BIBLIOMETRIC ANALYSIS OF RESEARCH ON GLASS IONOMER CEMENT IN DENTISTRY USING WEB OF SCIENCE DATABASE

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Abstract:
Objectives: The main objective of this study is to comprehensively analyze the research landscape of Glass Ionomer Cement (GIC) from 1989 to 2023, focusing on journals indexed by Web of Science. The motivation behind this investigation is the lack of a quantitative assessment of the growing body of scholarly works on GIC. The study aims to consolidate and examine the trends, patterns, and collaborative aspects within this research domain using bibliometric techniques.
Materials and Methods: To achieve this objective, we conducted a thorough analysis of published research articles related to GIC from the years 1989 to 2023. We specifically targeted journals indexed by Web of Science for inclusion in our study. Bibliometric techniques were employed as a quantitative approach to assess publishing trends, collaborative networks, and thematic keywords. Through systematic data collection and analysis, we identified the total number of documents, citations, and high-impact articles. Collaboration patterns among researchers were analyzed, highlighting interdisciplinary and cooperative approaches.
Results: Our findings reveal a sustained and growing interest in GIC within the research community, with citations steadily increasing since 1997. A comprehensive review of 1386 documents from 317 journals yielded a total of 28075 citations. Notably, highly cited articles predominantly appeared in Q1 category journals. Geographically, research contributions were led by established nations such as the USA, England, Brazil, Japan, and China, while emerging countries also made significant contributions. Collaboration emerged as a noteworthy feature, with researchers employing interdisciplinary approaches. Thematic keyword analysis emphasized recurring topics, including 'glass ionomer cement,' 'glass ionomer,' 'compressive strength,' 'mechanical strength,' and 'fluoride release,' outlining the trajectory of research in this field.
Conclusions: This study provides a comprehensive assessment of the research landscape surrounding Glass Ionomer Cement (GIC) from 1989 to 2023. The analysis underscores the enduring appeal of GIC within the research community, with a steady increase in citations over time. The study identified key collaboration patterns and recurrent thematic keywords that define the trajectory of research in this field. The insights gained from this bibliometric analysis hold implications for research prioritization, offering guidance for scholars, fund allocation entities, and policymakers alike. Overall, the study contributes to a better understanding of the evolving trends and collaborative dynamics in GIC research.

Keywords: glass ionomer cement, glass ionomer, compressive strength, mechanical strength, fluoride release, bibliometric analysis

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1. Introduction

Dental restorative materials are fundamental in dental practice for addressing tooth decay and structural issues.(1) Traditional materials such as amalgam and gold have been used for their durability and functionality.(2) In contrast, more recent materials like dental porcelain offer improved aesthetics and mimic natural teeth.(1) Glass Ionomer Cement (GIC) has emerged as a distinctive option due to its unique properties, including chemical adhesion to tooth structure and fluoride release.(3–6) Glass Ionomer Cement (GIC) holds significant importance in dentistry due to its biocompatibility, chemical adhesion, and versatile applications.(5) Its ability to form a chemical bond with tooth structure minimizes invasive tooth preparation, while fluoride release combats secondary caries.(6–8) GIC's use spans like restorative dentistry, luting restorations, and pediatric applications due to its simplified placement process and reduced post-operative sensitivity.(9) Advances like resin-modified GICs enhance esthetics, expanding its use to anterior teeth.(10) While GIC has lower mechanical strength and esthetic limitations, its cost-effectiveness and minimal tooth structure removal make it a valuable option.(11–18) In the pursuit of minimally invasive dentistry, GIC's unique properties continue to highlight its essential role in preserving tooth integrity and promoting oral health.(19) Glass Ionomer Cement (GIC), consists of two primary components fluoroaluminosilicate glass powder and a liquid containing polyacrylic acid.(20–23) When these components are mixed, they initiate an acid-base reaction, culminating in the creation of a hardened material that closely resembles the natural enamel of teeth. This setting process involves the interaction of carboxyl groups in the polyacrylic acid with ions present in the glass particles, resulting in the formation of a gel-like substance that solidifies over time, with the release of water as a byproduct.(24–29) Glass Ionomer Cement (GIC) boasts several key properties essential for dental applications. Its chemical adhesion to tooth structure minimizes preparation, while its biocompatibility reduces adverse reactions. GIC's gradual fluoride release aids remineralization, and advancements enhance esthetics. Moreover, its thermal expansion matches teeth, preventing gap formation. In various procedures prioritizing adhesion, fluoride, and biocompatibility, GIC's unique attributes ensure its lasting importance in dentistry.(30–36) Glass Ionomer Cement (GIC) finds diverse applications in dentistry. In restorative dentistry, it is employed to fill cavities of various types (Class I to V) and for core build-ups.(37–40) As a luting agent, GIC securely affixes crowns, bridges, inlays, and on lays to teeth surfaces while releasing fluoride for caries prevention. Additionally, GIC serves as a liner for pulp capping, providing protection and aiding healing for exposed pulp.(41–44) Glass Ionomer Cement (GIC) has limitations that impact its use in dentistry. Firstly, it has lower mechanical strength compared to materials like composite resin, making it less suitable for areas subjected to heavy chewing forces.(45,46) GIC is sensitive to moisture during placement, affecting its bond strength and requiring careful isolation.(47) It's best suited for low to moderate stress areas due to its inability to withstand high occlusal forces.(46) While GIC's esthetics have improved, it might not match natural tooth appearance as well as other materials, restricting its use in highly visible areas. These limitations highlight the importance of selecting GIC for appropriate cases, where its advantages in adhesion, fluoride release, and biocompatibility can be effectively utilized.(48) In recent years, the field of glass ionomer cement (GIC) in dentistry has witnessed remarkable progress through innovative modifications and developments. One significant advancement is the introduction of Resin-Modified Glass Ionomer Cement (RMGIC). This variation incorporates resin components into the GIC formulation, resulting in improved adhesion and moisture resistance. RMGIC amalgamates the strengths of conventional GIC and resin-based composites, boasting enhanced mechanical properties and a stronger bond to tooth structures. Particularly valuable for Class II restorations in posterior teeth, RMGIC provides heightened bond strength and better esthetics.(44,49–57) Nano-ionomer tech incorporates nano-sized particles into GICs, boosting durability, wear resistance, and translucency, overcoming old mechanical limits. Enhanced esthetic formulas counter opacity and unnatural look issues in traditional GICs, making them suitable for natural-looking anterior teeth treatments.(54,58) These modifications collectively underscore the commitment of researchers and manufacturers to overcoming the limitations of conventional GIC while preserving its inherent advantages. Through these advancements, the applications of glass ionomer cements have expanded significantly, solidifying their role in contemporary dental practice and offering more versatile and effective treatment options. In the realm of future developments for glass ionomer cement (GIC), several key avenues stand out. These include enhancing mechanical properties through material adjustments, thereby bolstering GIC's strength and durability for broader applications. Additionally, improving GIC's aesthetic qualities would make it more visually appealing for patients, while novel delivery systems could simplify application and reduce moisture-related challenges during setting. Furthermore, exploring combinations of GIC with other restorative materials, such as composites or ceramics, could yield hybrid materials with a blend of advantages. These innovations collectively aim to advance GIC's capabilities, expanding its utility and effectiveness in modern dentistry. Nonetheless, it remains crucial to meticulously examine studies pertaining to this subject. Such scrutiny is imperative in order to gauge their influence on the realm of applied dentistry. Among the approaches available for assessing the impact in applied science, bibliometric analysis stands out. Surprisingly, the existing literature appears to lack any comprehensive bibliometric investigation into the quantitative assessment of research on Glass Ionomer Cement (GIC). As a response to this gap, our study undertakes a multifaceted evaluation of publication and citation trends within the domain of GIC, spanning the years 1989 to 2023. In addition to this, our research endeavors to address the following research questions:

Research questions

1. What countries and institutions are at the forefront of research on GIC?
2. Which journals have the most significant impact on GIC?
3. What are the most popular and highly cited publications concerning the GIC?
4. Can you provide insights into the authorship and collaborative research patterns within the field of GIC?
5. What are the emerging research themes and keywords in the context GIC?

2. METHODOLOGY:

The objective of the bibliometric analysis is to delve into the evolving publication patterns within the academic realm pertaining to Glass Ionomer Cement (GIC). This study encompasses an examination of multifaceted aspects such as total citations (TC), overall publications (TP), publication years (PY), and prevailing authorship tendencies. The meticulous data acquisition process additionally facilitated the identification of eminent contributors, prominent journals, influential nations, and noteworthy institutions.

2.1Database and Bibliographic Information:

The present analysis relies on information sourced from the Web of Science (WoS) core collection database, renowned for its credibility and worldwide recognition in the realm of indexing and abstracting. Employing bibliometric analysis, a statistical approach to scrutinize scholarly endeavors, we delve into the publishing trends and research landscape within this domain. This specific study adopts a four-phased, all-encompassing search and selection strategy, as depicted in Figure 1, to encompass pertinent publications for our comprehensive analysis.

2.2Search Query:

On July 25th, an extensive search was carried out in the WoS database at Smt. Kishoritai Bhoyar College of Pharmacy in Kamptee, Nagpur. The search aimed to retrieve bibliographic data on Glass Ionomer Cement (GIC) using a meticulously crafted query that incorporated essential keywords such as [“Glass ionomer cement (Title) OR GIC (Title)”]. This query was executed within the WoS core collection to ensure a thorough exploration of relevant literature.

To enhance the search precision, Boolean operators were strategically employed to combine these keywords, resulting in a cohesive search strategy designed to yield the most pertinent and comprehensive outcomes.

