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ARQUIVOS EM ODONTOLOGIA

Glass Ionomer Cement: A Bibliometric Analysis of the 100 Most-Cited Papers

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Aim: To analyze the characteristics of the 100 most-cited papers on Glass Ionomer Cement (GIC) through bibliometric analysis.

Methods: A search was performed on November 28th, 2023, using the Web of Science Core and density of citations; year and journal of publication; study design; main topic (objective of the study and type of GIC); authors; institutions; keywords; countries and continents. Scopus and Google Scholar were used to compare the number of citations. Bibliometric networks were generated in VOSviewer.

Results: Papers received a total of 15,368 citations, ranging from 84 to 553. The papers were published between 1971 and 2018. The journal that predominated the most was Dental Materials (18%). The majority were laboratory studies (61%), evaluating the procedure performed with GIC (16%). GIC was applied mainly in restorative procedures (79%) the most used type was conventional (50%). The continent with the highest number of publications was Europe (63%), with emphasis on the United Kingdom (23%). The Government Chemist's Laboratory was the most frequent institution (14%), and Wilson AD had the most publications (13%).

Conclusion: The top 100 cited papers primarily originate from Europe and mostly consist of laboratory studies exploring GIC's clinical performance in restorative dentistry. It's recommended the development of further interventional studies on GIC, focused on the clinic improvement of the material.

Uniterms: glass ionomer cements; dental caries; bibliometrics; dental materials.

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INTRODUCTION

The material commonly referred to as Glass Ionomer Cement (GIC) derives from Glass Polyalkenoate Cement, owing to the utilization of polyalkenoic acids as polymers, which initiates an acid-base reaction, resulting in the formation of a durable material with an acceptable appearance[1]. This material exhibits bioactivity and releases fluoride, while also possessing adhesive properties[2]. These characteristics make it valuable as both a restorative and adhesive-feasible material[3].

Polyacrylate cement has shown innovation owing to its notable adhesion to enamel and dentin, along with low toxicity, initially used for

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orthodontic purposes. Additionally, polyacrylic acid has demonstrated antibacterial properties[4]. Its early manifestations date back to around 1972 when it was developed to enhance dental silicate cement. Wilson and Kent pioneered the production of the first glass with high fluoride content, which proved to be a functional cement[3].

Due to their multifunctionality, these cements are classified into various types, including those used for luting, restoration, and lining purposes[3,5]. The evolution of GIC has enabled improvements in properties through the incorporation of reinforcing particles. High-viscosity glass ionomer cement (HVGIC) is characterized by a higher powder-to-liquid ratio and smaller, more reactive glass particles, resulting in increased viscosity and faster initial setting. Consequently, this material is indicated for definitive restorations in primary and permanent teeth, particularly in small to medium-sized cavities, and is widely used in the Atraumatic Restorative Treatment (ART) approach[6,7]. Resin-modified glass ionomer cement (RMGIC) contains polyacrylic acid modified with hydrophilic monomers, mainly 2-hydroxyethyl methacrylate (HEMA), in addition to photo-initiators[8]. It sets through an acid–base reaction combined with light-activated polymerization (dual curing), exhibiting reduced sensitivity to moisture and dehydration during the initial setting phase, as well as improved mechanical properties, dimensional stability, and surface finish. Clinically, it is indicated for restorations subjected to low to moderate masticatory stress, non-carious cervical lesions, and for use as a base or surface sealan[9,10]. Metal-modified glass ionomer cement is obtained by incorporating metallic particles, typically silver, while maintaining the acid–base setting reaction. It exhibits increased wear, compressive resistance and antimicrobial potential; however, it presents a grayish color and higher surface roughness. Therefore, it is mainly indicated for core build-ups, provisional restorations, or clinical situations in which esthetics is not a priority[11].

Given an extended period of utilization in promoting oral health and demonstrating outstanding performance, GIC has been subject to extensive investigation and dissemination worldwide over the years. Studies comparing different brands of GICs have resulted in diverse findings about their mechanical properties, making it nearly impossible to compare them due to differences in the methodology employed across the majority of studies[12].

Hence, there is a necessity to undertake studies that comprehensively evaluate the vast repository of scientific evidence available, both qualitatively and quantitatively. In this context, bibliometric analysis serves as a valuable tool for evaluating the impact, growth, and trends in scientific production within a specific field of knowledge[13,14]. It's believed that highly cited papers have the potential to influence clinical practice and shape future research directions[13]. Therefore, the absence of a bibliometric review on GIC makes an interesting and necessary purpose. This paper aimed to examine the bibliometric characteristics of the 100 most-cited papers related to GIC.

METHODOLOGY

Information sources and search strategy

This bibliometric review was reported in accordance with the Methodological Guideline for Reporting Bibliometric Reviews in Dentistry (METRICS). The search was conducted on November 28, 2023, using the Web of Science Core Collection (WoS-CC) database. A comprehensive search strategy was developed to retrieve publications related to GIC. Controlled and non-controlled descriptors, including MeSH terms and commonly used synonyms, were identified based on the literature. The search string included "glass ionomer cement" and its variants: ("Glass Ionomer Cement*" OR "Cement*, Glass Ionomer" OR "Ionomer Cement, Glass" OR "Cement*, Glass-Ionomer" OR "Modified, Glass Ionomer Cement" OR "polyalkenoate Cement" OR "glass polyalkenoate cements" OR "Glass-Ionomer Cement"). Boolean operators were applied to maximize sensitivity and, when necessary, to restrict the results to the dental context. The strategy was adapted to the database-specific search fields (title, abstract, and keywords). Pilot research was performed to refine the terms and ensure alignment with the scope of the study. The retrieved papers were ranked in descending order according to the number of citations.

Eligibility criteria

The search was restricted to papers associated with GIC. It was not applied to any language, geographical, or year of publication filters. However, books, book chapters, editorials, letters to the editor, notes, and conference papers were excluded. Publications in which glass ionomer cement was not the primary focus of the study, including those that mentioned the material only marginally or as a secondary component, were also excluded. In addition, duplicated records, studies unrelated to dental applications, and publications lacking sufficient bibliographic information for citation analysis were not considered. Two independent researchers (AV and AOR) identified the 100 most-cited papers after reading the titles, abstracts, and full texts, when necessary. Any disagreement was resolved through discussion and consensus with a third researcher (MC).

Data selection

Information extracted from the papers included title, authorship, number of citations, year of publication, journal title, study design, topic, and keywords. Also, institutions, countries, and continents were determined based on the corresponding author's affiliation. Citation density was also evaluated, which corresponds to a bibliometric indicator defined as the average number of citations an article receives per year since its publication, calculated by dividing the total number of citations by the number of years elapsed. This metric helps normalize citation counts over time, allowing fairer comparisons between older and more recent publications by accounting for differences in exposure time[15]. All data were double-checked to avoid errors.

The papers were cross-matched with their citation counts using Scopus and Google Scholar databases. In the event of a tie, the papers' ranking on the list was determined by their WoS-CC citation density, calculated as the ratio of the number of citations to the publication period in years. The paper with the highest WoS-CC citation density was assigned to the higher position. In a tie persisted, the paper with the highest number of citations in Scopus was consulted for ranking[16].

Study design and topics

Study designs were categorized into systematic reviews, literature reviews, laboratory studies (*in vitro* or *in vivo* study), observational studies (cross-sectional, prospective, retrospective, or longitudinal studies), and interventional studies (clinical studies involving patient intervention or randomized clinical trial).

The included articles were grouped into three distinct themes: [1] main objective of the study - adherence of the GIC with the dental structure, release of fluoride from the GIC, assessment of GIC's antimicrobial activity, anticariogenic potential of the GIC, biocompatibility of the GIC with oral tissues, clinical evaluation of procedure performed with GIC, color analysis of the GIC, assessment of two or more properties (chemical, mechanical, or physical) of the GIC, material strength of the GIC, contraction of the GIC during healing, and scientific status; [2] clinical application of GIC - restoration, cementation and coating/base; and [3] type of GIC - conventional or resin-modified. Articles that did not specify the type of material were classified as "unidentified".

Bibliometric and statistical data analysis

The VOSviewer software was used to generate collaboration graphs between authors and the most frequent author keywords. Each point on the density map has a color that indicates the density of items at that point. The terms associated with the biggest points and written in a prominent font represent the most frequent data. The union between terms by lines indicates collaboration between the selected studies[17].

