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Contemporary research trends on nanoparticles in endodontics: a bibliometric and scientometric analysis of the top 100 most-cited articles

Sıla Nur Usta,* **Zeliha Uğur-Aydın**, **Kadriye Demirkaya**, **Cumhur Aydın**

Department of Endodontics, Gulhane Faculty of Dentistry, University of Health Sciences, Ankara, Turkey

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***Correspondence to**
Sıla Nur Usta, DDS
Department of Endodontics, Gulhane Faculty of Dentistry, University of Health Sciences, Emrah Mah. 06018 Etlik, Keçiören, Ankara, Turkey.
Email: silandeniz29@gmail.com

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No potential conflict of interest relevant to this article was reported.

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ABSTRACT

Objectives: Advancements in nanotechnology have led to the widespread usage of nanoparticles in the endodontic field. This bibliometric study aimed to determine and analyze the top 100 most-cited articles about nanoparticles in endodontics from 2000 to 2022.
Materials and Methods: A detailed electronic search was conducted on the "Clarivate Analytics Web of Science, All Databases" to receive the most-cited articles related to the topic. Articles were ranked in descending order based on their citation counts, and the first 100 were selected for bibliometric analysis. Parameters such as citation density, publication year, journal, country, institution, author, study design, study field, evidence level, and keywords were analyzed.
Results: The top 100 most-cited articles received 4,698 citations (16–271) with 970.21 (1.91–181) citation density in total. Among decades, citations were significantly higher in 2011–2022 ($p < 0.001$). *Journal of Endodontics* had the largest number of publications. Canada and the University of Toronto made the highest contribution as country and institution, respectively. Anil Kishen was the 1 who participated in the largest number of articles. The majority of the articles were designed *in vitro*. The main study field was "antibacterial effect." Among keywords, "nanoparticles" followed by "*Enterococcus faecalis*" were used more frequently.
Conclusions: Developments in nanotechnology had an impact on the increasing number of studies in recent years. This bibliometric study provides a comprehensive view of nanoparticle advances and trends using citation analysis.

Keywords: Bibliometrics; Endodontics; Nanoparticles; Nanotechnology

INTRODUCTION

Nanomaterial is defined as a "natural, incidental, or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, 1 or more external dimensions is in the range 1–100 nm" according to the European Commission's Recommendation [1]. These materials consist of nanoparticles with 1, 2, or 3 outer dimensions at the nanoscale [2]. Following the landmark lecture by Richard P. Feynman, nanomaterials have been used in various medical applications in parallel with technological developments [3,4].

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ORCID iDs
Sıla Nur Usta
https://orcid.org/0000-0001-9513-0841
Zeliha Uğur-Aydın
https://orcid.org/0000-0002-1773-9114
Kadriye Demirkaya
https://orcid.org/0000-0003-2040-3491
Cumhur Aydın
https://orcid.org/0000-0003-3009-0548

The use of nanoparticles has become an attractive topic in many types of research in health sciences, including dentistry, with the advancement of technology and the introduction of new inventions [2,5,6]. Some unique chemical, biological, and physical features have led to these particles being desirable in endodontics as well as other specialties in dentistry [4,7,8]. Especially, the higher antimicrobial characteristics having a large surface area and smaller sizes, which can enhance the efficacy of endodontic materials, are the most favorable factors since endeavors in the field of endodontics are directed toward ensuring complete disinfection of the root canal system and preventing reinfection [9,10]. In this sense, nanoparticles have been used alone or in combination with different endodontic materials such as calcium hydroxide, irrigation solutions, root canal sealers, gutta-percha, and calcium silicate-based cements in order to improve the efficiencies of materials [11,12]. Furthermore, these materials also have been employed in contemporary applications as follows: coating instruments, drug delivery systems, and tissue regeneration [13]. Although numerous types of nanoparticles are produced, chitosan, bioactive glass, and silver compounds are basically utilized in endodontic practice due to their antimicrobial and osteoinductive effects [14-16].