2.3Inclusion/Exclusion Criteria:

For the sake of precision, a comprehensive set of inclusion and exclusion criteria was employed, as depicted in Figure 1. There were no restrictions based on language, geography, or date. Initially, the search yielded a total of 7199 documents. Subsequently, utilizing Boolean operators, the keywords were specifically searched within document titles, resulting in the removal of 5296 documents and the presentation of 1903 remaining results.

To narrow down the scope, the search was confined to articles, review articles, paper proceedings, and early access materials. To achieve this, a "document types" filter was implemented, resulting in a refined collection of 1386 documents. This refinement process aided in the elimination of 517 documents that did not meet the criteria.

These 1386 documents were subsequently subjected to a thorough assessment for relevance and eligibility, resulting in a cumulative citation count of 12063, with 10980 citations excluding self-citations. Furthermore, the h-index for this set of documents was determined to be 71.

2.4Data Analysis and Visualization

Analyzed and visualized were 1386 carefully selected documents along with their associated data. Employing a range of tools and software, including MS-Excel, VOS Viewer (Version 1.6.19), and Biblioshiny (R-studio), we delved into the dataset. Comprehensive bibliometric indicators were scrutinized, encompassing citation documents, sources, authors, organizations, and countries. Furthermore, we explored publication and citation trends, authorship dynamics, as well as bibliographic couplings (journals, countries, and authors). Co-occurrences of keywords were examined, and an intricate co-citation network of authors was mapped out. Through these methods, we achieved a profound understanding of thematic evolution. Our analyses were facilitated by the aforementioned tools and software, enhancing our ability to present insightful visualizations.

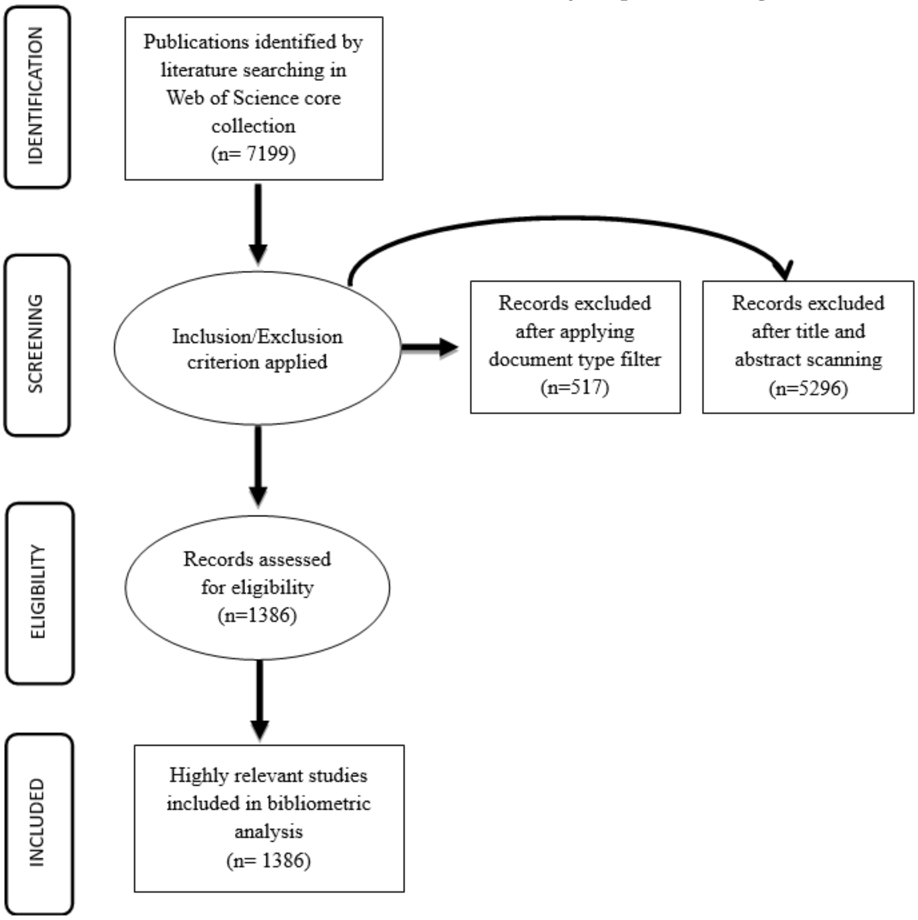

Fig 1: four-Phase flow diagram of data extraction and filtration process of GIC publications.

3. Results

3.1Analysis of Overall Growth Trend:

Figure 2 illustrates the yearly research output concerning glass ionomer cement, measured by the total count of publications and citations. It is evident that the inaugural publication, along with a cumulative total of 29 publications on this subject, emerged in 1989, garnering a mere 5 citations collectively. Subsequently, there has been a substantial escalation in research productivity. Significantly notable numbers of publications have emanated from the very inception year (1989), whereas a substantial upsurge in citations became apparent post-1999. The pinnacle of both publication and citation activity was observed in 2020 (TP= 85) and 2021 (TC= 2184), respectively.

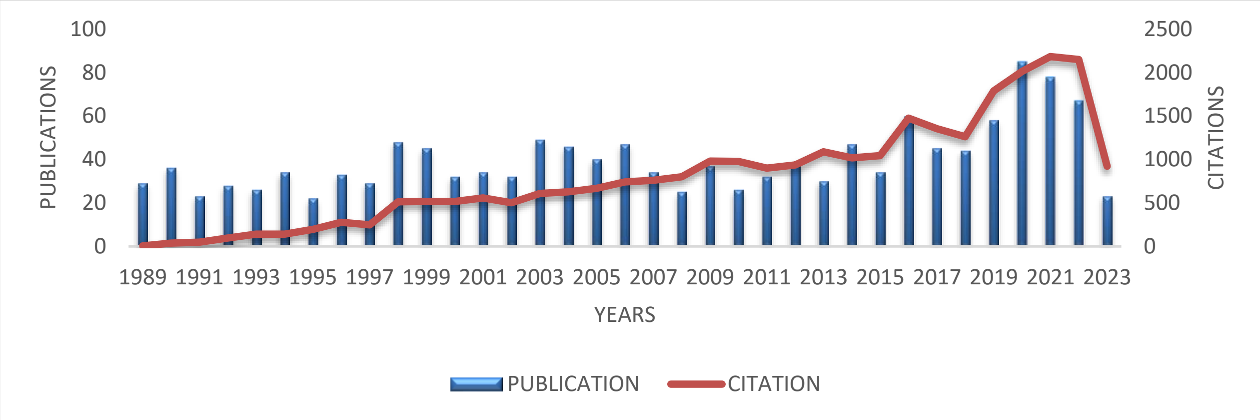

FIG 2: Publishing and citation trends in GIC research

3.2Most Productive Countries and Organizations on Glass Ionomer Cement:

The analysis aimed to identify the foremost 10 countries and organizations spearheading global publications, showcasing their remarkable contributions. Among these, five countries boast triple-digit publication figures, while the remaining five in the top 10 have each generated over 50 publications.

Leading the pack is the United States of America, securing the pinnacle with a staggering 165 publications. On the other end of the spectrum, Sweden occupies the bottom spot with 44 publications. England takes the lead in citations, amassing an impressive 4254, whereas Turkey trails with a more modest 905 citations. When assessing citation impact, Sweden exhibits the highest value at 34.93, in stark contrast to Turkey's lowest value of 12.93.

Shifting focus to citation impact, Sweden stands out with an impressive score of 34.93, while Turkey trails behind with a more modest score of 12.93. Furthermore, when gauging the collective strength of links, England takes the lead with a substantial score of 2217, whereas Sweden trails with the lowest score of 320.

In this panorama, India claims the 14th spot, contributing a total of 32 publications, accompanied by 410 citations, yielding a citation impact of 12.81, and earning a link strength score of 290.

RANK	SCOUNTRY	TP	TC	CI	TOTAL LINK STRENGTH
1	USA	165	3975	24.09	1401
2	ENGLAND	159	4254	26.75	2217
3	BRAZIL	157	2428	15.46	1689
4	JAPAN	115	2193	19.07	1074
5	PEOPLES R CHINA	102	1714	16.80	1159
6	TURKEY	70	905	12.93	757
7	CANADA	59	1386	23.49	474
8	GERMANY	56	1719	30.70	888
9	AUSTRALIA	55	1229	22.35	724
10	SWEDEN	44	1537	34.93	320
14	**INDIA**	**32**	**410**	**12.81**	**290**

Table 1. most influential countries in terms of total publication (TP), total citation (TC) and citation impact (CI)

RANK	ORGANIZATIONS	COUNTRY	TP	TC	CI	TOTAL LINK STRENGTH
1	THE UNIVERSITY OF SÃO PAULO	BRAZIL	72	1198	16.64	351
2	THE QUEEN MARY UNIVERSITY OF LONDON	ENGLAND	45	1086	24.13	290
3	THE UNIVERSITY OF HONG KONG	HONG KONG	35	916	26.17	260
4	THE UNIVERSITY OF MELBOURNE	AUSTRALIA	31	741	23.90	179
5	THE NATIONAL UNIVERSITY OF SINGAPORE (NUS)	SINGAPORE	26	565	21.73	157
6	UMEA UNIVERSITY	SWEDAN	17	711	41.82	20
7	THE STATE UNIVERSITY OF CAMPINAS	BRAZIL	17	259	15.24	118
8	THE UNIVERSITY OF ZAGREB	CROATIA	16	153	9.56	99
9	INDIANA UNIVERSITY–PURDUE UNIVERSITY INDIANAPOLIS	USA	15	326	21.73	105
10	KING'S COLLEGE LONDON	ENGLAND	15	594	39.60	123

Table 2. Most influential organization in terms of total publication (TP), total citation (TC) and citation impact (CI)

Among the top 10 organizations, the University of Sao Paulo stands out by producing a remarkable 72 publications, which have garnered an impressive 1198 citations, resulting in an outstanding citation impact of 16.64. Notably, it secures the highest link strength score of 351. Following closely is Queen Mary University of London, with 45 publications and 1086 citations. A noteworthy observation is the position of Umea University of Sweden, ranking sixth with 17 publications and 711 citations. Despite its modest publication count, Umea University achieves the highest citation impact among the top 10, an impressive CI of 41.82, while maintaining the lowest link strength score of 20.

