

The Evolving Trends In Vital Pulp Therapy Through the Application of Various Biomaterials: A Bibliometric Study

Perkembangan Tren Terapi Pulpa Vital melalui Aplikasi berbagai Biomaterial: Penelitian Bibliometrik

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Kata Kunci: bibliometrik, dentinogenesis, mineral trioxide aggregate, terapi pulpa vital.

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Abstract

Vital pulp therapy (VPT) is a crucial dental intervention designed to maintain the vitality of the dental pulp, particularly in carious lesions or trauma. The evolution of biomaterials in VPT has significantly affected dental practices by providing less invasive alternatives that safeguard tooth vitality and functionality. Continued exploration of the properties and effects of these materials is crucial for enhancing treatment strategies and optimizing dental care outcomes. Bibliometric analysis allowed the assessment of trends in the biomaterials used for VPT. Data mining was performed using the Scopus database and Boolean expressions. Data extraction and analysis were conducted using VOSviewer version 1.6.20., VOSviewer thesaurus, and Microsoft Excel. A total of 856 documents were identified, and the United States had the largest number of documents and citations (110 documents, 6,938 citations). The top three sources were the Journal of Endodontics, International Journal of Endodontics, and Dental Materials Journal. Mineral trioxide aggregate (MTA) is still the dominant biomaterial used in VPT to this day. MTA can accelerate dentinogenesis in VPT. The prominence of "MTA" and "VPT" as keywords highlights research on prevalence, causes, prevention, and evaluation, emphasizing the need to investigate biomaterial-driven healing, regeneration, stem cell activity, and gene expression.

Abstrak

Terapi pulpa vital (*Vital Pulp Therapy/VPT*) merupakan prosedur terapeutik esensial dalam praktik kedokteran gigi yang bertujuan mempertahankan vitalitas pulpa gigi, pada kasus kerusakan akibat karies atau trauma. Inovasi penggunaan biomaterial memberi kontribusi besar terhadap pendekatan klinis yang lebih konservatif, dengan tetap menjaga integritas biologis dan fungsional gigi. Penelitian terhadap karakteristik fisikokimia dan bioaktivitas biomaterial menjadi aspek fundamental dalam upaya optimalisasi protokol terapi dan peningkatan luaran klinis. Evaluasi bibliometrik memberikan wawasan kuantitatif terhadap dinamika perkembangan penelitian biomaterial pada VPT. Data diperoleh melalui basis data Scopus dengan penelusuran berbasis Boolean. Proses ekstraksi dan analisis informasi menggunakan perangkat lunak VOSviewer versi 1.6.20 yang didukung oleh VOSviewer Thesaurus dan pengolahan lanjutan melalui Microsoft Excel. Sebanyak 856 publikasi berhasil diidentifikasi, dengan Amerika Serikat sebagai kontributor utama berdasarkan jumlah publikasi 110 dokumen dan total sitasi 6.938 kutipan. Tiga sumber literatur ilmiah yang paling banyak memuat publikasi terkait topik ini adalah Journal of Endodontics, International Journal of Endodontics, dan Dental Materials Journal. Di antara berbagai jenis biomaterial yang digunakan, Mineral Trioxide Aggregate (MTA) menjadi material yang paling banyak diaplikasikan dalam prosedur VPT hingga saat ini. MTA diketahui berperan dalam merangsang proses dentinogenesis, menjadikannya bahan yang sangat relevan dalam konteks terapi regeneratif pulpa. Frekuensi kemunculan kata kunci "MTA" dan "VPT" dalam publikasi ilmiah menunjukkan tingginya minat riset terhadap aspek prevalensi, etiologi, tindakan preventif, serta evaluasi klinis terapi ini. Fenomena ini menyoroti pentingnya eksplorasi lanjutan terhadap mekanisme penyembuhan jaringan, proses regenerasi, aktivasi sel punca, dan regulasi ekspresi gen yang dimediasi oleh biomaterial.

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INTRODUCTION

Maintaining the integrity of the dental pulp is essential due to its role in supplying nourishment, sensibility, and protection against infection.¹ Vital pulp therapy (VPT) methodologies are intended to maintain the vitality and functional integrity of the dental pulp following damage caused by trauma, dental caries, or restorative interventions.^{2,3} VPT procedures have traditionally encompassed techniques such as indirect pulp capping, direct pulp capping, and partial and complete pulpotomy.⁴ These techniques help to eliminate the inflammatory response irreversibly. VPT also facilitates the healing of the pulp tissue and safeguards it from external stimuli, including mechanical, bacterial, traumatic, chemical, iatrogenic, and thermal factors, thereby preventing extensive tissue damage.¹ VPT is initiated at sites of either near-pulpal or direct pulp exposure and involves the application of a protective dressing or base. This shields the pulp from further injury while facilitating its healing and repair. This procedure refers to placing a biomaterial over a nearly exposed coronal pulp after caries excavation.³

An ideal pulp-capping material should have the ability to stimulate reparative dentin formation, preserve pulpal vitality, release fluoride to inhibit secondary caries, exhibit bactericidal or bacteriostatic properties, adhere effectively to both dentin and restorative materials, withstand mechanical forces during restoration placement and throughout its functional lifespan, be sterile and radiopaque, and establish an effective bacterial seal.^{2,5,6} Recently, the renewed interest in VPT can be attributed to advancements in diagnostic technologies, development of bioactive materials, improvements in magnification techniques, and an enhanced understanding of the pulp–dentin complex. The resurgence in interest has progressed notably since Hermann introduced calcium hydroxide (Ca(OH)₂) as a root-filling material in 1920. Notably, between 1928 and 1930, several studies investigating the use of Ca(OH)₂ concluded that it is a biocompatible material when applied to vital pulp tissue.² For several decades, Ca(OH)₂ has been the standard of excellence among pulp-capping materials.^{7,8} Ca(OH)₂ has been widely utilized as a pulp-capping agent because of its antibacterial properties and capacity to promote the formation of a robust tissue barrier.^{8,9}