Bibliometrics is the quantitative analysis of academic publications in various aspects in order to assess the historical progression of research fields and the scientific productivity of researchers, countries, institutions, and journals [17]. These analyses allow researchers to define past and present trends, identify gaps in the literature, and guide future studies [18]. Citation analysis is the most commonly performed method in bibliometrics and aims to describe the impact of publication by observing the citation data that a scientific study receives [19,20]. Similarly, Scientometric analysis aims to examine the data, usually by visualizing the information obtained from bibliometrics [21]. This analysis provides readers with a scientific map of the bibliometric output by examining collaborations between authors, institutions, or countries.

Although several bibliometric studies have already been conducted on different topics in endodontics, the publication trends related to nanoparticles have not been investigated yet [22-25]. Since nanotechnology is rapidly growing and affecting many treatments in endodontics, the main trends and future expectations need to be addressed. Thus, this bibliometric study aims to identify and analyze the top most-cited 100 articles about nanoparticles in endodontics from 2000 to 2022.

MATERIALS AND METHODS

An advanced electronic search was conducted in the "Clarivate Analytics Web of Science (WoS)" (http://www.webofknowledge.com) since WoS contains peer-reviewed, high-quality scientific journals published worldwide. The search strategy was designed by 2 investigators (SNU and KD) with experience in endodontics and/or bibliometrics. A detailed search strategy was performed using frequently used keywords related to the nanoparticles. This bibliometric study included only articles written in English between 01.01.2000 and 01.01.2022 since the studies on nanoparticles in endodontics have shown an increase after the 2000s. The articles that were not related to the usage of nanoparticles in endodontics, conference papers, and editorial letters were excluded from the scope of this study.

Initially, the below-mentioned 2 search queries were constructed on 9 September 2022, and articles were recovered:

1. Q1: (ALL=(endod*)) OR ALL=(root canal*). The 59,224 articles were received.
2. Q2: ((((ALL=(nanoparticle*)) OR ALL=(silver)) OR ALL=(chitosan)) OR ALL=(nanometal*)) OR ALL=(metal nanoparticle*)) OR ALL=(nanomaterial*). The 1,201,813 articles were received.

These 2 queries were combined as (Q1 AND Q2), and 1,727 articles were obtained in total. Subsequently, the data were downloaded in Microsoft Excel 15.0 (Microsoft, Redmond, WA, USA) format for bibliometric analysis, and the articles were ranked in descending order according to their citation counts. When more than one article had the same number of citations, the article had a higher citation density value was ranked first [19]. All articles were screened and analyzed by 2 independent investigators (SNU and ZUA) to specify whether they were related to nanoparticles in endodontics. Investigators accessed the full text when they could not receive adequate information from the abstract and/or title. Any disagreements were resolved by consulting with the third researcher (CA) until a consensus was reached. The search process is outlined in **Figure 1**.

The following variables were recorded for each article: citation count, citation density, publication year, journal, country, institution, first author, co-authors, study field, study design, evidence level (EL), and keywords. The citation density was calculated by dividing the total number of citations by the number of years since the article was published. The included years were divided into 2 groups (2000–2010 and 2011–2022) to detect time-dependent alterations of metrics. The study fields were categorized by a consensus among