3.3Highly influential Journals

Table 3 presents a comprehensive overview of the top ten journals known for their exceptional productivity in the realm of glass ionomer cement literature. The majority of these sources have contributed significantly, producing over 25 publications each. Leading the pack is the journal "Dental Materials," standing out with an impressive 110 publications, accompanied by a substantial citation count of 4050. This journal boasts a remarkable citation impact of 36.82 and comfortably resides in Quartile 1. Furthermore, it holds an esteemed impact factor of 5.304, solidifying its prominence. Following closely is the "Biomaterials" journal, securing the second position with 57 publications and an impressive citation count of 2552. Garnering a citation impact of 44.77, this journal also finds its place in Quartile 1. It's worth noting that "Biomaterials" boasts the highest impact factor within this cohort, standing at an impressive 14.

Notably, all the journals included in this analysis possess impact factors within Quartile 1–2, underlining their significance in the field. Interestingly, a significant proportion of these esteemed sources originate from the United Kingdom and the United States, with half of the total list hailing from these two nations. Additionally, one source each comes from Australia, the Netherlands, and Japan, further emphasizing the international reach and influence of this niche area of research.

SR NO	SOURCE	TP	TC	CI	TOTAL LINK STRENGTH	COUNTRY	PUBLISHER	IF	Q
1	Dental materials	110	4050	36.82	1023	United Kingdom	Elsevier	5.304	Q1
2	Biomaterials	57	2552	44.77	671	United States	Elsevier	14	Q1
3	Journal of dentistry	57	1180	20.70	579	United Kingdom	Elsevier	4.379	Q1
4	Operative dentistry	54	899	16.65	296	United States	Indiana University School of Dentistry	2.937	Q1
5	Journal of materials science-materials in medicine	50	890	17.80	333	Netherlands	Springer Science and Business Media	3.896	Q2
6	Dental materials journal	33	371	11.24	261	Japan	Japanese Society for Dental Materials and Devices	2.64	Q1
7	Australian dental journal	32	753	23.53	190	Australia	Wiley	2.259	Q2
8	American journal of orthodontics and dentofacial orthopedics	29	975	33.62	179	United States	Elsevier	1.98	Q1
9	Journal of oral rehabilitation	29	545	18.79	169	United Kingdom	Wiley-Blackwell Publishing Ltd	2.9	Q1
10	Journal of applied oral science	27	486	18.00	227	Brazil	Faculdade de Odontologia de Bauru da Universidade de Sao Paulo	3.144	Q1

TABLE 3: Highly influential journals in relation to published articles on GIC

3.4Authorship Pattern:

The data underwent sorting, primarily relying on the aggregate number of publications authored by diverse individuals. This process aimed to pinpoint and spotlight the leading 10 authors, characterized by their impressive productivity.

Additionally, an evaluation of total citations and citation impact was carried out, shedding light on the extent of their influence within the realm of this particular research area. Within Fig 3, a definitive ranking of the most prolific authors engaged in the study of glass ionomer cement (GIC) is illustrated.

In order to establish the benchmark for the designation of "most prolific author," a criterion was set where authors were required to have authored a minimum of five papers pertaining to GIC. This threshold was established as the basis for identifying these high-output contributors. Among the expansive pool of 4352 authors who contributed to GIC research, a subset of 91 authors successfully met this prescribed threshold. Further segmentation of these authors resulted in the formation of 34 distinct clusters, collectively characterized by a cumulative link strength of 425.

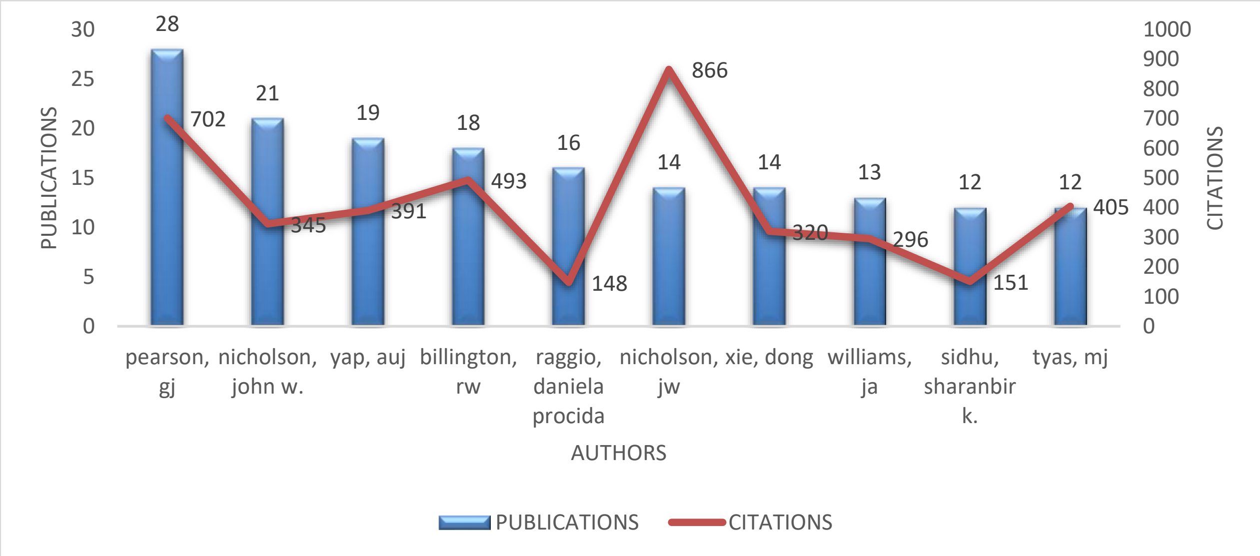

FIG 3: Authorship pattern of glass ionomer cement literature

3.5Authors Keyword Co-Occurrences Analyses on Glass Ionomer Cement

Figure 4 illustrates the outcomes of our keyword analysis pertaining to glass ionomer cement. To establish a meaningful threshold, we focused on keywords with a minimum occurrence count of ten. Consequently, out of a grand total of 2121 authors' keywords, 56 keywords met this stipulated criterion. These keywords are grouped into eight distinct clusters, collectively exhibiting a combined link strength of 943.

The delineation of these clusters is as follows: Cluster 1 comprises 11 items, Cluster 2 encompasses 9 items, Cluster 3 consists of 8 items, Cluster 4 includes 8 items, Cluster 5 spans 8 items, Cluster 6 comprises 4 items, Cluster 7 contains 4 items, and Cluster 8 encompasses 4 items. Each cluster is assigned a unique color, and their arrangement is based on both link strength and occurrence frequency. The size of each bubble in the visualization conveys the nature of the relationship between link strength and occurrence.

Among the keywords analyzed, five keywords stand out with the highest aggregate link strengths. These are:

Glass ionomer cement (link strength: 237)

Glass ionomer (link strength: 79)

Mechanical properties (link strength: 76)

Fluoride release (link strength: 74)

Compressive strength (link strength: 72)

This analysis provides valuable insights into the keyword relationships and emphasizes the significance of these highlighted keywords within the context of glass ionomer cement research.

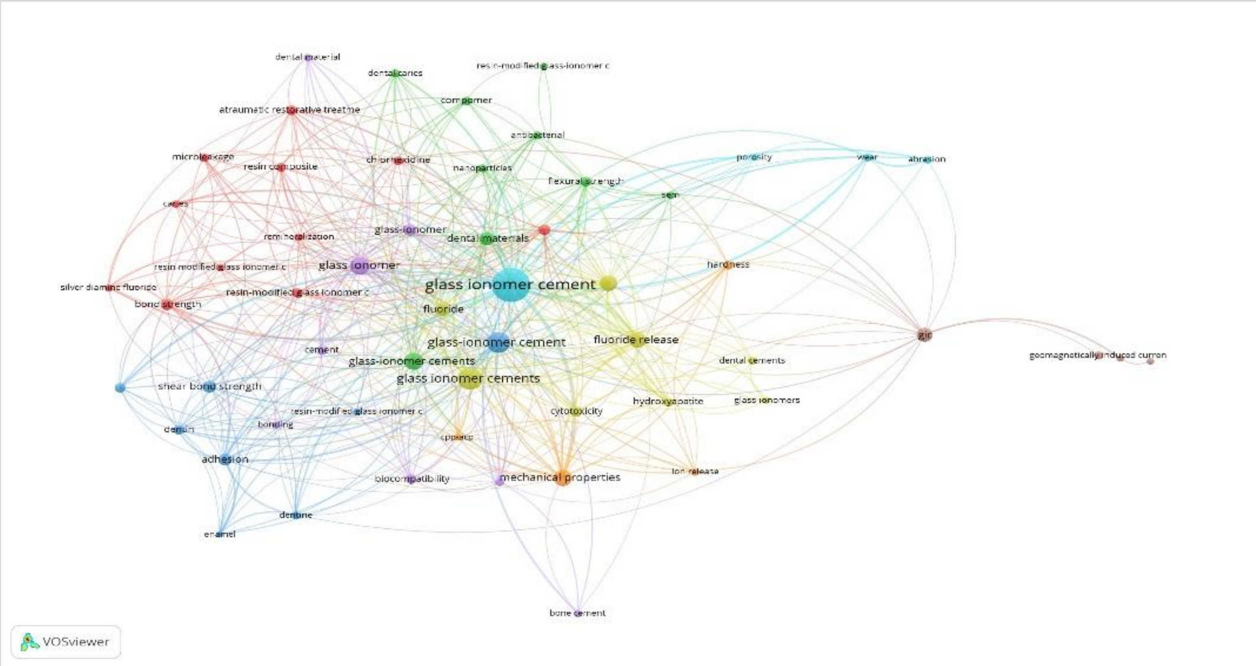

Figure 4. Co-occurrence network of author keywords (minimum number of occurrences: Ten)

A co-occurrence network is a relationship of two or more keywords occurring together. In this figure, there are eight clusters (indicating various colors) having relationship with each other. Cluster one is the strongest network relationship, followed by 2-8 clusters, respectively. The top keyword 'glass ionomer cement' having the strongest relationship and occurred maximum in glass ionomer cement literature.

