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Citation Classics on Dental Caries: A Systematic Review

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Abstract

Objective A systematic search was performed for the identification and analysis of the 100 most often cited articles on dental caries and to highlight the changing trends in the field of dentistry over time.

Materials and Methods The search was performed without any restriction on the study design, publication year, or language using the Web of Science (WoS) group of Clarivate Analytics enabling the search through "All Databases." Based on the citation count as available in WoS, the articles were sorted in a descending manner. Information regarding each article was then extracted, which included its authorship, counts of citation (in other databases), citation density, current citation index (2019), publication year, country of publication, journal of article, evidence level based on study design, and keywords description.

Results The count of citation for each article varied in each database, that is, 175 to 2,003 in WoS, 89 to 1,981 in Scopus, and 126 to 3,492 when searched in Google Scholar. The highest number of articles (n = 10) related to dental caries were published in 2004. A total of 301 authors made valuable contributions to this field, out of which J.D. Featherstone had coauthored 6 articles. A significant negative correlation ($p < 0.01$) was found between the age of the article and the citation density (r =–0.545). However, a nonsignificant correlation (p = 0.952) occurred between the age of publication and the citation count (r = 0.006).

Conclusion The results of this systematic review provide a critical appraisal of the context underpinning scientific developments in the field of dental caries and also highlighted trends in clinical management and research.

Keywords
► citation classics
► dental caries
► systematic review
► citation analysis
► *Streptococcus mutans*
► bibliometrics

Introduction

"Dental caries is a biofilm-mediated, sugar-driven, multifactorial, dynamic disease that results in the phasic demineralization and remineralization of dental hard tissues."[1] A multifactorial origin has been identified in which the presence of acidogenic bacteria, salivary disturbances, and sugar consumption/frequency are known to play a vital role in disease progression.[2] Caries is a common chronic disease which has a high prevalence rate among adults and

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children.[3] Approximately 2.4 billion people with untreated lesions have been estimated worldwide.[4] Untreated carious lesions commonly lead to functional, aesthetic, and psychological problems, as well as a poor quality of life.[5] Delay in the treatment of a carious tooth eventually leads to pulpal involvement and painful mastication potentially resulting in indigestion,[6] malnutrition,[7] and systemic infections, which in turn increase the treatment need and consequently increase the cost of dental and medical care provided to the patient.

The citation count of an article is an indicator of its impact in its respective field. A classic article is defined as an article having secured a citation count of 100 or above.[8] The growth of a particular field or specialty can be studied by performing a bibliometric analysis. It also provides vital information regarding the prominent areas of individual medical and dental specialties.[9] Various bibliometric analyses have documented the citation classics in the field of dentistry,[10-20] but no study has been performed to study the characteristic features of the publications on caries research which have been cited most often.

The current study is focused on identification and analysis of the top 100 publications which have been cited most often regarding dental caries and to highlight the change in current trends, centers of excellence in caries research, dominant types of methodology, and technological developments made during the elapsed time.

Materials and Methods

Protocol

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for the preparation of this report.[21]

Search Strategy

The Web of Science (WoS) group of Clarivate Analytics was used to perform a literature search on April 1, 2019 enabling the search through "All Databases." The title section was searched using the search terms described below in inclusion criteria. The database was searched without any restriction on the language of the article, study design, or publication year. Based on the WoS results, 31,584 articles were retrieved which were then arranged according to number of citations. One hundred articles with the largest number of citations were tabulated. A manual cross-matching of citation count was performed on the Elsevier's database (Scopus) and the Google Scholar (GS). The top 100 "classic" publications were selected by two reviewers independently and the final list was unanimously agreed upon. The ►**Supplementary Fig. S1** (online only) shows the process of selection of articles according to PRISMA guidelines.

Inclusion Criteria

Inclusion criteria were the presence of "caries" OR "carious" OR "cariogenic" OR "cariology" OR "tooth decay" OR "teeth decay" OR "tooth cavity" OR "teeth cavity" OR "tooth cavities" OR "teeth cavities" OR "dental cavity" OR "dental cavities" OR "dental decay" in the title of the article and publication in a peer-reviewed journal.

Exclusion criteria

Articles having less than 100 citations according the WoS "All Databases" and publications in journals with low (≤0.500) or no impact factor were excluded.

Data Extraction

Article authorship, title of article, counts of citation (WoS, Scopus, and GS), publication year, citation density, current citation index (CCI) (2019), institution and country of publication, journal of article, evidence level based on methodology, and keywords description were noted for each selected publication.

Graphical Analysis

VOSviewer is a free software platform which is used for bibliometric mapping based on visualization of similarities.[16] We used this software to visualize the clusters of author keywords which have been used in the top-cited articles. This method of mapping has been used previously and provides a simplistic representation of data.[18]

Statistical Analysis

IBM SPSS Statistics processes version 24 for Windows was used to perform descriptive and bivariate analyses. The Shapiro–Wilk test was performed to check data normality. Based on distribution and normality of the data, mean (standard deviation) or median (interquartile range) were calculated. The Kruskal–Wallis test was performed to analyze the median differences between the independent groups and differences within each group was checked by post hoc testing. The Mann–Kendall trend test was performed to analyze an increase or decrease in the time-dependent trends. To evaluate the correlation between the age of the journal and the publication count in the journal the Spearman-rank test was performed. A value of $p < 0.05$ was considered statistically significant.

Results

Authorship

Three hundred and one authors made contributions to the list of top 100 "classics." J.D. Featherstone ($n = 6$) had the highest publication count followed by P. Axelsson ($n = 5$), J. Lindhe ($n = 5$), B. Nyvad ($n = 4$), N.B. Pitts ($n = 4$), B. Krasse ($n = 3$), and J. van Houte ($n = 3$). Twenty-two authors contributed to two "classics" each, among the list of top 100 "classics." The ►**Supplementary Table S1** (online only) shows the number of instances at which an author appeared as the first author, as the corresponding author, as the first and the corresponding author, and as the coauthor.

Citation Count, Citation Density, and Current Citation Index

A total of 297,496 (WoS), 27,713 (Scopus), and 53,648 (GS) citations were calculated for the list of top 100 "classics."

The range of citations varied from 175 to 2,003 (WoS), 89 to 1,981 (Scopus), and 126 to 3,492 (GS). The average number of annual citations is termed as citation density which was calculated as 297.49 (WoS), 277.13 (Scopus), and 536.48 (GS) collectively. “Role of *Streptococcus mutans* in human dental decay” (citation density = 62.59) was the most cited “classic” article with 2,003 (WoS), 1,981 (Scopus), and 3,492 (GS) citations.[22] “Genome sequence of *Streptococcus mutans* UA159, a cariogenic dental pathogen” (citation density = 69.68) was ranked as the second “classic” article with 1,115 (WoS), 652 (Scopus), and 955 (GS) citations.[23] “Dental caries” (citation density = 82.27) was ranked as the third “classic” article with 905 (WoS), 952 (Scopus), and 1,954 (GS) citations.[24] “Global burden of untreated caries: A systematic review and meta-regression” had the highest citation density of 89.0.[25] The list of top 100 “classics” on dental caries are presented in ►**Table 1** along with their citation counts in WoS, Scopus, and GS and their citation density.

