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Ten years of minimally invasive access cavities in Endodontics: a bibliometric analysis of the 25 most-cited studies

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ABSTRACT

Objectives: This study aimed to analyze the main features of the 25 most-cited articles in minimally invasive access cavities.
Materials and Methods: An electronic search was conducted on the Clarivate Analytics' Web of Science 'All Databases' to identify the most-cited articles related to this topic. Citation counts were cross-matched with data from Elsevier's Scopus and Google Scholar. Information about authors, contributing institutions and countries, year and journal of publication, study design and topic, access cavity, and keywords were analyzed.
Results: The top 25 most-cited articles received a total of 572 (Web of Science), 1,160 (Google Scholar) and 631 (Scopus) citations. It was observed a positive significant association between the number of citations and age of publication ($r = 0.6907$, $p < 0.0001$); however, there was no significant association regarding citation density and age of publication ($r = -0.2631$, $p = 0.2038$). The *Journal of Endodontics* made the highest contribution ($n = 15$, 60%). The United States had the largest number of publications ($n = 7$) followed by Brazil ($n = 4$), with the most contributions from the University of Tennessee and Grande Rio University ($n = 3$), respectively. The highest number of most-cited articles were *ex vivo* studies ($n = 16$), and 'fracture resistance' was the major topic studied ($n = 10$).
Conclusions: This study revealed a growing interest for researchers in the field of minimally invasive access cavities. Future trends are focused on the expansion of collaborative networks and the conduction of laboratory studies on under-investigated parameters.

Keywords: Bibliometric analysis; Citation; Conservative endodontic cavity; Endodontics

INTRODUCTION

Bibliometric analysis is a scientific method to quantitatively evaluate the impact of scientific literature within a specific field [1]. The analysis of the citation data of the articles enables the researchers to map key study topics and designs that have the potential to influence trends in clinical practice and future research [2]. The citation counts of articles measure the impact of the studies since the information in the most-cited articles has the potential to achieve more readers [3]. The assessment of the most-cited articles is undertaken to determine the past and future trends in research, and to recognize the most influential

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topics, authors, contributing institutions and journals [3,4]. Besides that, new assessment tools for bibliometric mapping allow the identification and visualization of term maps and collaborative networks, with the intention to identify future research directions and to promote further collaboration opportunities [5].

Several studies addressed the trends in endodontic research by performing bibliometric analysis evaluating the most-cited articles in endodontics, the most-cited articles about specific topics such as regenerative endodontics and the management of fractured instruments, the most-cited articles in specific endodontic journals, or even the most-cited articles with specifics study designs [3,6-13].

Clark and Khademi are considered the forerunners of minimally invasive access cavities in endodontics. A decade ago, they published the first article describing a new concept to perform endodontic access cavities, followed by a case series performing it [14,15]. The goal of this concept was the maintenance of the pulp chamber roof and pericervical dentin to preserve the fracture resistance of root canal treated teeth [14]. Ever since, other designs of access cavities were described, such as ultraconservative access cavities and truss access cavities, and several studies were performed to assess the fracture resistance of root canal treated teeth with these minimally invasive access cavities [16-30], as well as their influence on the location of canals, shaping, cleaning and disinfection, filling, restoration, and retreatment procedures [17,21,28-40]. Therefore, this field has received great attention from researchers and clinicians, leading to a significant rise in the volume of publications during these 10 years.

Despite the high amount of scientific data regarding minimally invasive access cavities being published, the comparison of benefits and harms between these access cavities and traditional access cavities remains debatable. Thus, it is essential to evaluate the impact of such studies on research and clinical practices. Therefore, the aim of this study was to recognize the most-cited articles about minimally invasive access cavities, to identify the related topics and keywords, and to establish the importance of journals, authors, countries and institutions on the production of these impacting articles.

MATERIALS AND METHODS

Search strategy

A comprehensive literature search was performed without any parameter restriction on 30 November 2020, in Clarivate Analytics' Web of Science 'All Databases' using terms regarding the most used keywords related to the topic of minimally invasive access cavity. The search keywords were 'minimally invasive endodontic cavity,' 'minimally invasive access cavity,' 'endodontic access cavity,' 'access cavity design,' 'conservative endodontic cavity,' 'contracted endodontic cavity,' 'ultraconservative access cavity,' 'ultraconservative endodontic cavity,' 'truss access cavity,' and 'ninja access cavity' in the title and abstract section. The articles were screened by 2 reviewers independently (K.P.P. and N.C.A.) and the following studies were excluded: studies that did not address the topic of minimally invasive access cavity, studies of guided endodontics, and reviews about minimally invasive endodontics where the topic of minimally invasive access was not discussed. In case of discordance, a third reviewer with expertise in the area was consulted (E.J.N.L.S.). Also, it was performed a manual search on the references of the included studies and in Google Scholar to retrieve any relevant study that could be missing in the initial search. Out of a total of 79 articles selected, the top 25

most-cited articles were identified by a unanimous decision and ranked in descending order based on the citation counts received according to Web of Science (WoS) 'All Databases,' and these were then cross-matched with data from Elsevier's Scopus and Google Scholar. When more than one article had the same number of citations, the article with the higher citation density was ranked higher [8].