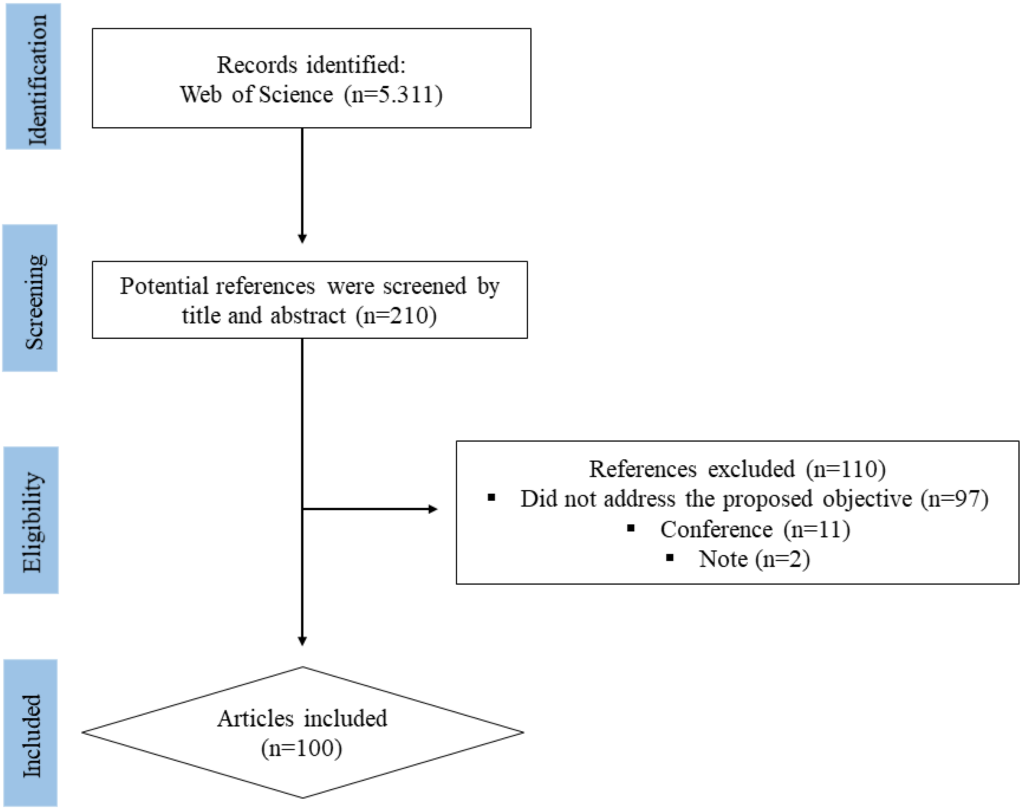
Data analysis was performed with the statistical package SPSS for Windows (SPSS, version 24.0; IBM Corp) to determine correlations in the number of citations between the databases. The Kolmogorov-Smirnov test was used to verify the normality of data distribution. The Spearman rank correlation coefficient test was used since the data did not present a normal distribution.

RESULTS

Search results

The WoS-CC search resulted in 5,311 documents which were arranged in descending order according to the number of citations to select the top 100 most-cited papers (Figure 1). The papers included in the review can be seen in Table 1.

Figure 1. Paper selection flowchart.



Source: authors.

Table 1. List of Top 100 papers in Glass Ionomer Cement.

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		Number of citations (Citation density)		
Rank	**Paper**	**Web of Science**	**Google Schoolar**	**Scopus**
1	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 Mar;23(3):343-62.	553 (34.6)	1164 (72.8)	629 (39.3)
2	Wilson AD, Kent BE. New translucent cement for dentistry - glass ionomer cement. Br Dent J. 1972 Feb 15;132(4):133-5.	548 (10.7)	1416 (27.8)	625 (12.3)
3	Davidson CL, Feilzer AJ. Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives. J Dent. 1997 Nov;25(6):435-40.	513 (19.7)	1090 (41.9)	556 (21.4)
4	Yoshida Y, Van Meerbeek B, Nakayama Y, Snauwaert J, Hellemans L, Lambrechts P, Vanherle G, Wakasa K. Evidence of chemical bonding at biomaterial-hard tissue interfaces. J Dent Res. 2000 Feb;79(2):709-14.	331 (14.4)	695 (30.2)	373 (16.2)
5	Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: A review of the current literature. J Prosthet Dent. 1998 Sep;80(3):280-301.	331 (13.2)	1036 (41.4)	375 (15.0)
6	Wilson AD, Kent BE. The glass-ionomer cement, a new translucent dental filling material. J Appl Chem. 1971 Nov;21(11):313-313.	321 (6.2)	619 (11.9)	352 (6.8)
7	Busscher HJ, Rinastiti M, Siswomihardjo W, van der Mei HC. Biofilm formation on dental restorative and implant materials. J Dent Res. 2010 Jul;89(7):657-65.	318 (24.5)	598 (46.0)	353 (27.2)
8	Xie D, Brantley WA, Culbertson BM, Wang G. Mechanical properties and microstructures of glass-ionomer cements. Dent Mater. 2000 Mar;16(2):129-38.	308 (13.4)	747 (32.5)	346 (15.0)
9	Mjör AJ, Moorhead JE, Dahl JE. Reasons for replacement of restorations in permanent teeth in general dental practice. Int Dent J. 2000 Dec;50(6):361-6.	307 (13.3)	610 (2.6)	347 (15.1)
10	Geurtsen W. Biocompatibility of resin-modified filling materials. Crit Rev Oral Biol Med. 2000;11(3):333-55.	292 (12.7)	561 (24.4)	325 (14.1)

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11	Goldberg M. In vitro and in vivo studies on the toxicity of dental resin components: a review. Clin Oral Investig. 2008 Mar;12(1):1-8.	281 (18.7)	543 (36.2)	314 (20.9)
12	Bagheri R, Burrow MF, Tyas M. Influence of food-simulating solutions and surface finish on susceptibility to staining of aesthetic restorative materials. J Dent. 2005 May;33(5):389-98.	274 (15.2)	814 (45.2)	335 (18.6)
13	Powis DR, Folleras T, Merson SA, Wilson AD. Improved adhesion of a glass ionomer cement to dentin and enamel. J Dent Res. 1982 Dec;61(12):1416-22.	255 (6.2)	479 (11.7)	286 (7.0)
14	Swartz ML, Phillips RW, Clark HE. Long-term f release from glass ionomer cements. J Dent Res. 1984 Feb;63(2):158-60.	250 (6.4)	432 (11.1)	264 (6.8)
15	Hotz P, McLean JW, Sced I, Wilson AD. The bonding of glass ionomer cements to metal and tooth substrates. Br Dent J. 1977 Jan 18;142(2):41-7.	227 (4.9)	417 (9.1)	243 (5.3)
16	Mjör IA. The reasons for replacement and the age of failed restorations in general dental practice. Acta Odontol Scand. 1997 Jan;55(1):58-63.	225 (8.7)	426 (16.4)	256 (9.8)
17	Feilzer AJ, De Gee AJ, Davidson CL. Curing contraction of composites and glass-ionomer cements. J Prosthet Dent. 1988 Mar;59(3):297-300.	222 (6.3)	528 (15.1)	255 (7.3)
18	Hilton TJ. Keys to clinical success with pulp capping: a review of the literature. Oper Dent. 2009 Sep-Oct;34(5):615-25.	187 (13.4)	535 (38.2)	238 (17.0)
19	Atmeh AR, Chong EZ, Richard G, Festy F, Watson TF. Dentin-cement interfacial interaction: calcium silicates and polyalkenoates. J Dent Res. 2012 May;91(5):454-9.	179 (16.3)	466 (42.4)	206 (18.7)
20	Ahovuo-Saloranta A, Forss H, Walsh T, Hiiri A, Nordblad A, Mäkelä M, Worthington HV. Sealants for preventing dental decay in the permanent teeth. Cochrane Database Syst Rev. 2013 Mar 28:(3):CD001830.	176 (17.6)	401 (40.1)	259 (25.9)
21	Lin A, McIntyre NS, Davidson RD. Studies on the adhesion of glass-ionomer cements to dentin. J Dent Res. 1992 Nov;71(11):1836-41.	173 (5.6)	356 (11.5)	204 (6.6)
22	Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. Biomaterials. 2003 Jun;24(14):2451-61.	172 (8.6)	440 (22.0)	219 (11.0)
23	Kopperud SE, Tveit AB, Gaarden T, Sandvik L, Espelid I. Longevity of posterior dental restorations and reasons for failure. Eur J Oral Sci. 2012 Dec;120(6):539-48.	169 (15.4)	363 (33.0)	187 (17.0)
24	Moshaverinia A, Ansari S, Moshaverinia M, Roohpour N, Darr JD, Rehman I. Effects of incorporation of hydroxyapatite and fluoroapatite nanobioceramics into conventional glass ionomer cements (GIC). Acta Biomater. 2008 Mar;4(2):432-40.	168 (11.2)	381 (25.4)	211(14.1)
25	Piwowarczyk A, Lauer HC, Sorensen JA. In vitro shear bond strength of cementing agents to fixed prosthodontic restorative materials. J Prosthet Dent. 2004 Sep;92(3):265-73.	165 (8.7)	418 (22.0)	185 (9.7)
26	Geurtsen W, Spahl W, Leyhausen G. Residual monomer additive release and variability in cytotoxicity of light-curing glass-ionomer cements and compomers. J Dent Res. 1998 Dec;77(12):2012-9.	156 (6.2)	282 (11.3)	170 (6.8)
27	Attar N, Tam LE, McComb D. Mechanical and physical properties of contemporary dental luting agents. J Prosthet Dent. 2003 Feb;89(2):127-34.	153 (7.7)	446 (22.3)	182 (9.1)
28	Lohbauer U. Dental glass ionomer cements as permanent filling materials? Properties, limitations, and future trends. Materials 2010;3(1):76-96;	153 (11.8)	391 (30.1)	166 (12.8)
29	Ahovuo-Saloranta A, Forss H, Walsh T, Nordblad A, Mäkelä M, Worthington HV. Pit and fissure sealants for preventing dental decay in permanent teeth. Cochrane Database Syst Rev. 2017 Jul 31;7(7):CD001830.	152 (25.3)	765 (127.5)	314 (52.3)
30	Fujimoto Y, Iwasa M, Murayama R, Miyazaki M, Nagafuji A, Nakatsuka T. Detection of ions released from S-PRG fillers and their modulation effect. Dent Mater J. 2010 Aug;29(4):392-7.	148 (11.4)	245 (18.8)	159 (12.2)
31	Chatzistavrou E, Eliades T, Zinelis S, Athanasiou AE, Eliades G. Fluoride release from glass ionomer cement invivo and invitro. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4):458.e1-8; discussion 458-9.	148 (4.6)	281 (8.8)	159 (5.0)
32	Xie D, Weng Y, Guo X, Zhao R, Gregory RL, Zheng C. Preparation and evaluation of a novel glass-ionomer cement with antibacterial functions. Dent Mater. 2011 May;27(5):487-96.	144 (12.0)	228 (19.0)	156 (13.0)
33	Inokoshi S, Burrow MF, Kataumi M, Yamada T, Takatsu T. Opacity and color changes of tooth-colored restorative materials. Oper Dent. 1996 Mar-Apr;21(2):73-80.	143 (5.3)	346 (12.8)	161 (6.0)
34	Derks A, Katsaros C, Frencken JE, van't Hof MA, Kuijpers-Jagtman AM. Caries-inhibiting effect of preventive measures during orthodontic treatment with fixed appliances - A systematic review. Caries Res. 2004 Sep-Oct;38(5):413-20.	141 (7.4)	334 (17.6)	160 (8.4)