The Shapiro–Wilk test revealed that the data distribution of citation count, age of publication, and citation density were not normal ($p < 0.01$). The trend towards a greater number of citation counts with publication age was not significant ($r = 0.006$, $p = 0.952$) as shown in ►**Fig. 1**. However, a negative trend towards an increased citation density with increasing time since publication was found to be significant ($r = -0.545$, $p < 0.01$) as shown in ►**Fig. 2**.

According to the CCI based on the year 2019, two out of the top six articles were systematic reviews, three were field expert reviews, and one was caries management system/tool. These findings highlight the sustainability and current relevance of information provided in systematic reviews and expert opinions.

Publication Year

The “classic” publications on the topic of caries were published between 1954[26] and 2015[25] as displayed in ►**Fig. 3**. Ten articles were published in 2004 which was the highest number of publications in any one year. Chronologically, 2 publications in 1950s, 10 in 1960s, 12 in 1970s, 10 in 1980s, 18 in 1990s, 44 in 2000s, and 4 since 2010 were classified as “classics.” From 2000 to 2005, peaks were noticed in the number of “classic” articles, that is, 32. Four out of 100 “classics” were published after the year 1999.

Institution and Country of Publication

The corresponding author of each article and their affiliations revealed that authors from 13 countries made contributions toward caries research. The highest number of publications originated from the United States ($n = 45$) followed by Sweden ($n = 14$), United Kingdom ($n = 11$), Switzerland ($n = 7$), Denmark ($n = 5$), Japan ($n = 4$), Finland ($n = 4$), Netherlands ($n = 3$), Norway ($n = 2$), Brazil ($n = 2$), Germany ($n = 2$), France ($n = 1$), and Australia ($n = 1$).

The highest number of publications originated from the “University of Gothenburg, Gothenburg, Sweden” ($n = 7$) among 50 other institutions, “School of Dentistry, University of Michigan, Ann Arbor, Michigan, United States” ($n = 6$), “National Institutes of Health, Bethesda, Maryland, United States” ($n = 5$), “School of Dentistry, University of California at San Francisco, San Francisco, California, United States” ($n = 5$), “Forsyth Dental Center, The Forsyth Institute, Massachusetts, United States” ($n = 4$), “Royal Dental College, Aarhus University, Aarhus, Denmark” ($n = 4$), “School of Dentistry, University of Lund, Lund, Sweden” ($n = 3$), “Dental Institute, King’s College London, London, United Kingdom” ($n = 3$), “School of Dentistry, Karolinska Institutet, Solna, Sweden” ($n = 3$), and “Institute of Dentistry, University of Helsinki, Helsinki, Finland” ($n = 3$).

Journal of Publication

The 100 “classic” publications on the topic of caries were published across 40 peer-reviewed journals. The journals associated with the most number of publications were “*Journal of Dental Research*” ($n = 19$), “*Caries Research*” ($n = 17$), and “*Archives of Oral Biology*” ($n = 6$). The impact factors of journals ranged from 0.784 (*Pan American Journal of Public Health*) to 53.254 (*The Lancet*). ►**Table 2** summarizes the complete list of all journals.

A significant trend ($p < 0.05$) occurred between a specific journal age and the quantity of “classics” published in that journal ($r = 0.321$). However, a statistically nonsignificant trend ($p = 0.196$) occurred between the quantity of “classics” published in a specific journal and the impact factor of that journal.

Methodological Design

The most common study design among “classics” was review-type ($n = 40$), clinical studies ($n = 23$), laboratory studies ($n = 16$), animal studies ($n = 15$), new classification/tool/technique ($n = 5$), and cohort studies ($n = 1$). Statistical significance was not detected ($p = 0.808$) when exploring the median difference in the citation count per “classic,” between review-type articles 238 (range: 175–2,003), clinical studies 258 (range: 176–567), laboratory studies 224 (range: 184–403), animal studies 250 (range: 176–442), and new classification/tool/technique 207 (range: 174–486).

Evidence Level

The top 100 most-cited “classic” articles could be categorized into all evidence levels. The greatest number of articles were within evidence level V ($N = 41$) followed by evidence level IV ($n = 26$), evidence level III ($n = 16$), evidence level II ($n = 13$), and evidence level I ($n = 4$). Among these evidence levels, the citation density ($r = 0.088$, $p = 0.383$) and the total citation counts ($r = -0.178$, $p = 0.077$) did not vary significantly.

Keywords

A total of 190 unique keywords were found among these “classic” articles. The frequency of occurrence of these keywords were counted as dental caries ($n = 24$) followed by caries ($n = 16$), *Streptococcus mutans* ($n = 14$), fluoride ($n = 6$), dentin ($n = 5$), lactobacillus ($n = 5$), saliva ($n = 5$), *Actinomyces* ($n = 4$), dental plaque ($n = 4$), and gingivitis ($n = 4$). ►**Fig. 4** shows the network analysis of the keywords.

Table 1 Ranking list of the top 100 most cited articles on caries research

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
1	Loesche WJ: Role of *Streptococcus mutans* in human dental decay. Microbiol Rev 1986;50:353–380	2,003	1,981	3,492	62.59	64
2	Ajdić D, McShan WM, McLaughlin RE, Savić G, Chang J, Carson MB, Primeaux C, Tian R, Kenton S, Jia H: Genome sequence of *Streptococcus mutans* ua159, a cariogenic dental pathogen. Proc Natl Acad Sci USA 2002; 99:14434–14439	1,115	652	955	69.68	29
3	Selwitz RH, Ismail AI, Pitts NB: Dental caries. Lancet 2007; 369:51–59	905	952	1,954	82.27	98
4	Gustafsson BE, Quensel C, Lanke LS, Lundqvist C, Grahnen H, Bonow B, Krasse B: The vipeholm dental caries study. The effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years. Acta Odontol Scand 1954; 11:232–364	567	323	976	8.86	4
5	Ismail A, Sohn W, Tellez M, Amaya A, Sen A, Hasson H, Pitts NB: The international caries detection and assessment system (ICDAS): An integrated system for measuring dental caries. Community Dent Oral Epidemiol 2007; 35:170–178	486	497	930	44.19	58
6	Keyes PH: Dental caries in the molar teeth of rats: II. A method for diagnosing and scoring several types of lesions simultaneously. J Dent Res 1958; 37:1088–1099	442	289	518	7.37	9
7	Featherstone JD: The science and practice of caries prevention. J Am Dent Assoc 2000; 131:887–899	437	496	1,132	24.28	24
8	Featherstone JD: Prevention and reversal of dental caries: Role of low level fluoride. Community Dent Oral Epidemiol 1999; 27:31–40	428	480	988	22.53	36
9	Fitzgerald RJ, Keyes PH: Demonstration of the etiologic role of streptococci in experimental caries in the hamster. J Am Dent Assoc 1960; 61:9–19	427	230	724	7.36	2
10	Axelsson P, Lindhe J: Effect of controlled oral hygiene procedures on caries and periodontal disease in adults. J Clin Periodontol 1978; 5:133–151	413	342	737	10.32	4
11	Terleckyj B, Willett N, Shockman G: Growth of several cariogenic strains of oral streptococci in a chemically defined medium. Infect Immun 1975; 11:649–655	403	230	431	9.37	6
12	Axelsson P, Nyström B, Lindhe J: The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults: Results after 30 years of maintenance. J Clin Periodontol 2004;31:749–757	400	421	816	28.57	36