Data extraction and bibliometric analysis

Data were obtained using WoS and VOS viewer software (version 1.6.7; Leiden University Center for Science and Technology Studies, Leiden, Netherlands) [5]. Article title, authors, contributing institution and country, collaborative institutions, year of publication, journal published, citation count, citation density, study design, article topic, type of minimally invasive endodontic access evaluated, and keywords were extracted to an Excel sheet by 2 independent reviewers (K.P.P and N.C.A.). The articles were imported to the VOS viewer software, which recorded and made the counts of all authors, institutions and keywords, and also provided the collaborative networks among authors and institutions.

The institution and country of origin of the papers were identified by the institutional affiliation of the corresponding author [12,13]. If the corresponding author was not reported, it was considered the first author. It was used a science mapping approach using the VOS software to summarize and visualize the collaboration network among co-authors and the co-occurrences of keywords of the 25 most-cited articles.

Statistical analysis

For testing correlations between variables, statistical analysis was performed using the Bioestat® software (Instituto Mamirauá, Tefé, AM, Brazil). Shapiro-Wilk test was used to detect departures from normality, and the Spearman test was performed. The significance level was set to $p < 0.05$.

RESULTS

Citation count and citation density

The top 25 most-cited articles received a total of 572 (WoS), 1,160 (Google Scholar) and 631 (Scopus) citations. The citation range, *i.e.* the maximum and minimum citation count a single study received in each database, was 68-5 (WoS), 172-4 (Google Scholar) and 77-5 (Scopus). Citation density, *i.e.* the average number of citations per annum, was 57.2 (WoS), 116 (Google Scholar) and 63.1 (Scopus) collectively. **Table 1** summarizes the ranking of the 25 most-cited articles about minimally invasive access cavities. The top 3 most-cited articles in descending order were: "Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars" with 68 (WoS), 151 (Google Scholar) and 77 (Scopus) citations, "Modern molar endodontic access and directed dentin conservation" with 62 (WoS), 172 (Google Scholar) and 75 (Scopus) citations, and "Fracture strength of endodontically treated teeth with different access cavity designs" with 54 (WoS), 103 (Google Scholar) and 56 (Scopus) citations. It was observed a positive significant association between the number of citations and age of publication (correlation coefficient = 0.6907, $p < 0.0001$) (**Figure 1**). The top 3 articles with the highest citation density were: "Fracture strength of endodontically treated teeth with different access cavity designs" with a citation density of 18, and "Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and