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35	Abdullah D, Pitt Ford TR, Papaioannou R, Nicholson J, McDonald F. An evaluation of accelerated Portland cement as a restorative material. Biomaterials. 2002 Oct;23(19):4001-10.	138 (6.6)	392 (18.7)	167 (8.0)
36	Takahashi Y, Imazato S, Kaneshiro AV, Ebisu S, Frencken JE, Tay FR. Antibacterial effects and physical properties of glass-ionomer cements containing chlorhexidine for the ART approach. Dent Mater. 2006 Jul;22(7):647-52.	135 (7.9)	305 (17.9)	167 (9.8)
37	McLean JW, Wilson AD. The clinical development of glass-ionomer cements .1. Formulations and properties. Aust Dent J. 1977 Feb;22(1):31-6.	133 (2.9)	262 (5.7)	135 (2.9)
38	Crisp S, Pringuer MA, Wardleworth D, Wilson AD. Reactions in glass ionomer cements .2. Infrared spectroscopic study. J Dent Res. 1974 Nov-Dec;53(6):1414-9.	131 (2.7)	215 (4.4)	135 (2.8)
39	Gorton J, Featherstone J. In vivo inhibition of dermineralization around orthodontic brackets. Am J Orthod Dentofacial Orthop. 2003 Jan;123(1):10-4.	129 (6.5)	344 (17.2)	145 (7.3)
40	Zhi QH, Lo E, Lin HC. Randomized clinical trial on effectiveness of silver diamine fluoride and glass ionomer in arresting dentine caries in preschool children. J Dent. 2012 Nov;40(11):962-7.	128 (11.6)	335 (30.5)	153 (13.9)
41	Walls AW. Glass polyalkenoate (glass-ionomer) cements - a review. J Dent. 1986 Dec;14(6):231-46.	128 (3.5)	239 (6.5)	146 (3.9)
42	McLean JW, Powis DR, Prosser HJ, Wilson AD. The use of glass-ionomer cements in bonding composite resins to dentin. Br Dent J. 1985 Jun 8;158(11):410-4.	126 (3.3)	344 (9.1)	188 (4.9)
43	McLean JW, Wilson AD. Fissure sealing and filling with an adhesive glass-ionomer cement. Br Dent J. 1974 Apr 2;136(7):269-76.	124 (2.5)	251 (5.1)	127 (2.6)
44	Matsuya S, Maeda T, Ohta M. IR and NMR analyses of hardening and maturation of glass-ionomer cement. J Dent Res. 1996 Dec;75(12):1920-7.	124 (4.6)	188 (7.0)	126 (4.7)
45	Wasson EA, Nicholson JW. New aspects of the setting of glass-ionomer cements. J Dent Res. 1993 Feb;72(2):481-3.	123 (4.1)	177 (5.9)	114 (3.8)
46	Burke FJ, Cheung SW, Mjör IA, Wilson NH. Restoration longevity and analysis of reasons for the placement and replacement of restorations provided by vocational dental practitioners and their trainers in the United Kingdom. Quintessence Int. 1999 Apr;30(4):234-42.	123 (5.1)	255 (10.6)	136 (5.7)
47	Auschill TM, Arweiler NB, Brecx M, Reich E, Sculean A, Netuschil L.The effect of dental restorative materials on dental biofilm. Eur J Oral Sci. 2002 Feb;110(1):48-53.	121 (5.8)	288 (13.7)	135 (6.4)
48	Tyas MJ, Burrow MJ. Adhesive restorative materials: A review. Aust Dent J. 2004 Sep;49(3):112-21; quiz 154.	119 (6.3)	354 (18.6)	139 (7.3)
49	Ahovuo-Saloranta A, Hiiri A, Nordblad A, Mäkelä M, Worthington HV. Pit and fissure sealants for preventing dental decay in the permanent teeth of children and adolescents. Cochrane Database Syst Rev. 2008 Oct 8:(4):CD001830.	119 (7.9)	343 (22.9)	314 (20.9)
50	Maldonado A, Swartz ML, Phillips RW. An in vitro study of certain properties of a glass ionomer cement. J Am Dent Assoc. 1978 May;96(5):785-91.	119 (2.6)	215 (4.8)	122 (2.7)
51	Benelli EM, Serra MC, Rodrigues Jr AL, Cury JA. In-situ anticariogenic potential of glass-ionomer cement. Caries Res. 1993;27(4):280-4.	117 (3.9)	265 (8.8)	124 ()4.1
52	Dauvillier BS, Feilzer AJ, De Gee AJ, Davidson CL. Visco-elastic parameters of dental restorative materials during setting. J Dent Res. 2000 Mar;79(3):818-23.	117 (5.1)	252 (11.0)	132 (5.7)
53	Hickel R, Kaaden C, Paschos E, Buerkle V, García-Godoy F, Manhart J. Longevity of occlusally-stressed restorations in posterior primary teeth. Am J Dent. 2005 Jun;18(3):198-211.	115 (6.4)	232 (12.9)	121 (6.7)
54	McLean JW, Wilson AD. The clinical development of glass-ionomer cement .II. Some clinical applications. Aust Dent J. 1977 Apr;22(2):120-7.	115 (2.5)	202 (4.4)	120 (2.6)
55	Kent BE, Lewis BG, Wilson AD. The properties of a glass ionomer cement. Br Dent J. 1973 Oct 2;135(7):322-6.	114 (2.3)	283 (5.7)	125 (2.5)
56	Attin T, Buchalla W, Kielbassa AM, Helwig E. Curing shrinkage and volumetric changes of resin-modifed glass ionomer restorative materials. Dent Mater. 1995 Nov;11(6):359-62.	113 (4.0)	259 (9.3)	118 (4.2)
57	Montanaro L, Campoccia D, Rizzi S, Donati MH, Breschi L, Prati C, Arciola CR. Evaluation of bacterial adhesion of Streptococcus mutans on dental restorative materials. Biomaterials. 2004 Aug;25(18):4457-63.	111 (5.8)	245 (12.9)	126 (6.6)
58	Creanor SL, Carruthers LM, Saunders WP, Strang R, Foye RH. Fluoride uptake and release characteristics of glass-ionomer cements. Caries Res. 1994;28(5):322-8.	111 (3.8)	234 (8.1)	123 (4.2)

