



Research trends on bioceramics in endodontics: A bibliometric analysis from 2001 to 2020

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Purpose: This study aimed to identify the top 100 articles about bioceramics in endodontics using the average number of citations per year (A/Y) metric and compare them with the top 100 most-cited articles.

Methods: A detailed search strategy was conducted on the “Clarivate Analytics Web of Science, All Databases”. After ranking the articles in descending order based on their A/Y and citation counts, 100 articles of each list were selected and analyzed concerning publication year, journals, country, institution, authors, study design, the field of study, evidence level, and keywords.

Results: The number of citations in 2001–2010 was significantly higher ($p < 0.05$). Journal of Endodontics, the United States, and the University of Bologna were the most productive journal, country, and institution. The most frequent first authors were Camilleri and Torabinejad. The main study fields and most used keywords were ‘material properties’ and ‘Silicates’.

Conclusion: The A/Y metric has allowed identifying fairly-recent influential articles about bioceramics; therefore, it could be used as a valid alternative. Future developments in the material properties of bioceramics could lead to the effective use of these materials for various endodontic treatments. Recent research trends implicating innovative materials or techniques might raise new interest areas regarding this field.

Keywords: Average number of citations, bibliometrics, bioceramics, endodontics.

Introduction

Choosing the best dental material for a better outcome in endodontic treatments can be challenging. Endodontic materials are constantly changing with the development of new technologies and techniques. Advances in endodontic materials aim to increase the success rate of treatments by

providing desirable features (1).

Bioceramics are relatively new and promising materials for the field of endodontics (2). These biocompatible ceramic materials, obtained by various chemical processes, have favorable features such as biocompatibility, antibacterial properties, and high sealing ability (3,4). A further advan-

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tage is their ability to form hydroxyapatite so that eventually a bond between dentin and the material is created (5). The first endodontic use of bioceramics was in the form of mineral trioxide aggregate (MTA), used to repair lateral root perforations by Dr. Torabinejad in 1993 (6). Since then, the field of endodontics has witnessed a huge influx of such materials for a wide array of clinical applications. Bioceramics can be used in vital pulp therapies, apexification treatments, regenerative endodontic treatments (RET), microsurgery, or root canal filling and canal sealer (7-9). However, MTA has some disadvantages, including a long setting time, poor handling properties, and coronal discoloration (10). To overcome these limitations, new bioceramic materials possess many similar and some different in vitro and in vivo characteristics have been introduced (11).

Bibliometric analysis is a quantitative method that serves to appraise scientific articles, books, or book chapters (12). It offers a general overview of academic literature that can be broken down by the field of the study, authors, journals, number of citations, organizations, and countries (13). Citation analysis -commonly used as a method in bibliometrics- is an effective way to discern the scientific value of articles (14). It can guide researchers in following developments within specific fields (15). Although the citation count metric is widely used to assess the quality of published articles, it is a time-dependent metric, and therefore; its effectiveness highly depends on academic field normalization (16). Citation analysis slows to reveal the scholarly use of articles and their overall implications by underlining the need for time normalization (17). For this reason, the Web of Science (WoS, Clarivate Analytics Co., Philadelphia, PA, USA) has released a metric called "average number of citations per year" (A/Y). It is calculated by dividing the total number of citations by the number of years since the article was published (18). Using the A/Y metric enables the determination of influential articles in the relevant field regardless of time, thus allowing the effectiveness of even a recently published article to be determined.

In endodontics, the first bibliometric analysis to include the top-cited articles in five endodontic journals was that of Fardi et al. in 2011 (19). Subsequently, various studies have addressed specific topics of endodontics (20-22). Since the use of bioceramics in endodontics has grown rapidly, it has become more representative of the scientific importance of publications. In addition, identifying areas that have already been studied on bioceramic materials make it easier to identify deficiencies in this field, along with collaboration between investigators and institutions with a particular interest. In the scope of the above-mentioned information, the present study aimed to identify

and analyze the top 100 articles about bioceramics in endodontics, i.e., having the highest A/Y values from 2001 to 2020 - and to compare them with the top 100 most-cited articles.

