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Original Article

Exploring vital pulp Therapies: A bibliometric analysis of the most cited articles

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ABSTRACT

Aim: The aim of this study was to identify and analyze the most cited articles on vital pulp therapies.
Methodology: Bibliographical data related to the abstract, citations, keywords, and other relevant information was extracted using different combinations of keywords. Further evaluation and visualization of the selected data were performed with the help of various tools, including MS Excel, Microsoft Word, Google open refine, BibExcel, and VOS viewer. An initial search revealed 91 documents, of which 40 were chosen for further analysis. We used the Kolmogorov–Smirnov test and Spearman correlation coefficient test, and our adopted significance level was $p < 0.05$.
Results: In total, the articles received 1,905 citations, with six of them receiving at least 100 citations. Among the top 40 articles, the United States of America (10 articles) and Ireland (6 articles) were the countries with the highest number of cited articles. The journals "Journal of Endodontics" (14 articles; 650 citations) and "International Endodontic Journal" (13 articles; 577 citations) published most of the articles among the 50 most cited ones. Duncan H. was the author with the highest number of works cited (11 articles; 339 citations). Of the articles, systematic reviews accounted for 32%, literature reviews for 14%, in vitro experimental studies for 12%, clinical trials for 8%. Among the biomaterials used in vital pulp therapies, mineral trioxide aggregate (MTA) was discussed in 37 articles (74%), followed by calcium hydroxide, mentioned in 30 studies (60%). Interestingly, the publication year did not demonstrate a significant impact on citation count.
Conclusion: The present study provided a detailed list of the top 50 most cited and classic articles on vital pulp therapies. This will help researchers, students, and clinicians in the field of endodontics with an impressive source of information.

1. Introduction

Faced with chemical, physical, and microbial aggressions, the pulp–dentin complex responds by combining inflammation with the production of tertiary or reactive dentin due to stimuli experienced by the odontoblasts (Chaves et al., 2022a; Chaves et al., 2022b). The pulp tissue defense pathways occur concomitantly and the inflammatory response orchestrates tissue activity, being related to the ability of pulp cells to organize an immunological response against aggressors (Moore et al., 2022; Kale et al., 2022).

Recently, the European Society of Endodontics has classified the technique of non-selective or total dentin removal as "overtreatment," and it is currently contraindicated unless the pulp organ has already been exposed (Duncan et al., 2019; Barros et al., 2020). However, complete removal of carious tissue and pulp exposure are still not considered definitive treatments by a large portion of dental surgeons and, therefore, pulp exposure is routine in clinical practice and, in some cases, unavoidable (Cushley et al., 2022).

Carious lesions in permanent teeth are traditionally treated with total removal of the carious tissue (Bjørndal et al., 2019; Duncan et al.,

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2023); but minimally invasive dentistry has encouraged the use of techniques to preserve the dentin structure, avoid damage to the dentine-pulp complex and maintain pulp vitality (Duncan et al., 2023). In response to conditions of pulp inflammation and in line with the minimally invasive proposal, vital pulp therapy (VPT) modalities are options that aim to preserve pulp vitality and maintain tooth functionality, through the correct management of pulp exposures and inflammation (Machado et al., 2020; Duncan et al., 2023).

Among the VPTs recommended for treating exposed dental pulp, three procedures are indicated in ascending order of tissue invasion: (1) direct pulp capping, (2) partial pulpotomy, and (3) total pulpotomy (Barros et al., 2020). The removal of contaminated tissue aims to prevent the progression of endodontic infection into the deepest parts of the pulp tissue, thereby averting pulp necrosis and the development of periradicular pathologies (Ricucci et al., 2023).

Although inflammation is a premise for the repair of the pulp tissue, in severe cases or in the prolonged presence of the irrigating agent, the regenerative processes suffer difficulties and, eventually, tissue necrosis will occur. Therefore, the key to the success of VPTs is to create a suitable environment to shift the inflammatory process to the repair phase (Giraud et al., 2019; Dahake et al., 2020).

For a long time, vital pulp therapies were considered a treatment modality with unpredictable outcomes, typically limited to deciduous and young permanent teeth. However, recent research has demonstrated that these therapies can serve as definitive alternatives to conventional endodontic treatment (Ricucci et al., 2022; Kahler et al., 2023). This increase in success rates may be related to greater care in avoiding contamination during the procedures, diagnosis and treatment plan based on the pulp condition and evolution of the biomaterials used (Ricucci et al., 2023; Farhadi et al., 2024).

The choice of pulp capping material in any of the three techniques mentioned above relates to its ability induce the formation of mineralized tissue and maintain tooth vitality (Fousolas et al., 2023). Therefore, the material selected for this procedure significantly influences the treatment prognosis (Pugdee, Klaisiri, Phumpatrakom, 2023).

The ideal pulp capping material must adhere to the substrate, have good sealing capacity, be insoluble, stable, non-resorbable, radiopaque, biocompatible and bioactive (Fasoulas et al., 2023). Although no capping material presents all of the qualities mentioned, as the repair process of the dentine-pulp complex becomes better understood, new materials emerge aiming at a more beneficial tissue response (Giraud et al., 2019; Tzanetakis, Koletsi e Georgopoulou, 2023). Currently, there are several techniques or agents that are supposed to maintain the vitality of the coronary or radicular pulp, including: calcium hydroxide, mineral trioxide aggregate (MTA) and repair bioceramics (Cushley et al., 2022; Silva et al., 2023).

Pointing out the prestige of a scientific article in a given subject or area is a difficult task, that can be achieved by observing the number of citations of a given publication in other articles (Usta et al., 2023). This is a quantitative analysis of academic publications, and through mathematical analysis, it aims to create knowledge predictions, publication trends by tracing the main subjects, authors and study centers (Mattos et al., 2021; Ye et al., 2023), in addition to establishing gaps in the literature and suggesting future work (Usta et al., 2023).

Although several bibliometric studies have already been carried out on different topics in endodontics, publication trends related to specific pulp therapies have not yet been investigated (Fardi et al., 2011; Adnan e Ullah, 2018; Ahmad et al., 2019; Yilmaz et al., 2019; Kodonas et al., 2021). The efforts of minimally invasive dentistry to preserve pulp vitality has brought great interest from the scientific community in vital pulp therapy modalities, therefore the main trends need to be addressed. Therefore, this bibliometric study aims to identify and analyze the 50 most cited articles on vital pulp therapies.