Table 1. List of the top 25 most-cited articles

Rank	Reference	No. of citation [Web of Science]	No. of citation [Google Schoolar]	No. of citation [Scopus]	Citation density
1	Krishan R, Paqué F, Ossareh A, Kishen A, Dao T, Friedman S. Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. J Endod 2014;40:1160–1166.	68	151	77	11.33
2	Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010:54:249–273.	62	172	75	6.2
3	Plotino G, Grande NM, Isufi A, Ioppolo P, Pedullà E, Bedini R, Gambarini G, Testarelli L. Fracture strength of endodontically treated teeth with different access cavity designs. J Endod 2017;43:995–1000.	54	103	56	18
4	Moore B, Verdelis K, Kishen A, Dao T, Friedman S. Impacts of contracted endodontic cavities on instrumentation efficacy and biomechanical responses in maxillary molars. J Endod 2016;42:1779–1783.	39	69	43	9.75
5	Clark D, Khademi J. Case studies in modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54:275–289.	35	85	47	3.5
6	Rover G, Belladonna FG, Bortoluzzi EA, De-Deus G, Silva EJNL, Teixeira CS. Influence of access cavity design on root canal detection, instrumentation efficacy, and fracture resistance assessed in maxillary molars. J Endod 2017;43:1657–1662.	34	58	36	11.33
7	Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging prevailing paradigms. Br Dent J 2014;216:347–353.	32	74	32	5.33
8	Alovisi M, Pasqualini D, Musso E, Bobbio E, Giuliano C, Mancino D, Scotti N, Berutti E. Influence of contracted endodontic access on root canal geometry: an *in vitro* study. J Endod 2018;44:614–620.	22	35	24	11
9	Yuan K, Niu C, Xie Q, Jiang W, Gao L, Huang Z, Ma R. Comparative evaluation of the impact of minimally invasive preparation vs. conventional straight-line preparation on tooth biomechanics: a finite element analysis. Eur J Oral Sci 2016;124:591–596.	21	34	19	5.25
10	Bóveda C, Kishen A. Contracted endodontic cavities: the foundation for less invasive alternatives in the management of apical periodontitis. Endod Topics 2015;33:169–186.	21	37	-	4.2
11	Corsentino G, Pedullà E, Castelli L, Liguori M, Spicciarelli V, Martignoni M, Ferrari M, Grandini S. Influence of access cavity preparation and remaining tooth substance on fracture strength of endodontically treated teeth. J Endod 2018;44:1416–1421.	20	41	24	10
12	Özyürek T, Ülker Ö, Demiryürek EÖ, Yilmaz F. The effects of endodontic access cavity preparation design on the fracture strength of endodontically treated teeth: traditional versus conservative preparation. J Endod 2018;44:800–805.	20	40	22	10
13	Silva EJNL, Rover G, Belladonna FG, De-Deus G, Teixeira CS, Fidalgo TKS. Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of *in vitro* studies. Clin Oral Investig 2018;22:109–118.	20	27	20	10
14	Eaton JA, Clement DJ, Lloyd A, Marchesan MA. Micro-computed tomographic evaluation of the influence of root canal system landmarks on access outline forms and canal curvatures in mandibular molars. J Endod. 2015;41:1888–1891.	20	37	23	4
15	Burklein S, Schafer E. Minimally invasive endodontics. Quint Int. 2015;46:119–124.	17	34	14	3.4
16	Neelakantan P, Khan K, Hei Ng GP, Yip CY, Zhang C, Pan Cheung GS. Does the orifice-directed dentin conservation access design debride pulp chamber and mesial root canal systems of mandibular molars similar to a traditional access design? J Endod 2018;44:274–279.	15	25	17	7.5
17	Sabeti M, Kazem M, Dianat O, Bahrololumi N, Beglou A, Rahimipour K, Dehnavi F. Impact of access cavity design and root canal taper on fracture resistance of endodontically treated teeth: an ex vivo investigation. J Endod 2018;44:1402–6.	13	31	17	6.5
18	Jiang Q, Huang Y, Tu X, Li Z, He Y, Yang X. Biomechanical Properties of First Maxillary Molars with Different Endodontic Cavities: A Finite Element Analysis. J Endod 2018;44:1283–1288.	10	20	10	5
19	Saygili G, Uysal B, Omar B, Ertas ET, Ertas H. Evaluation of relationship between endodontic access cavity types and secondary mesiobuccal canal detection. BMC Oral Health 2018;18:121.	10	14	8	5
20	Silva AA, Belladonna FG, Rover G, Lopes RT, Moreira E, De-Deus G, Silva E. Does ultraconservative access affect the efficacy of root canal treatment and the fracture resistance of two-rooted maxillary premolars? Int Endod J 2019; 53:265–275.	9	14	9	9
21	Zhang Y, Liu Y, She Y, Zheng T, Gao Z, Ma X, Wang Q. The effect of endodontic access cavities on fracture resistance of first maxillary molar using the extended finite element method. J Endod 2019;45:316–321.	7	11	7	7
22	Niemi TK, Marchesan MA, Lloyd A, Seltzer RJ. Effect of instrument design and access outlines on the removal of root canal obturation materials in oval-shaped canals. J Endod 2016;42:1550–155.	7	20	10	1.75
23	Abou-Elnaga MY, Alkhawas MAM, Kim HC, Refai AS. Effect of truss access and artificial truss restoration on the fracture resistance of endodontically treated mandibular first molars. J Endod 2019;45:813–817.	6	14	7	6
24	Mendes EB, Soares AJ, Martins JNR, Silva EJNL, Frozoni MR. Influence of access cavity design and use of operating microscope and ultrasonic troughing to detect middle mesial canals in mandibular first molars. Int Endod J 2020;54:1430–1437.	5	4	5	5
25	Marchesan MA, Lloyd A, Clement DJ, McFarland JD, Friedman S. Impacts of Contracted Endodontic Cavities on Primary Root Canal Curvature Parameters in Mandibular Molars. J Endod. 2018;44:1558–1562.	5	10	5	2.5

