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Bioceramic-Based Root Canal Sealers: A Bibliometric Analysis of the 100 Most-Cited Articles: Methodological Studies

Biyoseramik Esaslı Kök Kanal Patları: En Çok Atıf Alan 100 Makale: Bibliyometrik Analiz Çalışması: Metodolojik Çalışmalar

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ABSTRACT Objective: The aim of this study is to identify and evaluate the 100 most-cited publications related to bioceramic root canal sealers in endodontics through bibliometric analysis. **Material and Methods:** A detailed literature review was conducted using the Web of Science database. During the literature search, the following keywords were employed: "bioceramic sealer", "bioceramic root canal sealer", "BC root canal sealer", "calcium silicate-based root canal sealer", "hydraulic calcium silicate sealer", "MTA-based sealer", and "calcium silicate sealer". The retrieved articles were ranked based on their citation counts, from highest to lowest. The top 100 most-cited articles were selected. VOSviewer software was used as a visualization tool in the bibliometric analysis. **Results**: A total of 769 articles were retrieved during the search. From these articles, the top 100 most-cited publications were included in the study. According to the analysis, the highest number of publications was recorded in 2017. The most-cited article received a total of 338 citations. Among the most prolific researchers, Markus Haapasalo and Ya Shen stood out, with 9 publications and a total of 1,007 citations. The leading country in terms of publication volume was Brazil, while the most productive institution was São Paulo University. The journals with the highest number of publications on the topic were the "Journal of Endodontics" and the "International Endodontic Journal". **Conclusion:** The increase in the number of publications associated with various authors, institutes, and international collaborations indicates the growing importance of the topic of bioceramic sealers and the significant advancements made in this field.

Keywords: Analysis; bibliometrics; endodontics; root canal filling materials

ÖZET Amaç: Bu çalışmanın amacı, bibliyometrik analiz kullanılarak endodontide biyoseramik kök kanal patları konusu ile ilgili yayınlanmış en çok alıntı yapılan 100 makaleyi belirlemek ve değerlendirmektir. **Gereç ve Yöntemler:** Web of Science veritabanı kullanılarak detaylı bir literatür taraması yapıldı. Literatür taraması sırasında "bioceramic sealer", "bioceramic root canal sealer", "BC root canal sealer", "calcium silicate based root canal sealer", "hydraulic calcium silicate sealer", "MTA based sealer" ve "calcium silicate sealer" anahtar kelimeleri kullanıldı. Elde edilen makaleler atıf sayılarına göre en yüksekten en düşüğe doğru sıralandı. En çok atıf alan 100 makale seçildi. Bibliyometrik analizde görselleştirme aracı olarak VOSviewer yazılımı kullanıldı. **Bulgular:** Tarama sonucunda 769 makale elde edilmiştir. Bu makaleler arasından en çok atıf alan ilk 100 makale çalışmaya dâhil edilmiştir. Yapılan analizlere göre, en fazla makale 2017 senesinde yayınlanmıştır. En çok atıf alan makale, toplamda 338 atıf almıştır. En üretken araştırmacılar arasında Markus Haapasalo ve Ya Shen, 9 makale ve toplamda 1.007 atıf ile öne çıkmıştır. En fazla makale üreten ülke Brezilya, en fazla makale üreten kurum ise Sao Paulo Üniversitesi olarak belirlenmiştir. Konuyla ilgili en fazla makale yayınlayan dergiler ise "Journal of Endodontics" ve "International Endodontic Journal" olarak tespit edilmiştir. **Sonuç:** Çeşitli yazarlar, enstitüler ve uluslararası işbirlikleri ile ilişkili yayınların sayısındaki artış, biyoseramik sealer konusunun öneminin giderek arttığını ve bu alanda önemli ilerlemeler kaydedildiğini göstermektedir.