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
13	Becker MR, Paster BJ, Leys EJ, Moeschberger ML, Kenyon SG, Galvin JL, Boches SK, Dewhirst FE, Griffen AL: Molecular analysis of bacterial species associated with childhood caries. J Clin Microbiol 2002; 40:1001–1009	400	403	713	25.00	25
14	Marthaler T: Changes in dental caries 1953–2003. Caries Res 2004; 38: 173–181	397	408	866	28.35	13
15	Takahashi N, Nyvad B: The role of bacteria in the caries process: Ecological perspectives. J Dent Res 2011; 90:294–303	384	397	639	54.85	55
16	Wiegand A, Buchalla W, Attin T: Review on fluoride-releasing restorative materials—fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. Dent Mater 2007; 23:343–362	366	378	655	33.27	34
17	Beltrán-Aguilar ED, Barker LK, Canto MT, Dye BA, Gooch BF, Griffin SO, Hyman J, Jaramillo F, Kingman A, Nowjack-Raymer R: Surveillance for dental caries, dental sealants, tooth retention, edentulism, and enamel fluorosis; united states, 1988-1994 and 1999-2002. MMWR Surveill Summ 2005; 54:1–43	366	455	728	28.15	12
18	Van Houte J: Role of micro-organisms in caries etiology. J Dent Res 1994; 73:672–681	362	395	803	15.08	15
19	Tjäderhane L, Larjava H, Sorsa T, Uitto V-J, Larmas M, Salo T: The activation and function of host matrix metalloproteinases in dentin matrix breakdown in caries lesions. J Dent Res 1998; 77:1622–1629	356	360	561	17.80	18
20	Aas JA, Griffen AL, Dardis SR, Lee AM, Olsen I, Dewhirst FE, Leys EJ, Paster BJ: Bacteria of dental caries in primary and permanent teeth in children and young adults. J Clin Microbiol 2008; 46:1407–1417	351	337	641	35.10	39
21	Featherstone J, Ten Cate J, Shariati M, Arends J: Comparison of artificial caries-like lesions by quantitative microradiography and microhardness profiles. Caries Res 1983; 17:385–391	346	342	563	9.88	11
22	Bowen W, Koo H: Biology of *Streptococcus mutans*-derived glucosyltransferases: Role in extracellular matrix formation of cariogenic biofilms. Caries Res 2011; 45:69–86	340	344	525	48.57	49
23	Harris R, Nicoll AD, Adair PM, Pine CM: Risk factors for dental caries in young children: A systematic review of the literature. Community Dent Health 2004; 21:71–85	333	360	781	23.78	22

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
24	Bagramian RA, Garcia-Godoy F, Volpe AR: The global increase in dental caries. A pending public health crisis. Am J dent 2009; 22:3–8	330	357	694	36.66	31
25	Bratthall D, Hänsel-Petersson G, Sundberg H: Reasons for the caries decline: What do the experts believe? Eur J Oral Sci 1996; 104:416–422	328	377	744	14.90	10
26	Axelsson P, Lindhe J: Effect of controlled oral hygiene procedures on caries and periodontal disease in adults: Results after 6 years. J Clin Periodontol 1981; 8:239–248	304	284	614	8.21	8
27	Yamashita Y, Bowen W, Burne R, Kuramitsu H: Role of the *Streptococcus mutans* GTF genes in caries induction in the specific-pathogen-free rat model. Infect Immun 1993; 61:3811–3817	303	297	388	12.12	7
28	Näse L, Hatakka K, Savilahti E, Saxelin M, Pönkä A, Poussa T, Korpela R, Meurman JH: Effect of long–term consumption of a probiotic bacterium, *Lactobacillus rhamnosus* GG, in milk on dental caries and caries risk in children. Caries Res 2001; 35:412–420	299	314	592	17.58	14
29	Gibbons R, Berman K, Knoettner P, Kapsimalis B: Dental caries and alveolar bone loss in gnotobiotic rats infected with capsule forming streptococci of human origin. Arch Oral Biol 1966; 11:549–560	297	159	401	5.71	1
30	Krasse B: Human streptococci and experimental caries in hamsters. Arch Oral Biol 1966; 11:429–414	286	184	361	5.50	–
31	Marthaler TM, Brunelle J, Downer M, König K, Truin G, Künzel W, O'Mullane D, Møller I, von der Fehr F, Vrbic V: The prevalence of dental caries in Europe 1990-1995. Caries Res 1996; 30: 237–255.	281	331	679	12.77	6
32	Fejerskov O: Changing paradigms in concepts on dental caries: consequences for oral health care. Caries Res 2004; 38:182–191	279	306	817	19.92	23
33	Kaste LM, Selwitz RH, Oldakowski RJ, Brunelle J, Winn DM, Brown LJ: Coronal caries in the primary and permanent dentition of children and adolescents 1–17 years of age: United states, 1988–1991. J Dent Res 1996; 75:631–641	278	323	609	12.63	4
34	Vargas CM, Crall JJ, Schneider DA: Sociodemographic distribution of pediatric dental caries: Nhanes iii, 1988–1994. J Am Dent Assoc 1998; 129:1229–1238	277	328	603	13.85	4