2. Materials and methods

2.1. Search strategy

A bibliometric study was carried out in January 2023 to retrieve and analyze the 50 most-cited papers on the vital pulp therapy. A comprehensive search was conducted in the Web of Science Core Collection (WoS-CC) using the search strategy described in Table 1. There were no restrictions on language or year of publication.

The Web Of Science platform is the database exhaustively validated in the literature for the organization and completeness of the metadata of interest. In addition to indexing a large amount of peer-reviewed information, WoS-CC provides data on citations, making impact analysis and identification of trends and centers of excellence viable. Its interface and efficient tools for bibliometric studies make it a common choice among researchers (Ye et al., 2023).

The resultant list of papers was arranged in decreasing order by the number of citations in WoS-CC. Three researchers independently selected the papers and data extraction. Disagreement about paper inclusion or exclusion was resolved by consensus. Articles that addressed the use of the themes of total or partial pulpotomy, direct pulp capping, and use of dental biomaterials in these therapies in permanent teeth were included.

The selection was concluded when the 50th most-cited paper was retrieved. On the same day, a cross-match with the number of citations of each paper on the top 50 list was conducted in Scopus and Google Scholar databases for further comparisons. The final position of papers on the top 50 list was based on the highest number of citations in WoS-CC. In case of a tie, the position of a paper on the list was based on the highest WoS-CC citation density, followed by the highest number of citations in Scopus.

Table 1
Terms used for the search.

Term Description	Search term
#1 Terms related to pulpotomy	TS=("complete coronal pulpotomy" OR "coronal pulpotomy" OR "dental Pulp exposure" OR "full coronal pulpotomy" OR "full pulpotomy" OR "partial pulpotomy" OR "partial removal of coronal pulp tissues" OR "permanent pulpotomy" OR "pulp exposure" OR "pulpotomies" OR "pulpotomy" OR "total coronal pulpotomy")
#2 Terms related to used biomaterials	TS=("bioactive medicaments" OR "biodentine" OR "calcium silicate" OR "calcium silicate cement" OR "calcium silicate materials" OR "calcium silicate-based materials" OR "capping materials" OR "calcium enriched mixture" OR "chlorhexidine" OR "ferric sulfate and ferric sulfate" OR "formocresol" OR "glass-ionomer cements" OR "calcium hydroxide" OR "calcium hydroxide paste" OR "calcium hydroxide cements" OR "dycal" OR "mineral trioxide aggregate cements" OR "mineral trioxide aggregate" OR "proroot mta" OR "mta angelus" OR "orthomta" OR "pulp capping materials" OR "retromta" OR "sodium hypochlorite" OR "tricalcium cement" OR "tricalcium silicate cements" OR "tricalcium silicates")
#3 Terms related to conservative treatment of the pulp	TS=("conservative pulp therapy" OR "preserving pulp vitality" OR "vital pulp therapy" OR "vital pulp treatment")
#4 Terms related to direct pulp capping	TS=("dental pulp cappin" OR "dentin bridge formation" OR "direct capping" OR "direct pulp capping" OR "pulp capping" OR "pulp capping therapies" OR "pulp-capping" OR "reparative dentin")
Search key	**TS=(#1 AND #2 AND #3 AND #4)**

2.2. Data extraction

The following bibliometric parameters were extracted from each paper: title, number of citations in WoS-CC, Scopus, and Google Scholar, WoS-CC citation density (mean number of citations received per year) (Li et al., 2015), authorship (names and number), country and continent (based on the affiliation of the corresponding author at the time of the publication), year of publication, the title of the journal, study design, subject, keywords, biomaterials used and VPT modality. The data were double-checked for accuracy.

2.3. Data visualization and analysis

The extracted data were tabulated and categorized in Microsoft Excel® 2021 (Microsoft, Redmond, WA, USA). Subsequently, the data were transferred to the VOSviewer® software (Centre for Science and Technology Studies, University of Leiden) used to generate co-authorship maps of documents and co-occurrence of keywords (Visser et al., 2021).

In the co-authorship map, the author's names were entered into the software and linked based on the number of co-authored papers. The software analyzed the collaboration relationship among authors forming clusters. Each cluster was represented by a color (Visser et al., 2021). The most frequent terms had larger circles, and the strongly related terms were closer. Lines between terms indicate relationships, and thicker lines represent stronger connections.

Data analysis was performed using the SPSS statistical software for Windows (SPSS, version 27.0, IBM Corp, Chicago, USA) to evaluate the strength of correlations of the number of citations among the databases. The Kolmogorov-Smirnov test was used to verify the normality of the data distribution. Once the data presented non-normal distributions, the Spearman correlation coefficient test was used to verify the strength of correlations among the numbers of citations of the selected databases. The significance level was set at 5 %.

3. Results

The search strategy in WoS-CC yielded a total of 91 papers. After displaying the list in decreasing order by the number of citations, some papers were excluded for not focusing on vital pulp therapy. The 50 most-cited papers on the vital pulp therapy are listed in Table 2.

These articles received 1905 citations in WoS-CC, and six articles had over 100 citations. Self-citations accounted for 9.3 %. On the Scopus and Google Scholar platforms, the 50 most cited articles received 2,147 and 4,332 citations, respectively. Positive correlations were identified between the number of citations in WoS-CC and Scopus ($r = 0.917$, $p < 0.01$), between WoS-CC and Google Scholar ($r = 0.969$, $p < 0.01$), and between Scopus and Google Scholar ($r = 0.892$, $p < 0.01$).

3.1. Publication years

On the listed dates, the oldest article was from 2003 (Dominguez et al., 2003), and the most recent was from 2022 (Duncan, 2022; Cushley et al., 2022; Matoug-Elwerfelli et al., 2022; Tzanetakis et al., 2022; Donnelly et al., 2022). Most studies were published between 2018 and 2022, totaling 38 articles (76 %). In 2019, the largest number of studies published was 10 (20 %). The most cited article was "Vital pulp therapy in vital permanent teeth with cariously exposed pulp: a systematic review by Aguilar, P & Linsuwanont, P.; with 202 citations in WoS-CC, 130 in Scopus, and 455 in Google Scholar (Aguilar e Linsuwanont, 2010).

3.2. Countries and keywords

The co-occurring keyword density map (Fig. 1) revealed a total of 43 keywords. The most commonly used keywords were "mineral trioxide

Table 2
The 50 most cited articles on vital Pulp Therapy.