In the early 1990s, MTA was introduced as a bioactive material. Its mechanism of action of MTA is similar to that of Ca(OH)₂. MTA was developed for clinical applications where maintaining a dry field is challenging, such as in retrograde endodontic filling and perforation repair. Extended usage includes apexification, dressing over pulpotomized, and pulp-capping material.¹⁰ The benefits of MTA include its biocompatibility, effective sealing capability, bioactivity, and ability to induce the formation of mineralized tissue.¹⁰ With the use of MTA, dentin bridge formation following pulp capping was observed as early as 1 week, with a consistent increase in both length and thickness over 3 months.¹¹ Nevertheless, the setting time, mechanical properties, potential for discoloration, ease of manipulation, and mud-like consistency of the cement have historically been significant technical challenges associated with traditional MTA.¹⁰

Calcium silicate cement (CSCs) have gained significant attention for their application in VPT. They include tricalcium silicates, dicalcium silicates, hydraulic calcium silicate cement, and “bioceramics.” When MTA and other CSCs are used for VPT in permanent teeth with symptomatic or asymptomatic irreversible pulpitis, the success rate ranges from 85% to 100% at 1–2 years. Ca(OH)₂, glass ionomer cement, and resin-based materials show less favorable clinical outcomes, with success rates ranging from 43% to 92%.¹² Compared with those of calcium hydroxide-based materials, the quality of the formed mineralized barriers using CSCs has improved.¹² During dental pulp procedures, silicate materials also exhibit advantageous physicochemical properties, such as high alkalinity, intratubular mineralization, inhibition of biofilm formation, and reduction in potent proinflammatory mediators. It also has improved setting times, including modified compositions that reduce tooth discoloration.¹²

In recent years, bibliometrics has emerged as a prominent trend in academic research. Bibliometric analysis involves a systematic examination of the scientific literature to identify patterns, trends, and effects within a specific field. The key steps in this process include collecting data from relevant databases, cleaning and refining the data, and applying various bibliometric methods to generate meaningful insights.¹³ Bibliometrics reflects its applicability in handling huge scientific data and contributes significantly to impactful research.¹³

Despite increasing research on VPT, no bibliometric analysis has yet examined the most widely used materials from 2000 to 2024, the countries that utilize these materials most frequently, or the leading authors contributing to the study of pulp-capping materials in this field. Therefore, this review aimed to highlight the strengths and progress in the field by presenting the publication trends in dentistry related to VPT, identifying the most influential authors, sources, organizations, countries, and keywords, and describing the evolution of research on VPT needs over time.

METHODS

This bibliometric analysis report follows the guidelines of bibliometric reviews of the biomedical literature (BIBLIO). Bibliometric analysis is a systematic approach to examining scientific literature to identify patterns, trends, and effects within a specific field. The primary steps involve collecting data from relevant Scopus databases to perform a comprehensive literature search. Following data mining, cleaning, and refinement, data were analyzed using various bibliometric methods, a crucial step in deriving meaningful insights.¹³

Data sources and search strategy

This study conducted a bibliometric analysis of VPT-related scientific research. The aim was to assess the evolution of studies on VPT needs from 2000 to 2024 from Scopus. Scopus was selected because it includes peer-reviewed articles published by Elsevier, Springer, Wiley, Nature, and other reputable publishers.¹⁴ Moreover, Scopus is regarded as the largest citation and abstract repository, encompassing a broader spectrum of topics than the Web of Science database. To the best of the authors' knowledge, this study has employed all relevant keywords used by various researchers, organizing them into a query search string with appropriate field codes and Boolean operators.

Bibliometric analysis broadly comprises three phases: Phase I, which involves identifying of sources and criteria; Phase II, which consists of selecting software and extracting data; and Phase III, which involves data analysis and interpretation. Before the bibliometric analysis, keyword selection was considered fundamental to the study's framework. To this end, the authors reviewed >1,000 articles, spanning both recent publications and earlier works with substantial citation counts, sourced from Scopus.¹³

A preliminary research topic search was conducted on December 3, 2024, via Boolean sentences in Scopus. To search for phrases in Scopus, double quotes ("), wildcards (*), and Boolean operators (OR, AND, NOT) were used. Double quotes were used to indicate "loose phrases," ensuring that the words were kept together. Wildcards (*) were used to represent several characters, and Boolean operators were used to expand or narrow the search parameters when databases or search engines were used. The default search field in Scopus uses ALL with the description All Fields. The keywords used to guide the data search were ALL ("pulp inflammation") OR ALL "pulp exposure") OR ALL ("vital pulp therapy") OR ALL ("pulp capping") OR ALL ("direct pulp capping") OR ALL ("indirect pulp capping") AND ALL ("calcium hydroxide") OR ALL ("mineral trioxide aggregate") AND ALL ("dentin repair") OR ALL ("dentin bridges") OR ALL ("calcified barrier") OR ALL ("dentinogenesis").