Anahtar Kelimeler: Analiz; bibliyometri; endodonti; kök kanalı dolgu materyalleri

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Bioceramics have been introduced to the market due to their advantages, such as osteoinductive effects, the ability to set even in contact with tissue fluids, long-term antibacterial activity after placement in the canal, providing an effective seal, extended working time, expansion during setting to completely fill the root canal, and simplifying the single-cone technique.[1] Bioceramics are considered alternative materials in clinical practice, not only as root canal sealers but also for vital treatments such as amputation and direct pulp capping, as well as for apical plugs in teeth with open apices and retrograde filling materials after apical resections, due to the quality of healing they provide.[2] Bioceramic-based root canal sealers can be defined as "an endodontic material designed for professional use but non-sterile, in which the setting reaction depends on hydrophilic inorganic components and water".[3] The use of bioceramic-based root canal sealers provides 2 major advantages. First, due to their biocompatibility, they are not rejected by the surrounding tissues.[4] Secondly, bioceramics contain calcium phosphate, which is similar in chemical composition to the hydroxyapatite crystals found in teeth and bone structure. Calcium phosphate enhances the setting properties of bioceramics, strengthening the bond between the root dentin and the root canal sealer.[5]

The flowability, film thickness, solubility, dimensional stability, and radiopacity of bioceramic sealers comply with International Organization for Standardization standards. In addition to their advantages, such as low cytotoxicity, support for cell adhesion, and proliferation, challenges may arise during their removal from the canal. This material exhibits good physicochemical and biological properties *in vitro*.[1] Due to its high hydrophilic properties and low surface tension, it demonstrates easy spreading within the root canal system and accessory canals. This results in high sealing capability.[5]

Bibliometrics is a discipline that uses quantitative measurement methods to analyze and evaluate scientific literature. Bibliometric analysis, commonly used to determine research trends and the future of a specific field, is a review process aimed at summarizing the current state of the field by systematically, transparently, and reproducibly examining the published literature.[6] The journal's impact factor, analysis of the number of citations received by publications, study methodology, research area, author information, and collaborations are among the various elements examined, allowing for a comprehensive analysis of scientific articles.[7] This analysis provides readers with the opportunity to examine the complexity of specific topics by using a mapping method to visualize the information landscape.[8] Bibliometric analysis allows researchers to identify research trends and lay a solid foundation for the development of a field. This enables researchers to gain an overview, identify knowledge gaps, and uncover new research directions.[9] Bibliometric studies in the field of endodontics are of great importance. Additionally, bibliometric indicators are used to assess scientific and clinical activities. In the field of endodontics, bibliometric studies on various topics have made significant scientific contributions. For example, the use of microscopes in endodontics, regenerative endodontics, minimally invasive access cavities, endodontic microbiology, micro computed tomography, photodynamic therapy in endodontics and the management of fractured instruments.[7,10-15]

One of the parameters examined in bibliometric analyses, "citation count", is of great importance. The impact of an author and an article is typically evaluated by the number of citations it receives. The number of citations of a paper is considered an important metric that reflects the scientific value and impact of the work in its field. However, the citation count does not directly reflect the scientific quality of a paper; it only indicates the impact of that publication's citations on other works. The evaluation of citations based on articles, scientific activities, and countries is referred to as "citation analysis" in the field of bibliometrics.[16] The citation count depends on several factors, which can be classified as follows: factors related to the article, factors related to the journal, and factors related to the author(s).[17] Articles with a high citation rate are likely to serve as guiding examples for future research and clinical applications in that field.

Although there are several systematic reviews on bioceramic sealers and their applications, no bibliometric analysis has been published on this topic.

In this context, the bibliometric analysis of research outputs related to bioceramic sealers has been conducted for the first time. The aim of this bibliometric analysis is to examine and evaluate the 100 most-cited articles on bioceramic sealers. The analysis seeks to provide important insights by highlighting the strengths and weaknesses of the current literature, thereby guiding future research directions.