Table 2. List of the top 10 articles with higher citation density

Rank	Citation density	Title	Authors	Country	Journal
1	18	Fracture strength of endodontically treated teeth with different access cavity designs.	Plotino G, Grande NM, Isufi A, Ioppolo P, Pedullà E, Bedini R, Gambarini G, Testarelli L	Italy	J Endod
2	11.33	Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars.	Krishan R, Paqué F, Ossareh A, Kishen A, Dao T, Friedman S	Canada	J Endod
	11.33	Influence of access cavity design on root canal detection, instrumentation efficacy, and fracture resistance assessed in maxillary molars.	Rover G, belladonna FG, Bortoluzzi EA, De-deus G, Silva EJNL, Teixeira CS	Brazil	J Endod
3	11	The effects of endodontic access cavity preparation design on the fracture strength of endodontically treated teeth: traditional versus conservative preparation	Alovisi M, Pasqualini D, Musso E, Bobbio E, Giuliano C, Mancino D, Scotti N, Berutti E	Italy	J Endod
4	10	Influence of access cavity preparation and remaining tooth substance on fracture strength of endodontically treated teeth	Corsentino G, Pedullà E, Castelli L, Liguori M, Spicciarelli V, Martignoni M, Ferrari M, Grandini S	Italy	J Endod
	10	Influence of contracted endodontic access on root canal geometry: an *in vitro* study	Özyürek T, Ülker Ö, Demiryürek EÖ, Yilmaz F	Turkey	J Endod
	10	Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of *in vitro* studies	Silva EJNL, Rover G, Belladonna FG, De-deus G, Teixeira CS, Fidalgo TKS	Brazil	Clin Oral Invest
5	9.75	Impacts of contracted endodontic cavities on instrumentation efficacy and biomechanical responses in maxillary molars	Moore B, Verdelis K, Kishen A, Dao T, Friedman S	Canada	J Endod
6	9	Does ultraconservative access affect the efficacy of root canal treatment and the fracture resistance of two-rooted maxillary premolars?	Silva AA, Belladonna FG, Rover G, Lopes RT, Moreira E, de-deus G, Silva E	Brazil	Int Endod J
7	7.5	Does the orifice-directed dentin conservation access design debride pulp chamber and mesial root canal systems of mandibular molars similar to a traditional access design?	Neelakantan P, Khan K, He Ing GP, Yip CY, Zhang C, Pan Cheung GS	Hong kong	J Endod

molars" and "Influence of access cavity design on root canal detection, instrumentation efficacy, and fracture resistance assessed in maxillary molars," both with a citation density of 11.33. The top 10 articles according to the citation density are reported in **Table 2**. There was no significant association between the citation density and age of publication (correlation coefficient = −0.2631, $p = 0.2038$) (**Figure 2**).

Year and journal of publication

Most of the 25 most-cited articles were published in the last 3 years ($n = 15$), and the highest number of most-cited articles about minimally invasive access cavities published in a single year occurred in 2018 ($n = 9$). The articles were published across 10 different journals. The journal with the highest contribution was the *Journal of Endodontics* ($n = 15$), publishing 60% of these articles. *Dental Clinics of North America* and *International Endodontic Journal* published 2 articles each, and the following journals published one article each: *BMC Oral Health*, *British Dental Journal*, *Clinical Oral Investigations*, *Endodontic Topics*, *European Journal of Oral Sciences* and *Quintessence International* (**Figure 3**).

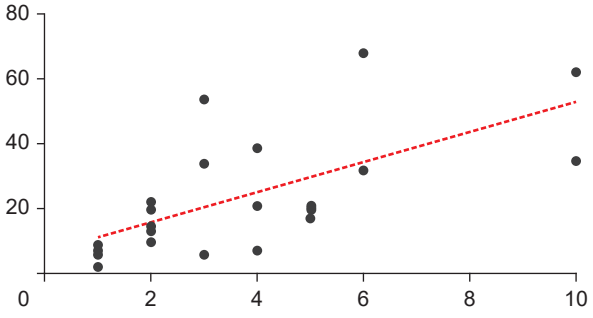

Figure 1. Association of citation count with age of publication.

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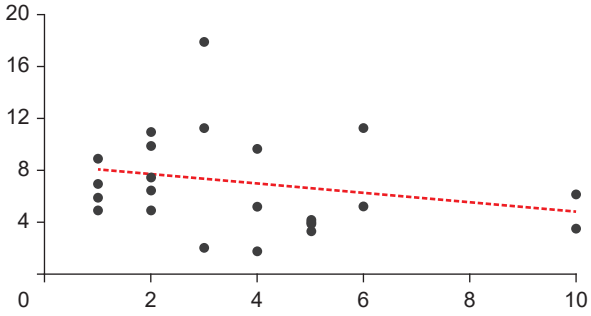

Figure 2. Association of citation density with age of publication.

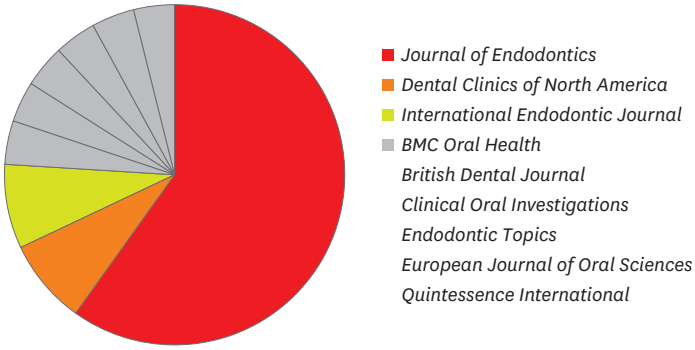

Figure 3. The journals of publication of the top 25 most-cited articles of minimally invasive endodontic access.

