index Expanded	111 (86.71)
Emerging Sources Citation Index	15 (11.71)
Conference Proceedings Citation Index – Science	5 (3.90)
Social Sciences Citation Index	2 (1.56)
Total number of citations	1,739
Average citations *per* document, %	13.59

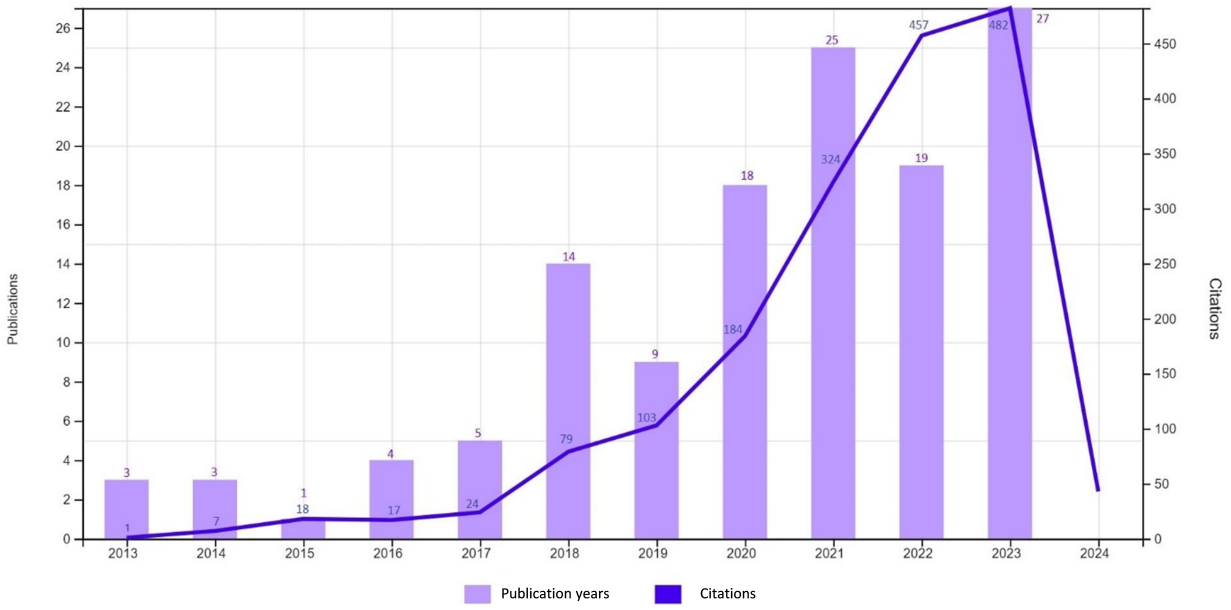

Fig. 1 – Times cited and publications over time.

Number of articles, review articles, and proceeding papers accounted for 113 (88.28%), 13 (10.15%), and 5 (3.90%), respectively. Forty-one (32.03%) of these publications were early access. When the annual publication numbers are examined, the number of annual publications, which was 3 in 2014, 1 in 2015, 4 in 2016, and 5 in 2017, increased rapidly to 14 in 2018, 18 in 2020, 25 in 2021, and 27 in 2023 (Figure 1). According to WoS categories, the five most published categories were Dentistry Oral Surgery Medicine [95 (74.21%)], Materials Science Multidisciplinary [10 (7.81%)], Education Scientific Disciplines [7 (5.46%)], Materials Science Biomaterials [7 (5.46%)], and Physics Applied [7 (5.46%)]. According to WoS indexes, 111 publications were indexed by Science Citation Index Expanded (SCIE), 15 publications by Emerging Sources Citation Index (ESCI), 5 publications by Conference Proceedings Citation Index – Science (CPCI-S), and 2 publications by Social Sciences Citation Index (SSCI). With an average of 13.59% of citations *per* publication, the collection received a total of 1,739 citations.

Most cited papers

Eleven publications [10–20] with the highest number of citations are listed in Table 2, including additional information about the journal and authors. Upon detailed analysis, it was seen that the ninth most cited article in the WoS search was not related to 3D printing [18], so the eleventh-ranked article was also included in the Table [20]. Five of the publications were Articles [10, 13, 14, 16, 18] and six were Review Articles [11, 12, 15, 17, 19, 20]. The total citation number of these publications was 825 (47.44% of the total citation number of all publications).