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
35	Lussi A, Imwinkelried S, Pitts N, Longbottom C, Reich E: Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro. Caries Res 1999; 33:261–266	276	307	533	14.52	6
36	Gibbons R, Houte J: Dental caries. Annu Rev Med 1975; 26:121–136	269	158	356	6.25	1
37	Kassebaum N, Bernabé E, Dahiya M, Bhandari B, Murray C, Marcenes W: Global burden of untreated caries: a systematic review and metaregression. J Dent Res 2015; 94:650–658	267	290	480	89.00	86
38	Nyvad B, Machiulskiene V, Bælum V: Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 1999; 33:252–260	262	282	544	13.78	19
39	Gibbons R, Banghart S: Synthesis of extracellular dextran by cariogenic bacteria and its presence in human dental plaque. Arch Oral Biol 1967; 12:11–24	260	125	315	5.09	2
40	Axelsson P, Lindhe J, Nyström B: On the prevention of caries and periodontal disease: Results of a 15-year longitudinal study in adults. J Clin Periodontol 1991; 18:182–189	260	264	557	9.62	8
41	Petersen PE, Lennon MA: Effective use of fluorides for the prevention of dental caries in the 21st century: The WHO approach. Community Dent Oral Epidemiol 2004; 32:319–321	258	212	511	18.42	19
42	Fried D, Xie J, Shafi S, Featherstone JD, Breunig T, Le CQ: Imaging caries lesions and lesion progression with polarization sensitive optical coherence tomography. J Biomed Opt 2002; 7:618–628	258	276	487	16.12	7
43	Axelsson P, Lindhe J: The effect of a preventive programme on dental plaque, gingivitis and caries in schoolchildren. Results after one and two years. J Clin Periodontol 1974; 1:126–138	257	222	430	5.84	2
44	Tanzer JM, Livingston J, Thompson AM: The microbiology of primary dental caries in humans. J Dent Educ 2001; 65:1028–1037	256	268	541	15.05	13
45	Sakanaka S, Kim M, Taniguchi M, Yamamoto T: Antibacterial substances in Japanese green tea extract against *Streptococcus mutans*, a cariogenic bacterium. Agric Biol Chem 1989; 53:2307–2311	252	273	497	8.68	–
46	Nakajima M, Sano H, Burrow M, Tagami J, Yoshiyama M, Ebisu S, Ciucchi B, Russell C, Pashley DH: Tensile bond strength and SEM evaluation of caries-affected dentin using dentin adhesives. J Dent Res 1995; 74:1679–1688	251	258	436	10.91	2

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
47	Keyes PH: The infectious and transmissible nature of experimental dental caries: Findings and implications. Arch Oral Biol 1960; 1:304–320	250	161	580	4.31	3
48	Moreno EC, Kresak M, Zahradnik RT: Fluoridated hydroxyapatite solubility and caries formation. Nature 1974; 247:64–65	244	237	314	5.54	10
49	Lussi A, Megert B, Longbottom C, Reich E, Francescut P: Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. Eur J Oral Sci 2001; 109:14–19	240	261	487	14.11	7
50	Loesche W, Rowan J, Straffon L, Loos P: Association of S*treptococcus mutans* with human dental decay. Infec Immun 1975; 11:1252–1260	240	187	394	5.58	1
51	Leme AP, Koo H, Bellato C, Bedi G, Cury J: The role of sucrose in cariogenic dental biofilm formation—new insight. J Dent Res 2006; 85:878–887	239	249	431	19.91	20
52	Mjör IA, Toffentti F: Secondary caries: A literature review with case reports. Quintessence Int 2000; 31:165–179	238	246	435	13.22	7
53	Chaussain-Miller C, Fioretti F, Goldberg M, Menashi S: The role of matrix metalloproteinases (MMPs) in human caries. J Dent Res 2006; 85:22–32	237	240	406	19.75	17
54	Nyvad B, Kilian M: Comparison of the initial streptococcal microflora on dental enamel in caries-active and in caries-inactive individuals. Caries Res 1990; 24:267–272	235	216	356	8.39	6
55	Moreno E, Kresak M, Zahradnik R: Physicochemical aspects of fluoride-apatite systems relevant to the study of dental caries. Caries Res 1977; 11:142–171	230	215	283	5.60	2
56	Aoki A, Ishikawa I, Yamada T, Otsuki M, Watanabe H, Tagami J, Ando Y, Yamamoto H: Comparison between er: Yag laser and conventional technique for root caries treatment in vitro. J Dent Res 1998; 77:1404–1414	227	246	399	11.36	5
57	Guggenheim B, Schroeder H: Biochemical and morphological aspects of extracellular polysaccharides produced by cariogenic streptococci. Helv Odontol Acta 1967; 11:131–152	224	111	287	4.39	–
58	Moynihan P, Kelly S: Effect on caries of restricting sugars intake: Systematic review to inform who guidelines. J Dent Res 2014; 93:8–18	222	249	466	55.50	57
59	Munson M, Banerjee A, Watson T, Wade W: Molecular analysis of the microflora associated with dental caries. J Clin Microbiol 2004; 42:3023–3029	221	220	370	15.78	14

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
60	Bratthall D: Introducing the significant caries index together with a proposal for a new global oral health goal for 12-year-olds. Int Dent J 2000; 50:378–384	216	219	576	12.00	10
61	Sheiham A: Dental caries affects body weight, growth and quality of life in pre-school children. Br Dent J 2006; 201:625–626	215	224	479	17.91	21
62	Byun R, Nadkarni MA, Chhour K-L, Martin FE, Jacques NA, Hunter N: Quantitative analysis of diverse lactobacillus species present in advanced dental caries. J Clin Microbiol 2004; 42:3128–3136	214	207	370	15.28	10
63	Fejerskov O, Thylstrup A, Larsen MJ: Rational use of fluorides in caries prevention: A concept based on possible cariostatic mechanisms. Acta Odontol Scand 1981; 39:241–249	214	202	378	5.78	6
64	Shi X-Q, Welander U, Angmar-Månsson B: Occlusal caries detection with KaVo DIAGNOdent and radiography: An in vitro comparison. Caries Res 2000; 34:151–158	207	233	376	11.50	6
65	Filstrup SL, Briskie D, Da Fonseca M, Lawrence L, Wandera A, Inglehart MR: Early childhood caries and quality of life: Child and parent perspectives. Pediatr Dent 2003; 25:431–440	206	219	449	13.73	15
66	Dreizen S, Brown LR, Daly TE, Drane JB: Prevention of xerostomia-related dental caries in irradiated cancer patients. J Dent Res 1977; 56:99–104	206	208	319	5.02	4
67	Takahashi N, Nyvad B: Caries ecology revisited: Microbial dynamics and the caries process. Caries Res 2008; 42:409–418	204	220	450	20.40	17
68	Levitch L, Bader J, Shugars D, Heymann H: Non-carious cervical lesions. J of Dent 1994; 22:195–207	201	202	447	8.37	4
69	Alaluusua S, Renkonen OV: *Streptococcus mutans* establishment and dental caries experience in children from 2 to 4 years old. Eur J Oral Sci 1983; 91:453–457	200	111	405	5.71	1
70	Van Nieuw Amerongen A, Bolscher JG, Veerman EC: Salivary proteins: Protective and diagnostic value in cariology? Caries Res 2004; 38:247–253	199	246	458	14.21	11
71	Lukacs JR, Largaespada LL: Explaining sex differences in dental caries prevalence: Saliva, hormones, and "life-history" etiologies. Am J Hum Biol 2006; 18:540–555	198	203	423	16.5	15
72	Pitts N: ICDAS-an international system for caries detection and assessment being developed to facilitate caries epidemiology, research and appropriate clinical management. Community Dent Health 2004; 21:193–198	198	225	405	14.14	18