Rank	Paper	*Number of citations (Citation od density[a])*			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations[b]*
1	Aguilar, P., & Linsuwanont, P. (2011). Vital pulp therapy in vital permanent teeth with cariously exposed pulp: a systematic review. *Journal of endodontics*, 37(5), 581–587. https://doi.org/10.1016/j.joen.2010.12.004	202 (0.09)	235 (0.11)	455 (0.22)	297.33
2	Parirokh M, Torabinejad M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview - part I: vital pulp therapy. 2018;51 (2):177–205. https://doi.org/10.1111/iej.12841.	192 (0.09)	211 (0.10)	387 (0.19)	263.33
3	Bjørndal L, Reit C, Bruun G, et al. Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. *European Journal of Oral Sciences*. 2010;118(3):290–297. https://doi.org/10.1111/j.1600–0722.2010.00731.x.	177 (0.08)	224 (0.11)	455 (0.22)	285.33
4	European Society of Endodontology (ESE) developed by:, Duncan HF, Galler KM, et al. European Society of Endodontology position statement: Management of deep caries and the exposed pulp. *International Endodontics Journal*. 2019;52 (7):923–934. https://doi.org/10.1111/iej.13080.	134 (0.06)	157 (0.07)	225 (0.11)	172.00
5	Dominguez MS, Witherspoon DE, Gutmann JL, Opperman LA. Histological and scanning electron microscopy assessment of various vital pulp-therapy materials. *Journal of Endodontics*. 2003;29(5):324–333. https://doi.org/10.1097/00004770–200305000-00003.	115 (0.05)	130 (0.06)	271 (0.13)	172.00
6	Bjørndal L, Simon S, Tomson PL, Duncan HF. Management of deep caries and the exposed pulp. *International Endodontic Journal*. 2019;52 (7):949–973. https://doi.org/10.1111/iej.13128.	104 (0.05)	123 (0.06)	209 (0.10)	145.33
7	Witherspoon DE. Vital pulp therapy with new materials: new directions and treatment perspectives–permanent teeth. *Journal of Endodontics*. 2008;34(7 Suppl):S25-S28. https://doi.org/10.1016/j.joen.2008.02.030.	87 (0.04)	107 (0.05)	325 (0.16)	173.00

(*continued on next page*)

Table 2 (*continued*)

Rank	Paper	Number of citations (Citation od density[a])			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations*[b]
8	Karabucak B, Li D, Lim J, Iqbal M. Vital pulp therapy with mineral trioxide aggregate. *Dental Traumatology*. 2005;21 (4):240–243. https://doi.org/10.1111/j.1600–9657.2005.00306.x.	76 (0.03)	89 (0.04)	165 (0.08)	110.00
9	Ricucci D, Siqueira JF Jr, Li Y, Tay FR. Vital pulp therapy: histopathology and histobacteriology-based guidelines to treat teeth with deep caries and pulp exposure. *Journal of Dentistry*. 2019;86:41–52. https://doi.org/10.1016/j.jdent.2019.05.022.	63 (0.03)	67 (0.03)	113 (0.05)	81.00
10	Alqaderi H, Lee CT, Borzangy S, Pagonis TC. Coronal pulpotomy for cariously exposed permanent posterior teeth with closed apices: A systematic review and *meta*-analysis. *Journal of Dentistry*. 2016;44:1–7. https://doi.org/10.1016/j.jdent.2015.12.005.	60 (0.02)	70 (0.03)	117 (0.05)	82.33
11	Liu S, Wang S, Dong Y. Evaluation of a bioceramic as a pulp capping agent in vitro and in vivo. *Journal of Endodontics*. 2015;41 (5):652–657. https://doi.org/10.1016/j.joen.2014.12.009.	59 (0.02)	63 (0.03)	112 (0.05)	78.00
12	Awawdeh L, Al-Qudah A, Hamouri H, Chakra RJ. Outcomes of Vital Pulp Therapy Using Mineral Trioxide Aggregate or Biodentine: A Prospective Randomized Clinical Trial. *Journal of Endodontics*. 2018;44(11):1603–1609. https://doi.org/10.1016/j.joen.2018.08.004.	49 (0.02)	58 (0.02)	126 (0.06)	77.67
13	Tabarsi B, Parirokh M, Eghbal MJ, Haghdoost AA, Torabzadeh H, Asgary S. A comparative study of dental pulp response to several pulpotomy agents. *International Endodontic Journal*. 2010;43 (7):565–571. https://doi.org/10.1111/j.1365–2591.2010.01711.x.	49 (0.02)	84 (0.04)	153 (0.07)	95.33
14	Asgary S, Hassanizadeh R, Torabzadeh H, Eghbal MJ. Treatment Outcomes of 4 Vital Pulp Therapies in Mature Molars. *Journal of Endodontics*. 2018;44 (4):529–535. https://doi.org/10.1016/j.joen.2017.12.010.	470.02)	53 (0.02)	94 (0.04)	64.67
15	Witherspoon DE. Vital pulp therapy with new materials: new directions and treatment perspectives–permanent teeth. *Pediatric Dentistry Journal*. 2008;30 (3):220–224.	43 (0.02)	52 (0.02)	325 (0.16)	140.00

Table 2 (*continued*)

Rank	Paper	Number of citations (Citation od density[a])			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations*[b]
16	da Rosa WLO, Cocco AR, Silva TMD, et al. Current trends and future perspectives of dental pulp capping materials: A systematic review. *Journal of Biomedical Materials Research*. 2018;106 (3):1358–1368. https://doi.org/10.1002/jbm.b.33934.	40 (0.01)	48 (0.02)	87 (0.04)	58.33
17	Cushley S, Duncan HF, Lappin MJ, et al. Efficacy of direct pulp capping for management of cariously exposed pulps in permanent teeth: a systematic review and *meta*-analysis. *International Endodontic Journal*. 2021;54 (4):556–571. https://doi.org/10.1111/iej.13449.	39 (0.01)	45 (0.02)	85 (0.04)	56.33
18	Elmsmari F, Ruiz XF, Miró Q, Feijoo-Pato N, Durán-Sindreu F, Olivieri JG. Outcome of Partial Pulpotomy in Cariously Exposed Posterior Permanent Teeth: A Systematic Review and Meta-analysis. *Journal of Endodontics*. 2019;45 (11):1296–1306.e3. https://doi.org/10.1016/j.joen.2019.07.005.	36 (0.01)	41 (0.02)	65 (0.03)	47.33
19	Pedano MS, Li X, Yoshihara K, Landuyt KV, Van Meerbeek B. Cytotoxicity and Bioactivity of Dental Pulp-Capping Agents towards Human Tooth-Pulp Cells: A Systematic Review of In-Vitro Studies and Meta-Analysis of Randomized and Controlled Clinical Trials. *Materials (Basel)*. 2020;13(12):2670. Published 2020 Jun 12. https://doi.org/10.3390/ma13122670.	25 (0.01)	28 (0.01)	42 (0.02)	31.67
20	Luiz de Oliveira da Rosa W, Machado da Silva T, Fernando Demarco F, Piva E, Fernandes da Silva A. Could the application of bioactive molecules improve vital pulp therapy success? A systematic review. *Journal of Biomedical Materials Research*. 2017;105 (3):941–956. https://doi.org/10.1002/jbm.a.35968.	24 (0.01)	0 (0.00)	31 (0.01)	18.33
21	Patel R, Cohenca N. Maturogenesis of a cariously exposed immature permanent tooth using MTA for direct pulp capping: a case report. *Dental Traumatology*. 2006;22 (6):328–333. https://doi.	22 (0.01)	25 (0.01)	65 (0.03)	37.33