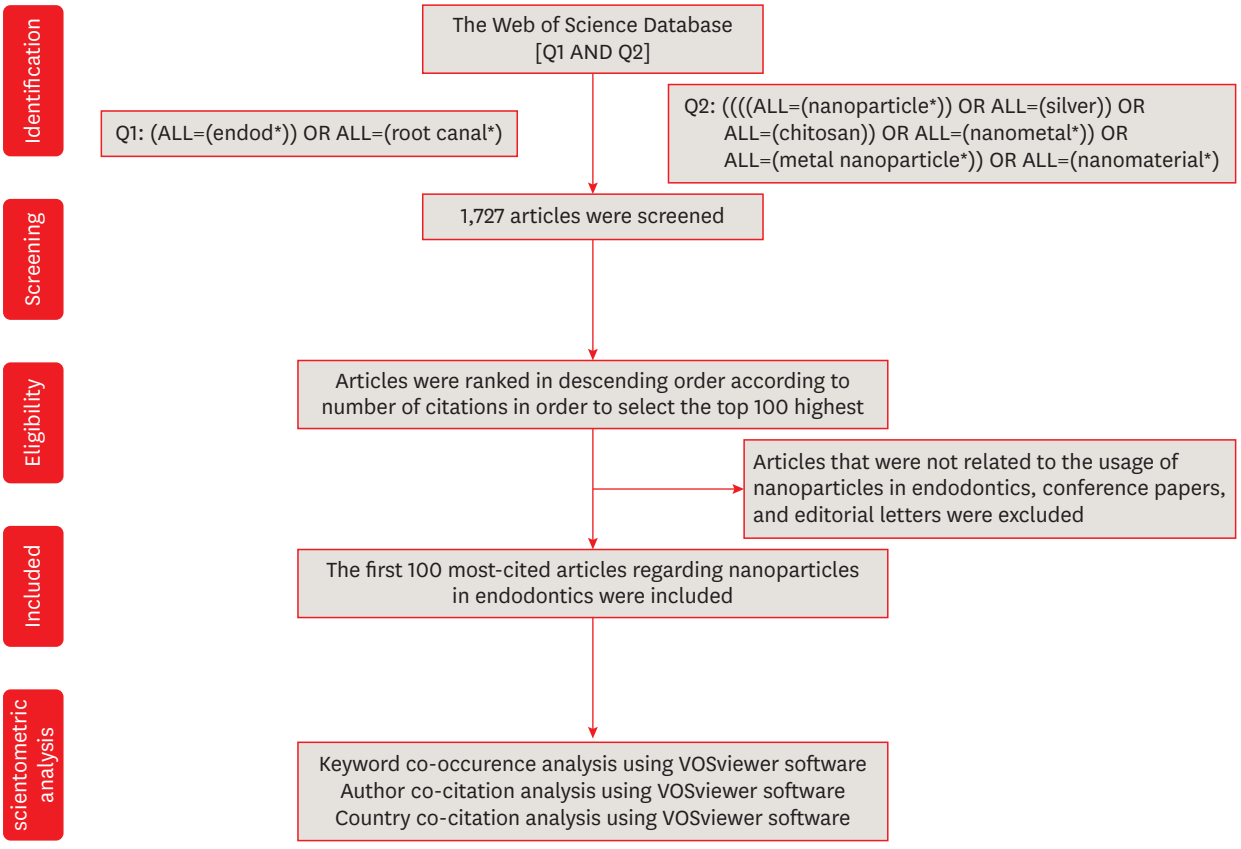

Figure 1. The flow diagram of the study.

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all investigators, taking into account the main focuses of the articles. Moreover, each article was assigned to 1 of the designed groups, according to the nature of design, as follows: review (narrative and systematic), *in vitro* (this sector includes studies of parts of dental tissue, sections of the tooth, and cell cultures), *ex vivo* (teeth and complete root from humans or animals). The top 100 most-cited articles were also evaluated regarding the used nanoparticles, the usage field, and the main findings.

After conducting the bibliometric analysis, scientometric analysis was performed to generate a network model and identify research areas. The selected articles were further analyzed according to the geographical distribution of the authors who contributed the most. Moreover, domestic and international collaborations between authors were determined and visualized. In addition, keywords with more than 2 co-occurrences were also evaluated and visualized.

The VOSviewer (version 1.6.18; Leiden University Center for Science and Technology Studies, Leiden, The Netherlands, available at https://www.vosviewer.com) was used to summarize and visualize the bibliometric data downloaded from the WoS by creating a science map. The minimum number of documents per author and country is set to "1" and for citations to "0" to optimize analysis. The size of the nodes indicates the frequency of the analyzed parameters; consequently, larger nodes are associated with a higher frequency. Moreover, the thickness of the edges presents the relationship of the interactions between 2 nodes, while their colors indicate the cluster to which the keyword belongs.