MATERIAL AND METHODS

This study did not require ethical approval as it did not involve patient data. The dataset was obtained from Web of Science, a globally recognized source, on November 1, 2024 (https://www.webofscience.com). An electronic search was conducted in the Web of Science Core Collection database. In this bibliometric analysis, articles evaluating or describing the use of bioceramic sealers in endodontics were included in the study without any year restriction. Articles categorized as "early access", "correction", and "proceeding paper" were excluded from the analysis. All other types of publications were included in the analysis. Articles unrelated to the topic were excluded from the study. Articles published in languages other than English were excluded from the study. For article selection, the following keywords were used: "bioceramic sealer*" OR "bioceramic root canal sealer*" OR "BC root canal sealer*" OR "calcium silicate based root canal sealer*" OR "hydraulic calcium silicate sealer*" OR "MTA based sealer*" OR "calcium silicate sealer*" (all fields) AND "endodontic*" (all fields). The retrieved publications were sorted in descending order according to citation count. The top 100 most-cited articles were included in the study. For each article, the title, publication year, citation count, first author's name, the country and institution the author is affiliated with were recorded. The collected data was exported in Tab Delimited File format.

The bibliometric analysis of the collected data and the visualization of this analysis were performed using VOSviewer (1.6.20 version) (Center for Science and Technology Studies, Leiden University, Holland) software, and Microsoft Excel (Microsoft, Inc., Redmond, USA) was used for data tabulation.

In the visual outputs produced by the software, terms associated with larger clusters and sources appear with higher frequencies, while terms associated with smaller clusters or sources are seen with lower frequencies. The lines representing connections between terms illustrate the collaboration or relationships between these terms. The size of the bubbles in the generated maps represents the number of related scientific publications, while the distance between the bubbles indicates the relationship and connection between these elements. The color of each bubble represents a different parameter, which carries a specific meaning in the individual visualization.

The abstracts of the 100 most-cited articles were reviewed to identify their research topics. This process highlighted the specific properties of bioceramic sealers that have been the focus of research and revealed areas where the literature is lacking. The articles were categorized based on their study types (review articles-original research) and subject areas (biological and physicochemical properties, mechanical properties, clinical studies, survey studies, dentinal tubule penetration, and retreatment).

RESULTS

A total of 779 articles were retrieved from the search. After excluding irrelevant articles, the remaining 769 studies were ranked from the highest to the lowest citation count. The top 100 most-cited articles were included in the study. Table 1 shows the titles, first authors, publication years, citation counts, and journals of the top 10 most-cited articles related to bioceramic sealers, based on the Web of Science database. Accordingly, the most-cited article is "calcium silicate bioactive cements: biological perspectives and clinical applications" by Prati and Gandolfi, published in Dental Materials in 2015.[18] It has received a total of 334 citations. Among the top 100 most-cited articles, the least-cited article is "*In Vitro* Osteogenic Potential of an Experimental Calcium Silicate-based Root Canal Sealer" by Bryan et al. published in Journal of Endodontics in 2010, with 41 citations.[19]

Fourteen of the top 100 most-cited articles were published in 2017, 12 in 2018, 10 in 2015, 9 in 2013-

TABLE 1: Top 10 most-cited articles, first authors, citation counts, published journals, and publication years

First author	Article title	Citations	Published journal	Publication year
Prati and Gandolfi[18]	Calcium silicate bioactive cements: Biological perspectives and clinical applications	338	Dental Materials	2015
Hui-min Zhou	Physical Properties of 5 Root Canal Sealers	253	Journal of Endodontics	2013
Hui Zhang	Antibacterial Activity of Endodontic Sealers by Modified Direct Contact Test Against Enterococcus faecalis	216	Journal of Endodontics	2009
Prasanna Neelakantan	Retreatability of 2 Mineral Trioxide Aggregate-based Root Canal Sealers: A Cone-beam Computed Tomography Analysis	204	Journal of Endodontics	2013
George Taccio de Miranda Candeiro	Evaluation of Radiopacity, pH, Release of Calcium Ions, and Flow of a Bioceramic Root Canal Sealer	202	Journal of Endodontics	2012
Afaf Al-Haddad	Bioceramic-Based Root Canal Sealers: A Review	185	International Journal of Biomaterials	2016
Bethany A. Loushine	Setting Properties and Cytotoxicity Evaluation of a Premixed Bioceramic Root Canal Sealer	178	Journal of Endodontics	2011
L Han	Bioactivity evaluation of three calcium silicate-based endodontic materials	146	International Endodontic Journal	2013
Zhejun Wang	Dental materials with antibiofilm properties	140	Dental Materials	2014
David Donnermeyer[1]	Endodontic sealers based on calcium silicates: a systematic review	130	Odontology	2019