Materials and Methods

Database Selection and Searching Strategy

A cross-sectional bibliometric study was performed to determine the articles on bioceramics in endodontics with the highest A/Y values from 2001 to 2020. The online platform WoS (<http://www.webofknowledge.com>) was accessed for bibliographic data in all databases since it is an easy and adequate tool for bibliometric analysis and has been used in many studies effectively (18). Moreover, the WoS contains peer-reviewed, high-quality scientific journals published worldwide (23). The terms and search strategy were designed by three researchers with experience in endodontics and/or bibliometrics. A detailed search strategy was carried out using terms related to bioceramics, and only articles written in English were included.

On November 18, 2021, the WoS search was performed. First, three main search groups were established:

Q1: (TS = (Bioceramic*)) OR TS = (Biomat*) OR TS = ("Endodontic cement") OR TS = (Calcium silicate*) OR TS = (Tricalcium silicate*) OR TS = ("Mineral trioxide aggregate") OR TS = (Biodentine)) OR TS = (MTA*) OR TS = (canal sealer)) OR TS = (Portland cement) and 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2014 or 2013 or 2012 or 2011 or 2010 or 2009 or 2008 or 2007 or 2006 or 2005 or 2004 or 2003 or 2002 or 2001 (Publication Years) and English (Languages). 478,774 articles were obtained.

Q2: (TS = (Pulp therapy)) OR TS = (pulp cap*) OR TS = (pulpectomy)) OR TS = (pulpotomy)) OR TS = (Regenerative endod*) OR TS = (apexification)) OR TS = (apexogenesis) and 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2014 or 2013 or 2012 or 2011 or 2010 or 2009 or 2008 or 2007 or 2006 or 2005 or 2004 or 2003 or 2002 or 2001 (Publication Years) and English (Languages). 29,248 articles were obtained.

Q3: (TS = (endod*)) OR TS = (root canal*) and 2001 or 2002 or 2003 or 2004 or 2005 or 2006 or 2008 or 2007 or 2009 or 2010 or 2011 or 2012 or 2013 or 2014 or 2015 or 2016 or 2017 or 2018 or 2019 or 2020 (Publication Years) and English (Languages). 57,523 articles were obtained.

The above search groups were combined as ([Q1 OR Q2] AND Q3) and 12,202 articles were obtained. The data were downloaded as an Excel file that also included the A/Y values as well as the number of citations for biblio-