3.6Highly Citated Articles

Table 4 illustrates the bibliographic details of the top ten most extensively referenced articles concerning GIC (Glass Ionomer Cement). The range of citations and publication years among these foremost 10 articles spanned from 165 to 308 citations and from 1992 to 2008, respectively. Notably, four articles garnered citations exceeding the 250 mark. At the pinnacle of the list, the article titled "Chemistry of glass ionomer cements: a review" by Nicholson, published in Biomaterials in 1998, stands out with the highest citation count (308). Following closely is an article authored by Xie, D; Brantly, Wa; Culbertson, Bm; Wang, G, titled "Mechanical properties and microstructures of glass ionomer cements," featured in Dental Materials in 2000, amassing 303 citations. Another significant contribution, "Substances released from dental resin composites and glass ionomer cements," penned by Geurtsen, W et al and released in 1998, secured 261 citations.

These articles collectively underscore the enduring influence and significance of research in the domain of glass ionomer cements.

SR NO	TITLE	AUTHOR	SOURCE	TC	YEAR
1	Chemistry of glass ionomer cements: a review	Nicholson et al.	Biomaterials, 16(6), 485-494	309	1998
2	Mechanical properties and microstructures of glass ionomer cements	Xie, D; Brantly, Wa; Culbertson, Bm; Wang, G et al.	Dental Materials, 16(2), 129-138	303	2000
3	Substances released from dental resin composites and glass ionomer cements	Geurtsen, W et al.	European journal of oral sciences, 106(2), 687-695	261	1998a
4	GIC: observations and studies in the hydro-quebec power system	Bolduc, I et al.	Journal of atmospheric and solar terrestrial physics, 64(16)/ 1793-1802	255	2002
5	On the so- called ''Semi-Ionic" "C-F bond character in fluorine-GIC	Sato, Y; Itoh, K; Hagiwara, r; Fukunaga, T; Ito, Y	Carbon, 42(15), 3243-3249	181	2004
6	Studies on the adhesion of glass ionomer cements to dentin	Lin, A; Mcintyre, NS; Davidson, RD	Journal of Dental Research, 71(11), 1836-1841	173	1992

7	Effect of incorporation of hydroxyapatite and fluorapatite nanobioceramics into conventional glass ionomer cement (GIC)	Moshaverini, Alireza; Ansari, Sahar; Moshaverini, Maryam; roohpour, nima; darr, jawwad A; Rehman, Ihtesham et al.	Acta Biomaterialia, 4(2), 432-440	166	2008
8	Residual monomer additive release and variability in cytotoxicity of light curing glass ionomer cement and compomers	Geurtsen, W; Spahl, W; Leyhausen, G et al.	Journal of Dental research, 77(12), 2012-2019	156	1998b
9	Fluoride release from glass ionomer cement invivo and invitro	Hatibovickofman et al	Swedish dental journal, 15(6), 253-258	148	1991
10	Dental glass ionomer cements as permanent filling material? Properties, limitation and future trends	Lohbauer, Ulrich et al	Materials, 3(1), 76-96	148	(2010)

Table 4: Top 10 highly citated articles on GIC

3.7Bibliographic Coupling of Countries

Figure 5 illustrates the bibliographic coupling among countries in the realm of GIC research. We focused on countries with a minimum of 10 documents or more, resulting in the inclusion of 37 out of the 85 countries initially considered. These 37 countries are organized into 5 distinct clusters, collectively exhibiting a total link strength of 264,773. These connections, rooted in both content proximity and scholarly associations, are elucidated through quantitative network indicators. Prominently engaged in bibliographic coupling are countries such as the United States of America (with 165 Documents, 3975 Citations, and a Total link strength of 46,790), England (with 159 Documents, 4254 Citations, and a Total link strength of 58,559), and Brazil (with 157 Documents, 2428 Citations, and a Total link strength of 47,876). Notably, the United States of America, possessing the highest research output on GIC as detailed in Table 1, aligns within cluster 2 alongside England, Japan, Sweden, France, Belgium, Canada, Denmark, Ireland, Poland, and Switzerland. Meanwhile, India finds its place within cluster 1.

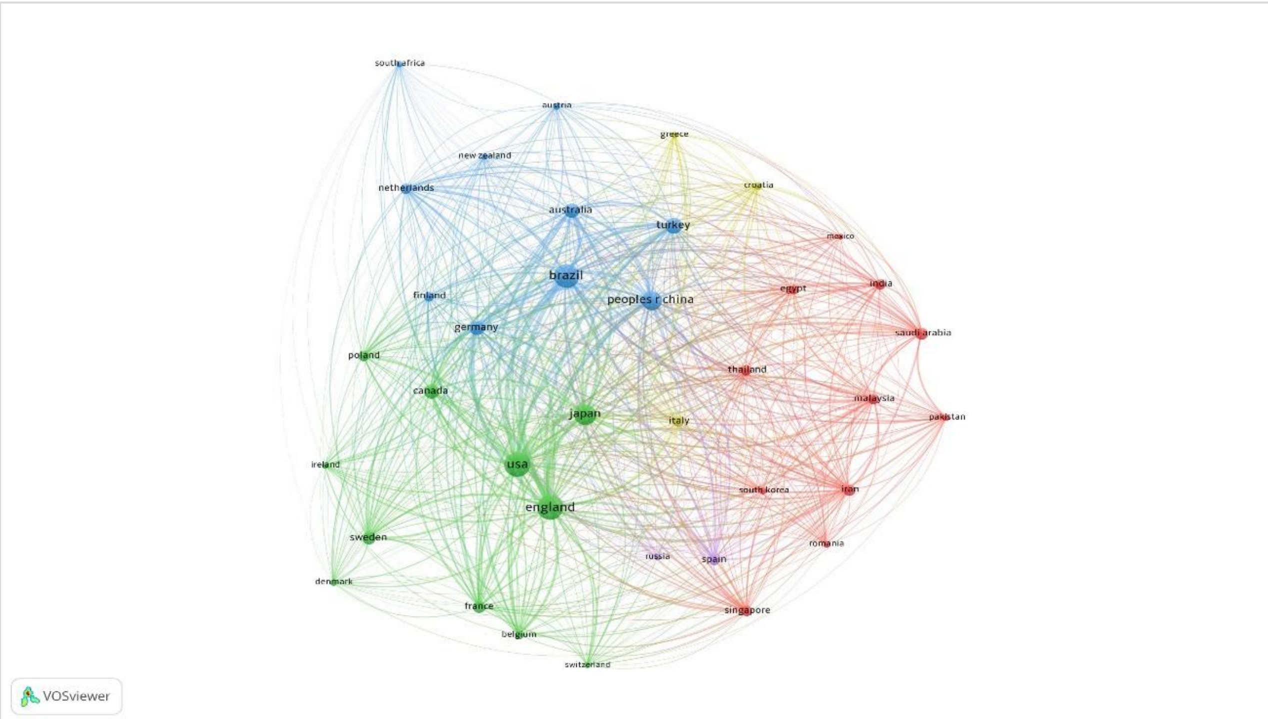

Fig 5: Bibliographic Coupling of Countries that published minimum 10 documents, 37 countries out of 85 countries met the threshold (generated using VOS Viewer)

3.8Bibliographic coupling of Authors

Figure 6 illustrates the bibliographic coupling of authors within the realm of GIC research. This analysis aims to unveil the extent to which a single reference author is shared between two documents. Authors with a publication count of at least 10 documents were considered, leading to the inclusion of 16 out of 4352 authors that met this criterion. These 16 authors were subsequently categorized into 3 distinct clusters, collectively demonstrating a total link strength of 11988. Specifically, there were 9 authors in Cluster 1, 5 authors in Cluster 2, and 2 authors in Cluster 3.