Data collection and analysis

Data were taken between 2000 and 2024. The data collection was initiated from the year 2000, as this period marks the beginning of a substantial increase in the number of publications indexed in Scopus

addressing the significance of vital pulp therapy. Do you want me to make it even more concise, like for a journal manuscript style? The query string initially yielded 1,282 articles. This analysis included all the literature about VPT, including articles, reviews, and case reports. Restricting to articles that used only the English language resulted in 1,254 articles. Other exclusion criteria were as follows: articles that did not contain the author name (blank) (n = 9); articles other than original articles, reviews, and cases (n = 110); articles with no specific titles (n = 122); and no specific keywords (n = 157). After the articles were filtered according to the exclusion criteria, up to 856 articles remained from Scopus.

All the acquired data were tabulated in Microsoft Excel 2019 (Microsoft Office, USA). Treatment needs to use Scopus. VOSviewer and Thesaurus were used to map and cluster the results based on the research questions. The bibliography analysis attributes in VOS viewer software 1.6.20 (Universiteit Leiden, Netherlands) include coauthorship, co-occurrence, and citation. After the data were processed using VOSviewer and several visualizations were generated, the information was further analyzed with VOSviewer thesaurus, and Microsoft Excel was employed to facilitate more interactive and user-friendly data visualization. The bibliometric analysis workflow is shown in **Figure 1**.

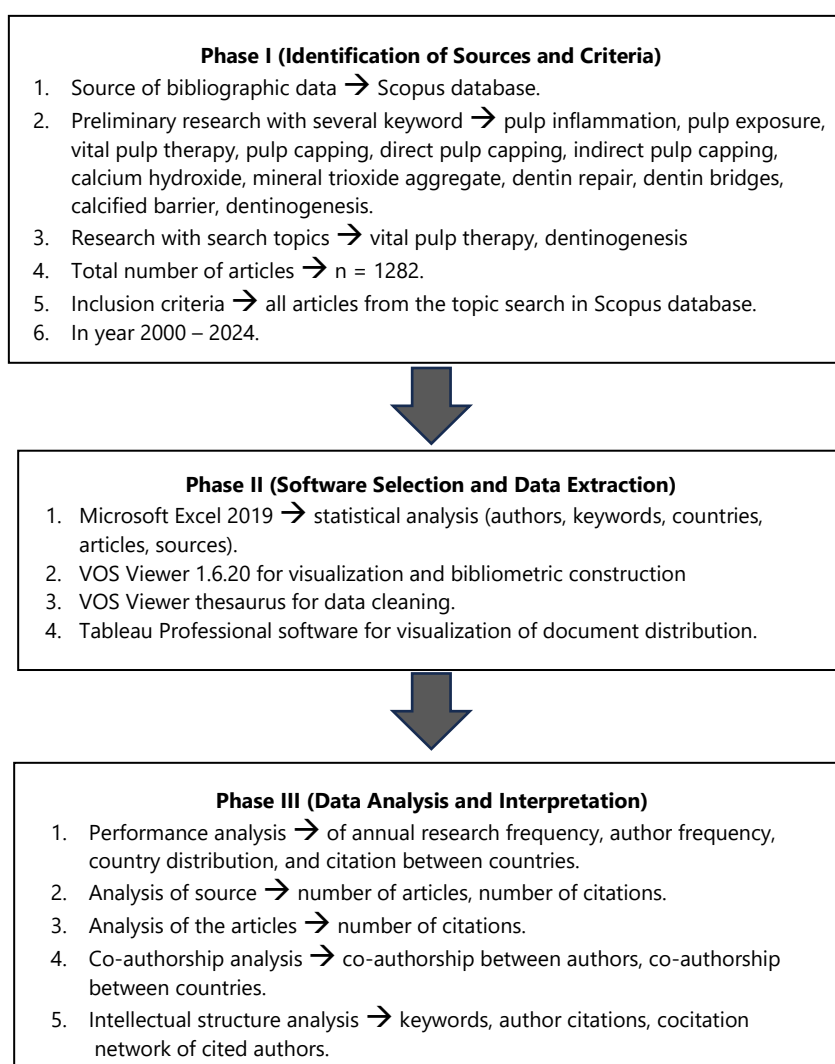


Figure 1. Flow diagram of the bibliometric analysis methodology process

DATA ANALYSIS RESULTS

1. Analysis of publication frequency by years

VPT has shown an increasingly interesting trend from year to year. This trend was evident from 2000 to 2004, when only 1–4 articles per year were identified. However, the number of articles increased significantly, starting from 10 articles in 2006 to 28 in 2010 and then 43 in 2014, and these figures were increasing through 2024. Notably, in 2021, 96 articles on VPT were published. As shown in **Figure 2**, a total of 3,617 citations across 29 articles were recorded in 2010.

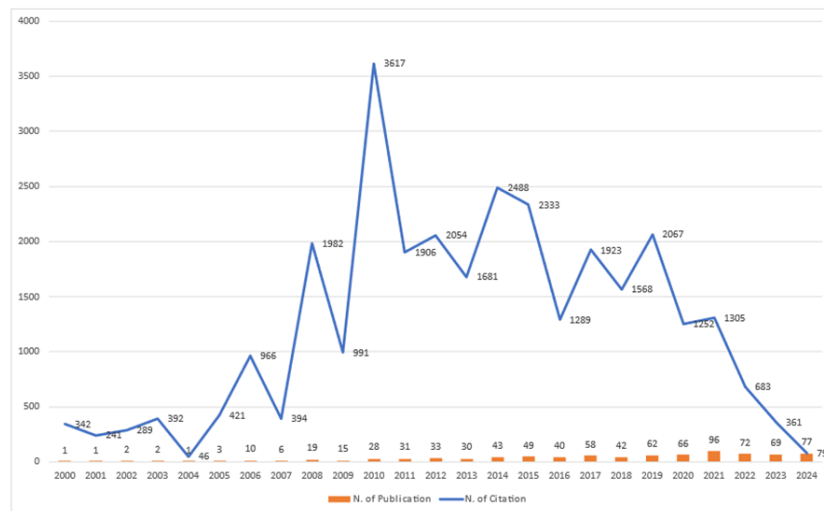


Figure 2. Trends in the number of publications and the number of citation articles from 2000-2024.