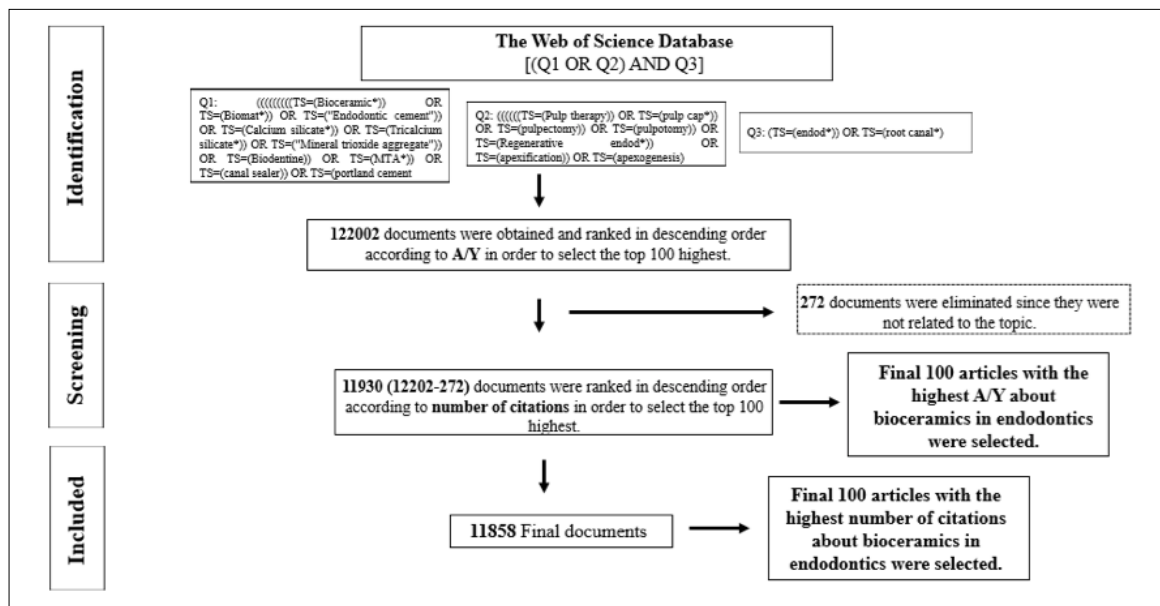


Fig. 1. The searching strategy process

metric analysis. Articles were ranked in descending order according to their A/Y values, and then the titles and/or abstracts of the downloaded articles were examined by two researchers (SNU and TAM) independently to confirm that the main focus was on bioceramics in endodontics. Researchers accessed the full text in cases they could not receive adequate information from the abstract and/or title. A total of 272 articles were eliminated as they were not related to the topic, and the 100 articles with the highest A/Y were derived. Afterward, the 11,930 (12,202-272) remaining articles were ranked in descending order according to the number of citations. The same researchers eliminated 72 more articles not related to the topic, and the top 100 most-cited articles were obtained. The search process is outlined in Fig. 1.

All documents were characterized by two researchers (SNU and PV). Disagreements regarding the indicators between these evaluators were resolved by additional discussion or consulting a third researcher (TAM). If articles were “tied” in terms of one parameter, the article having either more citations or the higher A/Y was selected.

The following characteristics of each article were evaluated: A/Y, the number of citations, year of publication, journal, country, the institution of origin of the first author, first author, co-authors, evidence level (EL), and keywords. ELs were categorized into 5 groups as follows (24): EL I: systematic reviews and meta-analysis of randomized clinical trials (RCTs), EL II: RCTs, EL III: cohort studies and clinical trials, EL IV: case-control series, EL V: case series, case reports. Moreover, each article was assigned to a more

specific field of study: “Vital pulp therapy,” “side effects,” “regenerative procedures,” “apexification/regeneration,” “clinical applications,” “material properties,” or “biocompatibility/biological properties.” The study designs were further categorized into five groups: Review (narrative, systematic, meta-analysis, and guideline), in vitro (including studies of parts of dental tissue, sections of the tooth, dentin powder, and cell cultures), ex vivo (teeth and complete root from humans or animals), clinical observational studies (case report, case series, retrospective case-control, cohort study), and clinical experimental studies (clinical trial, or RCT).

The VOSviewer 1.6.6.0 tool (Center for Science and Technology Studies, Leiden University, The Netherlands; available at <https://www.vosviewer.com>, accessed on December 20, 2021), was used to analyze the data downloaded from the WoS by creating a map of bibliometric networks based on keywords co-occurrences. Keywords with fewer than two co-occurrences were excluded to increase the clarity. The size of the nodes represents the frequency of the analyzed keywords; consequently, larger nodes are associated with a higher frequency. Moreover, the thickness of the edges reflects the relationship of the interactions between two nodes, while their colors indicate the cluster to which the keyword belongs.

Statistical Analysis

The Shapiro–Wilk test was used to test the Gaussian property of A/Y and the number of citations. To compare these metrics over decades, a Mann–Whitney test was applied;

Table 1. The 20 most influential trends on bioceramics in endodontics articles ranked according to the highest average number of citations per year (A/Y), 2001–2020