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Table 2 (*continued*)

Rank	Paper	Number of citations (Citation od density[a])			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations*[b]
	org/10.1111/j.1600–9657.2006.00471.x.				
22	Chen J, Cui C, Qiao X, et al. Treated dentin matrix paste as a novel pulp capping agent for dentin regeneration. *Journal of Tissue Engineering and Regenerative Medicine*. 2017;11(12):3428–3436. https://doi.org/10.1002/term.2256.	21 (0.01)	22 (0.01)	34 (0.01)	25.67
23	Zaen El-Din AM, Hamama HH, Abo El-Elaa MA, Grawish ME, Mahmoud SH, Neelakantan P. The effect of four materials on direct pulp capping: An animal study. *Australian Endodontic Journal*. 2020;46 (2):249–256. https://doi.org/10.1111/aej.12400.	20 (0.00)	21 (0.01)	27 (0.01)	22.67
24	Kodonas K, Fardi A, Gogos C, Economides N. Scientometric analysis of vital pulp therapy studies. *International Endodontic Journal*. 2021;54 (2):220–230. https://doi.org/10.1111/iej.13422.	18 (0.00)	19 (0.00)	25 (0.01)	20.67
25	Croft K, Kervanto-Seppälä S, Stangvaltaite L, Kerosuo E. Management of deep carious lesions and pulps exposed during carious tissue removal in adults: a questionnaire study among dentists in Finland. *Clinical Oral Investigations*. 2019;23 (3):1271–1280. https://doi.org/10.1007/s00784-018–2556-1.	15 (0.00)	14 (0.00)	32 (0.01)	20.33
26	Zanini M, Hennequin M, Cousson PY. Which procedures and materials could be applied for full pulpotomy in permanent mature teeth? A systematic review. *Acta Odontologica Scandinavica*. 2019;77 (7):541–551. https://doi.org/10.1080/00016357.2019.1614217.	14 (0.00)	0 (0.00)	31 (0.01)	15.00
27	Santos JM, Marques JA, Diogo P, et al. Influence of Preoperative Pulp Inflammation in the Outcome of Full Pulpotomy Using a Dog Model. *Journal of Endodontics*. 2021;47 (9):1417–1426. https://doi.org/10.1016/j.joen.2021.06.018.	13 (0.00)	13 (0.00)	16 (0.00)	14.00
28	Taha NA, About I, Sedgley CM, Messer HH. Conservative Management of Mature Permanent Teeth with Carious Pulp Exposure. *Journal of Endodontics*. 2020;46(9S):S33-S41. https://doi.org/10.1016/j.joen.2020.06.025.	13 (0.00)	18 (0.00)	25 (0.01)	18.67

Table 2 (*continued*)

Rank	Paper	Number of citations (Citation od density[a])			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations*[b]
29	Munir A, Zehnder M, Rechenberg DK. Wound Lavage in Studies on Vital Pulp Therapy of Permanent Teeth with Carious Exposures: A Qualitative Systematic Review. *Journal of Clinical Medicine*. 2020;9 (4):984. Published 2020 Apr 1. https://doi.org/10.3390/jcm9040984.	13 (0.00)	13 (0.00)	23 (0.01)	16.33
30	Manaspon C, Jongwannasiri C, Chumprasert S, et al. Human dental pulp stem cell responses to different dental pulp capping materials. *BMC Oral Health*. 2021;21 (1):209. Published 2021 Apr 26. https://doi.org/10.1186/s12903-021–01544-w.	11 (0.00)	11 (0.00)	17 (0.00)	13.00
31	Vu TT, Nguyen MT, Sangvanich P, Nguyen QN, Thunyakitpisal P. Acemannan Used as an Implantable Biomaterial for Vital Pulp Therapy of Immature Permanent Teeth Induced Continued Root Formation. *Pharmaceutics*. 2020;12(7):644. Published 2020 Jul 8. https://doi.org/10.3390/pharmaceutics12070644.	11 (0.00)	13 (0.00)	18 (0.00)	14.00
32	Careddu R, Duncan HF. A prospective clinical study investigating the effectiveness of partial pulpotomy after relating preoperative symptoms to a new and established classification of pulpitis. *International Endodontic Journal*. 2021;54 (12):2156–2172. https://doi.org/10.1111/iej.13629.	10 (0.00)	12 (0.00)	12 (0.00)	11.33
33	Careddu R, Plotino G, Cotti E, Duncan HF. The management of deep carious lesions and the exposed pulp amongst members of two European endodontic societies: a questionnaire-based study. *International Endodontic Journal*. 2021;54 (3):366–376. https://doi.org/10.1111/iej.13418.	10 (0.00)	9 (0.00)	16 (0.00)	11.67
34	Careddu R, Duncan HF. How does the pulpal response to Biodentine and ProRoot mineral trioxide aggregate compare in the laboratory and clinic? [published online ahead of print, 2018 Oct 19]. *Brazilian Dental Journal*. 2018;https://doi.org/10.1038/sj.bdj.2018.864. https://doi.org/10.1038/sj.bdj.2018.864.	9(0.00)	0 (0.00)	21 (0.01)	10.00
35	Duncan HF. Present status and future directions-Vital pulp treatment and pulp preservation strategies.	8(0.00)	8 (0.00)	11 (0.00)	9.00

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Table 2 (*continued*)