2. Analysis of countries to fields for VPT

To assess the number of articles published according to the author's country of origin, bibliometric coupling analysis was employed. Between 2000 and 2024, the 10 countries that published the most VPTs were the United States, with the highest number of articles at 192, followed by China with 147, Japan with 119, India with 116, Brazil with 100, United Kingdom with 100, Iran with 90, South Korea with 72, and Egypt and Turkey with 56 (**Figure 3**).

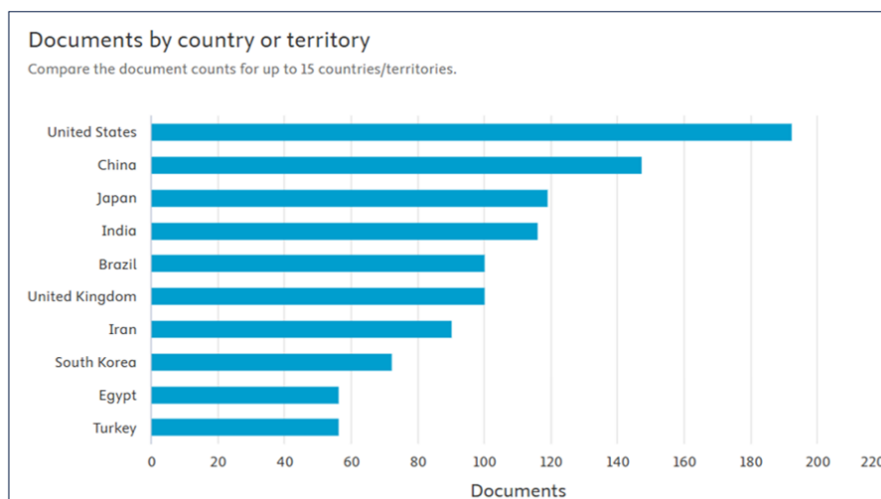


Figure 3. The trend of the distribution of articles by country or territory

Co-authorship analysis was conducted on country-level units, with a maximum of 25 countries per article and a minimum of five articles per country, excluding those with zero citations. We observed that 74 countries met these criteria; the largest group included 39 interconnected countries, along with 10 countries

exhibiting the highest levels of co-authorship (**Table 1**). The authors of these 36 countries were interconnected, except for the authors from three countries, namely, Serbia, Romania, and Mexico.

Table 1. Top 10 countries with the most significant number of documents and collaborating countries

Rank	Country	Region	Publication	Citation	Total link strength	Collaborating countries
1	United States	America	110	6,938	102	Brazil, Indonesia
2	China	China	105	2,474	40	Japan, Turkey, Belgium, Taiwan
3	Japan	East Asia	104	3,499	34	China, Turkey, Belgium, Taiwan
4	India	South Asia	79	1,170	17	Iran, South Korea, Egypt, Saudi Arabia, Australia, Canada, Malaysia, Jordan, Pakistan, Kuwait
5	Brazil	South America	66	2,133	33	United States, Indonesia
7	Iran	Middle East	63	3,546	22	India, South Korea, Egypt, Saudi Arabia, Australia, Canada, Malaysia, Jordan, Pakistan, Kuwait
8	South Korea	East Asia	60	1,573	13	India, Iran, Egypt, Saudi Arabia, Australia, Canada, Malaysia, Jordan, Pakistan, Kuwait
6	United Kingdom	Great Britain	50	4,430	80	Ireland, Switzerland, New Zealand, Denmark and Sweden
9	Egypt	Middle East	45	562	21	India, Iran, South Korea, Saudi Arabia, Australia, Canada, Malaysia, Jordan, Pakistan, Kuwait
10	Turkey	Middle East	39	763	7	Japan, China, Belgium, Taiwan

3. Analysis of the number of article citations by country

Citation analysis was performed on country-level units, with a maximum of 25 countries per article and a minimum of 10 articles per country (**Table 1**). The United States ranked first, with 6,938 citations from 110 publications.

4. Source analysis based on the number of documents

The analysis revealed that 239 Scopus-indexed sources contributed to the publication of 856 articles identified through data mining. The largest cluster of interconnected sources consisted of 13 journals. The *Journal of Endodontics* was the leading source, with 146 articles, followed by the *International Endodontic Journal* with 81 articles, *Dental Materials* with 27 articles, and *Biomaterials* with 21 articles (**Table 2**).

5. Analysis of the article

This analysis of articles and documents aimed to identify those that had the greatest influence on research trends related to VPT and biomaterials, or more specifically, research trends in VPT. VOSviewer was used for the analysis, with citation analysis as the method and documents as the unit of analysis. The number of citations for each document was set at 50. From 856 documents, 172 articles were found to have been cited 50 times, and 170 interconnected articles were identified.