2016, and 8 in 2019. When the citation counts of the top 100 articles are examined by year, the highest number of citations occurred in 2021 (1,202 citations), followed by 2022 with 1,166 citations. The total citation counts of the publications by year are shown in Figure 1. When looking at the number of articles, the journals they were published in, and their citation relationships, the Journal of Endodontics has published a total of 49 articles on this topic. Of the top 100 articles, 23 were published in the International Endodontic Journal. It is followed by Dental Materials with 5 publications. The 49 articles published in the Journal of Endodontics have received a total of 3,876 citations. The 23 articles published in the International Endodontic Journal have received a total of 1,538 citations.

Figure 2 shows the relationship between co-authors by year. Markus Haapasalo and Ya Shen were identified as the most prolific researchers, with 9 articles and a total of 1,007 citations each (Markus Haa-

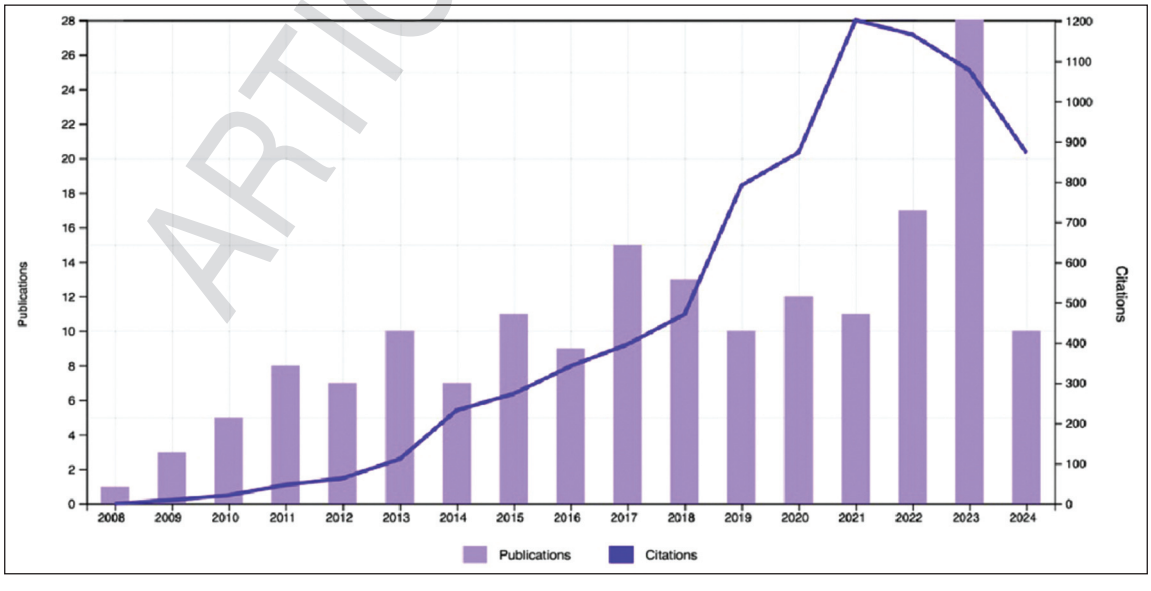

FIGURE 1: Publication distribution by year

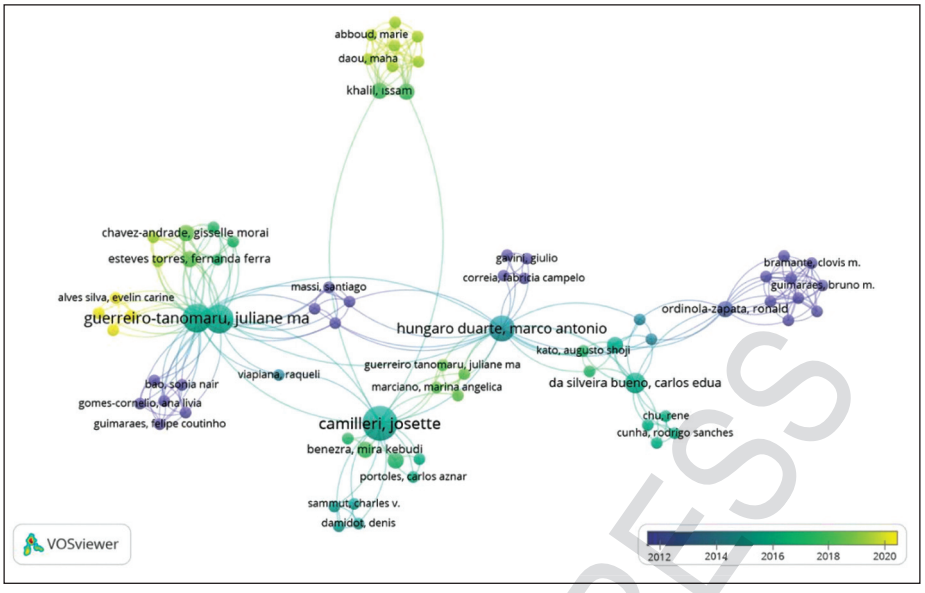

FIGURE 2: Collaboration network of authors by year

pasalo: 9 articles-1,007 citations) (Ya Shen: 9 articles-1007 citations). The researcher Josette Camilleri also has 9 articles in the top 100, which have received a total of 570 citations. When evaluating the institutions to which the authors are affiliated, it is observed that the institution with the most publications on this topic is the University of São Paulo, with 13 publications and a total of 983 citations (highest number of publications). The University of Malta has published 11 articles, which have received a total of 685 citations. The University of British Columbia has published 10 articles, which have received a total of 1,051 citations (highest number of citations) (Figure 3).

Figure 4 shows the keywords used in the studies included in the analysis, categorized by year. The most frequently used keywords were cytotoxicity, mineral trioxide aggregate, and biocompatibility. They were followed by calcium silicate.

Figure 5 shows the distribution of the studies by country. According to this, the most productive country in terms of publications is Brazil, with 36 publications (Citation count: 2,407). The second most productive country is the USA, with 20 publications (Citation count: 1,805). Türkiye ranks 8th in this list, with a total of 9 publications (9 publications: 451 citations).