All statistical analyses were performed using Statistical Package for Social Sciences (SPSS) for Windows software, version 26.0 (SPSS Inc., Chicago, IL, USA). Shapiro-Wilk test was performed to check the normality of both the number of citations and citation density. Kruskal-Wallis test was used to compare these metrics among decades. When the results were statistically significant, Mann-Whitney *U* test was used for pair-by-pair comparisons. The correlation between citation, citation density and age of publication was assessed using the square of the Spearman linear coefficient. The significance level was set at $p < 0.05$.

RESULTS

Number of citations, citation density, and publication year

The most-cited 100 articles about nanoparticles in endodontics received a total of 4,958 citations, with a mean citation number per article of 49.58. The total citation density was 982.5, with a mean citation density per article of 9.82. The ranges were 17 to 271 and 1.91 to 135.5 for citation number and density, respectively. The top 100 most-cited articles with type and the usage field of nanoparticles, along with the main findings of the studies, were given in **Supplementary Table 1**.

A significant positive association was found between the number of citations and the age of publication (correlation coefficient = 0.490, $p < 0.001$, R^2: 0.138). Additionally, there was a significant negative association between citation density and age of publication (correlation coefficient = −0.343, $p < 0.001$, R^2: 0.049). Correlations are shown in **Figure 2**.

Regarding the decades, while the number of citation values has presented a statistically significant difference ($p < 0.001$), the citation density values have not. Metrics of the top 100 most-cited articles about nanoparticles in endodontics in time periods are presented in **Table 1**.

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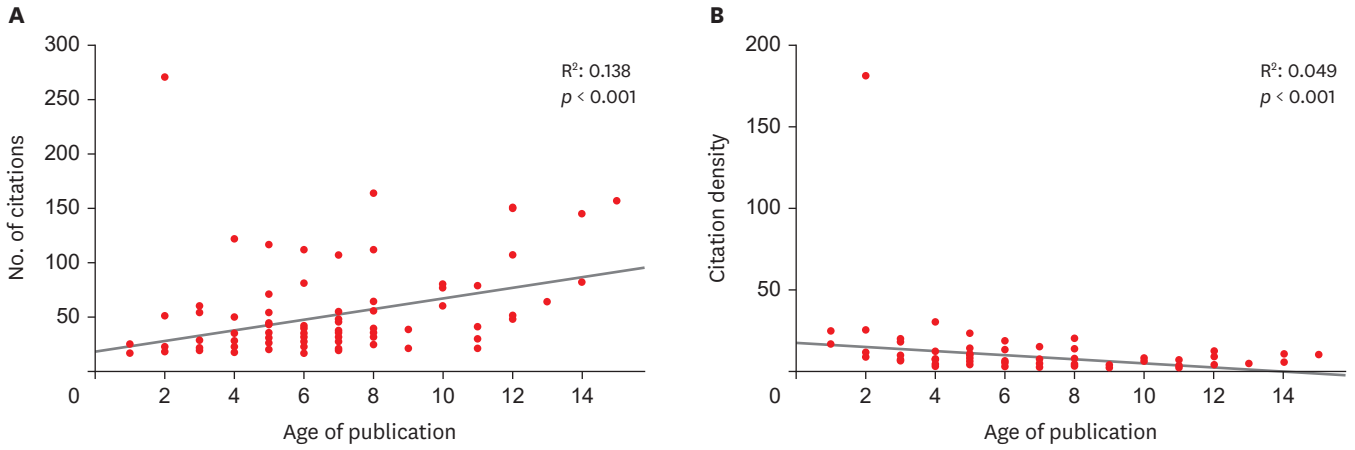

Figure 2. Association between the number of citations and age of publication (A), association between the citation density and age of publication (B).