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
73	Fusayama T: Two layers of carious dentin; diagnosis and treatment. Oper Dent 1979; 4:63–70	198	185	377	5.07	8
74	Edwardsson S: Characteristics of caries-inducing human streptococci resembling *Streptococcus mutans*. Arch Oral Biol 1968; 13:637–646	197	111	261	3.94	1
75	Ahola A, Yli-Knuuttila H, Suomalainen T, Poussa T, Ahlström A, Meurman JH, Korpela R: Short-term consumption of probiotic-containing cheese and its effect on dental caries risk factors. Arch Oral Biol 2002; 47:799–804	196	203	393	12.25	7
76	De Stoppelaar J, Van Houte J, Dirks OB: The relationship between extracellular polysaccharide-producing streptococci and smooth surface caries in 13-year-old children. Caries Res 1969; 3:190–199	195	179	331	3.97	–
77	Petersen PE: Sociobehavioural risk factors in dental caries–international perspectives. Community Dent Oral Epidemiol 2005; 33:274–279	193	196	479	14.84	6
78	Kleinberg I: A mixed-bacteria ecological approach to understanding the role of the oral bacteria in dental caries causation: An alternative to *Streptococcus mutans* and the specific-plaque hypothesis. Crit Rev Oral Biol Med 2002; 13:108–125	192	205	409	12.00	11
79	Casamassimo PS, Thikkurissy S, Edelstein BL, Maiorini E: Beyond the DMFT: The human and economic cost of early childhood caries. J Am Dent Assoc 2009; 140:650–657	191	207	377	21.22	17
80	Köhler B, Andréen I, Jonsson B: The earlier the colonization by mutans streptococci, the higher the caries prevalence at 4 years of age. Oral Microbiol Immunol 1988; 3:14–17	190	207	379	6.33	1
81	Loesche W, Syed S: Predominant cultivable flora of carious plaque and carious dentine. Caries Res 1973; 7:201–216	189	159	242	4.20	–
82	Beighton D: The complex oral microflora of high-risk individuals and groups and its role in the caries process. Community Dent Oral Epidemiol 2005; 33:248–255	187	187	375	14.38	12
83	Burne RA, Marquis RE: Alkali production by oral bacteria and protection against dental caries. FEMS Microbiol Lett 2000; 193:1–6	186	183	295	10.33	16
84	Makinen K, Bennett C, Hujoel P, Isokangas P, Isotupa K, Pape Jr H, Makinen P: Xylitol chewing gums and caries rates: A 40-month cohort study. J Dent Res 1995; 74:1904–1913	185	199	368	8.04	2
85	Zinner DD, Jablon JM, Aran AP, Saslaw MS: Experimental caries induced in animals by streptococci of human origin. Exp Biol Med 1965; 118:766–770	185	93	256	3.49	1

(*continued*)

Table 1 (*continued*)

Rank	Title of the article	No. of citation (Web of Science)	No. of citation (Scopus)	No. of citation (Google Scholar)	Citation density	CCI 2019
86	Yoshiyama M, Tay F, Doi J, Nishitani Y, Yamada T, Itou K, Carvalho R, Nakajima M, Pashley D: Bonding of self-etch and total-etch adhesives to carious dentin. J Dent Res 2002; 81:556–560	184	181	325	11.50	8
87	Marshall TA, Levy SM, Broffitt B, Warren JJ, Eichenberger-Gilmore JM, Burns TL, Stumbo PJ: Dental caries and beverage consumption in young children. Pediatrics 2003; 112:e184–e191	183	215	417	12.20	7
88	Hillson S: Recording dental caries in archaeological human remains. Int J Osteoarchaeol 2001; 11:249–289	183	191	374	10.76	–
89	Brunelle J, Carlos J: Recent trends in dental caries in us children and the effect of water fluoridation. J Dent Res 1990; 69:723–727	181	180	410	6.46	–
90	Brännström M: The hydrodynamic theory of dentinal pain: Sensation in preparations, caries, and the dentinal crack syndrome. J Endod 1986; 12:453–457	180	186	402	5.65	6
91	Narvai PC, Frazao P, Roncalli AG, Antunes J: Dental caries in Brazil: Decline, polarization, inequality and social exclusion. Rev Panam Salud Publica 2006; 19:385–393	179	156	126	14.91	2
92	Kidd EAM, Fejerskov O: What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. J Dent Res 2004; 83:35–38	178	228	580	12.71	15
93	Årtun J, Brobakken BO: Prevalence of carious white spots after orthodontic treatment with multibonded appliances. Eur J Orthod 1986; 8:229–234	178	170	372	5.56	7
94	Larsen M: The nature of early caries lesions in enamel. J Dent Res 1986; 65:1030–1031	176	164	346	5.50	4
95	Michalek SM, Mestecky J, Arnold R, Bozzo L: Ingestion of *Streptococcus mutans* induces secretory immunoglobulin A and caries immunity. Science 1976; 192:1238–1240	176	94	235	4.19	1
96	Von der Fehr FR, Loe H, Theilade E: Experimental caries in man. Caries Res 1970; 4:131–148	176	172	297	3.66	2
97	Fitzgerald R, Jordan H, Stanley H, Poole W, Bowler A: Experimental caries and gingival pathologic changes in the gnotobiotic rat. J Dent Res 1960; 39:923–935	176	89	256	3.03	–
98	Burt BA, Pai S: Sugar consumption and caries risk: A systematic review. J Dent Educ 2001; 65:1017–1023	175	188	407	10.29	5
99	Mitchell TJ: The pathogenesis of streptococcal infections: From tooth decay to meningitis. Nat Rev Microbiol 2003; 1:219–230	175	169	287	11.66	12
100	De Jong EdJ, Sundström F, Westerling H, Tranaeus S, Ten Bosch J, Angmar-Månsson B: A new method for in vivo quantification of changes in initial enamel caries with laser fluorescence. Caries Res 1995; 29:2–7	174	192	212	7.56	4

Abbreviation: CCI, current citation index.

