



Current State, Pioneering Studies and Future Trends in Orthodontic bonding: A Bibliometric Analysis

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CLINICAL SIGNIFICANCE

This bibliometric analysis offers crucial insights into the evolving trends and key contributors in orthodontic bonding research, providing a foundation for future studies aimed

ABSTRACT

Objectives: Orthodontic bonding plays a crucial role in the effectiveness of orthodontic treatment. This study aims to perform a bibliometric analysis of research in this field, identifying key contributors, influential studies, and emerging trends.

Materials and methods: A systematic search was conducted in the Web of Science (WoS) database for articles published between 1981 and 2023 using specific orthodontic bonding-related keywords. From 1,856 articles retrieved, 1,497 met the inclusion criteria. Bibliometric analyses were performed using VOSviewer software, focusing on co-authorship, co-occurrence, and citation patterns. The analysis evaluated the productivity of authors, institutions, countries, and journals and mapped frequently used keywords.

Results: The USA emerged as the leading country in publications and citations, followed by Turkey and Brazil. The University of Iowa was identified as the most productive institution. Samir E. Bishara was the most prolific and cited author. The study revealed a growing focus on topics such as shear bond strength, self-etch primers, and antimicrobial adhesives. The American Journal of Orthodontics and Dentofacial Orthopedics was the most influential journal, with the highest number of key publications.

Conclusion: This bibliometric analysis provides valuable insights into the orthodontic bonding literature, highlighting significant contributions and trends. Although limited to WoS and English-language publications, the study offers a comprehensive perspective on the field's development and suggests potential areas for future research.

1. Introduction

The most popular bonding system in orthodontics and restorative treatment is based on the micromechanical bond of resin composite materials to the enamel surface.¹ Direct bonding of orthodontic brackets to the tooth surface with composite resin and acid etching is widely used.^{2,3} Orthodontic adhesives play a crucial role in the success of orthodontic treatments, as they are responsible for securely bonding orthodontic attachments, such as brackets, to the enamel surface of teeth. The effectiveness of these adhesives directly influences the stability of the orthodontic appliances and, consequently, the overall treatment outcome. Given their importance, a significant amount of research has been devoted to improving the bonding strength, durability, and biocompatibility of these adhesives. Studies in this area have explored various types of adhesives, surface preparation techniques, and the effects of different bonding agents on both the mechanical properties and the long-term health of the tooth enamel. As orthodontic treatment evolves with new materials and techniques, understanding the developments in adhesive technology becomes essential for optimizing patient outcomes.

Literature reviews are meant to examine the general state of any research area. It is important to collect, and categorize existing knowledge in the research area and identify gaps.⁴ Bibliometric analysis is a systemic analysis that evaluates the literature using mathematical and statistical methods.⁵⁻⁷ Traditional literature reviews investigate a smaller and homogeneous area in depth. With bibliometric research, large fields of study can be assessed.⁴ The overall structure of the study area is assessed superficially and quantitatively.^{4,5,8} Bibliometric analyses are used to evaluate the development of the literature of the relevant field over time. The performance of scientific elements (study, journal, keyword, author, country, institution) is measured. It evaluates the effectiveness and productivity of researchers, institutions, journals, and countries by using bibliometric indicators and making

Visualizations.^{5,8-11}

Bibliometric analysis became widespread in the field of dentistry too.^{5,7,11-14} Orthodontic bonding is not only foundational to the success of orthodontic treatments but also directly impacts patient outcomes, from treatment efficiency to enamel preservation. Given the rapid development of new adhesive materials and techniques, it is essential to systematically analyze existing research to identify the most influential studies, leading authors, and emerging trends. Therefore, the aim of this study is to conduct a comprehensive bibliometric analysis of the orthodontic bonding literature, thereby providing valuable insights into the field's evolution, current state, and future directions.