Table 1. The number of citations and citation density values of the top 100 most-cited articles about nanoparticles in endodontics in time periods

Metrics	2000–2010 (n = 9)	2011–2022 (n = 91)	Comparison p value*
Number of citation†	106.11[1]	43.98[2]	< 0.05
Minimum–Maximum	48–157	17–271	
Total	955	4,003	
Citation density†	8.21	9.98	> 0.05
Minimum–Maximum	4–12.58	1.91–135.5	
Total	73.86	908.64	

*The Shapiro-Wilk test showed no normality. The Mann-Whitney *U* test analysed pair comparisons. Read horizontally; the different superscript numbers indicate a significant difference.
†Mean value.

The highest number of articles was published in 2017 (n = 15), followed by 2018 (n = 13), 2014, and 2015 (n = 12 for each).

Journal, country, institution, and authors

Among 49 different journals, the *Journal of Endodontics* had the largest number of publications (n = 25), followed by the *International Endodontic Journal* (n = 7), *International Journal of Nanomedicine* (n = 6), *Materials Science and Engineering: C* (n = 5), *Dental Materials* (n = 4), *Journal of Dentistry* and *Photodiagnosis and Photodynamic Therapy* (n = 3 for each).

A total of 31 countries participated in the nanoparticle-based studies in the scope of this bibliometrics. Canada was the most productive country with 20 publications followed by the USA (n = 19) and China (n = 17). International collaborations between contributed countries are shown in **Figure 3**. Accordingly, the first 3 countries that had the highest co-authorships were USA (n = 10), Canada (n = 9), and China (n = 8), respectively. In addition, South Korea, Taiwan, Thailand, Poland, and Israel had only domestic collaborations.

According to the institutional address of the first author, 21 countries were identified. Canada (n = 17) made the highest contribution, followed by China and Iran (n = 16 for each). Out of 57 specified institutions, the University of Toronto had the highest number of publications (n = 15), followed by the University of Sao Paulo and the University of Tehran (n = 6 for each) and the University of Wuhan (n = 5). Countries and institutions that published at least 2 articles are shown in **Figure 4**.

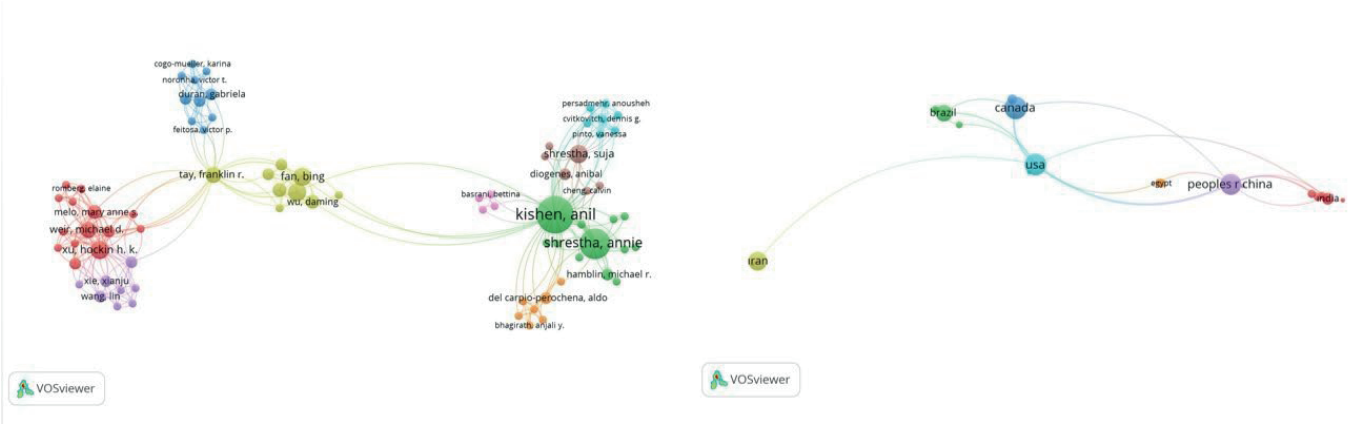

Figure 3. The visualization map of all contributed authors and countries to the articles about nanoparticles in endodontics, along with their collaboration.