The article titled, "Mineral Trioxide Aggregate: A Comprehensive Literature Review Part III: Clinical Application, Drawbacks, and Mechanism of Action," published in the *Journal of Endodontics* in 2010, has the highest citation count. Authored by Masoud Parirokh and Mahmoud Torabinejad (**Table 3**), this publication reflects the author's substantial contribution to the advancement of VPT.

Table 2. Top-ranking sources with a minimum of twenty documents

Rank	Sources	Country	ISSN	Publication	Citation	h-Index	Scimago	SJR (2023)
1	<i>Journal of Endodontics</i>	United States	00992399, 18783554	146	9,967	180	Q1	1.36
2	<i>International Endodontic Journal</i>	United Kingdom	01432885, 13652591	81	5,517	147	Q1	2.16
3	<i>Dental Material Journal</i>	Japan	02874547, 18811361	27	382	70	Q2	0.59
4	<i>Biomaterial</i>	United Kingdom	01429612, 18785905	21	1,452	435	Q2	3.02
5	<i>Clinical Oral Investigations</i>	Germany	14326981, 14363771	20	651	101	Q1	0.94
6	<i>Journal of Dental Research</i>	United States	00220345	20	971	211	Q1	1.91

Table 3. Top 10 most-cited articles

Rank	Title	Authors	Journal	Year	Citations
1	Mineral trioxide aggregate: a comprehensive literature review—Part III: Clinical applications, drawbacks, and mechanism of action	Masoud Parirokh and Mahmoud Torabinejad	<i>Journal of Endodontics</i>	2010	951
2	Mineral trioxide aggregate: a comprehensive literature review—part II: leakage and biocompatibility investigations	Mahmoud Torabinejad and Masoud Parirokh	<i>Journal of Endodontics</i>	2010	665
3	Calcium silicate bioactive cements: Biological perspectives and clinical applications	Carlo Prati and Maria Giovanna Gandolfi	<i>Dental Materials</i>	2015	390
4	Response of human dental pulp capped with biodentine and mineral trioxide aggregate	Alicja Nowicka, Mariusz Lipski, Mirosław Parafiniuk, Katarzyna Sporniak-Tutak, Damian Lichota, Anita Kosierkiewicz, Wojciech Kaczmarek, Jadwiga Buczkowska-Radlińska	<i>Journal of Endodontics</i>	2013	357
5	Mineral trioxide aggregate material use in endodontic treatment: a review of the literature	Howard W Roberts 1, Jeffrey M Toth, David W Berzins, David G Charlton	<i>Dental Materials</i>	2008	350
6	European Society of Endodontology position statement: Management of deep caries and the exposed pulp	H F Duncan, K M Galler, P L Tomson, S Simon, I El-Karim, R Kundzina, G Krastl, T Dammaschke, H Fransson, M Markvart, M Zehnder, L Bjørndal	<i>International Endodontic Journal</i>	2019	343
7	Designing new treatment strategies for vital pulp therapy	D Tziafas 1, A. J. Smith, H Lesot	<i>Journal of Dentistry</i>	2000	342
8	Biodentine (TM) induces TGF-β1 release from human pulp cells and early dental pulp mineralization	P Laurent, J Camps, I About	<i>International Endodontic Journal</i>	2012	339
9	Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview-Part I: vital pulp therapy	M Parirokh, M Torabinejad, P M H Dummer	<i>International Endodontic</i>	2018	325
10	The application of tissue engineering to regeneration of pulp and dentin in endodontics	Misako Nakashima, Akifumi Akamine	<i>Journal of Endodontics</i>	2005	323

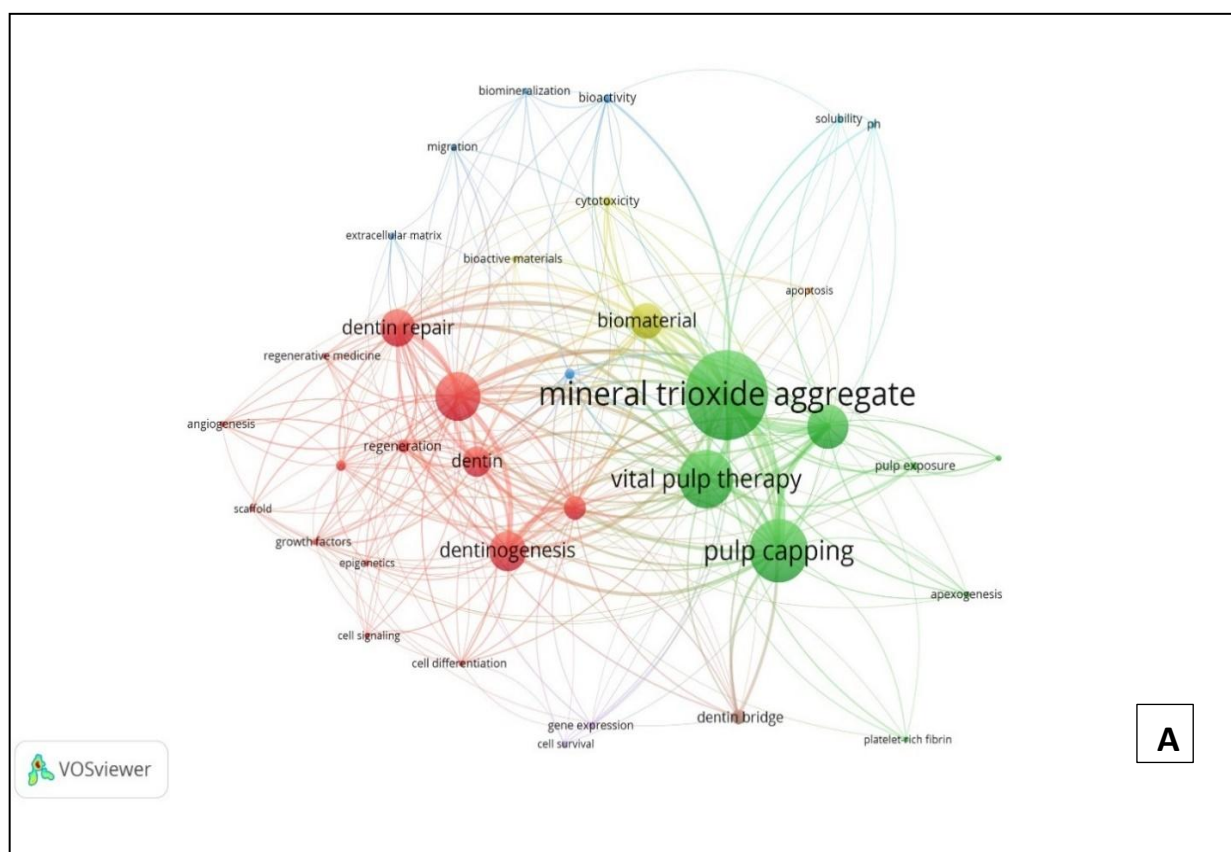
6. Analysis the intellectual structure of authors' keywords