2. Materials and Methods

2.1. Research methodology

This study was designed to conduct a bibliometric analysis of the orthodontic bonding literature. The Web of Science (WoS) database was selected as the primary data source due to its extensive coverage and reliability in providing comprehensive bibliometric data. The search was conducted on June 5, 2024, and was limited to articles published up until December 2023 to ensure a consistent and complete dataset. The search terms were used to find studies most relevant to the orthodontic bonding area. To enhance the precision of the search, the topic field was restricted to the keywords, abstract and title. The search was conducted as follows: Topic = ("orthodontic bonding and self-etch primer") OR Topic = ("orthodontic bonding" and "self-etch bond system") OR Topic = ("orthodontic bonding" and "etch-and-rinse") OR Topic = ("orthodontic bonding" and "total-etch") OR Topic = ("orthodontic bonding" and "phosphoric acid etching") OR Topic = ("orthodontic bonding" and "conventional acid-etch technique") OR Topic = ("orthodontic bonding adhesive") OR Topic = ("orthodontic bonding" and "adhesive composite resin").

2.2. Inclusion criteria

A total of 1,856 articles were retrieved from the database, and after applying inclusion criteria—such as relevance to the topic, language (English), and publication type (article, review, proceeding paper)—1,497 articles were deemed suitable for the bibliometric analysis.

2.3. Data analysis and visualization

Data analysis was performed using VOSviewer (version 1.6.14; Center for Science and Technology Studies, Leiden University) and Excel (Microsoft Office 2016). VOSviewer was used to apply bibliometric analysis techniques and design maps. The unit of analysis under study is symbolized by circles. The position of the circles relative to each other indicates similarity and relatedness. Relationship/ collaboration is represented by the lines between the circles. The meaning of circle colors varies according to the type of visualization. It is explained in detail in the figure descriptions. WoS functions (citation reports, analysis results) were also used for data analysis.

The bibliometric analysis involved several key techniques: Co-authorship analysis was performed to assess collaborative efforts among authors, institutions, and countries. This analysis helps to identify the networks and partnerships that contribute to research productivity in the field of orthodontic bonding. Co-occurrence analysis focused on the frequency and relationships of key terms and concepts found within the titles, abstracts, and keywords of the articles. This analysis highlights the central themes

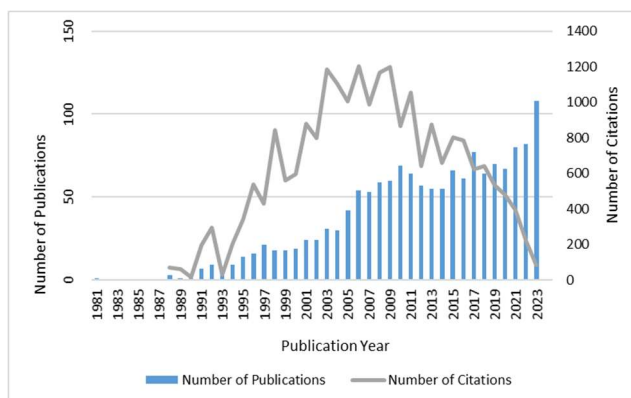


Fig 1. Total number of publications and total number of citations by publication year

and topics that have emerged in the literature over time. Citation analysis was conducted to determine the impact of specific studies, authors, institutions, and countries by analyzing the number of citations they received. This method provides insight into the most influential contributors to the field.

The Hirsch h-index is defined as the number of articles with a citation counts $\geq h$ and it is a useful index for assessing the scientific impact and productivity of journals and authors. The index (h-index) was obtained from the bibliometric data provided by WoS in the present study.

Table 1. Information of the 20 most cited articles.