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59	Friedman S, Löst C, Zarrabian M, Trope M. Evaluation of success and failure after endodontic therapy using a glass-ionomer cement sealer. J Endod. 1995 Jul;21(7):384-90.	110 (3.9)	310 (11.1)	126 (4.5)
60	Mejàre I, Lingström P, Petersson LG, Holm AK, Twetman S, Källestål C, Nordenram G, Lagerlöf F, Söder B, Norlund A, Axelsson S, Dahlgren H. Caries-preventive effect of fissure sealants:: a systematic review. Acta Odontol Scand. 2003 Dec;61(6):321-30.	109 (5.5)	321 (16.1)	134 (6.7)
61	Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BAC. Longevity and reasons for failure of sandwich and total-etch posterior composite resin restorations. J Adhes Dent. 2007 Oct;9(5):469-75.	109 (6.8)	233 (14.6)	115 (7.2)
62	Kleverlaan CJ, van Duinen R, Feilzer AJ. Mechanical properties of glass ionomer cements affected by curing methods. Dent Mater. 2004 Jan;20(1):45-50.	109 (5.7)	281 (14.8)	119 (6.3)
63	Itota T, Carrick TE, Yoshiyama M, McCabe JF. Fluoride release and recharge in giomer, compomer and resin composite. Dent Mater. 2004 Nov;20(9):789-95.	108 (5.7)	293 (15.4)	136 (7.2)
64	Tyas MJ. Cariostatic effect of glass ionomer cement - a five-year clinical study. Aust Dent J. 1991 Jun;36(3):236-9.	107 (3.3)	209 (6.5)	115 (3.6)
65	Moshaverinia A, Ansari S, Movasaghi Z, Billington RW, Darr JA, Rehman IR. Modification of conventional glass-ionomer cements with N-vinylpyrrolidone containing polyacids, nano-hydroxy and fluoroapatite to improve mechanical properties. Dent Mater. 2008 Oct;24(10):1381-90.	107 (7.1)	206 (13.7)	138 (9.2)
66	Retief DH, Bradley EL, Denton JC, Switzer P. Enamel and cementum fluoride uptake from a glass ionomer cement. Caries Res. 1984;18(3):250-7.	106 (2.7)	203 (5.2)	118 (3.0)
67	Okada K, Tosaki S, Hirota K, Hume WR. Surface hardness change of restorative filling materials stored in saliva. Dent Mater. 2001 Jan;17(1):34-9.	106 (4.8)	282 (12.8)	122 (5.5)
68	Gee AJ, van Duinen RN, Werner A, Davidson CL. Early and long term wear of conventional and resin-modified glass ionomers. J Dent Res. 1996 Aug;75(8):1613-9.	105 (3.9)	167 (6.2)	101 (3.7)
69	De Moor RJ, Verbeeck RM, De Maeyer EA. Fluoride release profiles of restorative glass ionomer formulations. Dent Mater. 1996 Mar;12(2):88-95.	104 (3.9)	181 (6.7)	109 (4.0)
70	Cattani-Lorente MA, Dupuis V, Payan J, Moya F, Meyer JM. Effect of water on the physical properties of resin-modified glass ionomer cements. Dent Mater. 1999 Jan;15(1):71-8.	104 (4.3)	255 (10.6)	117 (4.9)
71	van Dijken JWV, Pallesen U. Long-term dentin retention of etch-and-rinse and self-etch adhesives and a resin-modified glass ionomer cement in non-carious cervical lesions. Dent Mater. 2008 Jul;24(7):915-22.	103 (6.9)	189 (12.6)	114 (7.6)
72	Crisp S, Wilson AD. Reactions in glass ionomer cements .1. Decomposition of powder. J Dent Res. 1974 Nov-Dec;53(6):1408-13.	103 (2.1)	192 (3.9)	114 (2.3)
73	Massara MLA, Alves JB, Brandão PRG. Atraumatic restorative treatment: Clinical, ultrastructural and chemical analysis. Caries Res. 2002 Nov-Dec;36(6):430-6.	102 (4.9)	290 (13.8)	122 (5.8)
74	McLean JW, Wilson AD. The clinical development of glass-ionomer cement .III. The erosion lesion. Aust Dent J. 1977 Jun;22(3):190-5.	102 (2.2)	102 (2.2)	57 (1.2)
75	McKnight-Hanes C, Whitford GM. Fluoride release from 3 glass ionomer materials and the effects of varnishing with or without finishing. Caries Res. 1992;26(5):345-50.	102 (3.3)	186 (6.0)	107 (3.5)
76	Heithersay GH. Treatment of invasive cervical resorption: An analysis of results using topical application of trichloroacetic acid, curettage, and restoration. Quintessence Int. 1999 Feb;30(2):96-110.	101 (4.2)	243 (10.1)	118 (4.9)
77	Frencken JF, Leal SC, Navarro MF. Twenty-five-year atraumatic restorative treatment (ART) approach: a comprehensive overview. Clin Oral Investig. 2012 Oct;16(5):1337-46.	101 (9.2)	285 (25.9)	122 (11.1)
78	Zhou H, Shen Y, Wang Z, Li L, Zheng Y, Häkkinen L, Haapasalo M. In vitro cytotoxicity evaluation of a novel root repair material. J Endod. 2013 Apr;39(4):478-83.	101 (10.1)	287 (28.7)	129 (12.9)
79	Silverman E, Cohen M, Demke RS, Silverman M. A new light-cured glass-ionomer cement that bonds brackets to teeth without etching in the presence of saliva. Am J Orthod Dentofacial Orthop . 1995 Sep;108(3):231-6.	100 (3.6)	232 (8.3)	111 (4.0)
80	Hao Y, Huang X, Zhou X, Li M, Ren B, Peng X, Cheng I. Influence of dental prosthesis and restorative materials interface on oral biofilms. Int J Mol Sci. 2018 Oct 14;19(10):3157.	99 (19.8)	149 (29.8)	106 (21.2)
81	Cenci MC, Pereira-Cenci T, Cury JA, Ten Cate JM. Relationship between gap size and dentine secondary caries formation assessed in a microcosm biofilm model. Caries Res. 2009;43(2):97-102.	98 (7.0)	158 (11.3)	101 (7.2)

(conclusion)

82	Mallakh BF, Sarkar NK. Fluoride release from glass-ionomer cements in deionized water and artificial saliva. Dent Mater. 1990 Apr;6(2):118-22.	97 (2.9)	218 (6.6)	109 (3.3)
83	Sudjalim TR, Woods MG, Manton DJ, Reynolds EC. Prevention of demineralization around orthodontic brackets in vitro. Am J Orthod Dentofacial Orthop. 2007 Jun;131(6):705.e1-9.	96 (6.0)	317 (19.8)	111 (6.9)
84	Lucas ME, Arita K, Nishino M. Toughness, bonding and fluoride-release properties of hydroxyapatite-added glass ionomer cement. Biomaterials. 2003 Sep;24(21):3787-94.	96 (4.8)	224 (11.2)	119 (6.0)
85	Modena KCS, Casas-Apayco LC, Atta MT, Costa CAS, Hebling J, Sipert CR, Navarro MFL, Santos CF. Cytotoxicity and biocompatibility of direct and indirect pulp capping materials. J Appl Oral Sci. 2009 Nov-Dec;17(6):544-54.	96 (6.9)	320 (22.9)	131 (9.4)
86	Cattani-Lorente MA, Godin C, Meyer JM. Mechanical-behavior of glass-ionomer cements affected by long-term storage in water. Dent Mater. 1994 Jan;10(1):37-44.	96 (3.3)	214 (7.4)	106 (3.7)
87	Momoi Y, McCabe JF. Fluoride release from light-activated glass-ionomer restorative cements. Dent Mater. 1993 May;9(3):151-4.	95 (3.2)	227 (7.6)	103 (3.4)
88	Uno S, Finger WJ, Fritz U. Long-term mechanical characteristics of resin-modified glass ionomer restorative materials. Dent Mater. 1996 Jan;12(1):64-9.	95 (3.5)	195 (7.2)	104 (3.9)
89	Frencken JE, Makoni F, Sithole WD, Hackenitz E. Three-year survival of one-surface ART restorations and glass-ionomer sealants in a school oral health programme in Zimbabwe. Caries Res. 1998;32(2):119-26.	94 (3.8)	249 (10.0)	116 (4.6)
90	L Forsten. Resin-modified glass-ionomer cements - fluoride release and uptake. Acta Odontol Scand. 1995 Aug;53(4):222-5.	94 (3.4)	227 (8.1)	111 (4.0)
91	Hannig M. Transmission electron microscopic study of in vivo pellicle formation on dental restorative materials. Eur J Oral Sci. 1997 Oct;105(5 Pt 1):422-33.	93 (3.6)	203 (7.8)	98 (3.8)
92	Farrugia C, Camilleri J. Antimicrobial properties of conventional restorative filling materials and advances in antimicrobial properties of composite resins and glass ionomer cements-A literature review. Dent Mater. 2015 Apr;31(4):e89-99.	93 (11.6)	159 (19.9)	103 (12.9)
93	Prosser HJ, Powis DR, Wilson AD. Glass-ionomer cements of improved flexural strength. J Dent Res. 1986 Feb;65(2):146-8.	92 (2.5)	183 (4.9)	109 (2.9)
94	Schriks MCM, van Amerongen WE. Atraumatic perspectives of ART: psychological and physiological aspects of treatment with and without rotary instruments. Community Dent Oral Epidemiol. 2003 Feb;31(1):15-20.	91 (4.6)	249 (12.5)	98 (4.9)
95	Ilie N, Hickel R, Valceanu AS, Huth KC. Fracture toughness of dental restorative materials. Clin Oral Investig. 2012 Apr;16(2):489-98.	90 (8.2)	209 (19.0)	105 (9.5)
96	Yu H, Wegehaupt FJ, Wiegand A, Roos M, Attin T, Buchalla W. Erosion and abrasion of tooth-colored restorative materials and human enamel. J Dent. 2009 Dec;37(12):913-22.	90 (6.4)	190 (13.6)	93 (6.6)
97	H K Yip 1, F R Tay, H C Ngo, R J Smales, D H Pashley. Bonding of contemporary glass ionomer cements to dentin. Dent Mater. 2001 Sep;17(5):456-70.	89 (4.0)	208 (9.5)	99 (4.5)
98	Piwowarczyk A, Lauer HC. Mechanical properties of luting cements after water storage. Oper Dent. 2003 Sep-Oct;28(5):535-42.	89 (4.5)	215 (10.8)	96 (4.8)
99	Weerheijm KL, Kreulen CM, Soet JJ, Groen HJ, van Amerongen WE. Bacterial counts in carious dentine under restorations: 2-year in vivo effects. Caries Res. 1999;33(2):130-4.	86 (3.6)	178 (7.4)	104 (4.3)
100	Forss H, Jokinen J, Spets-Happonen S, Seppä L, Luoma H. Fluoride and mutans streptococci in plaque grown on glass ionomer and composite. Caries Res. 1991;25(6):454-8.	84 (2.6)	190 (5.9)	98 (3.1)