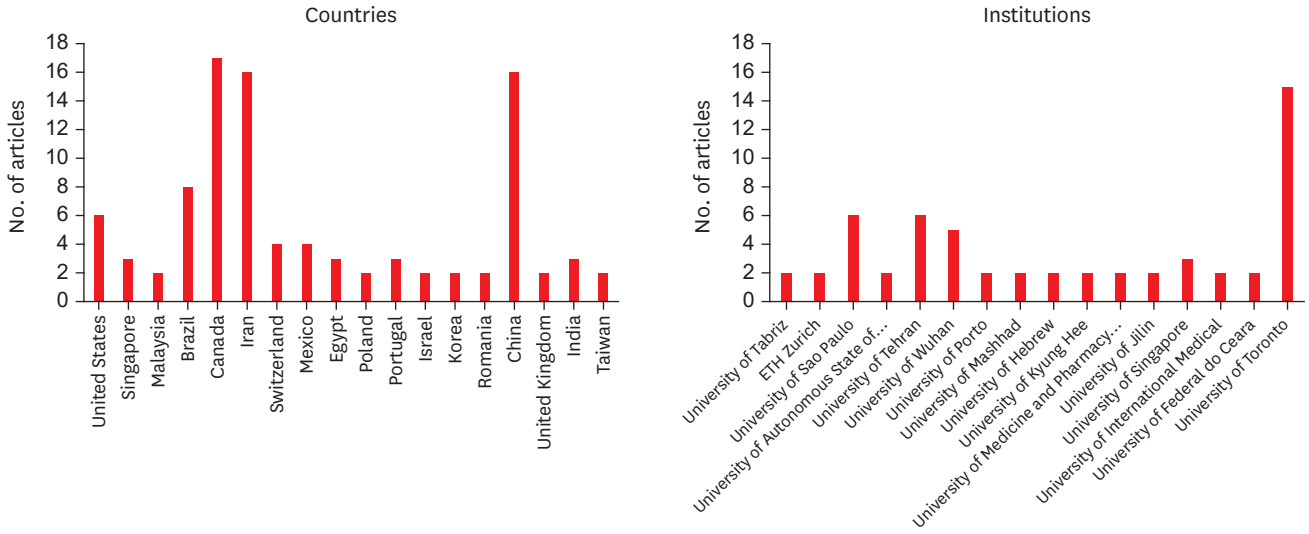

Figure 4. Participated countries and institutions with at least 2 publications.

Four hundred and fifty-eight authors participated in the top 100 most-cited articles list about nanoparticles in endodontics. The collaboration between different authors is shown in **Figure 3**. Although Anil Kishen (n = 21, links=38, total link strength = 56) was the most productive author, followed by Annie Shrestha (n = 14, links = 16, total link strength = 29), Annie Shrestha (n = 10) was the first author more frequently. **Table 2** also demonstrates the first 10 authors who had the highest participation in this bibliometric study, along with their countries and institutions.

Study design, study field, EL, and keywords

The majority of the publications were designed as *in vitro* (n = 64), followed by review (narrative = 20) and *ex vivo* (n = 16). Four different fields of study, highlighting the main idea of the selected articles, were defined by all investigators. "Antibacterial effect" was the most investigated area with 56 publications. "Application" (n = 18), "biological aspect" (n = 15), and "material properties" (n = 11) were the other study fields (**Table 3**).