The first and fourth most cited publications were consecutively linked studies [10, 13]. Considering the distribution of the subjects, the main focus of the studies was on 3D printed guided endodontics by four publications [10, 13, 16, 17], review of 3D printing in dentistry by two [11, 12], endodontic applications of 3D printing by two [15, 20], 3D printed replicas for endodontic education by one [14], cone-beam computed tomography (CBCT) for 3D reconstruction of artificially created periapical bone defects by one [18], review of advanced biomaterials and techniques including additive manufacturing (3D bioprinting) technologies for oral tissue engineering and regeneration by one [19].

Even the words endodontics and 3D printing were presented in the study by Tian et al. [12], the third most cited study. The study was mainly focused on prosthodontics, surgery, and implantology applications of 3D printing, and endodontics applications were vaguely mentioned. Therefore, this situation shows the deficiency of WoS keyword search for precise access to articles meeting the researcher's search interest.

Global cooperation and the most productive countries

The distribution of countries according to the number of publications and citations is given in Table 3. Considering the number of publications, the first three countries with the highest number of publications are the People's Republic of China (PRC), the United States of America (USA), and Germany. At the same time, the first three countries with the highest number of citations are Germany, Switzerland, and USA. It can be seen in the Table that seven countries have over 100 citations.

There were 10 countries in the country co-authorship mapping. This analysis yields three clusters represented in different colors. The first cluster was identified using green, the second cluster was identified with red, and the third was identified with yellow. According to Figure 2, co-authorship

Table 2

The 10 most cited publications

Number	Publications	Authors	Journal	Type of article	First author's country	Year	Total citations	Average citation/year
1.	Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location (Zehnder et al., 2016) [10]	Zehnder, MS; Connert, T; Weiger, R; Krastl, G; Kühl, S	International Endodontic Journal	Article	Switzerland	2016	134	14.89
2.	3D Printing-Encompassing the Facets of Dentistry (Oberoi et al., 2018) [11]	Oberoi, G; Nitsch, S; Edelmayer, M; Janjic, K; Müller, AS; Agis, H	Frontiers in Bioengineering and Biotechnology	Review Article	Austria	2018	95	13.57
3.	A Review of 3D Printing in Dentistry: Technologies, Affecting Factors, and Applications (Tian et al., 2021) [12]	Tian, YY; Chen, CX; Xu, XT; Wang, JY; Hou, XY; Li, KL; Lu, XY; Shi, HY; Lee, ES; Jiang, HB	Scanning	Review Article	People's Republic of China	2021	93	23.25
4.	Microguided Endodontics: a method to achieve minimally invasive access cavity preparation and root canal location in mandibular incisors using a novel computer-guided technique (Connert et al., 2018) [13]	Connert, T; Zehnder, MS; Amato, M; Weiger, R; Kühl, S; Krastl, G	International Endodontic Journal	Article	Switzerland	2018	77	11.00
5.	3D printed replicas for endodontic education (Reymus et al., 2019) [14]	Reymus, M; Fotiadou, C; Kessler, A; Heck, K; Hickel, R; Diegritz, C	International Endodontic Journal	Article	Germany	2019	72	12.00
6.	Endodontic applications of 3D printing (Anderson et al., 2018) [15]	Anderson, J; Wealleans, J; Ray, J	International Endodontic Journal	Review Article	United States of America	2018	71	10.14
7.	3D Computer aided treatment planning in endodontics (van der Meer et al., 2016) [16]	van der Meer, WJ; Vissink, A; Ng, YL; Gulabivala, K	Journal of Dentistry	Article	Netherlands	2016	71	7.89
8.	Clinical applications, accuracy and limitations of guided endodontics: a systematic review (Moreno-Rabié et al., 2020) [17]	Moreno-Rabié, C; Torres, A; Lambrechts, P; Jacobs, R	International Endodontic Journal	Review Article	Belgium	2019	60	10.00
9.	Detection and measurement of artificial periapical lesions by cone-beam computed tomography (Liang et al., 2014) [18]	Liang, YH; Jiang, L; Gao, XJ; Shemesh, H; Wesselink, PR; Wu, MK	International Endodontic Journal	Article	People's Republic of China	2014	55	5.00
10.	Advanced Biomaterials and Techniques for Oral Tissue Engineering and Regeneration-A Review (Matichescu et al., 2020) [19]	Matichescu, A; Ardelean, LC; Rusu, LC; Craciun, D; Bratu, EA; Babucea, M; Leretter, M	Materials	Review Article	Romania	2020	49	9.80
11.	3D imaging, 3D printing, and 3D virtual planning in endodontics (Shah and Chong, 2018) [20]	Shah, P; Chong, BS	Clinical Oral Investigations	Review Article	England	2018	48	6.86