Contributing authors

A total of 129 authors contributed to the top 25 most-cited articles, and 15 articles included at least 5 authors. The most contributions ($n = 4$) were made by Emmanuel J.N.L. Silva, followed by Felipe G. Belladonna, Gustavo De-Deus, Shimon Friedman, Anil Kishen, Adam Lloyd, Melissa A. Marchesan, and Gabriela Rover ($n = 3$). **Table 3** summarizes the most influential authors. A map of collaboration network was developed for the authors and co-authors who had contributed to 2 or more articles of the top-cited articles list (**Figure 4**).

Contributing countries and institutions

Based on the institutional address of the corresponding author, 10 countries contributed to the top 25 most-cited articles. Among these, the United States had the largest number

Table 3. The most influence authors and the number of articles the author appeared as the first author, as the corresponding author, as the first and the corresponding author, and as a co-author.

Rank	Name of the author	As first author	As corresponding author	As first and corresponding author	As co-author	Total
1	Silva EJNL	-	2	1	1	4
2	Belladonna FG	-	-	-	3	3
	De-deus G	-	-	-	3	3
	Friedman S	-	2	-	1	3
	Kishen A	-	-	-	3	3
	Lloyd A	-	2	-	1	3
	Marchesan MA	1	-	-	2	3
	Rover G	1	-	-	2	3
3	Clark D	-	-	2	-	2
	Clement DJ	-	1	-	1	2
	Dao T	-	-	-	2	2
	Khademi J	-	-	-	2	2
	Pedullà E	-	1	-	1	2
	Teixeira CS	-	1	-	1	2

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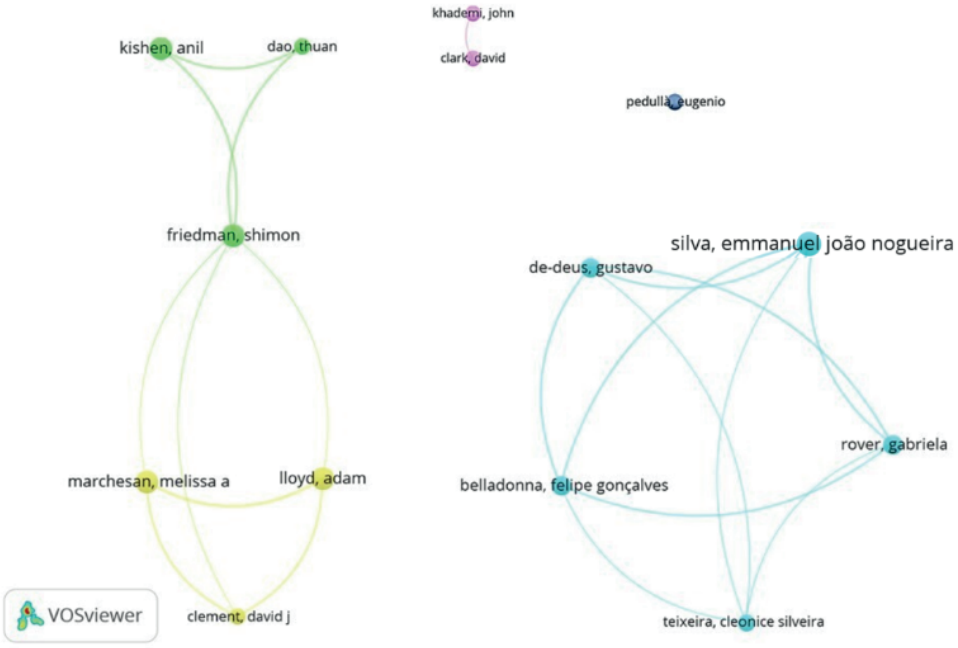

Figure 4. Authors that contributed with 2 or more articles in the top-cited papers and their collaboration networks: a node represents an author; the size of the node represents the number of articles in the top-cited list; a link shows collaboration and nodes with the same color represent collaborating clusters; the distance and thickness of the link between nodes show the relative strength of the relation.

of publications (n = 7), followed by Brazil (n = 4), China (n = 3), Italy (n = 3), Canada (n = 2), Turkey (n = 2), Egypt (n = 1), Germany (n = 1), Hong Kong (n = 1), and Venezuela (n = 1). Among the institutions of affiliation of the corresponding authors, the greatest contributions (n=3) were made by the Grande Rio University, Rio de Janeiro, Brazil and the University of Tennessee Health Science Center College of Dentistry, Tennessee, USA, followed by the University of Toronto, Ontario, Canada (n = 2). Ten studies did not have any additional collaborative institution, 6 studies had the collaboration of one more institution, 4 studies had the collaboration of 2 more institutions, 4 studies had the collaboration of 3 more institutions and one study had the collaboration of 4 more institutions.

Study design

The highest number of articles in the top 25 most-cited articles were laboratory studies (n = 16). Other methodological designs included finite element analysis (n = 3), narrative reviews (n = 3), systematic review (n = 1), case series (n = 1) and narrative review with technique description (n = 1).