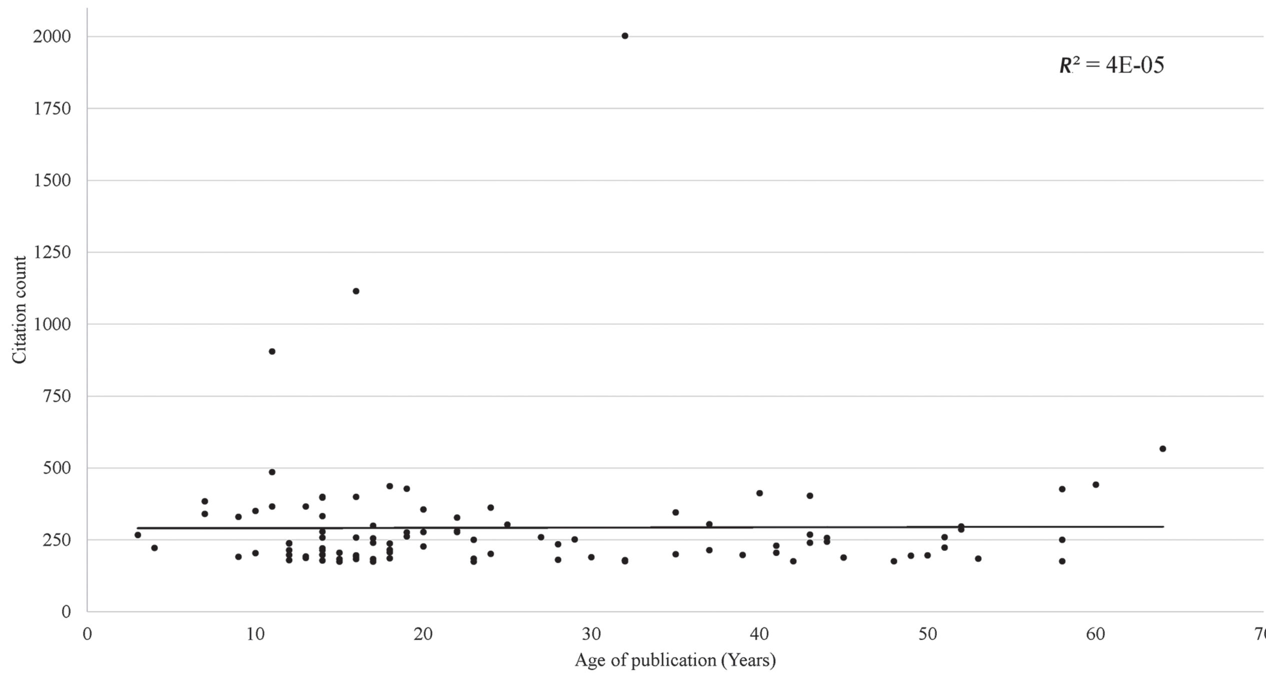

Fig. 1 Association of citation count with age of publication.

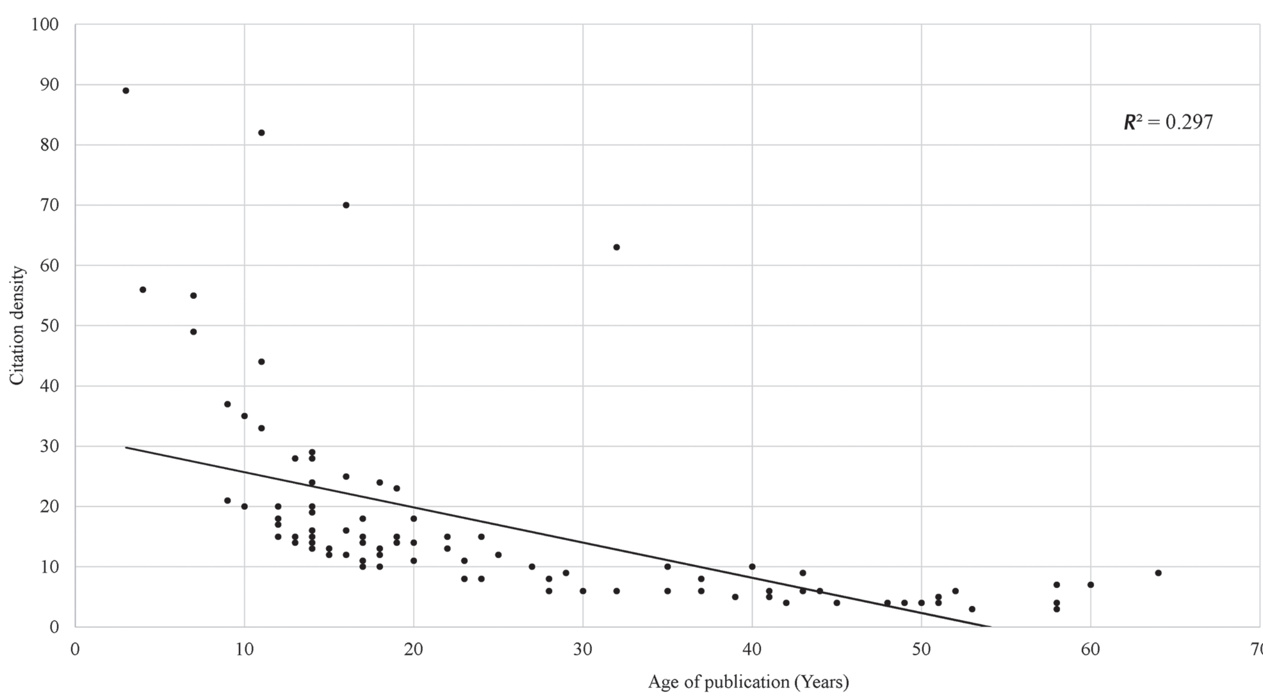

Fig. 2 Change of citation density with age of publication.

Where the keywords are presented as cluster of nodes and the node size represents the frequency of usage of a certain keyword. The size of the node is directly proportional to the usage frequency of a keyword. The thickness of the edges between two keyword nodes represents the closeness of interactions. The node color of the keywords represents their cluster.