Citation analysis

In total, the top 100 papers were cited 15,368 times in WoS-CC, including 203 self-citations (1.32%). The number of citations in WoS-CC ranged from 84 to 553 with 79 papers receiving at least 100 citations. The number of citations was higher in Google Scholar (34,761 citations, ranging from 102 to 1,164) and Scopus (17,672 citations, ranging from 57 to 629).

The most-cited paper in WoS-CC was "Review on fluoride-releasing restorative materials - Fluoride release and uptake characteristics, antibacterial activity and influence on caries formation"[18]. This study was cited 553 times, with an average of 34.6 citations/year in WoS-CC. It also held the top position in Scopus (629 citations) but ranked second in Google Scholar (1,164 citations). The most-cited paper on Google Scholar was "New translucent cement for dentistry - glass ionomer cement"[19]. This study was cited 1,416 times, with an average of 27.8 citations/year on Google Scholar. It ranked second in WoS-CC (548 citations) and Scopus (625 citations).

Furthermore, there was a strong positive correlation between the number of citations in WoS-CC and Google Scholar (rho = 0.805) as well as between Google Scholar and Scopus (rho = 0.897). Additionally, a very strong correlation observed between WoS-CC and Scopus (rho = 0.937).

Year of publication

The most recent paper was published in 2018[20], while the oldest paper dates to 1971[21]. The majority of studies were published in the decade spanning from 2003 to 2012, accounting for 37% of the total publications and receiving 5,553 citations. Specifically, the year 2003 had the highest number of papers (7%; 839 citations).

Contributing journals

As shown in Table 2, Dental Materials emerged as the most prominent journal in terms of the number of publications within the top 100 papers (18%; 2,559 citations), followed by the Journal of Dental Research (14%; 2,457 citations) and Caries Research (10%; 1,041 citations).

Table 2. Top 10 journals of the papers included in this top 100.

Source Title	Number of papers	Number of citations	Impact factor
Dental Materials	18	2,559	5.0
Journal of Dental Research	14	2,457	7.6
Caries Research	10	1,041	4.2
British Dental Journal	5	1,139	2.6
Journal of Dentistry	5	1,133	4.4
Australian Dental Journal	5	576	2.4
Journal of Prosthetic Dentistry	4	871	4.6
Biomaterials	4	517	14.0
Clinical Oral Investigations	3	472	3.4
Cochrane Database of Systematic Reviews	3	447	8.4

Study design

Laboratory studies were the most common study type (61%; 8,217 citations), followed by literature review (18%; 4,363 citations), intervention study (11%; 1,187 citations), observational (5%; 904 citations) and systematic review (5%; 697 citations).

Main assessment

The most discussed topic was clinical evaluation of procedure performed with GIC (16%; 2,141 citations), followed by material strength of the GIC (15%; 1,841 citations), adherence of the GIC with the dental structure (12%; 1,949 citations), anticariogenic potential of the GIC (12%; 1,458 citations), release of fluoride from the GIC (11%; 1,363 citations), evaluation of the antimicrobial activity of the GIC (9%; 1,194 citations), biocompatibility of the GIC with oral tissues (8%; 1,354 citations), evaluation of two or more properties (chemical, mechanical, or physical) of the GIC (7%; 1,322 citations), color analysis of the GIC (4%; 1,286 citations), contraction of the GIC during healing (3%; 848 citations), and scientific status (3%; 612 citations).

Type and clinical function of GIC

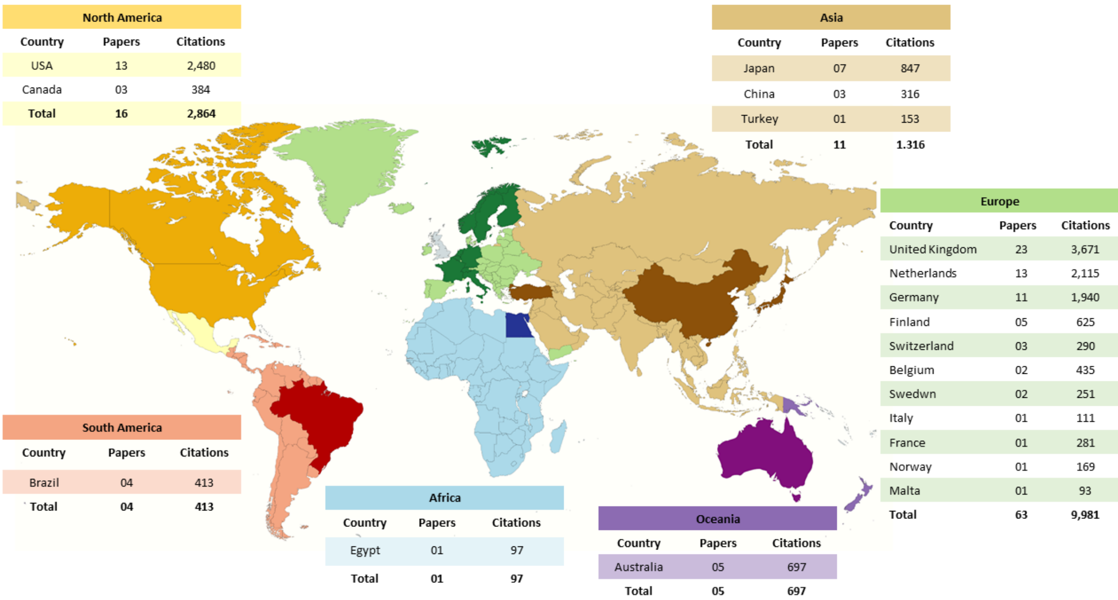
According to the type of GIC, it was found that GIC conventional (71%; 9,752 citations), followed by GIC conventional and GIC resin modified (14%; 3,776 citations), GIC resin modified (12%; 1,466 citations) and unidentified (3%; 374 citations).

In relation to their clinical function, the most studied theme was restorative (79%; 12,104 citations), cementation (16%; 2,607 citations), "lining/base" (2%; 283 citations). Three studies did not identify the type of material covered (3%; 374 citations).

Countries and continents

Europe hosted the largest number of papers and citations among the 100 most-cited papers (63%; 9,981 citations), followed by North America (16%; 2,864 citations) and Asia (11%; 1,316 citations). The most prominent country was the United Kingdom (23%; 3,671 citations), followed by the Netherlands (13%; 2,115 citations), and Germany (10%; 1,940 citations). The global distribution of publications is detailed in Figure 2.

Figure 2. Worldwide distribution of origin of publications on GIC.



Source: authors.

Contribution institutions

A total of 61 institutions contributed to the 100 most-cited papers on GIC. The Government Chemist's Laboratory in the United Kingdom (14%; 2,514 citations) was the institution with the highest number of publications, followed by the University of Amsterdam in the Netherlands (8%; 1,352 citations) and the University of Melbourne in Australia (4%; 596 citations). Table 3 displays the main institutions involved in these publications.

Table 3. Top 10 institutions with the highest number of papers among the 100 most-cited.