Table 3

Most productive countries according to the number of publications and citations

Country	Total publications	TC (Rank of TC)
People's Republic of China	24	235 (4)
United States of America	21	255 (3)
Germany	17	444 (1)
England	9	208 (5)
South Korea	9	189 (6)
France	8	63 (9)
Switzerland	8	257 (2)
Brazil	7	26 (10)
Canada	7	76 (8)
Belgium	6	165 (7)

TC – total citations

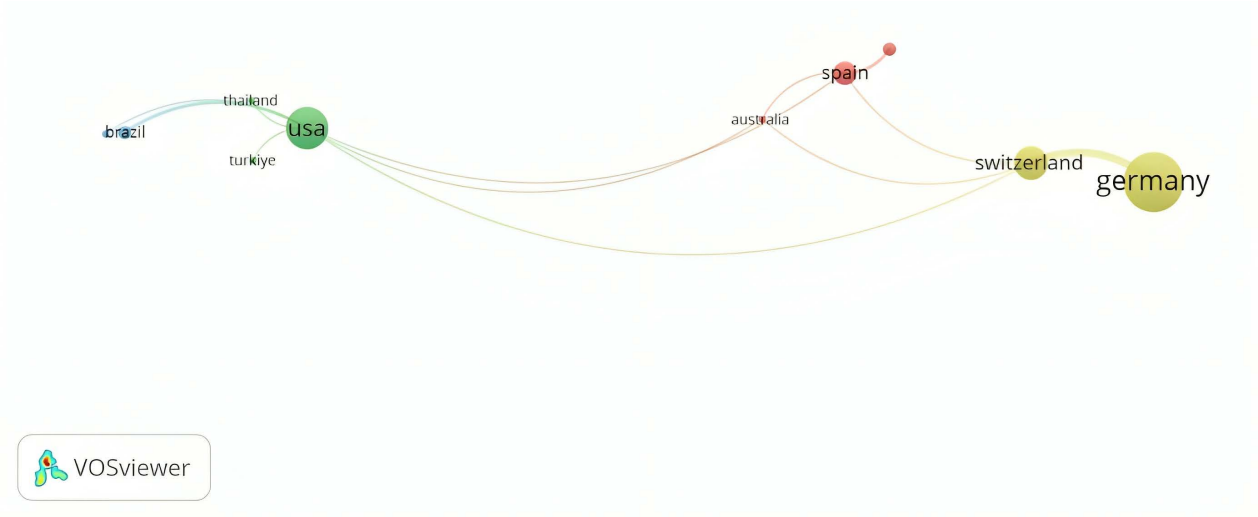

Fig. 2 – Co-authorship analysis of countries.

Table 4

Most productive authors

Author	Institution	Number of articles	Number of citations	H-index
Thomas Connert	University of Basel Univeristy Center for Dental Medicine Basel Eberhard Karls University of Tubingen	6	248	5
Gabriel Krastl	University of Wurzburg University of Birmingham University of Basel	6	248	5
Reinhilde Jacobs	Karolinska Institutet University Hospital Leuven KU Leuven	5	124	3
Marcel Reymus	University of Munich Ludwig Maximilians Univ Munchen	5	146	4
Andres Torres	Siemens EDA Universidade de Santiago de Compostela Universite Catholique Louvain	5	124	3

analysis yields the highest total link strength between Germany and Switzerland, while the USA has the highest number of co-authorships.

Most productive authors

The five most productive authors by number of articles are shown in Table 4. Note that an author may use multiple institutional affiliations, but the information shown in Table 4 was collected from their WoS profiles.