Title	Authors	Journal	Publication Year	Total Citations	Average per Year
1. Experimental antimicrobial orthodontic adhesives using nanofillers and silver nanoparticles	Ahn, SJ; Lee, SJ; Kook, JK; Lim, BS	Dental Materials	2009	203	12.63
2. Effect of a self-etch primer/adhesive on the shear bond strength of orthodontic brackets	Bishara, SE; VonWald, L; Laffoon, JF; Warren JJ	American Journal of Orthodontics And Dentofacial Orthopedics	2001	195	8.13
3. The use of bovine enamel in bonding studies	Oesterle, LJ; Shellhart, WC ; Belanger, GK	American Journal of Orthodontics And Dentofacial Orthopedics	1998	151	5.59
4. A comparison of shear bond strength and debonding characteristics of conventional, moisture-insensitive, and self-etching primers in vitro	Rajagopal, R; Padmanabhan, S; Gnanamani, J	Angle Orthodontist	2004	139	6.62
5. Enamel loss during bonding, debonding, and cleanup with use of a self-etching primer	Hoseini, I; Sherriff, M; Ireland, AJ	American Journal of Orthodontics And Dentofacial Orthopedics	2004	131	6.24
6. Influence of surface roughness on streptococcal adhesion forces to composite resins	Mei, L; Busscher, HJ; van der Mei, HC; Ren, YJ	Dental Materials	2011	125	8.93
7. The inappropriateness of conventional orthodontic bond strength assessment protocols	Eliades, T; Brantley, WA	European Journal of Orthodontics	2000	117	4.68
8. Surface preparation for orthodontic bonding to porcelain	Zachrisson, YO; Zachrisson, BU; Buyukyilmaz, T	American Journal of Orthodontics And Dentofacial Orthopedics	1996	111	3.83
9. Laser etching of enamel for direct bonding with an Er,Cr:YSGG hydrokinetic laser system	Üsümez, S; Orhan, M; Üsümez, A	American Journal of Orthodontics And Dentofacial Orthopedics	2002	101	4.39
10. Effect of water and saliva contamination on shear bond strength of brackets bonded with conventional, hydrophilic, and self-etching primers	Cacciafesta, V; Sfondrini, MF; De Angelis, M; Scribante, A; Klersy, C	American Journal of Orthodontics And Dentofacial Orthopedics	2003	97	4.41
11. Effect of an acidic primer on shear bond strength of orthodontic brackets	Bishara, SE; Gordan, VV; VonWald, L; Olson, ME	American Journal of Orthodontics And Dentofacial Orthopedics	1998	97	3.59
12. Shear bond strength and antibacterial effects of orthodontic composite containing TiO2 nanoparticles	Poosti, M; Ramazanzadeh, B; Zebajrad, M; Javadzadeh, P; et al.	European Journal of Orthodontics	2013	94	7.83
13. Effect of self-etching primers on bond strength - Are they reliable?	Buyukyilmaz, T; Usumez, S; Karaman, AI	Angle Orthodontist	2003	93	4.23
14. Shear bond strength of composite, glass ionomer and acidic primer adhesive systems	Bishara, SE; Gordan, VV; VonWald, L; Jakobsen, JR	American Journal of Orthodontics And Dentofacial Orthopedics	199	90	3.46
15. Depth of resin penetration into enamel with 3 types of enamel conditioning methods: A confocal microscopic study	Kumar, KRR; Sundari, KKS; Venkatesan, A; Chandrasekar, S	American Journal of Orthodontics And Dentofacial Orthopedics	211	88	6.29
16. Biomimetic Effect of Nano-Hydroxyapatite in Demineralized Enamel before Orthodontic Bonding of Brackets and Attachments: Visual, Adhesion Strength, and Hardness in In Vitro Tests	Scribante, A; Farahani, MRD; Marino, G; Matera, C; Baena, RRY; Lanteri, V; Butera, A	Biomed Research International	2020	85	17
17. Effect of using self-etching primer for bonding orthodontic brackets	Yamada, R; Hayakawa, T; Kasai, K	Angle Orthodontist	2002	80	3.48
18. Rapid curing of bonding composite with a xenon plasma arc light	Oesterle, LJ; Newman, SM; Shellhart, WC	American Journal of Orthodontics And Dentofacial Orthopedics	2001	76	3.17
19. Comparison of bond strength of three adhesives: Composite resin, hybrid GIC, and glass-filled GIC	Rix, D; Foley, TF; Mamandras, A	American Journal of Orthodontics And Dentofacial Orthopedics	2001	76	3.17
20. Porcelain surface treatment by laser for bracket-porcelain bonding	Akova, T; Yoldas, O; Toroglu, MS; Uysal, H	American Journal of Orthodontics And Dentofacial Orthopedics	2005	74	3.7

Table 2. The 10 most productive authors

Authors	Institution	Country	No of Publications
Bishara, Samir E.	University of Iowa	USA	51
Eliades, Theodore	University of Zurich	Switzerland	35
Uysal, Tancan	Izmir Katip Celebi University	Turkey	33
Laffoon, John F.	University of Iowa	USA	32
Francesca, Sfondrini Maria	University of Pavia	Italy	28
Scribante, Andrea	University of Pavia	Italy	27
Warren, John J.	University of Iowa	USA	23
Millett, Declan T.	Un. College Cork	Ireland	22
Eliades George	University of Athens	Greece	22
Vicente, Ascension	University of Murcia	Spain	19