A/Y Rank	Reference	No. A/Y	No. Cites (Cites rank)
1	Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review--Part III: Clinical applications, drawbacks, and mechanism of action. <i>J Endod.</i> 2010; 36:400-413.	53.42	641 (1)
2	Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review--Part I: chemical, physical, and antibacterial properties. <i>J Endod.</i> 2010; 36:16-27.	47.42	569 (2)
3	Torabinejad M, Parirokh M. Mineral trioxide aggregate: a comprehensive literature review--Part II: leakage and biocompatibility investigations. <i>J Endod.</i> 2010; 36:190-202.	38.83	466 (4)
4	Parirokh M, Torabinejad M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview - part I: vital pulp therapy. <i>Int Endod J.</i> 2018; 51:177-205.	36.50	146 (53)
5	Torabinejad M, Parirokh M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview - part II: other clinical applications and complications. <i>Int Endod J.</i> 2018; 51:284-317.	35.00	140 (66)
6	Prati C, Gandolfi MG. Calcium silicate bioactive cements: Biological perspectives and clinical applications. <i>Dent Mater.</i> 2015; 31:351-370.	29.57	207 (19)
7	Banchs F, Trope M. Revascularization of immature permanent teeth with apical periodontitis: new treatment protocol? <i>J Endod.</i> 2004; 30:196-200.	27.33	492 (3)
8	Sarkar NK, Caicedo R, Ritwik P, Moiseyeva R, Kawashima I. Physicochemical basis of the biologic properties of mineral trioxide aggregate. <i>J Endod.</i> 2005; 31:97-100.	27.12	461 (5)
9	Camilleri J, Sorrentino F, Damidot D. Investigation of the hydration and bioactivity of radiopaque tricalcium silicate cement, Biodentine and MTA Angelus. <i>Dent Mater.</i> 2013; 29:580-593.	22.89	206 (20)
10	Galler KM, Krastl G, Simon S, Van Gorp G, Meschi N, Vahedi B, et al. European Society of Endodontology position statement: Revitalization procedures. <i>Int Endod J.</i> 2016; 49:717-723.	22.00	132 (70)
11	Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. <i>J Endod.</i> 2006; 32:601-623.	21.75	348 (6)
12	Jeeruphan T, Jantarajit J, Yanpiset K, Suwannapan L, Khewsawai P, Hargreaves KM. Mahidol study 1: comparison of radiographic and survival outcomes of immature teeth treated with either regenerative endodontic or apexification methods: a retrospective study. <i>J Endod.</i> 2012; 38:1330-1336.	21.60	216 (15)
13	Laurent P, Camps J, About I. Biodentine(TM) induces TGF-β1 release from human pulp cells and early dental pulp mineralization. <i>Int Endod J.</i> 2012; 45:439-448.	21.00	210 (18)
14	Bose R, Nummikoski P, Hargreaves K. A retrospective evaluation of radiographic outcomes in immature teeth with necrotic root canal systems treated with regenerative endodontic procedures. <i>J Endod.</i> 2009; 35:1343-1349.	20.38	265 (9)
15	Roberts HW, Toth JM, Berzins DW, Charlton DG. Mineral trioxide aggregate material use in endodontic treatment: a review of the literature. <i>Dent Mater.</i> 2008; 24:149-164.	19.43	272 (8)
16	Hargreaves KM, Diogenes A, Teixeira FB. Treatment options: biological basis of regenerative endodontic procedures. <i>Pediatr Dent.</i> 2013; 35:129-140.	18.89	170 (37)
17	Zhou HM, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Physical properties of 5 root canal sealers. <i>J Endod.</i> 2013; 39:1281-1286.	18.22	164 (39)
18	Chen MY, Chen KL, Chen CA, Tayebaty F, Rosenberg PA, Lin LM. Responses of immature permanent teeth with infected necrotic pulp tissue and apical periodontitis/abscess to revascularization procedures. <i>Int Endod J.</i> 2012; 45:294-305.	18.00	180 (31)
19	Camilleri J, Montesin FE, Brady K, Sweeney R, Curtis RV, Ford TR. The constitution of mineral trioxide aggregate. <i>Dent Mater.</i> 2005; 21:297-303.	17.88	304 (7)
20	Grech L, Mallia B, Camilleri J. Investigation of the physical properties of tricalcium silicate cement-based root-end filling materials. <i>Dent Mater.</i> 2013; 29:e20-28.	17.67	159 (40)

Table 2. Metrics of the top 100 most influential trends on bioceramics in endodontics articles with the highest average number of citations per year: 2001–2020

	2001–2020 n=100	2001–2010 n=36	2011–2020 n=64	Comparison p-value ^a
Average/year ^a	13.41 (4.33)	14.39 (5.77)	12.98 (4.25)	0.211
Min-Max	9.91–53.42	9.92–53.42	9.91–36.50	
Weighted Average/year	1551.69	621.81	929.79	
Cites ^a	140 (100.5)	201.50 (99.75)	107 (71.25)	<0.001
Min-Max	21–641	124–641	21–216	
Total citations	15859	8861	6998	

^aMedian (interquartile range). Min-Max: Minimum and Maximum values. Weighted average/year: sum of the average per year for the articles in the group. ^bPair comparison by Mann-Whitney test. Previously the Shapiro-Wilk test showed no normality.

and among study designs (in vitro, ex vivo, review, observational clinical study, or experimental clinical study), and the seven subfields of study, a Kruskal–Wallis test was performed. When the results were statistically significant, a Mann–Whitney test for pair-by-pair comparison was used. This test likewise served to compare the top 34 A/Y against the 34 most-cited articles that were not common to both lists. The correlation between A/Y values and citations in the top 100 A/Y articles was evaluated using the square of the Pearson linear coefficient. Statistical analysis was performed using SPSS software version 26, licensed by the University. The significance level was set at $p < 0.05$.