Topic of the article

Research topics were clearly differentiated in the laboratory experimental studies. Some articles assessed more than one topic. The major topics covered by the most-cited articles included fracture resistance (n = 10), biomechanics (n = 3), instrumentation efficacy (n = 6), root canal detection (n = 3), filling ability (n = 1), and retreatment (n = 1). Regarding the design of minimally invasive access cavity evaluated, 13 studies assessed conservative access cavities, 2 studies assessed ultraconservative access cavities, 2 studies assessed both conservative and ultraconservative access cavities, and 2 studies assessed truss access cavities. Using the VOS software, the most frequent terms related to the main research topic of the articles were extracted and related to the year of publication (**Figure 5**).

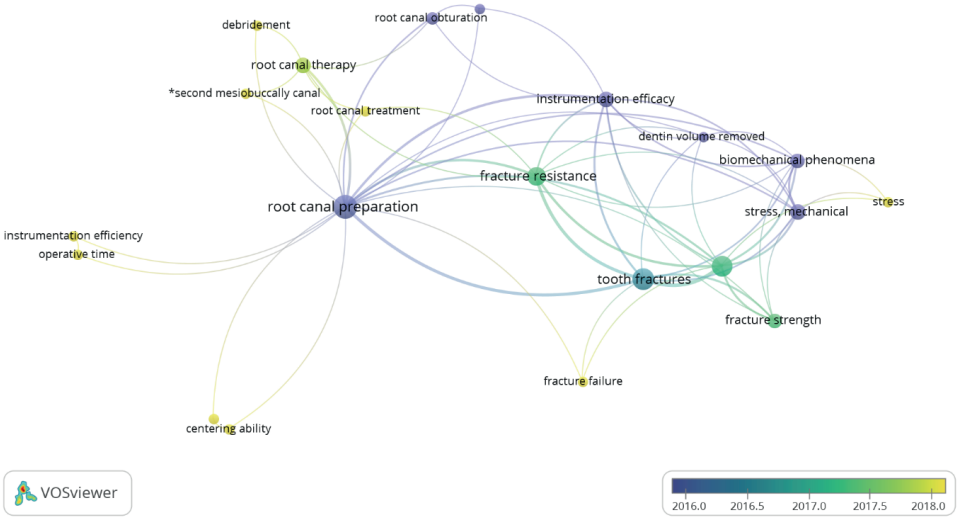

Figure 5. Overlay visualization of the term map of the most frequent terms related to the main research topic of the top 25 most-cited articles: the colors of the nodes and clusters are related to the year of publication of the articles; the size of the node represents the frequency of citation of the term; the distance and thickness of the link between nodes show the relative strength of the relation.

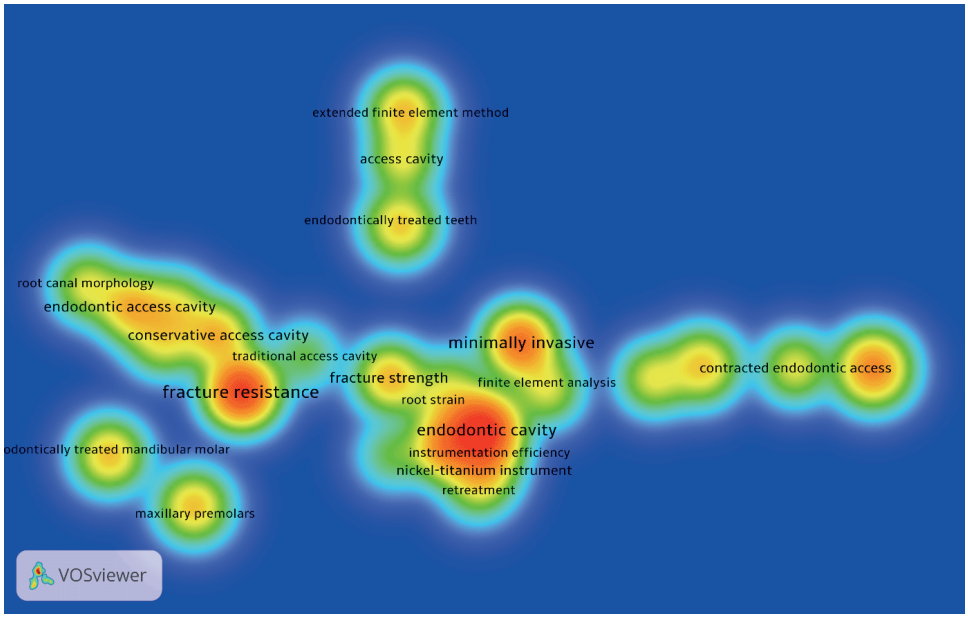

Figure 6. Density visualization of the keyword co-occurrence map. Data were extracted from the unique keywords of the top 25 most-cited articles; red color represents the terms that received higher amount of citation.