Table 3. The 10 most cited authors

Authors	Institution	Country	No of Citations
Bishara, Samir E.	University of Iowa	USA	1702
Laffoon, John F.	University of Iowa	USA	1050
Eliades, Theodore	University of Zurich	Switzerland	948
Warren, John J.	University of Iowa	USA	740
von Wald, Lisa	University of Minnesota Twin Cities	USA	666
Millett, Declan T.	University College Cork	Ireland	580
Scribante, Andrea	University of Pavia	Italy	539
Ajlouni, Raed	Texas A&M University College Station	USA	532
Jacobsen, Jane R.	University of Iowa	USA	522
Oonsombat, C	University of Iowa	USA	351

The average number of citations was calculated by dividing the total number of citations of a certain group of studies received by the number of studies. This parameter was also used when evaluating effective authors, studies, institutions, countries, and journals. Average normalized citation counts were used as a color scale in the Vosviewer visualizations. The average normalized number of citations were found by dividing the number of citations of the relevant study by the average number of citations of all studies published in the same year. It is a parameter that can be used to balance the effect of the year of publication on the number of citations.

Normalization procedures were implemented to ensure the accurate analysis of author and institution contributions. To prevent confusion between different authors with the same surname, full name and surname combinations were used, and authors were evaluated alongside their institutional affiliations. Unique author identifiers (Author ID) from the Web of Science database were employed to accurately track contributions from authors with the same name. Institutional names were standardized across the dataset to ensure consistency, combining different variations under a single unified name.

3. Results

The study was conducted with studies obtained from the WoS database. 1497 relevant studies published between 1981 and 2023

were evaluated. The total number of citations is 22413, average number of citations is 14.97 and the h-index is 56.

Fig. 1 shows total number of publications and the total number of citations over the years. In 1981 there was one publication. The analysis revealed a consistent upward trend in the number of publications over the years since 1988, with articles published between 2002 and 2009 being the most cited. Table 1 shows the information of the 20 most cited studies.

In terms of authorship, the analysis identified 4,161 authors who have contributed to the orthodontic bonding literature. The average number of citations per author is 5.38. Samir E. Bishara emerged as the most prolific, not only leading in the number of publications (Table 2) but also in total citations (Table 3), with 51 publication and 1702 citations and underscored his pivotal role in advancing the field. Other prominent authors was Theodore Eliades, Tancan Uysal, and John F. Laffoon. Regarding the collaborations between authors, it was observed that there were local collaborations (Suppl. Fig. 1).

In total, 1,170 institutions and 85 countries produced studies on the subject. The University of Iowa was the most productive and most cited institution, with 55 publications on this topic and a total of 1852 citations. This was followed by King Saud University with 37 publications and Selçuk University with 35 publications. (Table 4). Regarding the collaborations between institutions, it was observed that there were local collaborations (Suppl. Fig. 2). The USA was the country that published the most articles with 231