Rank	Paper	Number of citations (Citation od density[a])			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations*[b]
	International Endodontic Journal. 2022;55 Suppl 3 (Suppl 3):497–511. https://doi.org/10.1111/iej.13688.				
36	Leong DJX, Yap AU. Vital pulp therapy in carious pulp-exposed permanent teeth: an umbrella review. *Clinical Oral Investigations*. 2021;25(12):6743–6756. https://doi.org/10.1007/s00784-021–03960-2.	8(0.00)	9 (0.00)	9 (0.00)	8.67
37	Meschi N, Patel B, Ruparel NB. Material Pulp Cells and Tissue Interactions. *Journal of Endodontics*. 2020;46(9S): S150-S160. https://doi.org/10.1016/j.joen.2020.06.031.	8(0.00)	9 (0.00)	11 (0.00)	9.33
38	Ballal NV, Duncan HF, Rai N, Jalan P, Zehnder M. Sodium Hypochlorite Reduces Postoperative Discomfort and Painful Early Failure after Carious Exposure and Direct Pulp Capping-Initial Findings of a Randomized Controlled Trial. *Journal of Clinical Medicine*. 2020;9(8):2408. https://doi.org/10.3390/jcm9082408.	8 (0.00)	9 (0.00)	15 (0.00)	10.37
39	Asgary S, Nourzadeh M, Verma P, Hicks ML, Nosrat A. Vital Pulp Therapy as a Conservative Approach for Management of Invasive Cervical Root Resorption: A Case Series. *Journal of Endodontics*. 2019;45 (9):1161–1167. https://doi.org/10.1016/j.joen.2019.05.020.	7(0.00)	8 (0.00)	20 (0.00)	11.67
40	Brodén J, Davidson T, Fransson H. Cost-effectiveness of pulp capping and root canal treatment of young permanent teeth. *Acta Odontologica Scandinavica*. 2019;77(4):275–281. https://doi.org/10.1080/00016357.2018.1538536.	7 (0.00)	8 (0.00)	13 (0.00)	9.33
41	Sabeti M, Moeintaghavi A, Shiezadeh F, Salari Sedigh H, Tay R, Torabinejad M. Clinical and Histological Evaluation of Tissue Healing in Beveled or Perpendicular Vertical Releasing Incision. *Journal of Endodontics*. 2021;47(10):1625–1630. https://doi.org/10.1016/j.joen.2021.07.005	6 (0.00)	0 (0.00)	0 (0.00)	2.00
42	Tohma A, Ohkura N, Yoshiba K, et al. Glucose Transporter 2 and 4 Are Involved in Glucose Supply during Pulpal Wound Healing after Pulpotomy with Mineral Trioxide Aggregate in Rat Molars.	6(0.00)	6 (0.00)	8 (0.00)	6.67

Table 2 (*continued*)

Rank	Paper	Number of citations (Citation od density[a])			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations*[b]
	Journal of Endodontics. 2020;46(1):81–88. https://doi.org/10.1016/j.joen.2019.10.003.				
43	Cushley S, Duncan HF, Lundy FT, Nagendrababu V, Clarke M, El Karim I. Outcomes reporting in systematic reviews on vital pulp treatment: A scoping review for the development of a core outcome set. *International Endodontic Journal*. 2022;55 (9):891–909. https://doi.org/10.1111/iej.13785.	5(0.00)	5 (0.00)	6 (0.00)	5.33
44	Dou L, Yan Q, Yang D. Effect of five dental pulp capping agents on cell proliferation, viability, apoptosis and mineralization of human dental pulp cells. *Experimental and Therapeutic Medicine*. 2020;19 (3):2377–2383. https://doi.org/10.3892/etm.2020.8444.	5(0.00)	0 (0.00)	16 (0.00)	7.00
45	Matoug-Elwerfelli M, ElSheshtawy AS, Duggal M, Tong HJ, Nazzal H. Vital pulp treatment for traumatized permanent teeth: A systematic review. *International Endodontic Journal*. 2022;55 (6):613–629. https://doi.org/10.1111/iej.13741.	3 (0.00)	3 (0.00)	4 (0.00)	3.33
46	Edwards D, Bailey O, Stone SJ, Duncan H. How is carious pulp exposure and symptomatic irreversible pulpitis managed in UK primary dental care?. *International Endodontic Journal*. 2021;54 (12):2256–2275. https://doi.org/10.1111/iej.13628.	3(0.00)	0 (0.00)	3 (0.00)	2.00
47	Bogen, G. Clinical guidelines for vital pulp therapy. *Endo ept*, 2019; 13 (4): 283–286.	3(0.00)	0 (0.00)	2 (0.00)	1.67
48	Li M, Hu X, Li X, et al. Dentist-related factors influencing the use of vital pulp therapy: a survey among dental practitioners in China. *Journal of International Medical Research*. 2019;47 (6):2381–2393. https://doi.org/10.1177/0300060519843406.	3(0.00)	3 (0.00)	5 (0.00)	3.67
49	Tzanetakis GN, Tsiouma O, Mougiou E, Koletsi D. Factors Related to Pulp Survival After Complicated Crown Fracture Following Vital Pulp Therapy: A Systematic Review and Meta-analysis. *Journal of Endodontics*. 2022;48 (4):457–478.e4. https://doi.org/10.1016/j.joen.2022.01.013.	2(0.00)	2 (0.00)	2 (0.00)	2.00

(*continued on next page*)

Table 2 (*continued*)

Rank	Paper	*Number of citations (Citation od density[a])*			
		Web of Science	*Scopus*	*Google Scholar*	*Mean citations[b]*
50	Donnelly A, Foschi F, McCabe P, Duncan HF. Pulpotomy for treatment of complicated crown fractures in permanent teeth: A systematic review. *International Endodontic Journal.* 2022;55 (4):290–311. https://doi.org/10.1111/iej.13690.	2(0.00)	2 (0.00)	3 (0.00)	2.33

aggregate," "vital pulp therapy", "pulpitis," and "direct pulp capping.".

Fig. 2 demonstrates that most of the cited articles belong to the European Continent (21 articles; 649 citations), followed by Asia (16 articles; 89 citations) and Anglo-Saxon America (10 articles; 487 citations). Latin America and Oceania were represented by Brazil (2 articles; 64 citations) and Australia (1 article; 03 citations), respectively. The African continent was the only one that did not have articles included.

The United States of America (10 articles; 64 citations); Ireland (06 articles; 210 citations), and China (05 articles; 98 citations) were the countries with the highest number of articles cited among the top 50.

3.3. Journal and institutions

The Journal of Endodontics (14 articles; 650 citations) and International Endodontic Journal (13 articles, 577 citations) had the highest number of articles among the 50 most cited ones. Regarding authors, Duncan H. obtained the highest number of most cited articles (11 articles; 339 citations), followed by Bjørndal L. (3 articles; 421 citations) and Careddu R. (3 articles; 29 citations). The other authors and their productions are listed in Table 3.