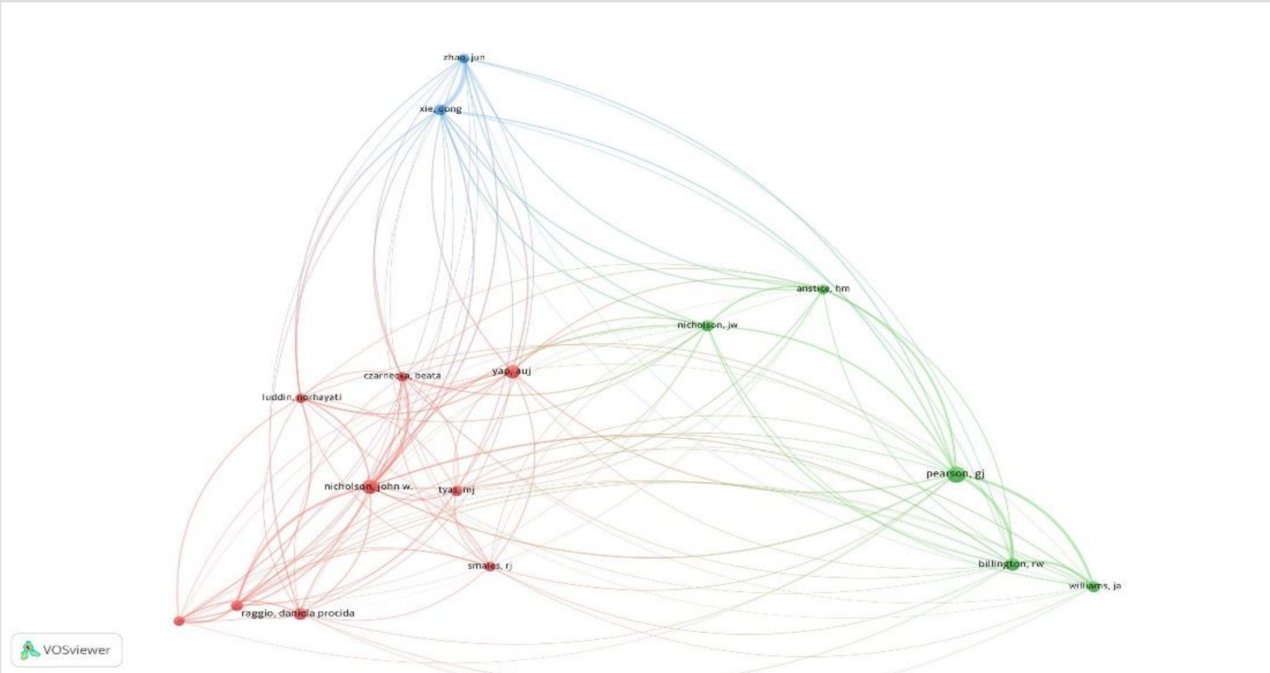

Fig 6: Bibliographic coupling of authors in GIC research

3.9Co-citation network of authors

Figure 7 illustrates the co-citation network encompassing authors within the realm of GIC research spanning the period from 1989 to 2023. Authors who have garnered 100 citations or more have been encompassed in the analysis. Out of the extensive pool of 12,988 authors, a selective 17 have met this citation criterion. These 17 distinguished authors have been segregated into two discernible clusters, collectively exhibiting a cumulative link strength amounting to 11,455. This network reveals the existence of two distinctive clusters of authors, designated as Cluster 1, comprising 9 authors, and Cluster 2, comprising 8 authors. Among these clusters, the list of top-tier authors is as follows: Wilson, AD (with 863 citations), Nicholson, JW (with 485 citations), Sidhu, SK (with 305 citations), McLean, JW (with 296 citations), and Xie, D (with 259 citations). It is notable that these authors have been effectively grouped into their respective clusters, and the network analysis employs quantitative indicators to establish connections and relationships among these distinct clusters.

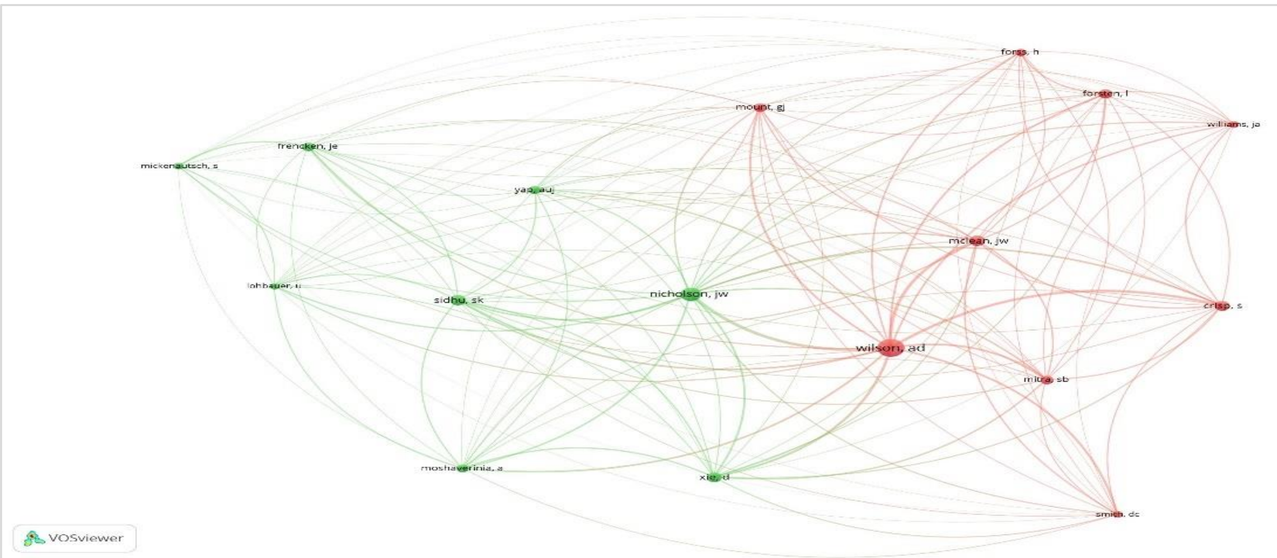

Fig7: Co-citation Network of Authors

3.10 Three Field Plot (Countries, Keywords, and Journals)

Figure 8 illustrates a three-field plot showcasing the intricate interplay between journals/sources (on the left), countries (in the middle), and keywords (on the right). The objective is to enhance comprehension regarding the optimal pairing of countries, keywords, and sources for publication. The analysis reveals that a group of five countries (Brazil, United Kingdom, China, Japan, and USA) have contributed significantly to the literature on Glass Ionomer Cement (GIC). This contribution is underpinned by the utilization of five primary keywords: "glass ionomer cement," "mechanical properties," "glass ionomer," "compressive strength," and "fluoride release." Notably, research on GIC with these keywords has emanated from the aforementioned countries, creating a strong thematic nexus. These seminal works have found their home in the pages of renowned journals, fostering a robust relationship between the research components. The journals "Dental Material," "Journal of Dentistry," "Biomaterials," "Journal of Material Science - Material in Medicine," and "Operative Dentistry" have been the preferred platforms for disseminating this insightful research.

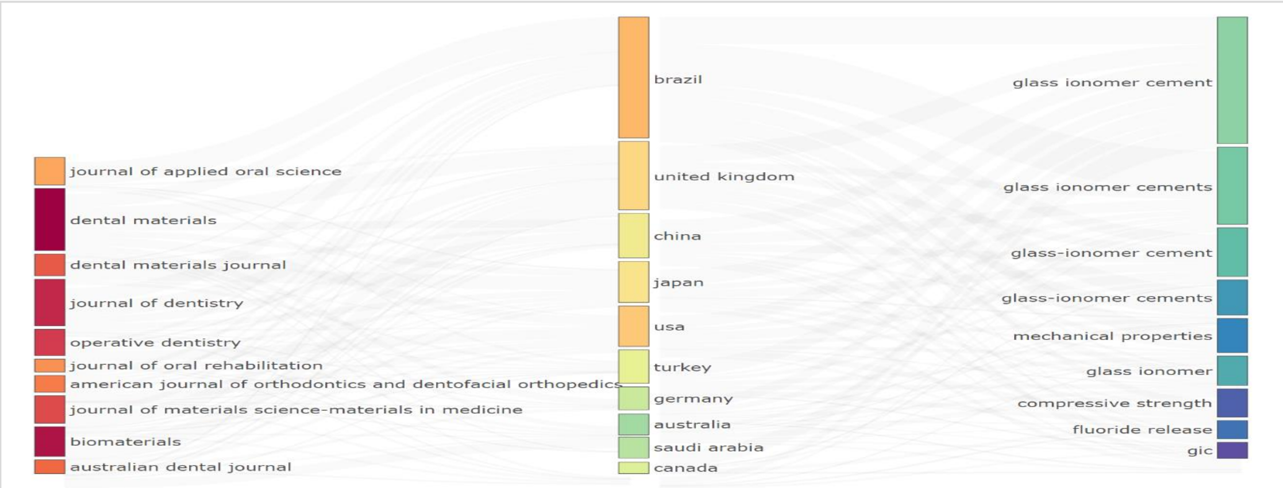

Figure 8: Three-factor plots of the relationship among sources (left), countries (middle), and keywords (right) on glass ionomer cement literature.

3.11 Thematic Evolution Map of Authors key word:

Figure 9 illustrates the dynamic progression of author keywords across five distinct timeframes: 1989-1995, 1996-2005, 2006-2015, 2016-2022, and 2023. It becomes evident that during the period of 1989-1995, notable attention and citations were directed towards the themes of GIC, adhesion, biocompatibility, and composite resins, indicative of their significant influence during that era. Moving into the span of 1996-2005, the dental research community displayed heightened interest in themes such as glass ionomer cement, glass ionomer, GIC, compomer, and polyacrylic acid, as evidenced by substantial researcher engagement. Analysis of documents published from 2006 to 2015 reveals a strong citation rate for themes like resin-modified glass ionomer, glass ionomer cement, surface toughness, amalgam, and micro tensile bond strength, underscoring their prominence during this period. In the interval of 2016-2022, the focus of researchers prominently centered around glass ionomer cement, composite resin, and ossiculoplasty, signifying a notable shift in research interests. Lastly, in the year 2023, the exploration of research domains revolved around fluoride release, glass ionomer cement, and fluoride. This demonstrates the ongoing evolution of themes and subjects within the field.