Results

Bibliometrics

Sixty-six of the top 100 articles with the highest A/Y value from 2001 to 2020 were also identified as being among the top 100 most-cited. However, 34 articles were not on both list. In the supplementary material, Table 1 shows all 134 articles, their A/Y values, the number of citations, and the ranking on each list. The 20 most relevant publi-

cations as ranked by their A/Y values are shown in Table 1 along with their citation ranking.

A significant correlation was found between A/Y values and citations ($R^2 = 58.83\%$). The A/Y values were similar for the periods, but the number of citations in 2001–2010 was significantly higher than in the period 2011–2020, as presented in Table 2 ($p < 0.05$).

Among the top 100 A/Y, most articles were published in 2013 ($n = 11$), followed by 2012 ($n = 10$) and 2014 ($n = 9$). The years 2003 and 2020 (each $n = 2$), and 2004 ($n = 1$) had the lowest number of articles. Among the 11 journals represented, the Journal of Endodontics had the largest number of publications ($n = 62$, 959.63 weighted A/Y and 10,130 citations), followed by the International Endodontic Journal ($n = 20$, 32.76 weighted A/Y and 3028 citations). Dental Materials had nine articles, while Clinical Oral Investigations had just two. Operative Dentistry, Odontology, International Journal of Biomaterials, Dental Traumatology, Dental Materials Journal, Pediatric Dentistry, and Journal of Dentistry journals had only one publication - and the article appearing in the International

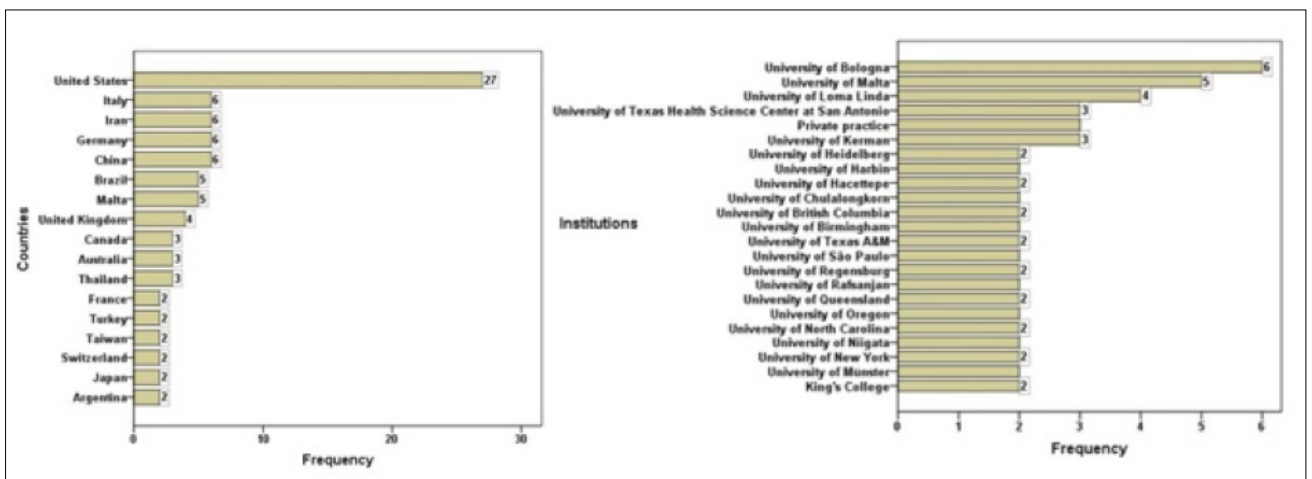


Fig. 2. Countries and institutions of three or more articles of the 100 articles with the highest A/Y on bioceramics in endodontics

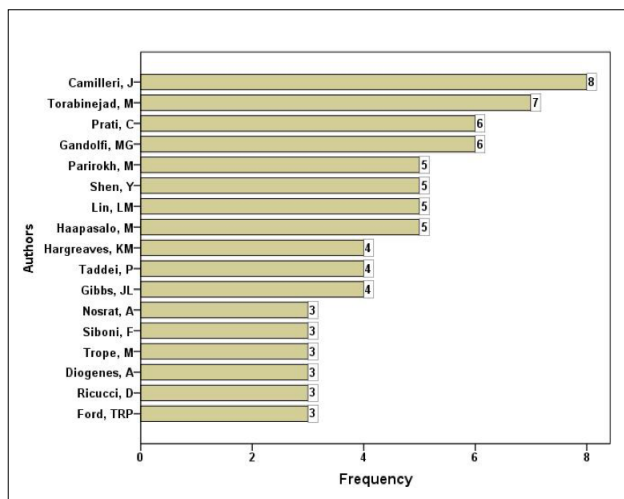


Fig. 3. Authors of three or more articles of the 100 articles with the highest A/Y on bioceramics in endodontics

Journal of Biomaterials is not indexed in Journal Citation Reports (JCR).