Keywords

Of the 25 top-cited studies, a total of 64 unique keywords were identified. The most frequent keywords were 'fracture resistance' ($n = 7$), 'endodontic cavity' ($n = 6$), and minimally invasive ($n = 5$) (**Figure 6**).

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DISCUSSION

The bibliometric analysis based on citation counts is an effective tool to access the worldwide impact of studies about minimally invasive access cavities and measure the attention given by the scientific community surrounding this topic. Although some authors reported that bibliometric analysis should be performed in articles about classic topics and after many years of publications to determine the true impact of the studies, a recent study showed that 73 of the 100 top-cited level 1 articles published in endodontic journals were published in the last 10 years, confirming the growing evolution of research in endodontics. Due to the crescent number of publications, the conduction of bibliometric analysis in more recent and specific fields becomes essential to guide future research, as performed by several previous studies [10,13,41-47].

In this study, the fluctuation in citation counts among Clarivate Analytics' WoS, Google Scholar and Elsevier's Scopus was evident and can be explained due to differences among these databases. The WoS is a well-established database that has been used as a reference to the citation-based bibliometric analysis, mainly because it comprises papers published since 1945 [48]. The Google Scholar includes citations from other publications those not journal articles, such as dissertations, conference reports, preprints and books, which affect the assessment of the top citations [3]. Scopus is a more recent database and for this reason, depending on the purpose of the bibliometric study, it can reproduce inaccurate measures [13]. In the present study, these last 2 databases were only used to improve the reliability of the findings of WoS [13].

In general, when performing a citation-based bibliometric analysis, the tendency is that old articles would be more cited [49]. In this study we could observe a positive association between the number of citations and age of publication (**Figure 1**); however, there was no association between the citation density and age of publication (**Figure 2**). Almost half of the most-cited articles were published in the last 2 years, which highlights the quality of these articles and their relevance to clinical practice and research. It is soon to estimate if these publications will gain even more citations as time passes but this is indicative of: 1) a continuous growth in the publication in this field, and 2) that these articles represent the latest trends emerging in the field of minimally invasive access where the researchers are more interested.

Most of the 25 top-cited articles were published in the *Journal of Endodontics* (impact factor 3.118), which is considered one of the leading journals in endodontics. This journal also published 8 of the 10 articles with the highest citation density. Other high impact journals made contributions with the top-cited articles in this study, such as the *International Endodontic Journal* (impact factor 3.801), *Clinical Oral Investigations* (impact factor 2.812) and *European Journal of Oral Sciences* (impact factor 2.22). Both journals have in common the publication of research in innovative fields and the wide reach to the international research community. When a research article is ranked in the list of the top-cited articles within a specific field, it confirms that the international community has acknowledged the study, authors and the journal of publication as having made a considerable contribution to the area of expertise [13].

Fifteen of the 25 most-cited studies (*i.e.* 60%) have 5 or more authors, and the same number of articles comprised at least 2 institutions in collaborative work. The great number of co-authors and collaborations between different institutions show an interest in minimally

invasive access cavities and that more collaboration among researchers could be expected in the future. E.J.N.L. Silva leads the rank of authorship of the top-cited articles ($n = 4$) and is the only author to contribute as both corresponding author, corresponding and first author and co-author (**Table 3**). Most of the leading authors contributed as co-authors and formed important collaborative research networks (**Table 3**, **Figure 4**). It is important to highlight the role of the lead authors, who are specialists with significant expertise on the subject matter and must be considered as important contributors in the field of minimally invasive endodontic access cavities.

Taking into consideration the number of institutions related to the corresponding author of the most-cited articles, this study reveals that the United States of America leads the science of minimally invasive access cavities, followed by Brazil, and then China, Italy, Canada and Turkey. Similarly, these 6 countries had a higher number of citations and were in the top 10 countries with the most-cited articles published in the *International Endodontic Journal* and *Journal of Endodontics* in the last decade [11]. Recent studies confirmed the leading of the United States of America in the science of Endodontology, which is expected and could be explained by the greater number of researchers and sufficient funding support from both government and private sectors for conducting the experiments [3,13,50]. It is worth mentioning that it is not necessary to have a great volume of publications to obtain the highest citation counts. Beyond the USA, Brazil, Italy, Canada and Turkey have the most influential research groups studying minimally invasive access cavities worldwide, which explains the high citation counts of their articles. In addition, China appears to be the leading country in studies using finite element analysis to assess tooth resistance to fracture, which is one of the main topics studied when evaluating minimally invasive access cavities. Clearly, in these countries, there is also great funding support to conduct the research, either by government, public funding agencies and private companies [11,51].