Institution	Country	Number of papers	Number of citations
Government Chemist's Laboratory	United Kingdom	14	2,514
University of Amsterdam	Netherlands	8	1,352
University of Melbourne	Australia	4	596
Indiana University	USA	3	513
University Tampere	Finland	3	447
Ohio State University	USA	2	639
Medical University Hannover	Germany	2	448
University of London	United Kingdom	2	275
University of Newcastle	United Kingdom	2	234
University of Glasgow	Scotland	2	234
University of Freiburg	Germany	2	234

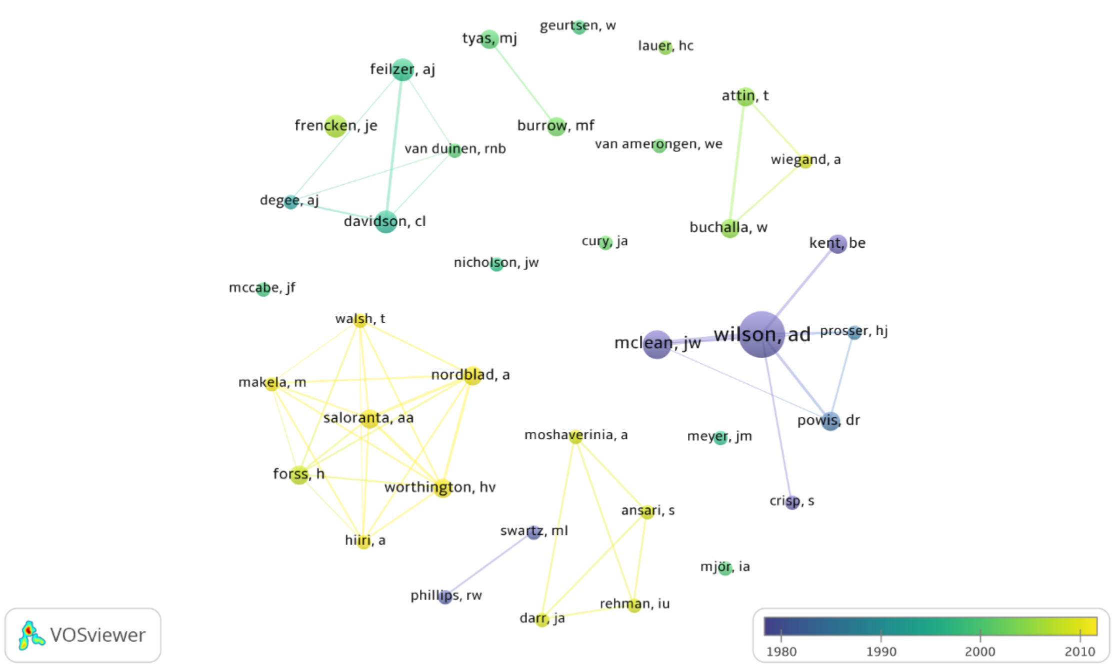
Contributing authors

Wilson AD was the most prolific author, accounting for 13% of the publications with a total of 2,391 citations, with the 1980s representing the most significant period of citation, followed by Mclean JW (6%; 827 citations) (Table 4). Together these authors worked mainly on laboratory studies evaluating the performance of GIC for restoration. In addition, Davidson CL (4%; 957 citations) and Feilzer AJ (4%; 961 citations) each contributed 4 publications. These authors mainly carried out laboratory studies to investigate the strength and healing contraction of restorative GIC. Another prominent author was Frencken JE (4%; 471 citations), carrying out reviews addressing the clinical condition of GIC restorations. Figure 3 shows the main authors and the principal research groups over the years.

Table 4. Top 10 authors with the most papers among the 100 most-cited.

Authors	Number of papers between 100 most-cited	Number of citations between 100 most-cited	Number of papers in WS-CC	Number of citations in WS-CC	H-Index
Wilson AD	13	2,391	208	6,214	43
Mclean JW	6	827	93	5,100	29
Davidson CL	4	957	275	9,906	53
Feilzer AJ	4	961	42	1,663	20
Frencken JE	4	471	176	5,196	39
Nordblad A	3	447	41	1,296	20
Solaranta AA	3	447	11	665	10
Worthington HV	3	447	429	15,400	73
Forss H	3	412	174	3,499	38
Powis DR	3	473	9	520	8

Figure 3. Frequency and interaction of the main authors associated with the study, names with largest points and written in a larger font means the most frequent author.

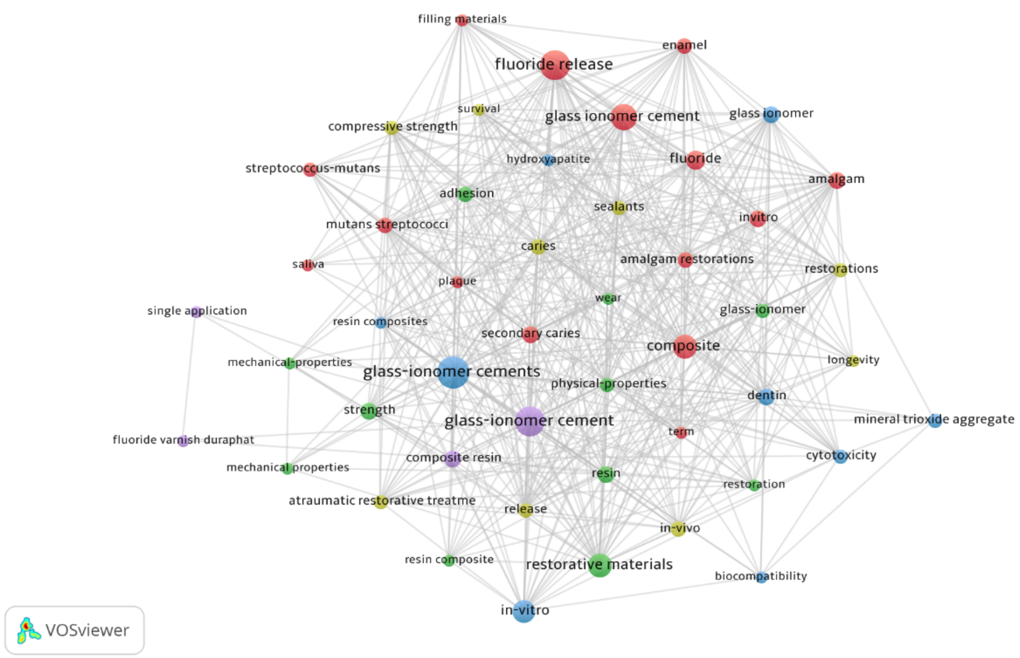


Source: authors.

Keywords

An author keyword network map was generated using VOSviewer to illustrate the most frequently used terms (Figure 4). It was possible to observe that the most common keywords were: “glass-ionomer cements” (20 occurrences), “fluoride release” (18 occurrences) and “glass-ionomer cement” (18 occurrences).

Figure 4. Frequency and interaction of the main keywords associated with the study, keywords with largest points and written in a larger font means they appear more frequent.



Source: authors.

DISCUSSION

This bibliometric analysis aimed to examine the characteristics of the most-cited papers on GIC. The results provided a comprehensive overview of the profile of publications in this field, serving as a valuable reference for researchers and institutions. Additionally, the analysis highlighted areas that have not been thoroughly explored, less common study designs, and the current state of evidence cited in clinical practice concerning the utilization of GIC. This information can guide future research endeavors and contribute to enhancing the understanding and application of GIC in dental practice.

Bibliometrics allows a wide range of data analysis. In the present study, a citation analysis was carried out to identify the top100 most-cited papers about GIC. To ensure the effective performance of this type of analysis, it is essential to select a single database as the reference for article selection and citation counting, thereby minimizing potential inconsistencies in data analysis, such as the inclusion of non–peer-reviewed publications and differences in citation metrics and counting filters across databases. Therefore, the database used for this study was WoC-CC, consistent with previous publications[22-25].

The report on the clinical application of GIC revealed that 79% of the studies focused on its restorative use. Ongoing efforts within the academic community aim to enhance GIC properties to make its definitive restorative indication increasingly broader. This is evident in the majority of studies being laboratory-based (61%), aiming to modify the liquid and powder components to improve several properties such as physical[26], adhesive[27-29], mechanical[30,31], antibacterial[26,32] and fluoride release[33,34]. Significantly, GIC plays an important role in ART, being the material of choice and considered a definitive restoration, especially in settings with limited access to dental care[35-37].

Another important factor is the type of

GIC evaluated in each study. Research in dental materials frequently compares the indications for each material to better elucidate properties and effectiveness in clinical application. All GIC have been divided into two major categories: conventional glass-ionomer cements (CGICs) and RMGICs[38]. The present bibliometrics found that 71% of the papers addressed the CGIC, 12% RMGIC and 14% evaluated both. This can be explained by the large number of citations referring to papers about the development and evaluation of CGICs properties[19,21,27-30,33], they represent foundational and pioneering studies in the field. These works establish the chemical, mechanical, and biological principles of the material and are therefore widely recognized as classic references for understanding its behavior in both laboratory and clinical settings. Moreover, such studies frequently serve as theoretical and methodological starting points for subsequent research, including investigations on material modifications, comparisons with emerging biomaterials, and assessments of clinical performance. Followed by research evaluating the addition of monomers and photo initiators in the GIC matrix to improve the low mechanical conditions presented in the CGIC, unsuitable for use in high-stress sites, such the Class I and II restorations[38-41].