Authors' keywords were analyzed to identify correlations between the keywords and the topics of the articles, thereby facilitating a deeper exploration of various aspects of research on the topic of VPT. The analysis was conducted using VOS Viewer, specifically employing a co-occurrence analysis of the authors' keywords with a minimum threshold of five occurrences per keyword. A total of 1,596 keywords were identified, of which 53 met the specified threshold.

The overlay visualization of the authors' keywords, organized into eight clusters with a total link strength of 2,025, highlights distinct research themes. Cluster 1 focuses on the biomolecular mechanisms underlying stem cell proliferation in the dental pulp. Cluster 2 emphasizes biomaterials, with MTA being the most frequently referenced, followed by $\text{Ca}(\text{OH})_2$ and platelet-rich fibrin. Cluster 3 explores the cytotoxicity of the bioactive materials, whereas cluster 4 examines the interaction between the inflamed pulp tissue and the applied biomaterials. Cluster 5 addresses gene expression in dental pulp stem cells stimulated by biomaterial application, and cluster 6 investigates the physical properties of these biomaterials. Cluster 7 is involved in the apoptotic process, and cluster 8 focuses on the mechanisms of dentin bridge formation.

The overlay mapping reveals that several keywords were particularly prominent in the literature. "Mineral Trioxide Aggregate" is the most frequently used keyword, with 367 cooccurrences and a total link strength of 635. Other significant terms include vital pulp therapy (213 occurrences, total link strength of 381), dental pulp stem cells (172 occurrences, total link strength of 365), $\text{Ca}(\text{OH})_2$ (154 occurrences, total link strength of 312), dentinogenesis (134 occurrences, total link strength of 270), biomaterial (117 occurrences, total link strength of 254), and dentin repair (125 occurrences and a total link strength of 268).

In addition to the prominent keywords, several less frequently encountered terms in the literature, including regenerative endodontics (2 cooccurrences, total link strength of 52) and gene expression (8 cooccurrences, total link strength of 17), were used. These terms indicate emerging research areas that are yet to gain widespread attention (**Figure 4**).