The thematic evolution map of author keywords spanning the past 34 years distinctly illustrates a significant transition towards the modification of glass ionomer cement research streams, indicating a noteworthy shift in the trajectory of dental research pursuits.

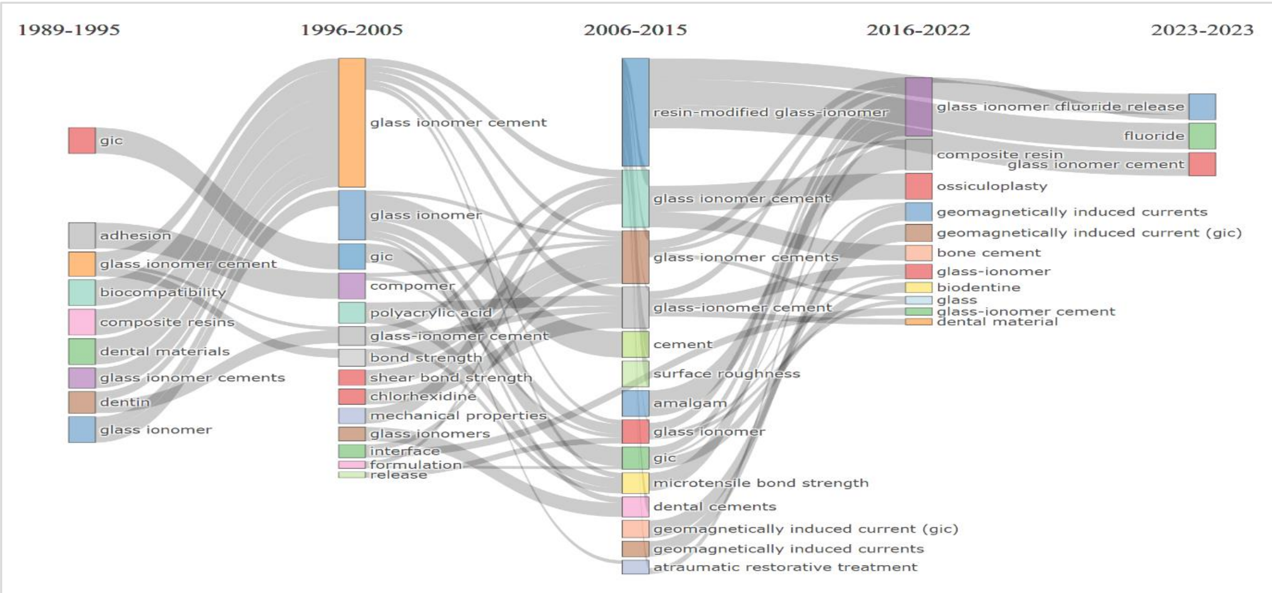

Fig 9: Thematic evolution of authors keywords from 1989- 2023 with respect to Glass ionomer Cement research.

4. Discussion:

This bibliometric analysis is the first of its kind as it aimed to identify and quantitatively evaluate the scientific research articles published on the use of GIC in dentistry during the last three decades.

4.1Yearly Trends of Publications

In conclusion, the analysis of yearly publications and citations pertaining to the research article on "The flexural strength of repaired glass-ionomer cements" provides valuable insights into the evolution of this field. The initial publication in 1989 marked the beginning of a steady rise in research output, with a noticeable surge in publications observed from the outset. While the citation count remained modest in the early years, a substantial upturn was evident from 1997 onward. This pattern underscores the enduring significance and growing interest in the study of glass-ionomer cements. The sustained upward trajectory in both publications and citations suggests a promising and enduring future for research in this domain.

4.2Leading countries, Organizations and bibliographic coupling of countries:

The analysis of productivity among countries and organizations revealed significant insights. The United States of America, England, and Brazil emerged as the top three most productive countries, while The University of São Paulo (Brazil), The Queen Mary University of London (England), and The University of Hong Kong (Hong Kong) stood out as the most productive organizations. Notably, the USA led with the highest number of publications, citations, and total link strength, showcasing its research prowess. The University of São Paulo demonstrated remarkable productivity among organizations, boasting the highest metrics across publications, citations, and total link strength. Furthermore, the bibliographic coupling of countries reaffirmed the dominance of USA, England, Brazil, Japan, and China in the field. These findings underscore the significance of collaboration and research efforts in driving productivity and impact within the global landscape of scholarly pursuits.

4.3Preferred Journals

In conclusion, the analysis of publication outlets for Glass Ionomer Cement research reveals a distinct preference for journals listed within the Q1 ranking of Web of Science. Among the top 10 preferred outlets, four have garnered significant attention, with two hailing from Elsevier Sci. Ltd. in the United Kingdom and one each from Elsevier Sci. Ltd. in the USA and Indiana University School of Dentistry, USA. Notably, Dental Materials emerges as the frontrunner with 110 articles and a substantial total citation count of 4050, followed closely by Biomaterials and Journal of Dentistry with 57 articles (2552) and (1180) citations respectively. However, Journal of Applied Oral Science finds itself at the lower end of the spectrum, having published 27 articles and garnered 486 citations. The discernible trend leans towards high impact factor journals, with a predominant presence in the Q1 (8) and Q2 (2) categories, reflecting the emphasis on influential publication avenues within this domain.

4.4Co-Citation Network of authors:

The application of co-citation network analysis in bibliographic studies offers valuable insights into the underlying specialties within a field by examining patterns of author co-citation in the relevant literature. This approach not only reveals clusters of authors who have been frequently cited together, but also sheds light on the interconnectedness of published works as perceived by domain experts. Notably, authors such as Wilson, AD, Nicholson, JW, Sidhu, SK, McLean, JW, and Xie, D have emerged as significant contributors in research collaborations within this field. The predominance of clustered research indicates a prevailing trend, yet there is a hopeful prospect for increased collaborative efforts among this cluster of authors in the near future.

4.5Keyword Co-Occurrence in GIC:

In conclusion, the analysis of keyword trends within the selected publications revealed valuable insights. Keyword co-occurrence networks, derived from titles, abstracts, and author-generated lists, provide a means to uncover relationships between concepts. The proximity of keywords within these networks reflects their semantic similarity, with closely related keywords appearing together. Notably, the examination of frequently utilized keywords like "glass ionomer cement," "glass ionomer," "mechanical properties," "fluoride release," and "compressive strength" underscores their significance in the domain. Interestingly, the persistent presence of "glass ionomer cement" or "glass ionomer" across all eight clusters reinforces their pivotal role. However, the absence of "antibacterial" as a highlighted keyword highlights a potential research gap in the existing literature. This analysis underscores the dynamic interplay of keywords and offers avenues for further exploration in the field.

4.6Authorship Pattern and Bibliographic Coupling of Authors:

In conclusion, the analysis of the top 10 authors based on Fig 3 reveals intriguing insights into their publication and citation patterns. Notably, Pearson, GJ and Nicholson, JW stand out for their remarkable contributions. Pearson, GJ has demonstrated an impressive balance between quantity and impact, with 28 publications and 702 citations. On the other hand, Nicholson, JW's comparatively modest publication count of 14 documents has been offset by an extraordinary 866 citations, underlining the substantial influence of their work. The results of the bibliographic coupling analysis further underscore the significance of certain authors. Pearson, GJ, Nicholson, John W., and Yap, Auj emerge as key figures, showcasing their strong collaborative linkages and substantial scholarly impact. These findings shed light on the intricate interplay between publication output, citations, and collaborative connections within the examined academic landscape.

4.7Three field Plot:

In conclusion, Figure 8 offers a comprehensive visualization of the intricate web connecting journals/sources, countries, and keywords within the realm of Glass Ionomer Cement (GIC) research. By meticulously analyzing this tripartite relationship, we gain valuable insights into the optimal pairing of countries with specific keywords and suitable publication sources.

Our analysis highlights the pivotal role played by five countries Brazil, United Kingdom, China, Japan, and USA in shaping the discourse on GIC. These countries have adeptly harnessed five key keywords "glass ionomer cement," "mechanical properties," "glass ionomer," "compressive strength," and "fluoride release" to steer their research endeavors. Consequently, a symbiotic synergy between these countries, keywords, and sources has given rise to a substantial body of knowledge.

The discerning choice of journals, such as "Dental Material," "Journal of Dentistry," "Biomaterials," "Journal of Material Science - Material in Medicine," and "Operative Dentistry," has facilitated the propagation of this research, fostering a dynamic interplay between academia and practical application.

In essence, Figure 8 and its underlying analysis not only elucidate the current landscape of GIC research but also provide a roadmap for scholars and practitioners seeking to contribute meaningfully to this field. As the nexus between countries, keywords, and sources continues to evolve, this visual representation stands as a testament to the global collaborative effort driving advancements in GIC and its multifaceted applications.

4.8Thematic Evolution Maps of Keywords

In conclusion, the journey through the thematic evolution of author keywords over the past 34 years offers valuable insights into the changing landscape of dental research. The shifts observed in the focus of research themes highlight the dynamic nature of scientific exploration and the ever-evolving interests within the field.

The retrospective analysis showcases periods of concentrated attention on specific topics, such as the prevalence of GIC, adhesion, biocompatibility, and composite resins during the late 1980s to mid-1990s. This demonstrates the influence of these themes on shaping the research landscape of that time.