The topic main assessment of GIC presented more frequently evaluations of procedure performed with GIC (16%), material strength (15%), adherence of the GIC to the dental structure (12%), anticariogenic potential (12%) and fluoride release (11%). The evaluations of procedure performed with GIC and the material strength were related to laboratory studies that verified the resistance of materials through the evaluation of compressive strength[31,42-45], flexural strength[31,42,45,46], diametral tensile strength[31,42,47], fracture toughness[48], surface hardness[49], wear rate[39] and shear strength[50]. The adherence of the GIC with the dental structure could also be observed. The release of fluoride and anticariogenic potential of the GIC may be due mainly to the initial burst, which occurs in the first 24 hours after insertion of the GIC into the tooth cavity[51]. At this stage, a high release of fluoride occurs capable of favoring the remineralization process and reducing the size and viability of adjacent populations of oral bacteria[52]. The fluoride release decreases in the first week and can last for years at a very small rate[53]. The fluoride recharge ability from water, fluoridated paste and professional application helps maintain fluoride levels with anticariogenic activity, preventing secondary caries in teeth restored with GIC[54,55].

The United Kingdom emerged as the most productive country in this top100 list. This finding is largely attributable to the Laboratory of Government Chemist. Notably, GIC was developed at this institution in 1968, with a patent requested in 1969[19]. The Laboratory of the Government Chemist, presently operating as a private entity named LGC Group, is an international life sciences measurement and tools company. It provides the role and duties of the UK Government Chemist, a statutory monitor to the government. The institution's efforts are multifaceted, encompassing the management of global pandemics, pioneering precision medicine, enhancing agricultural outputs, and ensuring the safety of food and medicines[56]. In line with this finding, the European continent was the most productive. This trend can be explained to initiatives such as the European Research Area (ERA), a policy aimed at promoting a pan-European science-based network, creating a new financing mechanism at the European level to support advancements in research and knowledge.

Two prominent researchers in the field of dental materials, Alan Wilson and John McLean, emerged as the most prolific authors in this study. Alan Wilson, a distinguished British dental materials specialist, and co-inventor of GIC, conducted important research during his tenure at the Laboratory of Government Chemist, where he served as part of the United Kingdom's Civil Scientific Service for 24 years. Alongside John McLean, he spearheaded a research network focused on dental materials[52]. John McLean, in turn, has a scientific background centered on the development of dental ceramics, resins and the advancement of GIC. As a Clinical Consultant at the Laboratory of Government Chemist, McLean pioneered numerous avenues of research, thereby establishing a new frontier in dental materials science[57].

Although bibliometric analysis allows a comprehensive overview of the scientific production on GIC, this type of study has inherent limitations that should be considered. The use of citation counts as an indicator of impact tends to favor classical articles related to the development and properties of the material, to the detriment of more recent studies or those with greater clinical applicability. Furthermore, bibliometric analysis does not assess methodological quality, level of evidence, or the consistency of the results of the included studies, primarily reflecting the historical and academic relevance of the publications. In addition, terminological heterogeneity associated with the different classifications of GIC may influence article retrieval, as well as the inability to distinguish between positive and negative citations or to measure the clinical and social impact of publications, reinforcing the complementary nature of this method in relation to systematic reviews and clinical studies.

Strengths can be identified through the evaluation of the most cited papers on GIC. It was evident that a significant number of citations were attributed to studies focusing on the characterization of properties and enhancements of the cement matrix through laboratory experimentation. This underscores the importance of laboratory findings in the dental material context. Nevertheless, clinical studies assessing the practical applicability and effectiveness of GIC received comparatively fewer citations, which demonstrates a need for research groups to focus their efforts on developing an evidence-based dentistry based on interventional studies.

CONCLUSION

In conclusion, it was stated that the top 100 cited papers related to GIC primarily originated from Europe and mostly consisted of laboratory studies exploring GIC's clinical performance in restorative dentistry. It's recommended the development of further interventional studies on GIC, focused on the clinic improvement of the material.

CONFLICT OF INTEREST

The authors do not have any conflict of interest to declare.

AUTHOR CONTRIBUTIONS

Vasques A participated in data acquisition and interpretation, created the tables, and drafted and critically revised the manuscript. **Pereira TS** participated in data acquisition and interpretation, drafted and critically revised the manuscript. **Rocha AO** participated in data acquisition and interpretation, and drafted and critically revised the manuscript. **Anjos LM** participated in data acquisition and interpretation, and critically revised the manuscript. **Paschoal MAB** participated in data acquisition and interpretation, and critically revised the manuscript. **Machado RG** contributed to the conception, data interpretation, and drafted and critically revised the manuscript. **Martins-Júnior PA** contributed to the conception, data interpretation, and drafted and critically revised the manuscript. **Cardoso M** contributed to the conception, data interpretation, and drafted and critically revised the manuscript.

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STATEMENT OF ETHICS

Ethical approval was not required because the study was not conducted directly with humans, but analyzed data from previous studies.

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REFERENCES

1. Berg JH, Croll TP. Glass ionomer restorative cement systems: an update. Pediatr Dent. 2015;37(2):116-24.
2. Sidhu SK, Nicholson JW. A review of glass-ionomer cements for clinical dentistry. J Funct Biomater. 2016;28;7(3):16. 10.3390/jfb7030016.
3. Nagaraja UP, Kishore G. Glass ionomer cement – the different generations. Trends Biomater Artif Organs. 2005;18(2):158-65.
4. Smith DC. Development of glass-ionomer cement systems. Biomaterials.

1998;19(6):467-78. 10.1016/S0142-9612(97)00126-9.
5. Alaohali A, Brauer DS, Gentleman E, Sharpe PT. A modified glass ionomer cement to mediate dentine repair. Dent Mater. 2021;37(8):1307-15. 10.1016/j.dental.2021.05.003.
6. Hilgert LA, Amorim RG, Leal SC, Mulder J, Creugers NH, Frencken JE. Is high-viscosity glassionomer-cement a successor to amalgam for treating primary molars? Dent Mater. 2014;30(10):1172–8. 10.1016/j.dental.2014.07.01
7. Cribari L, Madeira L, Roeder RBR, Macedo RM, Wambier LM, Porto TS, et al. High-viscosity glass-ionomer cement or composite resin for restorations in posterior permanent teeth? A systematic review and meta-analyses. J Dent. 2023;137:104629. 10.1016/j.jdent.2023.104629.
8. Mitra SB. Adhesion to dentin and physical properties of a light-cured glass-ionomer liner/base. J Dent Res. 1991;70(1):72-4.
9. Heboyan A, Vardanyan A, Karobari MI, Marya A, Avagyan T, Tebyaniyan H, et al. Dental luting cements: an updated comprehensive review. Molecules. 2023;28(4):1619. 10.3390/molecules28041619.
10. Silva CLD, Cavalheiro CP, Silva CGOD, Raggio DP, Casagrande L, Lenzi TL. Restoration-repair potential of resin-modified glass ionomer cement. Braz Oral Res. 2024;23;38:e076. 10.1590/1807-3107bor-2024.vol38.0076.
11. Danelon M, Nunes GP, Sterzenbach T, Hannig C. Enhancing antimicrobial properties of glass ionomer cement through metallic agent reinforcement: A systematic review and meta-analysis. J Dent. 2025;160:105892. 10.1016/j.jdent.2025.105892.
12. Navarro MFL, Pascotto RC, Borges AFS, Soares CJ, Raggio DP, Rios D, et al. Consensus on glass-ionomer cement thresholds for restorative indications. J Dent. 2021;107:103609. 10.1016/j.jdent.2021.103609.
13. Rocha AO, Anjos LMD, Vitali FC, Santos PS, Bolan M, Santana CM, et al. Tooth bleaching: a bibliometric analysis of the top 100 most-cited papers. Braz Dent J. 2023;34(2):41-55. 10.1590/0103-6440202305290.
14. Lima TO, Rocha AO, Anjos LM, Meneses Júnior NS, Duarte MAH, Alcalde MP, et al. A global overview of guided endodontics: a bibliometric analysis. J Endod. 2024;50(1):10-6. 10.1016/j.joen.2023.10.002.
15. Garfield E. Citation analysis as a tool in journal evaluation. Sci. 1972;178(4060):471-9.
16. Rocha AO, Anjos LM, Freire-Maia J, Henriques B, Cardoso M, Júnior PAM. Analysis of the profile of metric-based reviews published in dentistry and proposal for a standardized guideline: metrics. Odontology. 2025. 10.1007/s10266-025-01208-z.
17. Van Eck NJ, Waltman L. Citation-based clustering of publications using CitNetExplorer and VOSviewer. Scientometrics. 2017;111(2):1053-70.
18. 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(3):343-62. 10.1016/j.dental.2006.01.022.
19. Wilson AD, Kent BE. A new translucent cement for dentistry. The glass ionomer cement. Br Dent J. 1972;132(4):133-5. 10.1038/sj.bdj.4802810.
20. Hao Y, Huang X, Zhou X, Li M, Ren B, Peng X, Cheng L. Influence of dental prosthesis and restorative materials interface on oral biofilms. Int J Mol Sci. 2018;19(10):3157. 10.3390/ijms19103157.
21. Wilson AD, Kent BE. The glass-ionomer cement, a new translucent dental filling material. J Appl Chem Biotechn. 1971;21(11):313. 10.1038/sj.bdj.4802810.
22. Shi S, Gao Y, Liu M, Bu Y, Wu J, Tian J, et al. Top 100 most-cited articles on exosomes in the field of cancer: a bibliometric analysis and evidence mapping. Clin Exp Med. 2021;21(2):181-94. 10.1007/s10238-020-00624-5.
23. Park BS, Kim IH, Park KM. Top 100 cited articles on sleep medicine: a bibliometric analysis. Eur Neurol. 2020;83(1):111-20. 10.1159/000507393.
24. Manuel Vázquez A, Latorre Fragua R, López Marcano A, Ramiro Pérez C, Arteaga Peralta V, de la Plaza-Llamas R, et al. The top 100: a review of the most cited articles in Surgery. Cir Esp (Engl Ed). 2019;97(3):150-5. 10.1016/j.ciresp.2018.10.013.
25. Clementino LC, Souza KSC, Castelo-Branco M, Perazzo MF, Ramos-Jorge ML, Mattos FF, et al. Top 100 most-cited oral health-related quality of life papers: bibliometric analysis. Community Dent Oral Epidemiol. 2022;50(3):199-205. 10.1111/cdoe.12652.
26. Takahashi Y, Imazato S, Kaneshiro AV, Ebisu S, Frencken JE, Tay FR. Antibacterial effects