Dublin Dental University Hospital (n = 4), Chulalongkorn University (n = 3) were the institutions with the highest number of publications in the list of 50 most cited articles on vital pulp therapies.

3.4. Study Design, field of study and biomaterials

Fig. 3A presents the most frequent study designs. Systematic reviews totaled 16 articles, literature reviews (7 articles), in vitro experimental studies (6 articles), clinical trials (4 articles), and case reports (3 articles).

Fig. 3B demonstrates that most of the listed studies generally addressed vital pulp therapies since 66 % of the published articles considered all modalities (direct pulp capping and partial and total pulpotomy).

Works focused on a single modality of VPT represented 22 %, with 10 % directed to direct pulp capping, 8 % to partial pulpotomy, and 4 % to total pulpotomy. The other works focused on two different modalities.

Among the biomaterials applied in vital pulp therapies, mineral trioxide aggregate was addressed in 37 articles (74 %), followed by calcium hydroxide, mentioned in 30 works (60 %), and the new repairing hydraulic cements were included in 20 articles (40 %). highlighted by a growing interest for Biodentine.

4. Discussion

This study identified and analyzed the 50 most cited articles on vital pulp therapies. A highly cited article can be considered a milestone in health and can influence research and clinical practice (Van Noorden et al., 2014; Gondivkar et al., 2018; Khayat & Rajeh, 2022).

The 50 most cited articles received 1,905 citations in WoS-CC. When compared to other bibliometric studies in dentistry, this number is lower than in other areas, such as laser therapy (21,627 citations) and

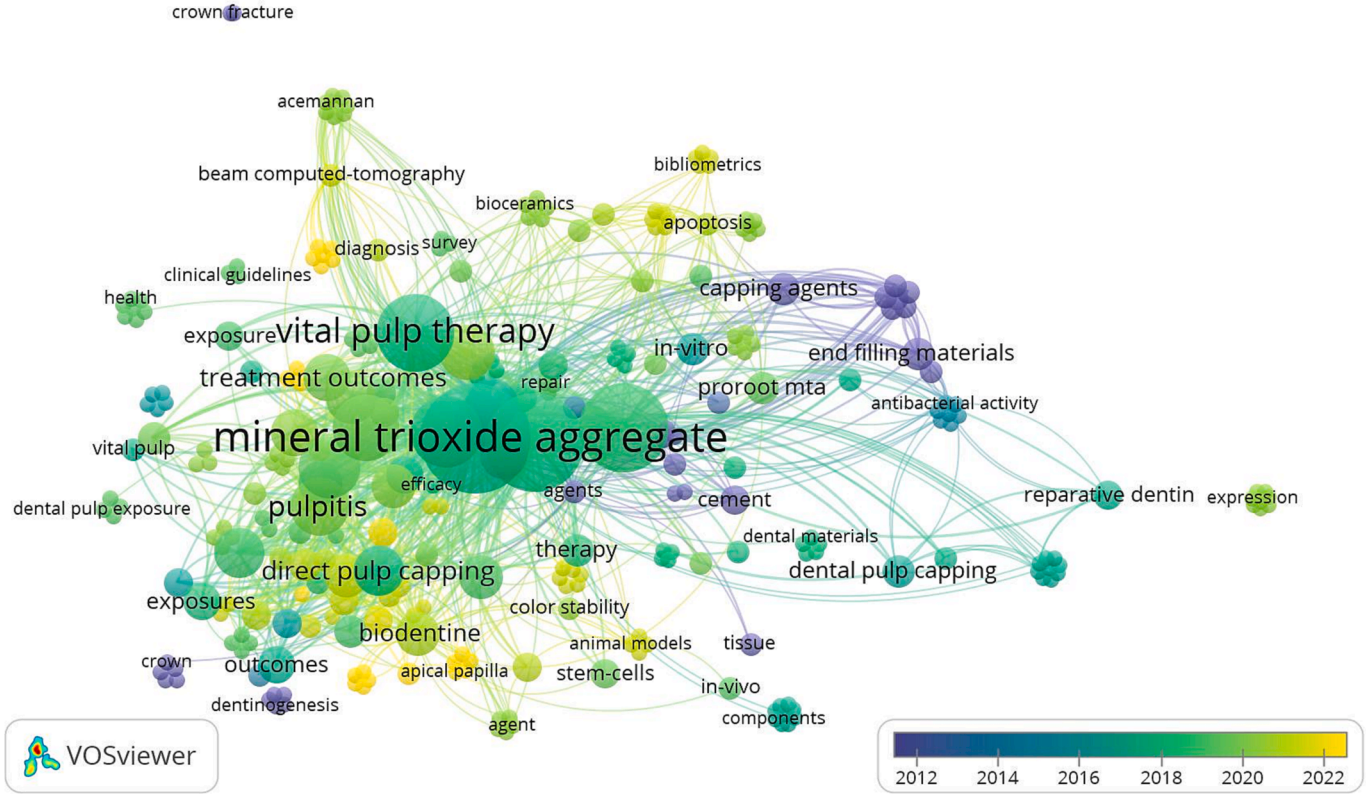

Fig. 1. Keyword Co-occurrence Density Map of the Top 50 Most Cited Articles on Vital Pulp Therapies.