As time progressed, the emergence of glass ionomer cement, glass ionomer, and related subjects as prominent keywords during the 1996-2005 period reveals a discernible shift in focus. This trend continues, with different themes taking center stage in subsequent periods, reflecting the changing priorities and advancements in dental science.

Notably, the trajectory witnessed a distinct transition towards the modification of glass ionomer cement research streams in recent years, showcasing the adaptability of researchers to embrace new challenges and opportunities. This evolution underscores the field's capacity to respond to emerging needs and technological developments.

The thematic evolution map acts as a historical roadmap, guiding us through the ebb and flow of dental research interests. It underscores the interdisciplinary nature of scientific exploration, with themes spanning from material science to clinical applications. Ultimately, this analysis serves as a testament to the vitality of the dental research community and its commitment to advancing oral health through innovative investigations and insights.

4.9Limitations and Future Research Directions:

This study's scope is subject to several limitations. The review may have certain limitations such as inclusion of pivotal studies, absence of universally acknowledged mechanism for self-citation identification, only web of science search engine have been used and no additional categories like meetings, case reports, letters, abstracts, biographies, and editorials were included.

Despite these limitations, the current exploration of GIC presents promising avenues for future investigators to identify research prospects and address existing gaps. Researchers within the realm of dental material sciences can chart strategies pertaining to nascent and minimally addressed subjects from previous investigations. Moreover, they can pinpoint influential papers, authors, and journals to discern research lacunae and emergent insights.

Emergent research trajectories guided by this bibliometric analysis encompass:

1. Focused investigations into the antibacterial attributes of GIC, honing in on specific facets like antibacterial monomers, nanoparticles, peptides, etc.
2. Comparative examinations of this subject across diverse socioeconomic contexts, encompassing both developed and developing nations.
3. Incorporating more comprehensive and expansive demographic variables for a more holistic analysis.

5. Conclusion:

The primary objective of this research was to conduct an exhaustive bibliographic examination of the body of work focused on Glass Ionomer Cement (GIC). The publication trajectory was segmented into five distinct time spans: 1989–1995, 1996-2005, 2006-2015, 2015-2022, and 2023. Remarkably, the very first year of inquiry exhibited a remarkable surge in publications, setting the tone for subsequent years. Notably, the trajectory of citations experienced a substantial uptick from 1997 onwards.

Prominent contributors to this field were predominantly affiliated with institutions in the United States, England, Brazil, Japan, and China, making these countries the driving forces behind influential GIC research. Particularly noteworthy were The University of São Paulo, Brazil, and The Queen Mary University of London, which emerged as the most prolific institutions in terms of output.

Articles predominantly found their home in Dental Material and Biomaterial journals, cementing their significance within the scientific community. Encouragingly, collaboration among multiple authors was a discernible trend, with collective efforts yielding high-impact papers that garnered substantial citations. Notably recurrent keywords such as "glass ionomer cement," "compressive strength," "mechanical properties," and "fluoride release" underscored the thematic core of the research landscape.

The outcome of this quantitative bibliometric investigation stands to offer invaluable insights to researchers, funding bodies, and policy shapers. By highlighting strengths and identifying gaps in the realm of antibacterial GIC research, this study aspires to guide future directions, spurring innovation and advancement in this domain.

Declaration of Interest

The authors report no conflict of interest.

REFERENCES:

1. 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. Dental Materials. 2015 Apr 1;31(4):e89–99.
2. Hafshejani TM, Zamanian A, Venugopal JR, Rezvani Z, Sefat F, Saeb MR, et al. Antibacterial glass-ionomer cement restorative materials: A critical review on the current status of extended release formulations. Journal of Controlled Release. 2017 Sep 28;262:317–28.
3. Geurtsen W. Substances released from dental resin composites and glass ionomer cements. Eur J Oral Sci [Internet]. 1998 Apr 1 [cited 2023 Aug 10];106(2p2):687–95. Available from: https://onlinelibrary.wiley.com/doi/full/10.1046/j.0909-8836.1998.eos10602ii04.x
4. Lohbauer U. Dental Glass Ionomer Cements as Permanent Filling Materials? – Properties, Limitations and Future Trends. Materials 2010, Vol 3, Pages 76-96 [Internet]. 2009 Dec 28 [cited 2023 Aug 10];3(1):76–96. Available from: https://www.mdpi.com/1996-1944/3/1/76/htm
5. Smith DC. Development of glass-ionomer cement systems. Biomaterials. 1998 Apr 1;19(6):467–78.
6. Meyer JM, Cattani-Lorente MA, Dupuis V. Compomers: between glass-ionomer cements and composites. Biomaterials. 1998 Apr 1;19(6):529–39.
7. Xie D, Brantley WA, Culbertson BM, Wang G. Mechanical properties and microstructures of glass-ionomer cements. Dental Materials. 2000 Mar 1;16(2):129–38.
8. Nicholson JW. Chemistry of glass-ionomer cements: a review. Biomaterials. 1998 Apr 1;19(6):485–94.
9. Nicholson JW, Czarnecka B. The biocompatibility of resin-modified glass-ionomer cements for dentistry. Dental Materials. 2008 Dec 1;24(12):1702–8.
10. Forsten L. Resin-modified glass ionomer cements: Fluoride release and uptake. http://dx.doi.org/103109/00016359509005976 [Internet]. 2009 [cited 2023 Aug 10];53(4):222–5. Available from: https://www.tandfonline.com/doi/abs/10.3109/00016359509005976
11. Yip HK, Tay FR, Ngo HC, Smales RJ, Pashley DH. Bonding of contemporary glass ionomer cements to dentin. Dental Materials. 2001 Sep 1;17(5):456–70.
12. Garcia-Contreras R, Scougall-Vilchis RJ, Contreras-Bulnes R, Sakagami H, Morales-Luckie RA, Nakajima H. Mechanical, antibacterial and bond strength properties of nano-titanium-enriched glass ionomer cement. Journal of Applied Oral Science [Internet]. 2015 Jul 28 [cited 2023 Aug 10];23(3):321–8. Available from: https://www.scielo.br/j/jaos/a/CGKVZzv5LP38qMSCjrhL6YR/?lang=en
13. Najeeb S, Khurshid Z, Zafar MS, Khan AS, Zohaib S, Martí JMN, et al. Modifications in Glass Ionomer Cements: Nano-Sized Fillers and Bioactive Nanoceramics. International Journal of Molecular Sciences 2016, Vol 17, Page 1134 [Internet]. 2016 Jul 14 [cited 2023 Aug 10];17(7):1134. Available from: https://www.mdpi.com/1422-0067/17/7/1134/htm
14. Sidhu SK. Glass-ionomer cement restorative materials: a sticky subject? Aust Dent J [Internet]. 2011 Jun [cited 2023 Aug 10];56(SUPPL. 1):23–30. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1834-7819.2010.01293.x
15. Cattani-Lorente MA, Dupuis V, Moya F, Payan J, Meyer JM. Comparative study of the physical properties of a polyacid-modified composite resin and a resin-modified glass ionomer cement. Dental Materials. 1999 Jan 1;15(1):21–32.
16. Fritz UB, Finger WJ, Uno S. Resin-modified glass ionomer cements: Bonding to enamel and dentin. Dental Materials. 1996 May 1;12(3):161–6.
17. Boyd D, Towler MR. The processing, mechanical properties and bioactivity of zinc based glass ionomer cements. J Mater Sci Mater Med [Internet]. 2005 Sep [cited 2023 Aug 10];16(9):843–50. Available from: https://link.springer.com/article/10.1007/s10856-005-3578-1
18. Williams JA, Billington RW, Pearson GJ. The comparative strengths of commercial glass-ionomer cements with and without metal additions. British Dental Journal 1992 172:7 [Internet]. 1992 Apr 11 [cited 2023 Aug 10];172(7):279–82. Available from: https://www.nature.com/articles/4807843
19. Francisconi LF, Scaffa PMC, de Barros VR dos SP, Coutinho M, Francisconi PAS. Glass ionomer cements and their role in the restoration of non-carious cervical lesions. Journal of Applied Oral Science [Internet].