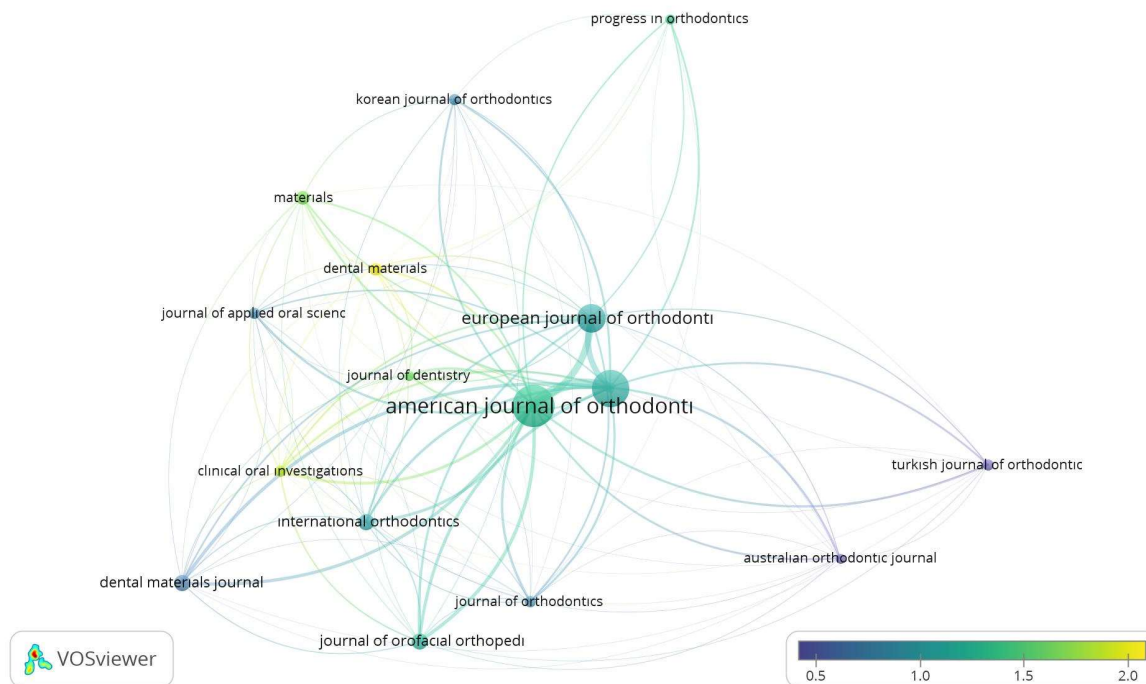


Fig 2. Mapping of the journal analysis with VosViewer. The circles represent the journals. The size of the circles represents the number of publications in the journal. Journals with 15 or more publications were analyzed and visualized. The color of the circles is represented on the scale below. Yellow circles represent a high average normalized citation count.

Table 4. The 10 most productive institution

Institution	Country	Number of Articles	Number of Citations	Citations per Article	H-Index
University of Iowa	USA	55	1852	33.67	27
King Saud University	Saudi Arabia	37	367	9.92	12
Selçuk University	Turkey	35	682	19.49	15
University of Zurich	Switzerland	35	616	17.6	15
Erciyes University	Turkey	31	375	12.1	14
Tehran University of Medical Science	Iran	29	359	12.38	10
University of Pavia	Italy	29	570	19.66	13
University of London	England	28	568	20.29	14
Nihon University	Japan	27	373	13.81	11
On Dokuz Mayıs University	Turkey	26	457	16.98	14

articles, which constitutes 15.43% of the total number of articles published. Turkey (216 publications) and Brazil (121 publication) were the most productive countries after the USA. Approximately 1/3 of the studies were conducted in these countries. The USA also ranked first in terms of the total number of citations with 5,582 citations. Turkey and the England followed the USA with 3,061 and 1,742 citations, respectively. (Table 5). England and Italy showed most high citation rate per article after USA, with 24.16, 21.24 and 16.11 respectively (Table 5). USA, Saudi Arabia and England were active countries in terms of collaboration (Suppl. Fig. 3).

234 journals had articles on the subject. American Journal of Orthodontics and Dentofacial Orthopedics (258 publications) had the highest number of publications and citations. This was followed by Angle Orthodontics (203 publications) and European Journal of Orthodontics (118 publications). Dental Materials and Clinical Oral Investigations were the journals with the highest average number of normalized citations (Fig. 2).

The co-occurrence map (Fig. 3) shows the most frequently used key terms and concepts in the studies. Shear bond strength (341), orthodontic brackets (274), orthodontic (126), bond strength (105), and adhesive (103) were used more than 100 times.

4. Discussion

The stability of the orthodontic attachments on the teeth carries the force produced by the archwire to the teeth. Bonding success plays an important role in the effectiveness and success of orthodontic treatment.¹⁵ Table 1 shows the 20 most cited articles in orthodontic bonding. In the top 20 most cited studies, there are 19 original articles and 1 review. It is inevitable that older studies receive more citations regardless of their impact. The true impact of an article can only really be determined after at least 20 years from the date of publication.¹⁶ In this analysis studies with high average normalized citation counts were presented in Suppl. Fig. 4.

A bibliometric study conducted to evaluate the trend in orthodontic publications¹⁷ and bibliometric studies evaluating the 100 most cited articles published in the field of orthodontics^{18,19}, found that the most productive country is the USA, as in this study. And also the leading name in the orthodontic bonding field with the highest number of publications and citations is Samir E. Bishara, University of Iowa (USA).