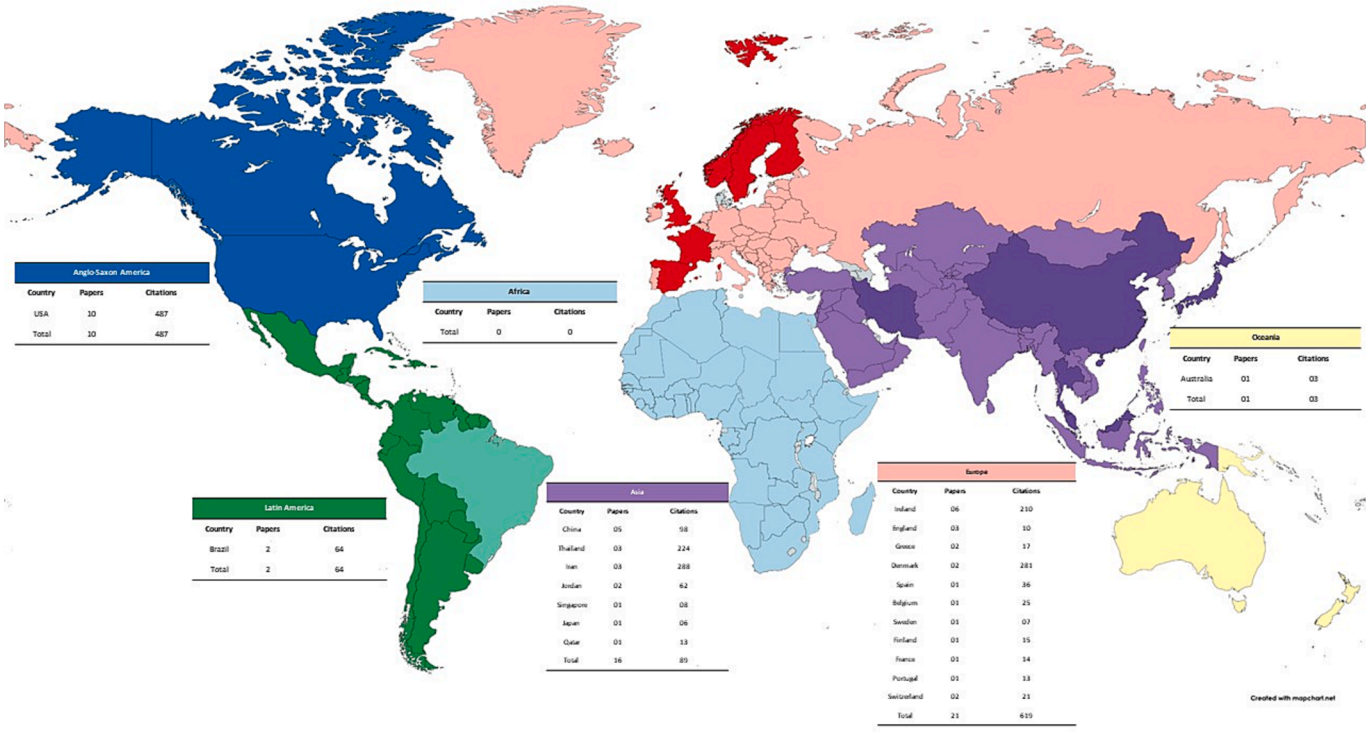

Fig. 2. Global Distribution of the Top 50 Most Cited Articles on Vital Pulp Therapies.

Table 3
Bibliometric indicators of authors with at least two manuscripts in the list of the 50 most cited articles on vital pulp therapy.

Authors	Number of 50 most-cite papers on vital pulp therapy	Number of citations in 50 most-cite paper on Vital pulp therapy	Number of papers in WoS-CC	Number of citations in WoS-CC	H-index
Duncan H	11	339	78	1.728	22
Bjorndal L	3	421	71	1.728	22
Careddu R	3	29	5	47	5
Simon S	3	246	408	4	4
Witherspoon D	3	245	31	6.490	16
Zehnder M	3	160	119	5.682	41
Fransson H	3	321	27	577	10
Dummer P	2	329	305	7.209	46
Parirokh M	2	242	43	3.331	26
Piva E	2	64	125	2.633	27
Tomson P	2	243	10	375	5

periodontics (21,276 citations) (Paschoal et al., 2022). Yilmaz et al. (2019); Adnan and Ullah (2018), when evaluating the most relevant articles in regenerative endodontics, found a total of 5,948 citations. When comparing the present work with the results mentioned above, it is clear that the number of total citations is lower, possibly because it is a less broad topic and evaluates only 50 articles.

Ahmad et al. (2019) identified seven papers with over 100 citations, a number compatible with what was found in the present study. Six articles were found to have over 100 citations (Dominguez et al., 2003; Bjorndal et al., 2010; Aguilar e Linsuwanont, 2011; Parirokh et al., 2018; Bjorndal et al., 2019; Duncan et al., 2019).

The year of publication is directly related to the number of citations, and classic articles may tend to be even more cited, without a reassessment of their scientific impact, considering that it is unpredictable to determine the relevance of a work with less than two decades of its publication (Lefaivre et al., 2011; Feijoo et al., 2014). However, a different trend was observed in this study since five of the six classic articles identified were published in the last 13 years, demonstrating a relatively recent interest of the scientific community on the topic in question.

In a scientometric analysis of studies on vital pulp therapies, Kodonas et al., (2021) have reported a growth trend in publications from 2012, with a peak in 2017, attributing this event to a growing interest owing to published innovative works.

The Journal of Endodontics (14 articles; 650 citations) and International Endodontic Journal (13 articles, 577 citations) were the periodics with the highest number of articles among the 50 most cited articles. When evaluating the bibliometrics in endodontics, Yilmaz et al. (2019); Adnan e Ullah (2018); Ahmad et al. (2019) obtained similar results regarding the journals where the most cited articles were published, indicating the great resource of information that both journals offer to their readers.

In this study, the United States of America was identified as the country with the highest number of articles among the 50 most cited articles (10 articles). Other bibliometric analyses in endodontics and other specialties also indicated the United States of America as the most prominent nation (Adnan e Ullah, 2018).

Ireland ranks as the second country with the highest production of articles (6 articles, 210 citations). China is the third country with the highest number of publications (5 articles, 98 citations), and the country's growing scientific production is in line with that of other studies, (Adnan e Ullah, 2018) which can be attributed to economic development and various partnerships with institutions of research in the United States of America (Kolars & Zhan, 2021).

The scientific production of low and middle-income countries is lower, with little representation in high-impact journals. This fact may be related to the low investment in science and innovation (Okafor et al., 2022). The absence of works from the African continent highlights this finding. The results of this work corroborate with those of other studies (Fardi et al., 2011; Adnan e Ullah, 2018; Ahmad et al., 2019; Yilmaz et