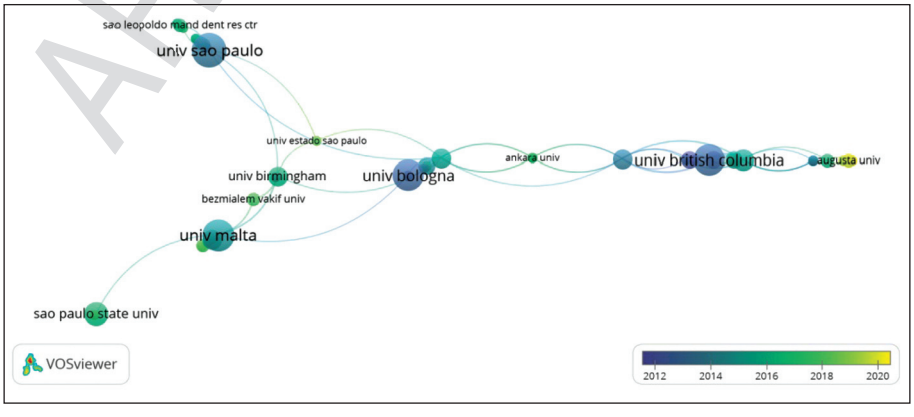

FIGURE 3: The relationship between institutions over the years

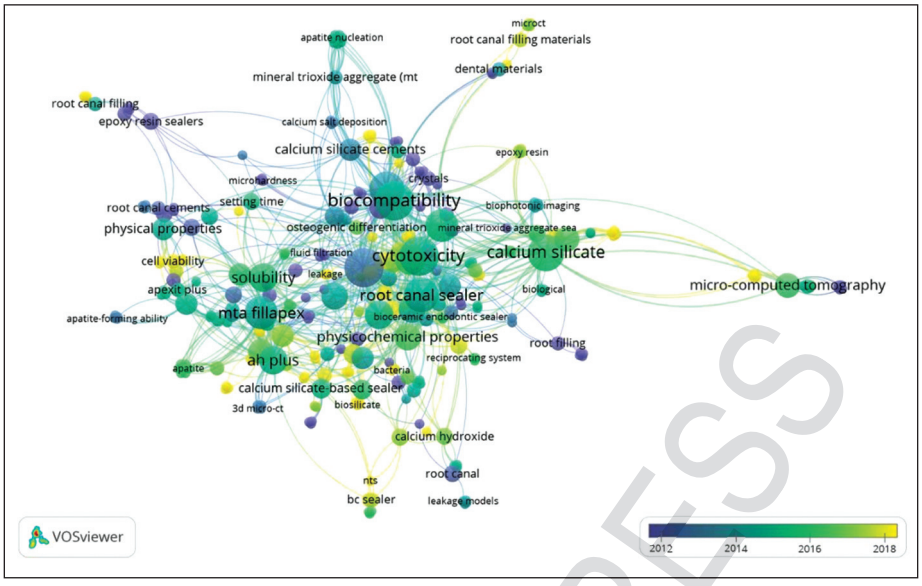

FIGURE 4: Keywords by year of publication

FIGURE 5: The distribution of top-cited articles by country

When evaluating the top 100 most cited articles based on their topics:

- 10 articles are review articles, while the remaining studies are original research (10%).
- 1 study is a survey conducted with clinicians regarding the use of bioceramic root canal sealers. Only 1 out of the 100 studies is a survey study (1%).
- 6 studies investigate the retreatability of bioceramic root canal sealers. 6 out of the 100 studies are related to retreatment (6%).
- 1 study is a clinical trial, representing the only clinical study on the use of bioceramic root canal sealers (1%).
- 5 studies examine the penetration of bioceramic root canal sealers into dentinal tubules (5%).
- In 60 studies, the biological and physicochemical properties of bioceramic-based root canal sealers (such as antibacterial properties, cytotoxic effects, pH, radiopacity, flowability, film thickness, ion release, and setting time) have been investigated (60%).
- 17 studies focus on the mechanical properties of bioceramic-based root canal sealers (such as fracture resistance, sealability properties, dislocation resistance, filling quality, and push-out bond strength) (17%). One of these studies investigates the fracture resistance of teeth filled with bioceramic root canal sealers *in vitro*.

DISCUSSION

Bibliometric studies not only examine the historical development of a specific topic but also reveal its evolution over time and help identify key points in current research. Bibliometric studies can focus on the scientific output of a particular country or research field.[8] This is also in line with the aim of this study. Research on the use of bioceramic sealers in endodontics is continuously increasing, with studies on the physical properties of various sealers and their clinical outcomes. In this context, bibliometric analysis may enable researchers and dental professionals to better understand the advancements in this field.