and physical properties of glass-ionomer cements containing chlorhexidine for the ART approach. Dent Mater. 2006;22(7):647-52. 10.1016/j.dental.2005.08.003.
27. Hotz P, Mclean JW, Sced I, Wilson AD. The bonding of glass ionomer cements to metal and tooth substrates. Br Dent J. 1977;142(2):41-7. 10.1038/sj.bdj.4803864.
28. Powis DR, Folleras T, Merson SA, Wilson AD. Improved adhesion of a glass ionomer cement to dentin and enamel. J Dent Res. 1982;61(12):1416-22.
29. Yoshida Y, Van Meerbeek B, Nakayama Y, Snauwaert J, Hellemans L, Lambrechts P, et al. Evidence of chemical bonding at biomaterial-hard tissue interfaces. J Dent Res. 2000;79(2):709-14. 10.1177/00220345820610120801.
30. Xie D, Brantley WA, Culbertson BM, Wang G. Mechanical properties and microstructures of glass-ionomer cements. Dent Mater. 2000;16(2):129-38. 10.1016/s0109-5641(99)00093-7.
31. Moshaverinia A, Ansari S, Moshaverinia M, Roohpour N, Darr JA, Rehman I. Effects of incorporation of hydroxyapatite and fluoroapatite nanobioceramics into conventional glass ionomer cements (GIC). Acta Biomater. 2008;4(2):432-40. 10.1016/j.actbio.2007.07.011.
32. Xie D, Weng Y, Guo X, Zhao J, Gregory RL, Zheng C. Preparation and evaluation of a novel glass-ionomer cement with antibacterial functions. Dent Mater. 2011;27(5):487-96. 10.1016/j.dental.2011.02.006.
33. Swartz ML, Philips RW, Clarl HE. Long-term F release from glass ionomer cements. J Dent Res. 1984;63(2):158-60. 10.1177/00220345840630021301.
34. Xie D, Feng D, Chung ID, Eberhardt AW. A hybrid zinc-calcium-silicate polyalkenoate bone cement. Biomaterials. 2003;24(16):2749-57. 10.1016/s0142-9612(03)00090-5.
35. Massara MLA, Alves JB, Brandão PRG. Atraumatic restorative treatment: clinical, ultrastructural and chemical analysis. Caries Res. 2002;36(6):430-6. 10.1159/000066534.
36. Schriks MCM, Van Amerongen WE. Atraumatic perspectives of ART: psychological and physiological aspects of treatment with and without rotary instruments. Community Dent Oral Epidemiol. 2003;31(1):15-20. 10.1034/j.1600-0528.2003.00021.x.
37. Frencken JE, Leal SC, Navarro MF. Twenty-five-year atraumatic restorative treatment (ART) approach: a comprehensive overview. Clin Oral Investig. 2012;16(5):1337-46. 10.1007/s00784-012-0783-4.
38. Attin T, Buchalla W, Kielbassa AM, Helwig E. Curing shrinkage and volumetric changes of resin-modifed glass ionomer restorative materials. Dent Mater. 1995;11(6):359-62. 10.1016/0109-5641(95)80035-2.
39. Gee AJ, van Duinen RN, Werner A, Davidson CL. Early and long-term wear of conventional and resin-modified glass ionomers. J Dent Res. 1996;75(8):1613-9. 10.1177/00220345960750081401.
40. Cattani-Lorente MA, Dupuis V, Payan J, Moya F, Meyer JM. Effect of water on the physical properties of resin-modified glass ionomer cements. Dent Mater. 1999;15(1):71-8. 10.1016/s0109-5641(99)00016-0.
41. Geurtsen W. Biocompatibility of resin-modified filling materials. Crit Rev Oral Biol Med. 2000;11(3):333-55. 10.1177/10454411000110030401.
42. Cattani-Lorente MA, Godin C, Meyer JM. Mechanical-behavior of glass-ionomer cements affected by long-term storage in water. Dent Mater. 1994;10(1):37-44. 10.1016/0109-5641(94)90020-5.
43. Matsuya S, Maeda T, Ohta M. IR and NMR analyses of hardening and maturation of glass-ionomer cement. J Dent Res. 1996;75(12):1920-7. 10.1177/00220345960750120201.
44. Kleverlaan CJ, van Duinen R, Feilzer AJ. Mechanical properties of glass ionomer cements affected by curing methods. Dent Mater. 2004;20(1):45-50. 10.1016/s0109-5641(03)00067-8.
45. Piwowarczyk A, Lauer HC. Mechanical properties of luting cements after water storage. Oper Dent. 2003;28(5):535-42.
46. Prosser HJ, Powis DR, Wilson AD. Glass-ionomer cements of improved flexural strength. J Dent Res. 1986;65(2):146-8. 10.1177/00220345860650021101.
47. Uno S, Finger WJ, Fritz U. Long-term mechanical characteristics of resin-modified glass ionomer restorative materials. Dent Mater. 1996;12(1):64-9. 10.1016/s0109-5641(96)80066-2.
48. Ilie N, Hickel R, Valceanu AS, Huth KC. Fracture toughness of dental restorative materials. Clin Oral Investig. 2012;16(2):489-98. 10.1007/s00784-011-0525-z.
49. Okada K, Tosaki S, Hirota K, Hume WR. Surface hardness change of restorative filling materials stored in saliva. Dent

Mater. 2001;17(1):34-9. 10.1016/s0109-5641(00)00053-1.
50. Piwowarczyk A, Lauer HC, Sorensen JA. In vitro shear bond strength of cementing agents to fixed prosthodontic restorative materials. J Prosthet Dent. 2004;92(3):265-73. 10.1016/j.prosdent.2004.06.027.
51. Kumari PD, Khijmatgar S, Chowdhury A, Lynch E, Chowdhury CR. Factors influencing fluoride release in atraumatic restorative treatment (ART) materials: a review. J Oral Biol Craniofac Res. 2019;9(4):315-20. 10.1016/j.jobcr.2019.06.015.
52. Nicholson J. Alan Donald Wilson OBE (1928-2011). Dent Mater. 2012:28;465-6.
53. Rao BS, Moosani GK, Shanmugaraj M, Kannapan B, Shankar BS, Ismail PM. Fluoride release and uptake of five dental restoratives from mouthwashes and dentifrices. J Int Oral Health. 2015;7(1):1-5.
54. Rothwell M, Anstice HM, Pearson GJ. The uptake and release of fluoride by ion-leaching cements after exposure to toothpaste. J Dent. 1998;26(7):591-7. 10.1016/s0300-5712(97)00035-3.
55. Neelakantan P, John S, Anand S, Sureshbabu N, Subbarao C. Fluoride release from a new glass-ionomer cement. Oper Dent. 2011;36(1):80-5. 10.2341/10-219-lr.
56. Chair PB, Beattie R, Branch S, Damant A, Foster L, Franklin D, et al. The Laboratory of the Government Chemist Revie, Departament for business, Energy and Industrial Strategy, 2020.
57. NHFW, HWP John Walford McLean OBE. Br Dent J. 2009;207(4):187. 10.1038/sj.bdj.2009.729.