Discussion

The current study focused on the identification and analysis of the top 100 "classics" on dental caries and to highlight the change in current trends, centers of excellence in caries research, dominant types of methodology, and technological developments made over time. In the research

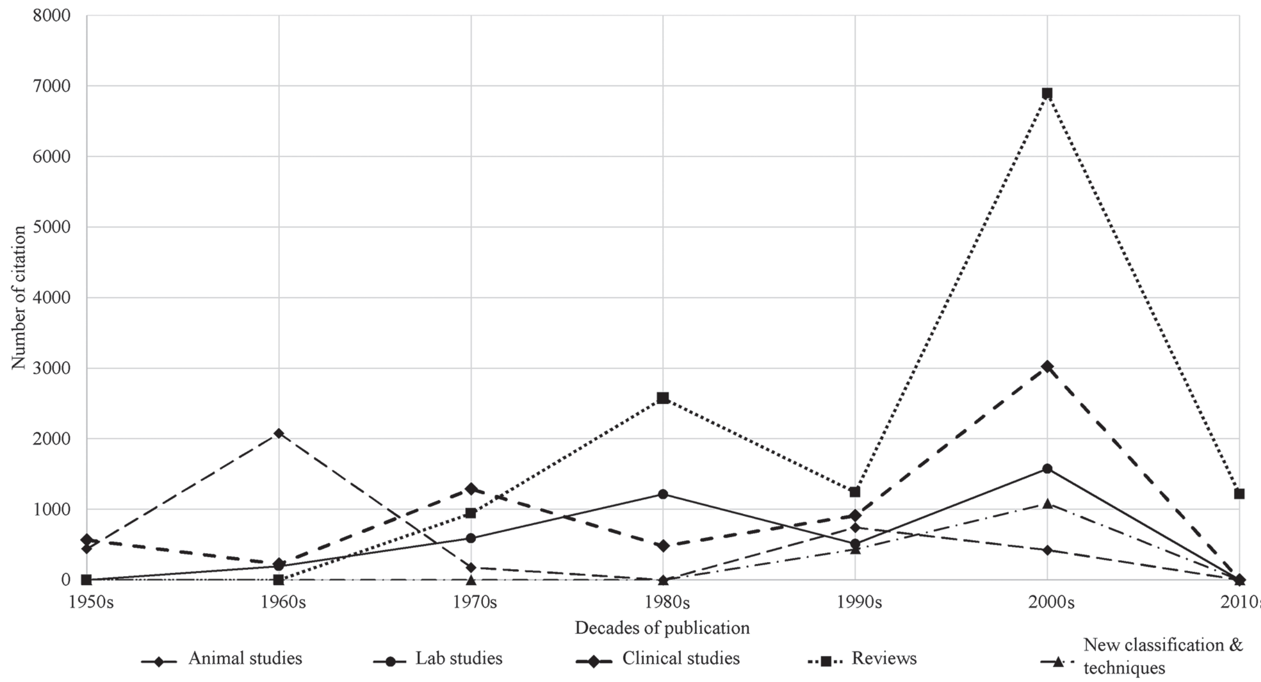

Fig. 3 The time trends in the top 100 most cited caries research articles according to their categories.

field, a publication cited 100 or more times is considered as a "classic" article.[27] Therefore, all articles included in this study can be termed as "classic" in the field of dental caries. WoS was used as a benchmark database as it is capable of measuring the number of citations since 1945 until date.[17] Upon cross-matching the citation counts of "classic" publications with Scopus and GS, a considerable fluctuation was evident which varied between 89 to 952 (Scopus), and it ranged between 126 to 1,954 (GS). The evident fluctuation in the citation counts among different databases emphasizes the role of database selection in scientometry. The chance of duplicate article was not expected as only one database was utilized. Nevertheless, it is noteworthy that only citations from 1996 onwards are measured by Scopus. GS includes in its list different forms of cited materials including Web pages, thesis/dissertations/notes, etc., which can provide misleading results while performing an assessment of the most often cited scientific articles in peer-reviewed journals.[28]

Publication age tends to increase the number of citations for any field regardless of their journal impact.[29] Nevertheless, this assumption is not supported by the current study as 48% publications were from 2000 to 2015 and 52% were from 1954 and 1999. Although recently published articles (past 15 years) have a lower probability of making it to the "classic" list,[15] 29 publications were included from 2004 to 2018. This finding emphasizes the relevance, quality, and impact of the topic of a publication on the clinical practice and research. Recently published articles (after 2015) have also been highly cited; however, it is still too early to foresee how the publication age influences the citation count of these publications.

In addition to current study, other bibliometric studies have documented that authors from Africa, South America, Asia, and the Middle East whether being the corresponding or first authors did not make a major contribution which could be counted toward the "classic" articles.[30-33] Possible explanations might include language barriers, gaps in professional networking, conducting research, and limited information access. The findings of current study identify a need to turn the focus of caries research toward developing countries where it is more widespread.[34] The United Nations Organization and the World Health Organization could play a key role in promoting these health care developments.

A total of 301 authors contributed to these "classic" articles. Most of the authors contributed as the first author and the corresponding author simultaneously. J.D.B. Featherstone contributed the most as the corresponding author in three articles. A single author wrote 21 articles and only 2 authors contributed in another 32 articles. Interestingly, N.B. Pitts contributed as the last author of two of the top five "classic" articles which were written by the same author.

The United States have ample financial resources, a larger scientific population, and active researchers which explains its significant contribution to the field of dental caries and explains its greater contribution to the list of top 100 "classics".[13,31,33,35-38] In addition to the unparaleled research activity of the United States, authors have shown a tendency to favor citation of publication originating from within the United States.[39] It is interesting to note that 35 out of 45 articles originating from the United States were published in the journals of origin other than the United States. The Scandinavian countries despite their smaller population size made considerable contributions ($n = 21$).

In research, the highest quality of evidence is extracted from randomized controlled trials (RCTs) and presented in systematic reviews which are then subjected to meta-analyses to form an evidence base.[40] The current study identified 13 RCTs and 4

Table 2 List of journals which published the top 100 "classic" articles on caries research

Journal name	No. of publication	Impact factor	Journal name	No. of publication	Impact factor
Journal of Dental Research	19	5.383	Caries Research	17	2.188
Archives of Oral Biology	6	2.050	Community Dentistry and Oral Epidemiology	5	1.992
Journal of the American Dental Association	4	2.486	Journal of Clinical Periodontology	5	4.046
Journal of Clinical Microbiology	4	4.054	European Journal of Oral Sciences	3	1.655
Infection and Immunity	3	3.256	Community Dental Health	2	0.956
Acta Odontologica Scandinavica	2	1.522	Journal of Dental Education	2	1.102
The Lancet	1	53.254	Nature	1	41.577
Science	1	41.058	Nature Reviews Microbiology	1	31.851
Annual Review of Medicine	1	14.970	Microbiology and Molecular Biology Reviews	1	13.439
MMWR: Morbidity and Mortality Weekly Report	1	12.888	Proceedings of the National Academy of Sciences of the United States of America	1	9.504
Pediatrics	1	5.515	Dental Materials	1	4.039
Journal of dentistry	1	3.770	Journal of Endodontics	1	2.886
Oral Microbiology and Immunology (Molecular Oral Microbiology)	1	2.853	Experimental Biology and Medicine	1	2.413
Journal of Biomedical Optics	1	2.367	Operative Dentistry	1	2.130
European Journal of Orthodontics	1	2.033	Pediatric Dental Journal	1	1.947
FEMS Microbiology Letters	1	1.735	American Journal of Human Biology	1	1.575
International Journal of Osteoarchaeology	1	1.432	International Dental Journal	1	1.389
British Dental Journal	1	1.274	Agricultural and Biological Chemistry	1	1.255
Helvetica Odontologica Acta	1	1.209	Quintessence International	1	1.088
Pan American Journal of Public Health	1	0.784	American Journal of Dentistry	1	0.760