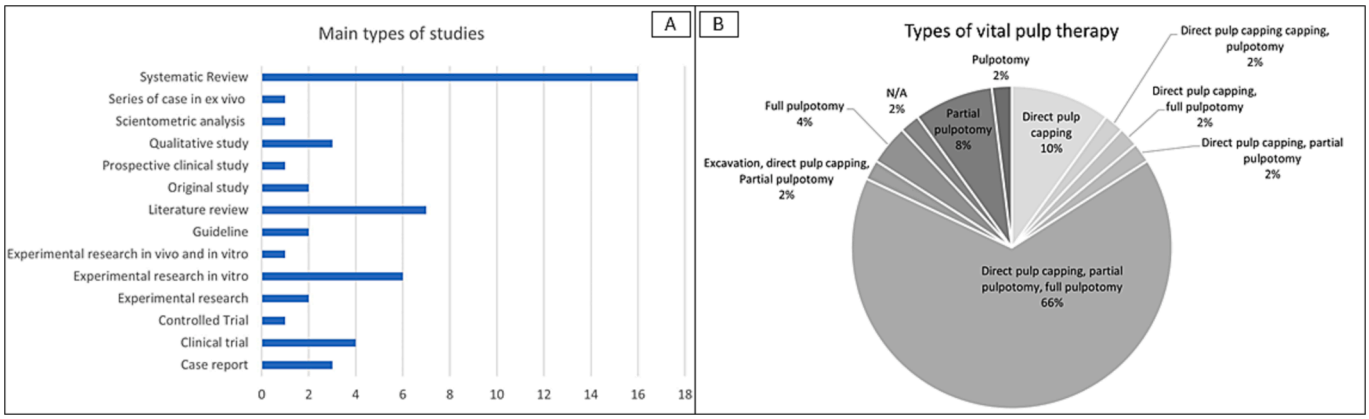

Fig. 3. (A) Distribution of Study Designs in the Top 50 Most Cited Articles on Vital Pulp Therapies, (B) Most Frequently Discussed Vital Pulp Therapies in the Top 50 Most Cited Articles.

al., 2019; Kodonas et al., 2021) and highlight the urgency of democratizing science production in these countries.

The keyword analysis provided an overview of the evolution of vital pulp therapies. "Mineral trioxide aggregate" was also a very prominent keyword identified by Konodas et al. (2021). Another fact that corroborates the findings of Konodas et al. (2021) is the recent interest in other materials in vital pulp therapies, with emphasis on Biodentine. As for study designs, systematic reviews and *meta*-analyses have gained great importance in healthcare since they are used as an update method on a certain subject, and the degree of relevance of the information obtained can guide future clinical protocols (Swingler et al., 2003). The present work agrees with this statement, since 16 of the 50 most cited articles are systematic reviews.

The different types of studies observed in similar works (Adnan e Ullah, 2018; Ahmad et al., 2019; Yilmaz et al., 2019; Kodonas et al., 2021), such as in-vitro studies, non-randomized experimental, and systematic reviews are in line with the results of this study.

The list of the 50 most cited articles in VPTs compiled some areas of interest. Aguilar & Linsuwanont (2011) and Elmsmari et al. (2019) developed systematic reviews that analyzed long-term success rates. Da Rosa et al. (2017), Parirokh, Torabinejad & Dummer (2018), Da Rosa et al. (2018), Pedano et al. (2020), Meschi, Patel & Ruparel (2020) e Cushley et al. (2021) also wrote systematic reviews, which focus more on the evidence on biomaterials, such as MTA, tricalcium silicate hydraulic cements and calcium hydroxide and its results in VPTs. Dominguez et al. (2003), Witherspoon (2008), Tabarsi et al. (2010), Liu, Wang & Dong (2015), Chen et al. (2017), Awawdeh et al. (2018), Careddu & Duncan (2018), Zaen El-Din et al. (2020), Dou, Yan & Yang, (2020), Tohma et al. (2020), Manaspon et al. (2021) and Careddu & Duncan (2021) were also works dedicated to biomaterials. However, they are in vitro and in vivo research, randomized and non-randomized clinical studies sought to elucidate the behavior of pulp tissue, in addition to evaluating clinical performance through long-term follow-up.

Other studies from Ricucci et al. (2019) and Sabeti et al. (2021), discussed pulp histological condition after the necessary pulp procedures, while Santo et al. (2021) clearly sought the impact of previous pulp inflammation on the success rate of necessary pulp therapies. The selective removal of decayed dentin, the management of deep carious lesions and the application of VPTs in pulp exposures were the topics of interest in Bjørndal et al. (2010), Duncan et al. (2019), Bjørndal et al. (2019) and Taha et al. (2020), while the subject covered in Croft et al. (2019), Careddu et al. (2021) and Edwards et al. (2021), also encompassed the topics mentioned above. However, the research investigated the clinical attitude of professionals.

The impact of the solution used to wash the pulp exposure was the topic addressed by Munir, Zehnder & Rechenberg (2020) and Ballal et al. (2020). Articles like Alqaderi et al. (2016), Bogen (2019), Li et al. (2019), Zanini et al. (2019), Zanini, Hennequin & Cousson (2019), Konodas et al. (2021), Leong & Yap (2021), Cushley et al. (2022) and Duncan (2022) were comprehensive reviews of the literature, which sought to understand the current perspectives and future of VPTs. The use of specific pulp therapies in traumatized teeth was addressed in Matoug-Elwerfelli et al. (2022), Tzanetakis et al. (2022) and Donnelly et al. (2022), while an approach for teeth with incomplete rhizogenesis was given by Karabucak et al. (2005), Patel et al. (2006), Asgary et al. (2018), Brodén, Davidson & Fransson (2019) and Vu et al. (2020). Despite the classic applicability of VPTs in this context, few studies have highlighted the degree of root development in their methodologies, since the authors addressed permanent teeth in a broad way and root development was one of the ways to evaluate the success of the therapy. However this is a gap identified in the literature, making it necessary to work with more robust methodologies that evaluate VPTs in permanent teeth with incomplete rhizogenesis.

Since this is the first study in which a bibliometric analysis on vital pulp therapies was performed, some topics, such as the main types of therapies, cannot be compared. Nevertheless, our study revealed that 66 % of articles on pulp therapy considered all modalities, 12 % evaluated two different modalities, and 22 % focused on only one modality.

However, this study has a limitation that needs to be considered. Articles without keywords or an informative title that matches the current search strategy may have been excluded from the search. This fact highlights the need for standardization in the use of keywords by the authors, as well as the elaboration of a title that is concise and sufficiently informative to be identified in a search strategy of a specific area.

5. Conclusion

The present study provided a detailed list of the top 50 most cited and classic articles on vital pulp therapies. This will help researchers, students, and clinicians in the field of endodontics with an impressive source of information.

Ethical Statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

CRediT authorship contribution statement

Gustavo Henrique Sousa: Writing – original draft, Validation, Project administration, Methodology, Formal analysis, Conceptualization. **Rodolfo Lima Gonçalves:** Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Barbara Figueiredo:** Visualization, Investigation, Data curation. **Vilton Cardozo Moreira Dias:** Software, Investigation, Data curation. **Ana Carolina Soares Mendes:** Resources, Data curation, Investigation. **Valéria de Cássia**

Bueno Melo: Visualization, Resources, Investigation, Conceptualization. **Adriana Guimarães Rodrigues:** Resources, Investigation, Data curation, Visualization. **Hebertt Gonzaga dos Santos Chaves:** Methodology, Formal analysis, Conceptualization, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sdentj.2024.02.007.

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