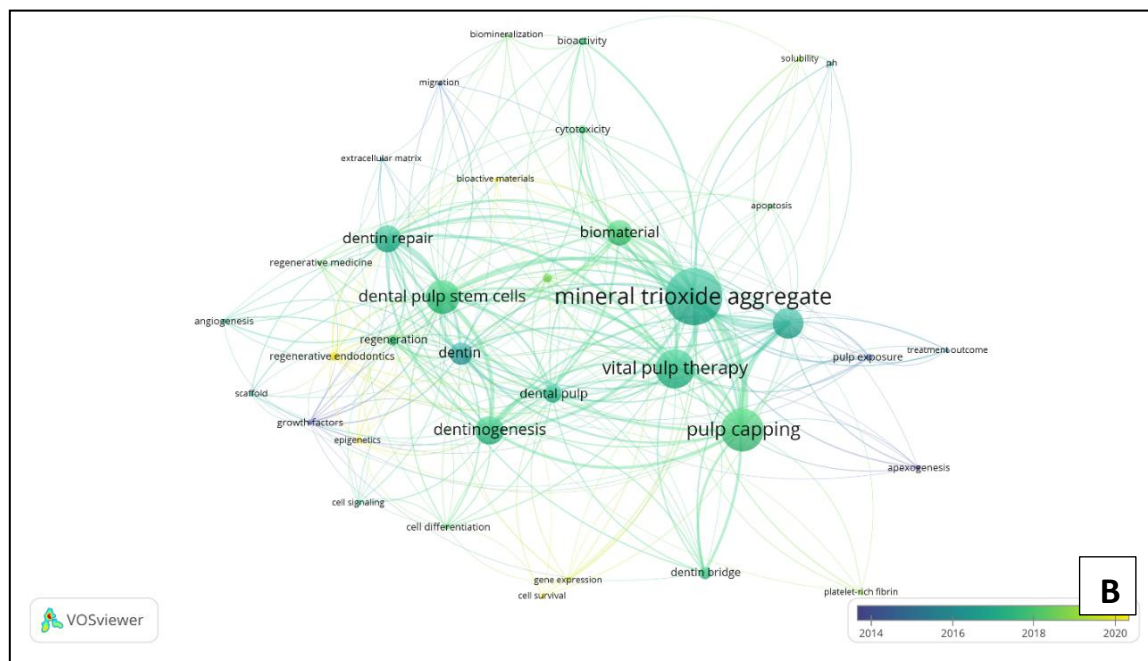


Figure 4. The overlay visualization **A.** Clustering map; **B.** Evolving research trends, indicating a shift in focus toward emerging areas such as regenerative endodontics, biomaterials, and gene expression. These trends reflect the current direction of scientific inquiry and highlight key priorities in contemporary medical research.

DISCUSSION

Scopus was chosen as the source of bibliographic data for this study because of its comprehensive coverage, superior data quality, and accuracy. It also offers advanced bibliometric analysis tools and is widely verified and academically acknowledged as a reliable resource for scholarly research.¹⁵ Falagas et al.; evaluated the strengths and limitations of PubMed, Scopus, Web of Science, and Google Scholar. They noted that both PubMed and Google Scholar are freely available, with PubMed being suited for biomedical research, whereas Google Scholar has varied accuracy. In contrast, Scopus provides 20% more comprehensive citation analysis coverage than the Web of Science.^{15,16} Sing et al.; compared the Web of Science, Scopus, and Dimensions. Nearly all journals indexed in the Web of Science are also included in Scopus and Dimensions. Scopus also contains 66.07% more unique journals than the Web of Science. Although both the Web of Science and Scopus primarily focus on the life sciences, physical sciences, and technology, Dimensions offers broader coverage in social sciences, arts, and humanities.¹⁷ This bibliometric analysis revealed that journal age, open-access status, subject matter, quality, and impact factors critically influence the number of document citations.¹⁵

The bibliometric analysis, based on data retrieved from Scopus up to December 2024, identified 856 articles on VPT and related biomaterials. Publications on VPT showed a steady upward trend between 2000 and 2021. A marked increase was observed in 2010, when 28 articles collectively received 3,617 citations. The peak occurred in 2021, with 96 publications that together accrued 1,305 citations. After 2021, both the number of publications and their citation counts declined, likely reflecting shifts in treatment approaches and the introduction of diverse new medicament regimens.

The increasing number of published VPT articles may be due to the development of materials that support treatment. $\text{Ca}(\text{OH})_2$, which was introduced by Hermann in 1930, is the main material used in VPT. Over time, MTA, another material that emerged, was able to replace the previous material.² However, this material is still unable to provide maximum results, so further research is needed on materials that can provide maximum results for VPT as early as possible. The limitations of biomaterials were previously the subject of various questions in this bibliometric analysis.

Pulp therapy intends to maintain the vitality of teeth damaged by caries or dental trauma, keep the tooth structure intact, and maintain optimal function. The pulp is crucial in preserving tooth vitality, as it contains various cellular components that respond to stimuli that affect the teeth.¹⁸ Recent advancements in biotechnology and translational research have enabled the development of therapeutic strategies for vital pulp protection, with a focus on the modulation of reactionary and reparative dentinogenesis.¹⁹ Regenerative treatment in VPT is intended to induce the differentiation of odontoblast-like cells, leading to the formation of tertiary dentin at the exposed site while preserving the integrity of the tissue structure. The success of this treatment is primarily determined by how the dental pulp cells respond to the materials in direct contact with the pulp. Several pulp-dressing agents have been used to promote the health of the radicular pulp.²⁰

An analysis of global trends in VPT indicates that the United States holds the leading position in article production. The United States has published the highest number of articles, totaling 110, followed closely by China with 105 articles, Japan with 104, India with 79, and Brazil with 66. The United States has the highest number of articles published across countries and the highest citation count. However, an analysis of the most-cited countries revealed that a higher article count does not necessarily correlate with a greater citation impact. For instance, France ranks fifth among the top 10 countries with the highest number of citations, having garnered 3,117 citations from its 34 articles.

The Journal of Endodontics ranks as the most-cited journal, followed by the International Endodontic Journal, which has received 146 publication and 9,967 citations, respectively. The Journal of Endodontics stands out the most, the official publication of the American Association of Endodontists, publishes scientific articles, case reports, and comparative studies that assess materials and techniques related to pulp conservation and endodontic treatment. This journal has been in publication since 1975, with an h-index of 180 and a Q1 ranking.

The International Endodontic Journal is published monthly and aims to feature original, high-quality articles that contribute to the dissemination of scientific and clinical knowledge. Original scientific articles related to endodontic diseases and their management and the restoration of root-treated teeth have been published in the fields of biomedical science, applied materials science, bioengineering, epidemiology, and social science. The International Endodontic Journal was ranked Q1, with an h-index of 147.

The Dental Materials Journal ranked third, with 382 total citations from 27 articles. This journal is a publication of the Japanese Society for Dental Materials and Devices that aims to introduce the progress of basic and applied sciences in dental materials and biomaterials. The journal also encompasses clinical science related to dental materials and instrumental technologies. It covers materials such as synthetic polymers, ceramics, metals, and tissue-derived biomaterials. In addition, cutting-edge dental materials and biomaterials used in emerging fields such as tissue engineering, bioengineering, and artificial intelligence are favorably considered in this review. The Dental Materials Journal has been in existence since 1982, with the journal ranking Q2 and an h-index of 70.