A collaborative network of 26 co-authors having published more than two papers (isolated authors not included). Each node maps to an author. Node size is proportional to the number of articles, while lines between nodes indicate the strength of collaboration. Six groups of co-authorship have been formed. The biggest two clusters consist

of seven authors (red and green), one cluster consists of five authors (blue), one cluster of three authors (yellow), and two clusters of two authors (purple and turquoise) (Figure 3).

Most popular journals

Table 5 shows the top ten journals that have published the most papers related to the given keywords. Only one journal (International Endodontic Journal) published nine articles. One journal does not qualify for the WoSCC (Dentistry Journal), and the remaining nine were qualified for SCIE. Among the top ten journals, three were classified in the first quartile (Q1), three in the second (Q2), two in the third (Q3), and one in the fourth quartile (Q4).

Main topics of the research

Keyword co-occurrence analysis is based on the comparative study of the terms of all keywords in order to determine the close relationship between concepts. Within

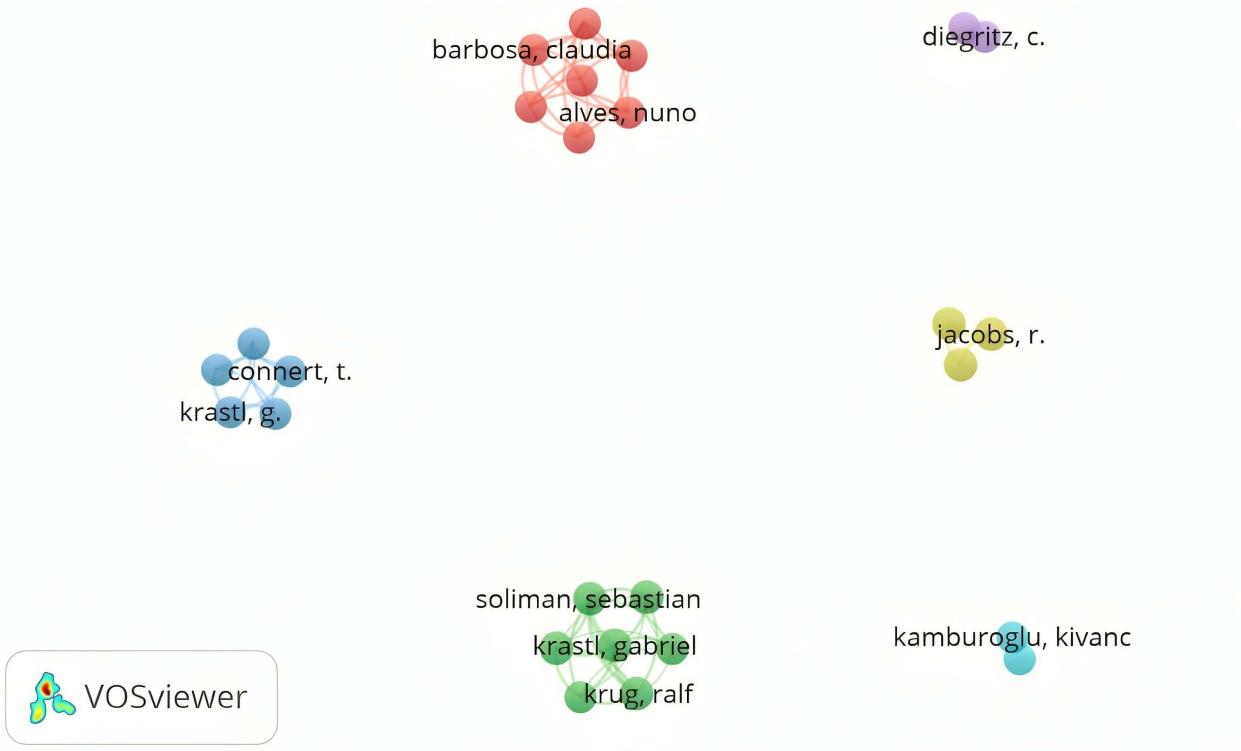

Fig. 3 – Co-authorship network of authors.