systematic reviews which were included as "classic" articles. It is noteworthy to mention that the Cochrane reviews could not secure a position in the current study although they are internationally recognized as the highest level of evidence base.[34] A possible explanation of this exclusion is the lower number of citations received by Cochrane reviews is that WoS covers the updated version of Cochrane reviews which started in 2005 and have not yet gained significant age of publications.[34] Although narrative reviews are classified as a lower level of evidence, 29 review-type publications made to the list of "classic" articles. The presence of so many reviews (36%) signifies the preference of several authors in compiling existing knowledge and information on the topics within the field of caries for the advantage of coresearchers and readers. With the changing trends, evidence-based dentistry has gained significant importance, whereas the current study indicates that the most often cited articles had lower levels of evidence and not necessarily the greatest scientific importance[41]; this finding has been previously documented.[13,15]

High impact factor journals such as the *The Lancet*, *Nature*, *Science*, *Annual Review of Medicine*, *Journal of Dental Research*, and *Caries Research* have published most of the "classic" publications. An inclination toward publishing in influential journals was noted which follows Bradford's law, that "most researchers secure their citations from a few specific core journals."[42] Publication by these authors in other journals may result in reduction of impact of their publication. *Journal of Dental Research*, *Journal of Clinical Periodontology*, and *Caries Research* are identified as the specific nucleus journals of research related to the caries research.

Keywords are the most important component of a research paper in terms of accessibility. Keywords act as "sources codes" which are used to retrieve the relevant published literature from an infinite database of knowledge.[43,44] We identified the most commonly used keywords relevant to the dental caries to enable and facilitate study of dental caries through different search engines. "Fluoride" was identified as the fourth most commonly used keyword by authors after "*Streptococcus mutans*." The presence of increased levels of *Streptococcus mutans* in saliva has been correlated with an increased prevalence of caries in numerous studies.[45,46] Therapeutic effect of fluoride on reducing the prevalence of dental caries has been widely reported.[47,48] Nevertheless, limitation of dosage according to the recommendations plays a key role to avoid further complications.[49]

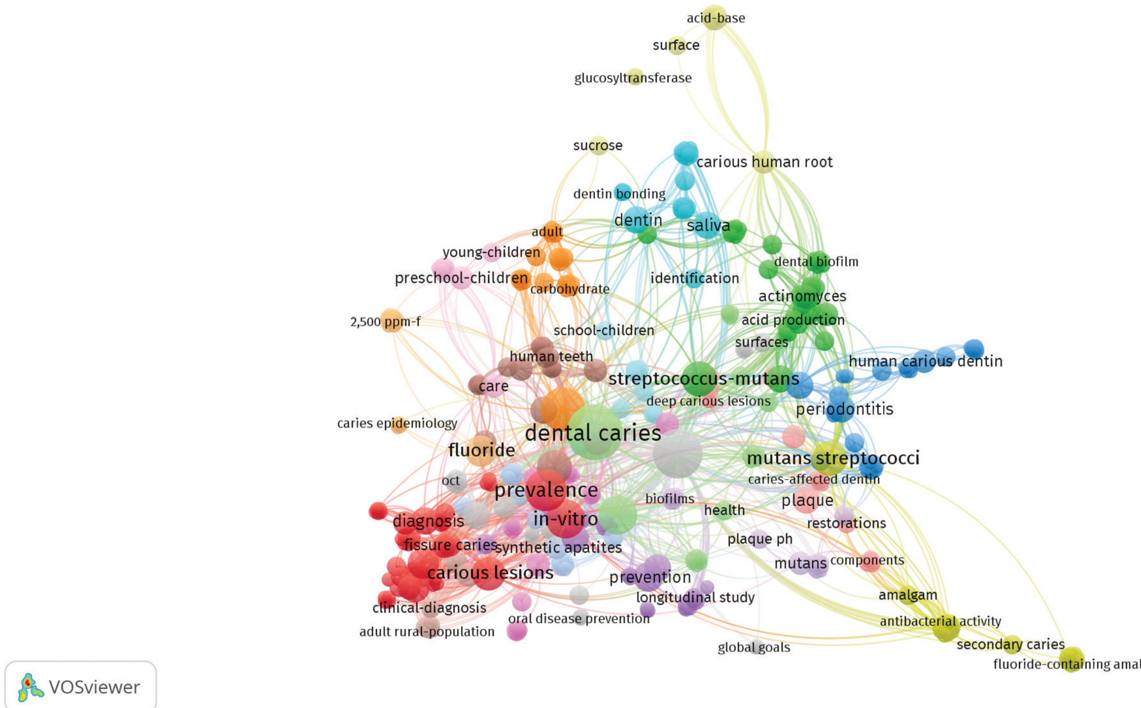

Fig. 4 Keyword network analysis.

Although it is questionable to judge the validity of a publication based on citation counts, a strong association between impact on a field and high citation counts has been reported.[50] Factors which influence the counts of citation of a publication include recitation of highly cited article, author reputation in a specific field, and preference of a specific (reputable) journal. The factors described above and others make the number of citations an impartial reflector of the impact and quality of a publication. Modern day platforms such as hashtags, likes, tweets, shares, downloads, and trends depict the influence of electronic media and the impact of a publication on a day-to-day basis which might project a publication as the most cited within the first 3 days of its publication.[51]

The strengths of this study are: an accepted and commonly used technical methodology, high interrater reliability due to simple inclusion and exclusion criteria, and quality control through two independent investigators and discussion to resolve inconsistencies. The limitations of this study include the fact that the WoS "All Databases" did not measure citations for articles published before 1945. Hence, there might be a possibility of omission of important publications before this date. Second, a publication can have many coauthors from different regions of the world, but the address and affiliation of the corresponding author could only be recognized and has been documented which could have resulted in the possible contributions from other countries and institutions of the world being missed. Third, only the articles published in indexed journals were included: however, it appears unlikely that such a publication would have a high citation count.

Conclusion

This is the first study reporting the list of top 100 "classics" on dental caries. Citation density and citation count did not have a significant association with the publication year. This study despite its inherent limitations attempts to provide a quantitative measure of the impact that a publication imparts on its relevant specialty/field.

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Conflict of Interest

None declared.

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