2009 [cited 2023 Aug 10];17(5):364–9. Available from: https://www.scielo.br/j/jaos/a/QVQxgVdBXQzTtC4Xx6wGSgP/?lang=en

20. Wilson AD, Hill RG, Warrens CP, Lewis BG. The Influence of Polyacid Molecular Weight on Some Properties of Glass-ionomer Cements. http://dx.doi.org/101177/00220345890680021401 [Internet]. 1989 Feb 1 [cited 2023 Aug 10];68(2):89–94. Available from: https://journals.sagepub.com/doi/10.1177/00220345890680021401
21. Vermeersch G, Leloup G, Delmée M, Vreven J. Antibacterial activity of glass–ionomer cements, compomers and resin composites: relationship between acidity and material setting phase. J Oral Rehabil [Internet]. 2005 May 1 [cited 2023 Aug 10];32(5):368–74. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2842.2004.01300.x
22. Akinmade AO, Nicholson JW. Glass-ionomer cements as adhesives - Part I Fundamental aspects and their clinical relevance. J Mater Sci Mater Med [Internet]. 1993 Mar [cited 2023 Aug 10];4(2):95–101. Available from: https://link.springer.com/article/10.1007/BF00120376
23. Kao EC, Culbertson BM, Xie D. Preparation of glass ionomer cement using N-acryloyl-substituted amino acid monomers — Evaluation of physical properties. Dental Materials. 1996 Jan 1;12(1):44–51.
24. Wasson EA, Nicholson JW. New Aspects of the Setting of Glass-ionomer Cements. http://dx.doi.org/101177/00220345930720020201 [Internet]. 1993 Feb 1 [cited 2023 Aug 10];72(2):481–3. Available from: https://journals.sagepub.com/doi/10.1177/00220345930720020201
25. Cattani-Lorente MA, Godin C, Meyer JM. Early strength of glass ionomer cements. Dental Materials. 1993 Jan 1;9(1):57–62.
26. Li J, Beetzen M von, Sundström F. Strength and setting behavior of resin-modified glass ionomer cements. http://dx.doi.org/103109/00016359509005993 [Internet]. 2009 [cited 2023 Aug 10];53(5):311–7. Available from: https://www.tandfonline.com/doi/abs/10.3109/00016359509005993
27. Van Duinen RNB, Kleverlaan CJ, De Gee AJ, Werner A, Feilzer AJ. Early and long-term wear of 'Fast-set' conventional glass–ionomer cements. Dental Materials. 2005 Aug 1;21(8):716–20.
28. Ana ID, Matsuya S, Ohta M, Ishikawa K. Effects of added bioactive glass on the setting and mechanical properties of resin-modified glass ionomer cement. Biomaterials. 2003 Aug 1;24(18):3061–7.
29. Zainuddin N, Karpukhina N, Hill RG, Law R V. A long-term study on the setting reaction of glass ionomer cements by 27Al MAS-NMR spectroscopy. Dental Materials. 2009 Mar 1;25(3):290–5.
30. Kan KC, Messer LB, Messer HH. Variability in Cytotoxicity and Fluoride Release of Resin-modified Glass-ionomer Cements. http://dx.doi.org/101177/00220345970760081301 [Internet]. 1997 Aug 1 [cited 2023 Aug 10];76(8):1502–7. Available from: https://journals.sagepub.com/doi/10.1177/00220345970760081301
31. Leyhausen G, Abtahi M, Karbakhsch M, Sapotnick A, Geurtsen W. Biocompatibility of various light-curing and one conventional glass-ionomer cement. Biomaterials. 1998 Apr 1;19(6):559–64.
32. Yli-Urpo H, Närhi M, Närhi T. Compound changes and tooth mineralization effects of glass ionomer cements containing bioactive glass (S53P4), an in vivo study. Biomaterials. 2005 Oct 1;26(30):5934–41.
33. Donly KJ, Istre S, Istre T. In vitro enamel remineralization at orthodontic band margins cemented with glass ionomer cement. American Journal of Orthodontics and Dentofacial Orthopedics [Internet]. 1995 May 1 [cited 2023 Aug 10];107(5):461–4. Available from: http://www.ajodo.org/article/S0889540695701125/fulltext
34. Nicholson JW. Adhesion of glass-ionomer cements to teeth: A review. Int J Adhes Adhes. 2016 Sep 1;69:33–8.
35. Mazzaoui SA, Burrow MF, Tyas MJ. Fluoride release from glass ionomer cements and resin composites coated with a dentin adhesive. Dental Materials. 2000 May 1;16(3):166–71.
36. Yan Z, Sidhu SK, Carrick TE, McCabe JF. Response to thermal stimuli of glass ionomer cements. Dental Materials. 2007 May 1;23(5):597–600.
37. Six N, Lasfargues JJ, Goldberg M. In vivo study of the pulp reaction to Fuji IX, a glass ionomer cement. J Dent. 2000 Aug 1;28(6):413–22.
38. Croll TP, Bar-Zion Y, Segura A, Donly KJ. Clinical performance of resin-modified glass ionomer cement restorations in primary teeth: A retrospective evaluation. Journal of the

American Dental Association [Internet]. 2001 Aug 1 [cited 2023 Aug 10];132(8):1110–6. Available from: http://jada.ada.org/article/S0002817714636588/fulltext
39. Qvist V, Laurberg L, Poulsen A, Teglers PT. Class II restorations in primary teeth: 7-year study on three resin-modified glass ionomer cements and a compomer. Eur J Oral Sci [Internet]. 2004 Apr 1 [cited 2023 Aug 10];112(2):188–96. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1600-0722.2004.00117.x
40. Xie H, Zhang F, Wu Y, Chen C, Liu W. Dentine bond strength and microleakage of flowable composite, compomer and glass ionomer cement. Aust Dent J [Internet]. 2008 Dec 1 [cited 2023 Aug 10];53(4):325–31. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1834-7819.2008.00074.x
41. Ten Cate JM, Van Duinen RNB. Hypermineralization of Dentinal Lesions Adjacent to Glass-ionomer Cement Restorations. http://dx.doi.org/101177/00220345950740060501 [Internet]. 1995 Jun 1 [cited 2023 Aug 10];74(6):1266–71. Available from: https://journals.sagepub.com/doi/10.1177/00220345950740060501
42. Neelakantan P, John S, Anand S, Sureshbabu N, Subbarao C. Fluoride Release From a New Glass-ionomer Cement. Oper Dent [Internet]. 2011 Jan 1 [cited 2023 Aug 10];36(1):80–5. Available from: https://dx.doi.org/10.2341/10-219-LR
43. Costa CADS, Ribeiro APD, Giro EMA, Randall RC, Hebling J. Pulp response after application of two resin modified glass ionomer cements (RMGICs) in deep cavities of prepared human teeth. Dental Materials. 2011 Jul 1;27(7):e158–70.
44. Biocompatibility of a resin-modified glass-ionomer cement applied as pulp capping in human teeth - PubMed [Internet]. [cited 2023 Aug 10]. Available from: https://pubmed.ncbi.nlm.nih.gov/11763899/
45. Magni E, Ferrari M, Hickel R, Ilie N. Evaluation of the mechanical properties of dental adhesives and glass-ionomer cements. Clin Oral Investig [Internet]. 2010 Jan 25 [cited 2023 Aug 10];14(1):79–87. Available from: https://link.springer.com/article/10.1007/s00784-009-0259-3
46. Lohbauer U, Krämer N, Siedschlag G, Schubert EW, Lauerer B, Müller F, et al. Strength and wear resistance of a dental glass-ionomer cement with a novel nanofilled resin coating. Am J Dent. 2011;
47. Yiu CKY, Tay FR, King NM, Pashley DH, Sidhu SK, Neo JCL, et al. Interaction of Glass-ionomer Cements with Moist Dentin. http://dx.doi.org/101177/154405910408300403 [Internet]. 2004 Apr 1 [cited 2023 Aug 10];83(4):283–9. Available from: https://journals.sagepub.com/doi/10.1177/154405910408300403
48. De Bruyne MAA, De Moor RJG. The use of glass ionomer cements in both conventional and surgical endodontics. Int Endod J [Internet]. 2004 Feb 1 [cited 2023 Aug 10];37(2):91–104. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.0143-2885.2004.00769.x
49. Yap AUJ. Resin-modified glass ionomer cements: a comparison of water sorption characteristics. Biomaterials. 1996 Oct 1;17(19):1897–900.
50. Pereira PNR, Yamada T, Inokoshi S, Burrow MF, Sano H, Tagami J. Adhesion of resin-modified glass ionomer cements using resin bonding systems. J Dent. 1998 Jul 1;26(5–6):479–85.
51. Effect of home-use fluoride gels on resin-modified glass-ionomer cements - PubMed [Internet]. [cited 2023 Aug 10]. Available from: https://pubmed.ncbi.nlm.nih.gov/9610326/
52. Effect of resin-modified glass ionomer cements on secondary caries - PubMed [Internet]. [cited 2023 Aug 10]. Available from: https://pubmed.ncbi.nlm.nih.gov/9590903/
53. Williams JA, Billington RW, Pearson GJ. A long term study of fluoride release from metal-containing conventional and resin-modified glass–ionomer cements. J Oral Rehabil [Internet]. 2001 Jan 1 [cited 2023 Aug 10];28(1):41–7. Available from: https://onlinelibrary.wiley.com/doi/full/10.1046/j.1365-2842.2001.00628.x
54. Lin J, Zhu J, Gu X, Wen W, Li Q, Fischer-Brandies H, et al. Effects of incorporation of nano-fluorapatite or nano-fluorohydroxyapatite on a resin-modified glass ionomer cement. Acta Biomater. 2011 Mar 1;7(3):1346–53.
55. Akashi A, Matsuya Y, Unemori M, Akamine A. The relationship between water absorption characteristics and the mechanical strength of resin-modified glass-ionomer cements in long-

term water storage. Biomaterials. 1999 Sep 1;20(17):1573–8.

56. Carey CM, Spencer M, Gove RJ, Eichmiller FC. Fluoride Release from a Resin-modified Glass-ionomer Cement in a Continuous-flow System: Effect of pH. http://dx.doi.org/101177/154405910308201013 [Internet]. 2003 Oct 1 [cited 2023 Aug 10];82(10):829–32. Available from: https://journals.sagepub.com/doi/10.1177/154405910308201013
57. Yelamanchili A, Darvell BW. Network competition in a resin-modified glass-ionomer cement. Dental Materials. 2008 Aug 1;24(8):1065–9.
58. Menezes-Silva R, Cabral RN, Pascotto RC, Borges AFS, Martins CC, De Lima Navarro MF, et al. Mechanical and optical properties of conventional restorative glass-ionomer cements - a systematic review. Journal of Applied Oral Science [Internet]. 2019 Feb 21 [cited 2023 Aug 10];27:e2018357. Available from: https://www.scielo.br/j/jaos/a/cLbKQyW5WMmk4Q3cc7zrZpd/?lang=en