Table 5

Most productive journals

Journals	Publishing	Number of articles	Number of citations	WoSCC	Quartile
International Endodontic Journal	Wiley	9	533	SCIE	Q1
Clinical Oral Investigations	Springer	4	67	SCIE	Q2
European Journal of Dental Education	Wiley	4	49	SCIE	Q3
BMC Oral Health	Springer	4	23	SCIE	Q2
Journal of Dentistry	Elsevier	3	71	SCIE	Q1
International Journal of Computerized Dentistry	Quintessence Publishing	3	20	SCIE	Q4
International Journal of Environmental Research and Public Health	MDPI	2	11	SCIE	Q2
Dentistry Journal	MDPI	2	0	N/A	-
Frontiers in Bioengineering and Biotechnology	Frontiers	1	95	SCIE	Q1
Scanning	Hindawi	1	93	SCIE	Q3

WoSCC – Web of Science Core Collection; SCIE – Science Citation Index Expanded; BMC – BioMed Central; MDPI – Multidisciplinary Digital Publishing Institute; N/A – not applicable.

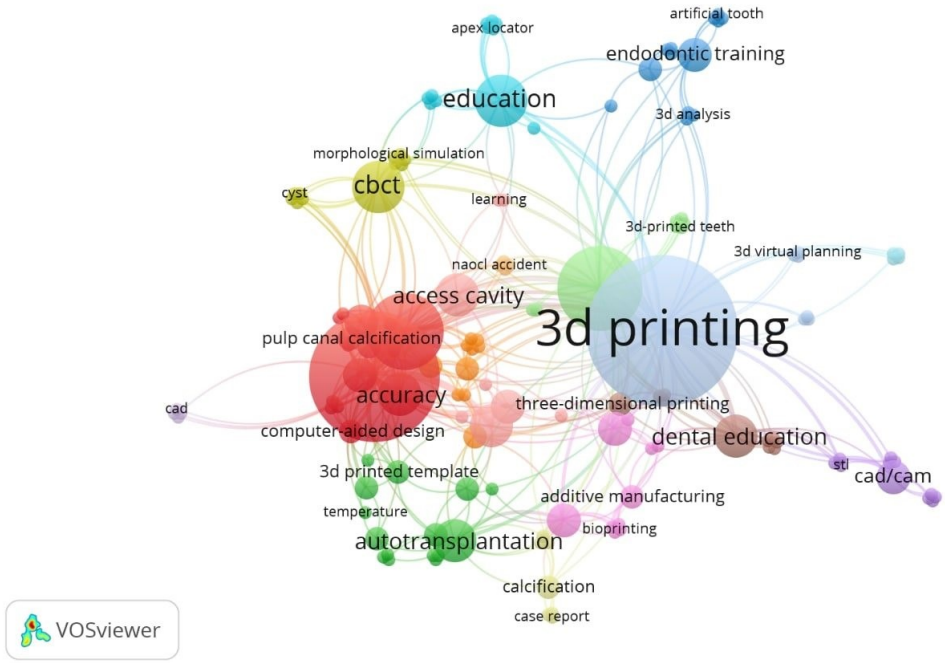

Fig. 4 – Co-occurrence analysis of keywords.

the results obtained by VOSviewer, a visualization of keywords was created in the software and grouped according to the co-occurrence analysis (Figure 4). According to the keyword association analysis, the top five keywords with the highest total link strength were “3D printing”, “guided endodontics”, “endodontics”, “root canal treatments”, and “CBCT”.

Discussion

To the best of our knowledge, this is the first study to use comprehensive bibliographic data from the WoS databases to provide valuable quantitative information about 3D printing in the endodontics field of research. Although this is a new area, this analysis shows that the number of annual publications is gradually increasing, with a sharp increase in 2018 (14 in 2018, 18 in 2020, and 25 in 2021, compared to only 5 publications in 2017).

Most publications are articles, and a small portion are review articles. No book chapters or conference papers on the subject could be found. The subject is open to development, new and current, and it is thought that more reviews, chapters, and conference papers will be produced in the future.

Most productive writers come from developed countries (e.g., USA, Germany, England, PRC). The countries that published the most on the use of 3D printing in endodontics were the PRC and the USA, while the countries that received the most citations were Germany and Switzerland. These high-quality studies from developed countries make great contributions to the global literature.