Countries, Institutions, and Authors

According to the institutional address of the first author, 31 countries participated in the output. United States (US) published 27 articles, followed by Italy, Iran, Germany, and China ($n = 6$ each). Out of 65 identified institutions, the University of Bologna had the highest number of articles ($n = 6$), followed by the University of Malta (n

$= 5$) and the University of Loma Linda ($n = 4$). Countries and institutions that published at least two articles are presented in Fig. 2.

Altogether, 420 authors contributed to the top 100 A/Y. Josette Camilleri was ranked number one with eight articles, followed by Mahmoud Torabinejad, Maria Giovanna Gandolfi, and Carlo Prati, who published six articles. The authors contributing to at least three articles are shown in Fig. 3.

Study Design, Field of Study, Evidence Level, and Keywords

In vitro studies ($n = 32$) were the most frequent study design, followed by reviews (narrative = 21, systematic review/meta-analysis = 4, and guideline = 1), clinical observational studies (case report = 8, case series = 8, cohort = 5, case control studies = 4), clinical experimental studies (clinical trial = 1, RCT = 6) and ex vivo ($n = 11$).

The frequency of the articles based on their study design and subfield of study, as well as the median (interquartile range) of the A/Y and citations are given in Table 3. There was no statistically significant difference among the fields of study in terms of the two metrics. A difference between study designs was found only for A/Y ($p < 0.05$) Since reviews (except systematic reviews of RCTs), in vitro, and ex vivo studies belong to the bottom of the EL pyramid, the frequency of each level was as follows: EL I

Table 3. Study design and field of study of the top 100 articles on bioceramics in endodontics by the highest average number of citations per year (A/Y). 2001–2020. Weighted A/Y and total citations. Median (interquartile range)

Study design	n	A/Y		Citations	
		Weighted	Median (IR)	Total	Median (IR)
In vitro	32	423.53	12.30 (4.02) ¹	4573	148.5 (100.75)
Ex vivo	11	134.49	12.63 (6.79) ^{1,2}	1459	115 (80.5)
Review	26	535.01	14.43 (10.87) ²	4930	136 (157.5)
Clinical observational	24	338.34	12.25 (4.53) ¹	3761	143 (86.25)
Clinical experimental	7	120.23	13 (3.27) ^{1,2}	1136	122 (138.5)
Comparison p-value	0.042*		0.922*		
Field of study					
Vital pulp therapy	11	165.18	12 (4.49)	1478	143 (97)
Side effects	7	84.5	11.85 (1.63)	731	101 (87)
Regenerative procedures	26	385.12	14.15 (4.14)	4013	130.5 (76.75)
Apexification/Regeneration	5	74.59	13.6 (6.7)	668	68 (181)
Clinical applications	6	163.39	25.66 (27.45)	1531	176 (303.75)
Material properties	31	457.42	12.06 (4.65)	5213	149 (100)
Biocompatibility/Biological properties	14	221.85	13.84 (4.68)	2225	147 (148.5)
Comparison p-value			0.162*		0.528*

Weighted average per year: Summary of the A/Y for the articles of each study design or field of study. *Global comparison by Kruskal-Wallis test. Data not following normal distribution determined by Shapiro-Wilk test. Pair-by-pair comparison by Mann-Whitney test. Read vertically. The same superscript number indicates a non-significant difference.