Biomaterials ranks fourth, which has 1,452 citations, a Q1 ranking, and an h-index of 435. This international journal covers the science and clinical application of biomaterials. It covers a wide range of physical, biological, and chemical sciences that underpin the design of biomaterials and clinical disciplines in which they are used. Clinical applications include medical technology and regenerative medicine in all clinical disciplines and diagnostic systems that rely on innovative contrast and sensing agents.

The article titled, "Mineral Trioxide Aggregate: A Comprehensive Literature Review Part III: Clinical Applications, Drawbacks, and Mechanism of Action", holds the highest citation count, with 951 citations, securing the top position. It was authored by Masoud Parirokh and Mahmoud Torabinejad in 2010 from the Neuroscience Research Center at Kerman University of Medical Sciences, Iran. This publication highlights their significant contribution to VPT. The contents of this article are the results of MTA as a promising material for root-end filling, perforation repair, VPT, and apical barrier formation for teeth with necrotic pulps and open apices. Despite numerous case reports and case series concerning its applications, few studies have investigated the clinical applications of this material. MTA has several known drawbacks, such as a long setting

time, high cost, and potential for discoloration. Hydroxyapatite crystals form over MTA when they come in contact with the synthetic fluid. This can act as a nidus for the formation of calcified structures after using this material in endodontic treatments.^{2,21,22}

The article titled, "Mineral trioxide aggregate: a comprehensive literature review--part II: leakage and biocompatibility investigations", was the second most-cited article. It was written by Mahmoud Torabinejad and Masoud Parirokh, with 651 citations. This study focused on the sealing ability and biocompatibility of MTA.²³ According to these two articles, MTA is the most commonly used material in VPT, offering advantages and limitations.^{24,25} These limitations have driven ongoing research into identifying the optimal dental biomaterial for VPT and enhancing the regenerative processes of dental pulp stem cells to maintain pulp vitality for as long as possible.

The analysis of publications from 2000 to 2024 reveals a notable pattern of collaboration among authors. The authors in cluster 4 demonstrate strong connections with those in clusters 2, 3, and 1. Furthermore, the authors in clusters 2 and 1 have contributed to the most recent publications, reflecting the ongoing research activity in these groups. In addition to author collaboration, international collaboration patterns are also evident. The United States is leading in publication output and citation count and collaborates extensively with Brazil and Indonesia. Similarly, China has demonstrated strong research partnerships with Japan, Turkey, Belgium, and Taiwan.

The relationships between the keywords of existing articles are organized into clusters that represent the progression of VPT research. Cluster 1 focuses on the biomolecular mechanisms underlying stem cell proliferation in the dental pulp. Cluster 2 highlights commonly used biomaterials, including MTA, Ca(OH)_2 , and platelet-rich fibrin. Notably, although Ca(OH)_2 has long been considered the gold standard in VPT, it has gradually been replaced by MTA. Cluster 3 addresses the cytotoxicity of bioactive materials, whereas cluster 4 explores the correlation between biomaterials and pulp inflammation. Cluster 5 investigates gene expression in dental pulp stem cells stimulated with biomaterials. Cluster 6 focuses on the physical properties of the biomaterials, cluster 7 examines the apoptosis process, and cluster 8 discusses dentin bridge formation, underscoring the effectiveness of these biomaterials in VPT. Across all the clusters, research areas such as regenerative endodontics, gene expression, and biomaterials remain underrepresented, with relatively few articles published in these fields.

This bibliometric analysis offers authors a quantitative and descriptive overview of country citations, journals, articles, authors, and authors' keywords related to VPT and the biomaterials used. Despite its utility, bibliometric analysis has several limitations. The key limitation is the necessity of open access to scientometric data, as obtaining data with sufficient accuracy is crucial. Accurate analysis requires crucial information, such as metadata, author data, affiliations, and citations. Another limitation involves the potential incompleteness of downloaded data, the presence of duplicates, and instances where articles are published in languages other than English, typically the language of the country of origin of the article. The complexity and diversity of the bibliographic data are the primary challenges in bibliometric analysis, which require authors to carefully consider various dimensions of data. In addition, the number of citations is directly related to the age of the publication, which indicates that older articles tend to accumulate more citations than those published more recently.

CONCLUSION

This bibliometric analysis reveals a clear paradigm shift in vital pulp therapy (VPT) research from calcium hydroxide toward mineral trioxide aggregate (MTA) and calcium silicate-based biomaterials between 2000 and 2024. MTA's dominance as both a clinical material and research keyword underscores its central role in regenerative approaches, particularly in dentinogenesis and pulp vitality preservation. The steady growth of publications confirms that VPT remains a dynamic and expanding research field, strongly shaped by advances in bioactive and bioceramic materials.

However, several methodological limitations must be acknowledged, including language and citation bias, restricted database coverage, and the inability of bibliometric mapping to assess qualitative outcomes such as clinical translation.

Future research should therefore broaden database inclusion, integrate non-English literature, and complement bibliometric methods with altmetric and qualitative analyses. Scientifically, the field would benefit from comparative studies of novel bioceramics, bioengineered scaffolds, and regenerative strategies involving stem cells and gene-editing technologies. These directions may facilitate the translation of laboratory discoveries into predictable, biologically based VPT protocols that improve long-term clinical outcomes.

CONFLICT OF INTEREST

There is no conflict of interest between the authors in this manuscript.

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