Dao et al. [21] highlighted that the most productive contributions to Education 4.0 research predominantly emerged from developing countries such as Mexico, Malaysia, and Indonesia rather than developed countries. They emphasized the notable absence of scholars from developed nations, including the USA, the United Kingdom (UK), Canada, the PRC, Japan, and Australia, in key productivity rankings, arguing that strong advancements in Education 4.0 research require collaboration and contributions from scholars in developed economies. In alignment with their findings, our bibliometric analysis also revealed a lack of collaboration in the field of endodontics and 3D printing. However, a significant distinction is evident – all leading contributors in this field are based in developed countries. To bridge this gap, developing countries require access to advanced technological infrastructure and opportunities for collaboration with research institutions in developed economies. Such efforts would enable broader participation and innovation, ultimately fostering the growth of this emerging field.

The largest number of the most cited articles were published in the same journal. This may be related to the high interest of the journal’s editors in this issue and the fact that the mentioned journal publishes a high level of publications on this developing topic. Nine of the ten journals with the most publications are indexed in SCIE, and the quartiles of the journals are generally high. This also increases the value of the studies done on the subject.

The study subjects of Thomas Connert and Gabriel Krastl, the two collaborating authors who have the most publications on this subject (6 publications), are 3D-

printed templates for gaining guided access to root canals [22], guided endodontic treatment in a case of dentin dysplasia with pulp canal calcification on a 3D-printed template [23], and 3D printing in endodontic education [24]. Likewise, Reinhilde Jacobs and Andres Torres, who have many publications on the subject, are two authors in collaboration and have studied the 3D-printed guide to gain access to obliterated root canals [25–27] and augmented reality for guided access cavity preparation in 3D-printed jaws [28]. However, in addition to his studies on guided endodontic access procedures in 3D-printed teeth in collaboration with Gabriel Krastl [22], Marcel Reymus has focused more in his studies on using 3D printing in endodontic education [14, 29, 30] and virtual reality in endodontic education [14].

Cooperation between countries on the subject is limited. In the international cooperation network, only 10 countries are on the map (Figure 2). When looking at country collaborations, the strongest relationship was between Switzerland and Germany. However, it was noteworthy that various countries such as Turkey, Thailand, and Saudi Arabia managed to get on the map even with limited collaborations. Additionally, cooperation between different groups is very weak. This situation highlights the need for much stronger cooperation in the future in order to be able to promote the development of this field. Organizing more meetings and congresses in this emerging field is a good way to consider as these meetings are good for scientists to exchange ideas and build networks for collaboration.

In the analysis of the most popular keywords co-occurrence network, the following keywords attract attention: “guided endodontics”, “access cavity”, “CBCT”, “pulp canal obliteration”, “dental pulp calcification”, and “dental education”. Based on these maps, useful information can be obtained to help identify the research gap and potential research topics, as well as topics of greater interest in the community.

Study limitations

The limitation of the study is the fact that only 128 articles could be accessed in the WoS database. It is thought that new studies that will include other databases, such as the Scopus, and other disciplines will contribute to the holistic perspective. The second limitation is that we only used the VOSviewer tool and not some other bibliographic tools such as BiblioShiny, Science Mapping Analysis Software Tool (SciMAT), or CiteSpace. Using tools other than VOSviewer will help perform other bibliometric analyses that are unavailable in VOSviewer. As seen in the most cited paper analysis, it can also be reported as a limitation that WoS may not always give accurate results in keyword searches.

Furthermore, some important articles related to the subject may be skipped because 3D printing is not included in the keyword and title analysis. For instance, the article in which Ordinola-Zapata et al. [2] investigated the shaping ability of different systems in curved canals of rapid microcomputed tomography based prototyping molar replicas could not be included in the search because 3D and endodontics were not mentioned in the title and keywords. Therefore, future research should be designed with a wider range of keywords.

Conclusion

To our knowledge, this study is the first bibliometric analysis of worldwide research on the use of 3D printing in the endodontic field. With the rapid development of technology today, the number of articles discussing the effects of 3D printing on endodontic clinical cases and its use in education and the construction of standardized novel experimental models will increase. Consequently, such analyses need to be conducted regularly to closely monitor the development of this research field.

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