The most prevalent study design was laboratory study and the majority of research topics covered by the most-cited studies link the types of access cavities and fracture resistance, including biomechanics and stress distribution. This is logical since the concept of minimally invasive access cavities emerged as an idea to reduce the removal of dentin and increase the fracture resistance of the endodontically treated teeth [14]. Although not considered on the top of evidence in terms of study designs, laboratory studies have their relevance to develop new procedures, improve methodologies, and provide preliminary data for subsequent studies with higher evidence levels, like randomized clinical trials and systematic reviews. Four reviews were included in the top-cited list, however, most of them were narrative reviews, which is a design far from the highest level of scientific evidence. Only one systematic review was included in the top-cited list. An important aspect of the bibliometric analysis is that the quality of evidence in the content of the published articles is not evaluated, and the citation count may not be representative of the quality of the study. However, the study design is identified in the bibliometric analysis and can indicate the level of evidence of the study. Moreover, if the article is well cited by other researchers and experts in the field, it is expected that this is indicative of the quality of the conducted research [50].

Keywords are usually representative of the topics of interest and methodologies used by the studies, and when analyzed using the VOS software, can reveal the trend line in research. The VOS software removes general terms not linked to any specific topic by calculating its relevance score, and chooses only the 60% most relevant keywords used in the most-cited studies in order to keep the focus on the more informative terms [5,52]. Thus, the keywords

found by the present study may accurately represent how the research in the field of minimally invasive access cavities has been performed. The most-cited articles published in the last 3 years comprise other topics in addition to the fracture resistance, showing a trend in research on the influence of these minimal access cavities on root canal treatment, instrumentation efficiency, shaping outcomes, centering ability, and operative time (**Figure 5**). Also, the list of most-cited articles includes studies published in the last 3 years assessing the stress distribution by finite element analysis. This is a promising model to study stress distribution patterns and the fracture mechanism of root canal treated teeth [53]. Moreover, the most-cited studies published in the last 3 years covered more extreme minimally invasive access cavities, such as the ultraconservative access cavities and the truss access cavities.

Bibliometric analysis helps in identifying what direction future research might take [2]. If a huge amount of studies regarding a specific procedure showing promising results has already been published and cited, future research can be conducted on outcomes and follow-ups, or focused on study designs that have not been applied yet. In a logical evolution, it would be expected the conduction of well-designed clinical trials for the various suggested access cavities to provide clinical recommendations for these procedures. However, despite there is above the scope of this review to discuss the findings and conclusions of the top-cited articles, it is important to highlight that most of the top-cited studies that had evaluated the fracture resistance of teeth did not prove that minimally invasive access cavities improve the fracture resistance, when compared to traditional access cavities [54]. In fact, minimally invasive access cavities can impair the detection of extra root canals, result in higher amounts of remaining pulp tissue and hard tissue debris, result in a major deviation of the root canal anatomy, and hinder the removal of filling materials in retreatment procedures [21,31,33-35]. In addition, recent studies showed that instruments used in higher angles of file access and minimally invasive access cavities presented less cyclic fatigue resistance, compared to their use in traditional access cavities [55-57]. Moreover, the studies included in this bibliometric analysis present several methodological limitations, such as sample selection using external measurements or bidimensional images, fracture resistance test performed in teeth without root canal treatment, obturation and restoration, and in teeth with occlusal cavities prepared prior to access cavity, which are important factors that can affect the fracture resistance of teeth [16-18,22,24-26]. Therefore, the benefits of performing minimal access cavities remain controversial and inconclusive, and future studies should be performed. At this moment, it cannot be recommended the conduction of clinical studies based on the results of the laboratory studies. It seems that the trend in future research is toward laboratory studies with improved methodologies assessing the influence of these access cavities on several other parameters that could affect the outcome of root canal treatment.

Bibliometric studies have some limitations that should be noted. As above mentioned, citation analysis did not provide a depth analysis of each top-cited study. Moreover, citation is a dynamic process that grows over time; therefore, older studies have more time to receive citations [58]. For this reason, the articles were also tabulated and analyzed according to the average citation received per year since publication. Also, several articles were not included in the present study since only the 25 most-cited articles were selected; 2 articles that have the same citation counts as the last ranked articles but with lower citation densities were not included [20,23]. Another important point is that authors, institutions and publishers may use self-mentions to stimulate the propagations of their own studies [59] and this is not taking into consideration in bibliometric counts. Despite is already known that this is a common practice among research groups and journals, several studies on this matter have shown that there is no need to exclude

self-mentions in bibliometric analysis in Dentistry, as it does not appear to significantly influence the results and seems to be a healthy practice within the dental scientific community [60,61]. In the present study, it was considered the institutional address of the corresponding author of the top-cited article to list the main contributing institutions, and for this reason, only those institutions and countries could be recognized.

CONCLUSIONS

This bibliometric analysis revealed that the highest number of the most-cited articles about minimally invasive access cavities were published in the last 3 years, indicating a growing interest for researchers in this field. It was found that laboratory studies evaluating the influence of minimally invasive access cavities on fracture resistance were the predominant study design and topic, respectively. Based on the present analysis, the trend in future research should be toward laboratory studies with improved methodologies assessing the influence of minimally invasive access cavities on several other parameters that could affect the outcome of root canal treatment.

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