In the present study, most of the studies in dataset are original articles. There are 49 reviews, 22 proceeding papers, and 2 book chapters. Most of the studies were planned in vitro. In contrast to our study, bibliometric analyses in the field of orthodontics

showed a high proportion of clinical¹⁸, cross-sectional^{17,19}, longitudinal¹⁹, and prospective studies²⁰.

In the study of the 100 most cited systematic review and meta-analysis in orthodontics²¹, there is one study²² on orthodontic bonding and this is a meta-analysis of in vitro studies. In theory, clinical studies are hypothetically the best way to determine the properties of bonding systems. However, it does not seem possible to clinically determine the adhesion capacity and other properties of bonding systems independently from other variables that can influence the quality and the longevity of bracket bonding to enamel.²³ In vitro studies appear to enable the creation of more standardized study protocols.²²

In the twenty most cited articles, one of the most popular topics is the use of self-etch primers. In the use of self-etch primers, the bond strength and the area of adhesion failure (ARI Score) were evaluated.²⁴⁻²⁸ The bonding efficiency of hydrophilic primer, conventional primer, and self-etch primer against contamination was investigated.^{29,30} There are also studies evaluating the effects of self-etch on enamel compared to conventional etch. Enamel loss³¹, depth of penetration in the enamel³², and surface roughness (with SEM)^{26,27} are the issues evaluated. One of the most important problems encountered during orthodontic treatment is enamel demineralization. The modified composite with antimicrobial nanoparticles on adhesion and antimicrobial properties are among the topics of interest.³³

When we look at co-occurrence analysis, the most frequently mentioned key terms and concepts were shear bond strength, orthodontic brackets, orthodontic, bond strength and adhesive. Evaluating the bond strength of brackets has been an important objective. The most appropriate parameter to evaluate this in an in vitro study is shear bond strength measurement. In bibliometric studies on dental adhesives, bond strength^{34,35} and shear bond strength³⁵ were found to be frequently used key terms and concepts. In recent years, frequently used key terms and concepts are demineralization, antibacterial, white lesion, nanoparticle, surface roughness and laser. It has been seen that the preservation of tooth structure has gained importance. It is desired to prevent irreversible changes in the enamel during and after orthodontic treatment. More clinical studies can be done on modified adhesives containing antibacterial nanoparticles and fluoride-releasing adhesives. Widespread clinical use may offer an alternative that can preserve tooth structure regardless of patient cooperation.

Nowadays, orthodontic treatments with clear aligners are becoming more common. There is one study in this data set on

Table 5. The 10 most productive country.

Country	Number of Articles	Proportion of Articles	Number of Citations	Citations per Article	H-Index
USA	231	%15.43	5582	24.16	41
Turkey	216	%13.36	3061	15.24	29
Brazil	121	%8.08	1289	10.65	19
Iran	97	%6.48	887	9.14	15
Japan	85	%5.67	1139	13.4	20
England	82	%5.47	1742	21.24	25
Saudi Arabia	79	%5.27	606	7.67	14
Germany	78	%5.21	1082	13.87	20
India	74	%4.94	600	8.11	14
Italy	63	%4.20	1015	16.11	19