Citation count is an important metric used to evaluate the scientific impact of a research article. If a paper makes a significant contribution to the existing literature in a particular field, it is typically referenced by subsequent studies. This process leads to an increase in the citation count of an important, reputable, and prestigious paper. Citation tracking can be done through various academic databases such as ISI Web of Knowledge, Web of Science, Scopus, and Google Scholar.[7,9,15] In the absence of other reliable tools, citations have been regarded as the sole indicator of a paper's usefulness and quality.[20] Since citation count is a parameter that changes over time, older publications are generally expected to receive more citations compared to newer ones.[21] However, some studies have indicated that the most-cited papers were published within the last 10 years. The results of our study also support these findings.[7,22] In order for a paper to become a classic by receiving a sufficient number of citations, it typically requires a publication period of 6 to 15 years.[23]

According to this literature review conducted in the electronic environment, the number of studies on bioceramic sealers has been increasing over time. This increase is an indication of the growing popularity of bioceramic sealers and the rising number of scientific studies in this field. The analysis shows that citation rates have risen over the past decade, reflecting the increasing interest in the field of bioceramic sealers (Figure 1). In recent years, the increase in the number of electronic journals published with open access options has allowed articles to spread more quickly and widely within the scientific community. Furthermore, the rise in the number of social networking platforms has facilitated the rapid sharing of articles, which, in turn, enhances the visibility of these papers and positively impacts their citation counts.

It is widely accepted that journals with high impact factors are typically preferred by researchers for submitting their articles, and these journals tend to attract high-quality research.[24] However, some studies suggest that there is no significant correlation between a journal's impact factor and the number of most-cited papers.[25,26] In many citation analyses, it has been concluded that the distribution of relevant papers across journals follows Bradford's Law.[27,28] This law suggests that certain journals, which are influential in specific fields, account for a large proportion of the papers published in that field.[29] In this way, articles published in high-impact factor journals are more likely to be cited. Therefore, the Journal of Endodontics and International Endodontic Journal can be considered as leading journals in the field of endodontics, as the majority of the most-cited papers in the field have been published in these journals. According to the findings of the present study, more than half of the top 100 most-cited papers were published in these journals. Our findings are consistent with Bradford's Law.[30] However, high-impact, multidisciplinary journals that are not specific to a particular field can also have high citation rates. In various bibliometric analyses of the dental literature, journals such as Clinical Oral Investigations, Dental Materials, and Materials have been observed to stand out in terms of publications related to material topics.[31] In the current analysis, the inclusion of these journals among the top 100 most-cited papers supports this finding.

After reviewing the existing literature, it was decided to conduct a comprehensive search process in this study and to use only the Web of Science database. Web of Science is a widely used and preferred database for citation analysis due to its inclusion of studies published as far back as 1945.[32] The use of multiple databases can lead to the occurrence of duplicate records, which may become a potential source of error requiring manual removal. The pres-

ence of duplicate records can affect all quantitative bibliometric parameters in subsequent stages, potentially leading to misinterpretation of the relationships between different research components. In the present study, the Scopus and Google Scholar databases were not preferred because it has been reported that some records in the Scopus database for articles published before 1995 are incomplete.[33] This situation leads to a significant limitation in identifying the most cited articles. Google Scholar, on the other hand, was not preferred because it provides a broader range of data, including citations from non-academic sources (such as conference papers, theses/dissertations, technical reports, and preprints), which may not be relevant to the scope of the study.[34] For this reason, Web of Science was selected as the most suitable database to provide a more accurate and reliable overview. Additionally, compared to similar databases in the health sciences field, Web of Science offers access to a broader collection of articles.