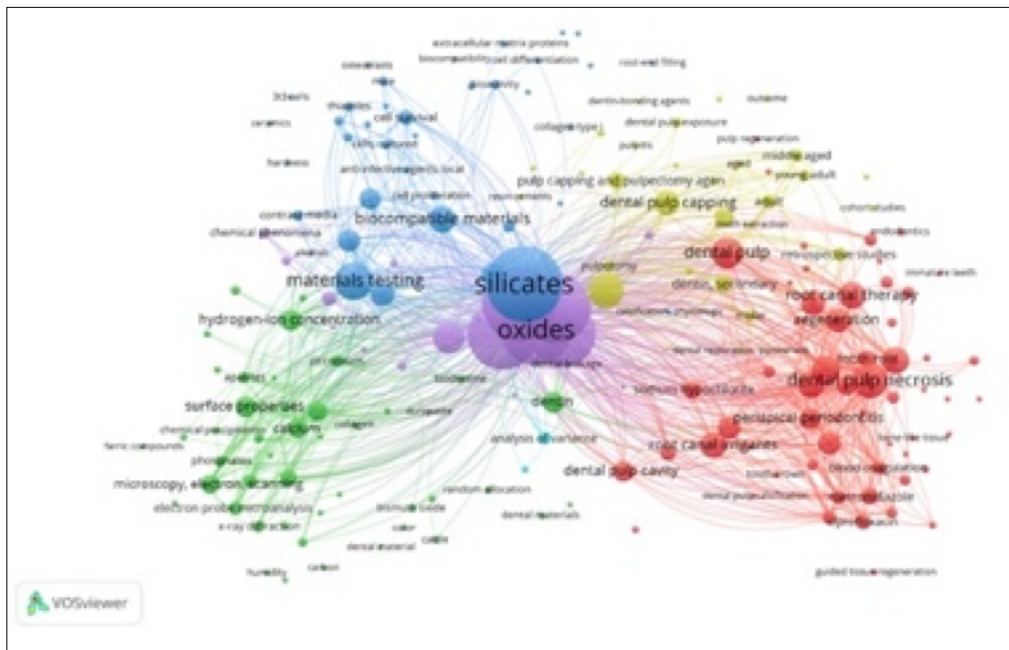


Fig. 4. The network of three or more co-occurring keywords of the top 100 A/Y articles on bioceramics in endodontics. A total of 187 nodes, six clusters, and a maximum of 900 lines

(n = 1), II (n = 6), III (n = 6), IV (n = 3), and V (n = 84). From the top 100 articles according to A/Y, the software recovered 496 keywords. After reducing the number of co-occurrences to two, a total of 187 keywords (nodes) were grouped into 6 clusters, and a maximum of 900 lines were loaded. The network of three or more co-occurring keywords is depicted in Fig. 4. The most frequent were: “Silicates” (n = 78), “Calcium compounds” (n = 75), “Oxides” and “Drug combinations” (n = 69), “Root canal filling materials” (n = 68), “Aluminum compounds” (n = 63) and “Dental pulp necrosis” (n = 27).

Top 100 A/Y versus Top 100 Most-Cited

A comparison of the top 100 A/Y and the top 100 most-

cited revealed that 66 articles were present in both lists, while 34 + 34 articles were not (Supplementary Materials, Table S1). The bibliometric characteristics of these 34 articles are presented in Table 4. A statistically significant difference was found for the year of publication, A/Y, and citations (p < 0.05).

Discussion

Bioceramic materials have swiftly gained acceptance in endodontic applications owing to their physicochemical and biological properties (2). Therefore, this cross-sectional bibliometric study aimed to identify the most 100 influential articles -with the highest A/Y- and their main characteristics, as well as to identify recent trends in the

Table 4. Comparison of characteristics of bioceramic articles with the highest average number of citations per year (A/Y) and most-cited. The 34 articles were not common to both lists. 2001–2020

	Top A/Y n=34	Most-Cited n=34	Comparison p-value*
Year ^a	2016 (3)	2005 (3.25)	<0.001
Min-Max	2011–2020	2001–2010	
Average per year ^a	11.45 (1.7)	8.54 (1.93)	<0.001
Min-Max	10.17–14.60	5.38–9.8	
Weighted RCR	405.03	279.94	
Cites ^a	72.5 (40.25)	132 (29)	<0.001
Min-Max	21–108	109–178	
Total citations	2493	4579	

^aMedian (interquartile range). Min-Max: Minimum and Maximum values. Weighted Average per year: Summary of the Average per year for the articles in the group. *Mann-Whitney test. Previously the Shapiro-Wilk test showed no normality.

field of bioceramics, which is relatively new in endodontics. With some exceptions (17), the vast majority of bibliometric studies harvest influential articles in endodontics using citations that do not identify recent articles (19-22). Hence, the time-normalized A/Y metric was selected so as not to penalize recent articles, and compensate for the active lifespan of an academic journal to ensure a fair comparison in terms of junior academics (25).