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Table 2. The top 10 leading authors contributed to the nanoparticle-based research in endodontics with institutions and countries

Author	Institution	Country
Anil Kishen	University of Toronto	Canada
Annie Shrestha	University of Toronto	Canada
Suja Shrestha	University of Toronto	Canada
Hockin H K Xu	University of Maryland	USA
Wei Fan	University of Wuhan	China
Bing Fan	University of Wuhan	China
Abbas Bahador	University of Tehran	Iran
Franklin R Tay	University of Augusta	USA
Michael D Weir	University of Maryland	USA
Mary Anne S Melo	University of Maryland	USA

Table 3. Study types and main study fields of the top 100 most-cited articles about nanoparticles in endodontics

Variables	Number	Narrative review	Animal study
Study types			
Review	20	20	-
In vitro	64	-	-
Ex vivo	16	-	6
Study fields			
Antibacterial effect	56	-	-
Application	18	-	-
Biological aspect	15	-	-
Material properties	11	-	-

Reviews (except systematic reviews of randomized clinical trials), *in vitro*, and *ex vivo* studies belong to the bottom of the evidence-level pyramid [26]. Therefore, EL V (n = 100) was the only identified EL.

Considering the top 100 most-cited articles, the VOSviewer software recovered a total of 239 keywords. Following the reduction of the number of co-occurrences to 2, 58 keywords (nodes) were grouped into 7 clusters, and a maximum of 1,000 lines were loaded. The visualizing map of keywords is shown in **Figure 5**. "Nanoparticles" (n = 26) was the most

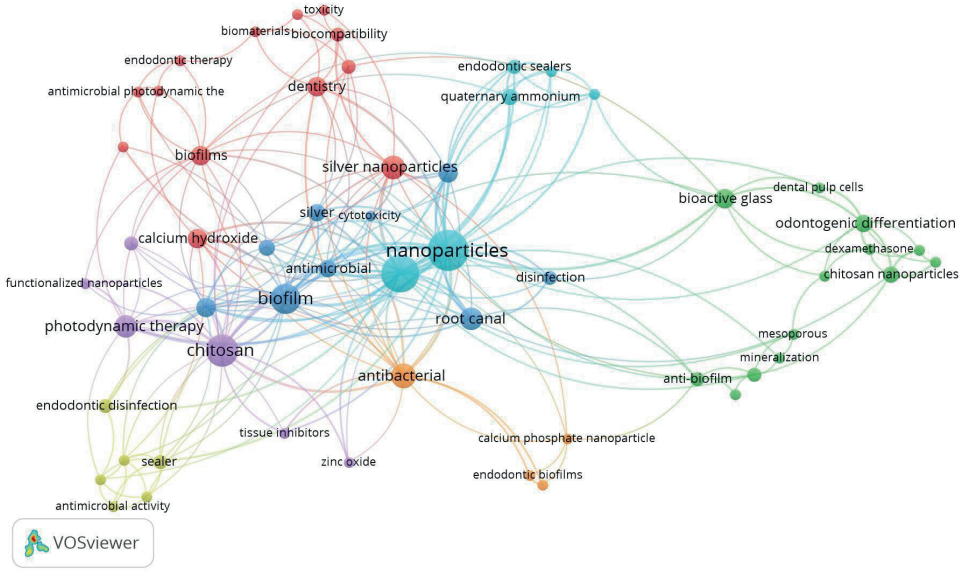

Figure 5. The visualization map of frequently used 2 or more co-occurring keywords of the top 100 most-cited articles about nanoparticles in endodontics.

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frequently used keyword, followed by "*Enterococcus faecalis*" ($n = 22$), "chitosan" ($n = 16$), "biofilm" ($n = 14$), and "antibacterial" ($n = 10$).

DISCUSSION

Many studies have been carried out over the years about nanoparticles since there is an enormous interest in nanotechnology and the properties of nanomaterials [27]. Thus, this bibliometric study aimed to highlight the global research trends about nanoparticles in endodontics based on citation counts. Receiving more citations partially reflects the scientific impact of the publication since it is a time-dependent metric and is affected by various other factors, such as the reputation of the authors, the institutions with which the authors are affiliated, or even the countries in which the authors are located [28]. Therefore, evaluating the quality of the paper is challenging. Even so, drawing a citation-based ranking list allows researchers to set a time period for literature analysis and provides a comprehensive guide to the research topic [25].