VOSviewer software was used for data analysis. These analyses can be visualized as shown in Figures 2 and Figure 3. The use of VOSviewer as a tool for visualizing bibliometric data networks in the field of dentistry has been documented in various scientific metric studies in recent years. This methodology has become an increasingly popular and effective tool for evaluating the evolution and current status of a research field within the context of bibliometrics or scientific metrics.[8,9,13]

A study's citation count can be increased by reaching a wider readership through open-access journals. This is often possible in countries with more favorable economic conditions. In parallel, countries that are socioeconomically less developed or have limited research infrastructure generally tend to have a more restricted level of scientific contribution.[35] In the present study, it was observed that the countries represented in the top 100 most cited articles exhibit a global distribution, with significant contributions from the USA, China, Brazil, and Canada. This can be attributed to the presence of a high number of institutions, research centers, and researchers, as well as the availability of sufficient funding for scientific research.[26] Moreover, this situation demonstrates that research on bioceramic sealer applications in endodontics spans a wide geographical area globally, and despite differences in public funding between countries, research activities are widespread.

It should be noted that when interpreting these results, some limitations must be taken into account. Citation analysis is considered an ideal method for measuring the impact of a paper in the academic field, but this approach does not always provide a complete and sufficient indication. Particularly, newer publications, due to the shorter time elapsed since their publication, may not yet have accumulated a significant number of citations, which puts these works at a disadvantage. The accuracy of citation analysis studies can be negatively affected by the limitations of the database used in the research. In the present study, the data were obtained from a single database. While Web of Science is widely regarded as a prestigious and suitable database for bibliometric analysis, using only one database can introduce a potential source of bias. Additionally, only English-language publications, the most commonly used language in the literature, were analyzed. This may have led to the overlooking of significant papers in other languages that may have a high citation count. Additionally, one of the limitations of this study may be the possibility that articles written with different topics and keywords, which were not aligned with the keywords we defined, were not considered in the analysis process.

An analysis of the 100 most-cited articles indicates that, while these studies represent significant advancements in the research on bioceramic sealers, they also highlight the need for further investigation in certain areas. Approximately 60% of the studies focus on the biological and physical properties of these materials, which are clearly critical for clinical efficacy. However, most of these findings are laboratory-based, and clinical validation is needed. Research on mechanical properties (17%) assesses the durability and sealing performance of the materials. The limited number of surveys (1%) and clinical studies (1%) underscores the need for additional data to better understand the clinical observations and practical performance of these materials. Additionally, studies on retreatment and dentinal tubule penetration (6-5%, respectively) provide valuable

insights into the clinical effectiveness of these materials, but further large-scale and long-term studies are required. Overall, more research is needed on the clinical success and long-term performance of bioceramic sealers.

CONCLUSION

This bibliometric analysis has highlighted the development and key trends in research on bioceramic-based root canal sealers. The top 100 most-cited articles reveal a broad range of studies assessing the contributions, properties, and clinical efficacy of bioceramic sealers in endodontic treatment.

The increasing number of publications and citations related to bioceramic sealers indicates a growing focus on this topic within the current endodontic literature. The findings suggest that research on bioceramic sealers will continue to expand in the coming years, further solidifying their importance in endodontic practice.

Current research on bioceramic sealers provides comprehensive information regarding their biological, physicochemical, and mechanical properties. However, there are still significant gaps in areas such as clinical trials, survey-based studies, and the retreatment properties of bioceramics. Future research should focus on filling these gaps and evaluating the clinical efficacy of bioceramics in a more comprehensive manner. In particular, studies assessing the clinical performance and long-term success of bioceramic sealers, retreatment processes, and the challenges encountered in the clinical applications of these materials will be crucial for advancing the field and making significant contributions to its development.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Merve Gökyar;* ***Design:*** *Merve Gökyar, İdil Özden;* ***Control/Supervision:*** *Hesna Sazak Öveçoğlu;* ***Data Collection and/or Processing:*** *Merve Gökyar, İdil Özden;* ***Analysis and/or Interpretation:*** *İdil Özden;* ***Literature Review:*** *Merve Gökyar, Hesna Sazak Öveçoğlu;* ***Writing the Article:*** *Merve Gökyar;* ***Critical Review:*** *Hesna Sazak Öveçoğlu;* ***References and Fundings:*** *Merve Gökyar, İdil Özden.*

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