Among the top 100 articles having the highest A/Y, there was no statistically significant difference between decades. This result signals it is a time-normalized metric. Contrariwise, the number of citations was significantly higher for 2001–2010 than for 2011–2020, as expected. Citations are time dependent, hence the total number of citations received by an article tends to increase over time (16). However, time is still needed to see if these publications will receive more citations as time goes on.

The majority of the top A/Y articles appeared in the *Journal of Endodontics*, followed by *International Endodontic Journal* which is the leading journal englobing all aspects of research and clinical practice in endodontics and is highly ranked (Q1) in the JCR. This result is very understandable since the journal ranking reflects the value of the contents for scientists interested in innovative fields such as bioceramics (14). As an interesting point, the majority of the journals in this bibliometric study tended to publish in multidisciplinary fields. It can be explained by the fact that bioceramics are actively used in almost every field of dentistry with different techniques and treatment methods.

The first (7), second (3), and third articles (4) with the highest A/Y were published by Parirokh and Torabinejad in 2010 and they were ranked first, second, and fourth in the most-cited list. It was an expected result since these three review articles focused on the general properties of MTA and gave various important information of the material itself. Interestingly, although the updated overviews about bioceramic-based materials in 2018 published by the same two authors ranked fourth and fifth in A/Y list, these two articles were ranked as 53 and 66 in the most-cited list. This is another finding that proves the limitation of citation analysis, as this method is insufficient to retrieve newly-published articles.

In agreement with other bibliometric studies in different specialties of medicine and dentistry (26,27), the US was the leading country in bioceramic materials-based research. In this sense, research and development funding from governmental and private sectors is essential to create innovation in science and technology (28). Likewise, among the institutions where most first authors were affiliated, although US universities were more productive

in overall output, the University of Bologna was the most prolific institution in the list of highest A/Y. It is helpful to keep in mind that the main focus of researchers in institutions is also another essential factor affecting scientific output. Regarding this, Josette Camilleri and Mahmoud Torabinejad published the highest number of articles. These two authors are well-known professors in endodontics since their influential articles include endodontic materials such as root-end filling materials and root canal sealers, with a particular interest in MTA (29,30).

Before using the recently-developed materials in routine clinical practice, their properties must be defined with well-designed *in vitro* and animal studies (31). In addition, review articles are also needed to be published to provide overall information regarding the topic. In line with this, the majority of the articles in this bibliometric study was *in vitro* and review studies. Moreover, these articles mainly focused on the material properties with various aspects and application trends of bioceramics. The improvement of the properties of the produced materials with the aid of technology leads to the use of these materials in a wide variety of treatment methods. In particular, the publication of a large number of articles, especially on the use of bioceramics in regenerative endodontic treatments, can be interpreted as revealing the need for development in this area.

Sixty-six articles were common to both lists, with values very close to previous studies applying a normalized metric over time (17,32). A comparison of the 34 articles that were not common showed differences in years, A/Y, and citations. The 34 articles with the highest A/Y belong to the period 2011–2020, and the 34 most-cited to 2001–2010. Hence, the median of citations is higher in the citations group, whereas the median of the A/Y metric is higher in the top A/Y group. Using A/Y allows one to effectively retrieve a significant number of fairly recent articles and identify new trends.

One of the limitations of this study is that the A/Y metric, being a new system, does not facilitate comparison with other studies. In addition, the WoS was held to be the most appropriate database to obtain the articles. However, it is difficult to ascertain whether this database conclusively records all endodontic articles published in all journals for the research area. Subsequently, not covering the articles written in languages other than English, or gathered in books or conference proceedings might have caused missing information. Finally, the institutional addresses and countries of the first authors were selected to the main list; therefore, only those institutions and countries could be identified.

Conclusions

The frequent use of bioceramic materials in various endodontic treatments as well as other applications in dentistry has led to the publication of many influential articles in this field. In order to compensate for the time-dependent nature of the citation analysis and provide comprehensive information regarding the topic, using the A/Y metric that determines fairly-recent articles could be considered a valid alternative. Research trends could focus on promising developments in enhanced material properties and different fields of usage in endodontics. Moreover, future clinical studies are needed to observe the actual impact of these materials on clinical usage definitively.

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