Due to the nature of citation analysis, old articles are expected to receive more citations than recently published ones [29]. Accordingly, a positive association was found between the number of citations and the age of publication. Although lower citation values were observed in 2010–2022, the total citation counts were higher in this period than in 2000–2010. This could be because fewer articles about nanoparticles in the previous decade were published. The improvement in knowledge and experience of researchers about nanoparticles with the development of technology has increased the number and quality of studies in recent times. However, time is needed to evaluate the long-term scientific contributions of new studies to the literature. Therefore, the evaluation of citation density as a time-independent metric could be an alternative analysis to measure the influence of an article.

While older articles are expected to be cited more often, interestingly, the study with the highest citation count and density was performed by Yin *et al.* [30] in 2020 in this bibliometrics. Although it was published very recently, the broad scope of the article about the antibacterial mechanism of silver nanoparticles and its application might have led to its being highly cited. The second most-cited article performed by Wu *et al.* [16] aimed to evaluate the antibacterial efficacy of silver nanoparticles against *E. faecalis* biofilm. And the third most-cited article was published by Waltimo *et al.* [31] intended to describe the antimicrobial effect of bioactive glass 45S5. These 3 studies have purposed to underline the antimicrobial properties of nanoparticles. Since the primary goal of utilizing nanoparticles in endodontics is to take advantage of their disinfection abilities, these results are in line with current knowledge.

A large number of articles have been published in the *Journal of Endodontics* and the *International Endodontic Journal*, which are considered to be the leading journals in the field of endodontics [32]. However, most of the journals were multidisciplinary, prioritizing publications on nanomaterials and nanotechnology. This can be explained by the fact that the design, the production stage, and the usage areas of nanoparticles require the collaboration of different working fields.

Anil Kishen and Annie Shrestha were the most productive authors, and this has led to Canada and the University of Toronto having the highest number of articles as a country

and an institution, respectively. These 2 authors are well-known researchers in the field of endodontics due to the large number of influential articles about nanoparticles they have published [33,34]. In this context, it is concluded that the investments of countries and institutions in scientific studies affect the outputs significantly.

In this bibliometrics, more than half of the studies were designed *in vitro*, followed by narrative reviews. *In vitro* studies are essential for evaluating the efficacy of relatively newly produced materials before conducting animal and *in vivo* studies [17]. However, clinical studies with high evidence levels are needed to apply the developed materials and technologies in routine dental practice. Furthermore, reviews are more likely to be cited because they provide general information on the topic and can guide a large number of researchers by addressing the subject from different aspects [35]. Reviewing the first most-cited article in this study is consistent with the above-mentioned information.

The main study field was the antibacterial effect of nanoparticles in endodontics. This is an understandable result since complete disinfection of the root canal system still poses a challenge due to the various anatomical and meteorological factors, and this promotes researchers to discover alternative materials and technologies [4]. The superior antibacterial properties of nanoparticles have made these molecules favorable in endodontic treatments [30]. In line with the mostly investigated study field, keywords such as *E. faecalis*, biofilm, and antibacterial also highlight the main interest in using these particles in endodontics.

Some limitations should be indicated in the scope of this bibliometric study. One of those is that it is unclear whether the preferred database WoS includes all the articles related to the topic, although it is considered a very appropriate database. Moreover, the time-dependent nature of citation analysis is insufficient to accurately determine the scientific value of studies and makes it impossible to evaluate fairly recent published influential articles [36]. In addition, self-citations may be considered a bias factor since the authors promote the citation of their studies. Finally, only the institutional address and the countries of the first authors were recorded and assessed; therefore, multicenter studies could not be identified.

CONCLUSIONS

Antibacterial effects of nanoparticles, in particular, have a promising scope for various endodontic applications. With the development of nanotechnology and gaining more experience in this field, very influential studies have been published in recent years. It is considered that this bibliometric study serves as a guide for future studies by demonstrating the current knowledge and frontiers of these materials.

SUPPLEMENTARY MATERIAL

Supplementary Table 1
The top 100 most-cited articles about nanoparticles in endodontics

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