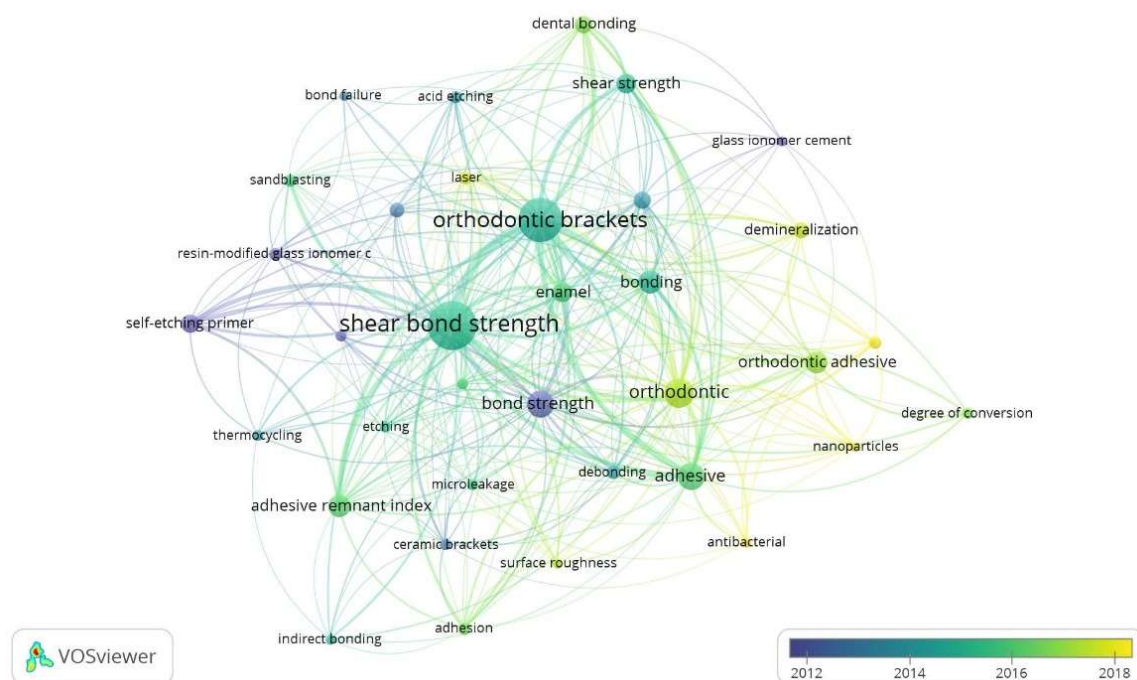


Fig 3. Mapping of the Co-occurrence analysis with VosViewer. The circles represent the words and concepts used. The size of the circles is the frequency of use. Words and concepts used 15 times or more were analyzed and visualized. The color of the circles indicates years as indicated in the scale below.

the bonding of composite attachments used during aligner treatments.³⁶ In the bibliometric analysis of the 50 most cited studies on clear aligners, there is no study on the bonding of composite aligner attachments.³⁷ The number of studies evaluating the bonding of attachments used in clear aligner treatment should be increased.

There are three journals with over 100 publications in this field. (American Journal of Orthodontics and Dentofacial Orthopedics, Angle Orthodontics, European Journal of Orthodontics). These are the most established and prestigious journals in the field of orthodontics. In a bibliometric study conducted to evaluate the trend in orthodontic publications, these three journals were the main journals with regard the production volume.¹⁷ Among the top ten journals, there are three journals related to dental materials. Dental Materials is a journal with a high normalized citation count in this field. With the development of adhesives and adhesive techniques, studies is shifting towards the materials used.

The limitations of this study were as follows: The WoS database was used as the data source in this study. WoS widely utilized source database for bibliometric and citation analysis across all academic disciplines.³⁸ Scopus does not record citations published before 1995. Google Scholar also includes citations from non-scholarly publications.³⁹ These two situations are likely to produce inappropriate results. The most important reason why the WoS database was chosen in our study is that it measures citations in scientific articles from 1945 to the present.⁴⁰ But some studies may not be available in all databases. Studies not included in WOS could not be included in the dataset of this study. Secondly, studies in English were included in the data set. Studies in other languages were neglected. And thirdly, citation analysis finds influential studies. However, the reason for the citation is not clear. The citation may have been made to support the related studies, or it have may been made to refute it. It does not reveal high quality but under-cited studies. New studies appear less influential than older studies.

5. Conclusion

This bibliometric analysis offers a detailed examination of the orthodontic bonding literature, illuminating the field's growth, key

contributors, and emerging research trends. The study found that the USA, Turkey, and Brazil are the leading countries in research output, with significant contributions from authors like Samir E. Bishara and institutions such as the University of Iowa. The focus on topics like shear bond strength, self-etch primers, and antimicrobial adhesives indicates a shift towards developing materials that improve bonding efficiency while minimizing harm to tooth enamel. These insights provide a clearer understanding of the current research landscape and highlight the areas where further innovation is needed.

However, this study has its limitations, primarily the reliance on the WoS database and the exclusion of non-English publications, which may have led to the omission of relevant research from other databases or languages. Future studies could address these limitations by incorporating additional data sources and expanding the linguistic scope. Despite these constraints, this analysis lays a solid foundation for future research in orthodontic bonding, guiding researchers, clinicians, and industry professionals toward new opportunities for innovation and improvement in adhesive technologies.

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Conflict of Interest

The authors declare that no conflict of interest is available

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