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Evaluation of the Most Cited Articles About Clear Aligners in the Last 10 Years: A Bibliometric Analysis (Methodological Studies)

Son 10 Yılda Şeffaf Plaklar Hakkında En Çok Atıf Alan Makalelerin Değerlendirilmesi: Bibliyometrik Analiz (Metodolojik Çalışmalar)

Ömer Faruk SARI[a], Elif ALBAYRAK[b], Muhammed Hilmi BÜYÜKÇAVUŞ[c]

[a]Ankara Medipol University Faculty of Dentistry, Department of Orthodontics, Ankara, Türkiye
[b]Süleyman Demirel University Faculty of Dentistry, Department of Orthodontics, Isparta, Türkiye
[c]Antalya Bilim University Faculty of Dentistry, Department of Orthodontics, Antalya, Türkiye

ABSTRACT Objective: The aim of this study is to determine the most cited articles on clear aligners in the last 10 years and to evaluate them using bibliometric analysis and to determine the most researched and applied methods. **Material and Methods:** A comprehensive electronic literature search was conducted on the Web of Science (WoS) database on January 28, 2024, with keywords related to clear plates, without any restrictions. The 116 most cited articles on clear aligners were analyzed, and the relationship between popular research topics, institutions, important authors, countries, and journals in this field was determined using the bibliometric analysis method. **Results:** A total of 458 authors contributed to the most cited articles in the last 10 years. The total number of citations of the articles varied between 21-162. The highest number of publications was found in the Angle Orthodontist journal with 8 articles in 2017. The highest number of articles was published in Italy and the USA (32). A significant collaboration was observed between Italy, the USA and China. The majority of the macro-level studies (108 articles) were conducted in the field of "Dentistry and Oral Medicine", followed by "Health Literacy and Telemedicine" (5 articles). **Conclusion:** This bibliometric analysis provides valuable information about trends in clear aligner research from the most cited articles. This analysis contributes to the development of more effective treatment methods in the clear aligner field and to the identification of methods to increase patient comfort.

Keywords: Bibliometrics; orthodontics; clear aligner; orthodontic treatment

ÖZET Amaç: Bu çalışmanın amacı, son 10 yılda şeffaf plaklar üzerine en çok atıf alan makaleleri belirleyip bibliyometrik analiz yöntemi ile değerlendirmek ayrıca en çok araştırılan ve uygulanan yöntemleri belirlemektir. **Gereç ve Yöntemler:** 28 Ocak 2024 tarihinde Web of Science (WoS) veri tabanında, şeffaf plaklarla ilgili aranan anahtar kelimelerle, herhangi bir kısıtlama olmaksızın kapsamlı bir elektronik literatür taraması yapıldı. Şeffaf plaklar hakkında en çok atıf alan 116 makale analiz edilerek, bu alandaki popüler araştırma konuları, kurumlar, önemli yazarlar, ülkeler ve dergiler arasındaki ilişki bibliyometrik analiz yöntemi ile belirlendi. **Bulgular:** Son 10 yılda en çok atıf alan makalelere toplam 458 yazar katkıda bulunmuştur. Makalelerin toplam atıf sayısı 21-162 arasında değişmektedir. En fazla yayın 2017 yılında 8 makale ile "Angle Orthodontist" dergisinde bulundu. En fazla makale İtalya ve ABD'de (32) yayınlandı. İtalya, ABD ve Çin arasında önemli bir iş birliği olduğu gözlendi. Makro düzeydeki çalışmaların çoğunluğu (108 makale) "Diş Hekimliği ve Ağız Hastalıkları" alanında yürütüldü, bunu "Sağlık Okuryazarlığı ve Telemedikal" (5 makale) alanı izledi. **Sonuç:** Bu bibliyometrik analiz, en çok atıf alan makalelerden şeffaf plak araştırmalarındaki eğilimler hakkında değerli bilgiler sağlar. Bu analiz, şeffaf plak alanında daha etkili tedavi yöntemlerinin geliştirilmesine ayrıca hasta konforunun artırılmasına yönelik yöntemlerin belirlenmesine katkıda bulunmaktadır.

Anahtar Kelimeler: Bibliyometrik; ortodonti; şeffaf plak; ortodontik tedavi

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Correspondence: Ömer Faruk SARI
Ankara Medipol University Faculty of Dentistry, Department of Orthodontics, Ankara, Türkiye
E-mail: omerf_sari@hotmail.com

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Along with the development of dental materials and 3D technology, with the introduction of the Invisalign system (Align Technology, Inc.USA) in 1998, clear aligners have become increasingly popular and have become more common in orthodontic applications.[1] Considering their superior aesthetics, ease of oral hygiene and comfort, they are quite advantageous compared to fixed orthodontic appliances. However, their effectiveness in treating certain types of malocclusion is still under debate, and there is no broad consensus among academics on the effectiveness of aligners.[2] Therefore, practitioners of clear aligner treatment must rely on clinical experience and published studies.[3] Considering this situation, it is very important to evaluate the quality of published studies.

Bibliometrics is the term used for the statistical analysis of academic publications in the literature.[4,5] Bibliometric studies are research methods that evaluate the results of scientific data related to the research topic in many research fields, especially medicine and dentistry, and guide these studies. This technique enables us to track many scientific developments and identify missing studies in the literature.[6]

The number of citations is one of the bibliometric parameters that allow us to evaluate active articles and their impact on their fields.[7] Citations also reveal the connections between authors, research groups, study topics or countries.[8] In addition, the use of visualized analyses to map bibliometric networks can provide a comprehensive view of a large dataset.[9] Bibliometric analyses can provide an overview of the scientific literature, helping to identify various research themes, clarify the research area on a certain topic, identify research gaps, future research directions and leading study trends.[10] Evaluating the most cited articles in the field of clear aligners can help orthodontists and researchers clarify the specific characteristics of research activity. Recently published articles with a high citation rate can indicate interest in a new topic and important current trends in a certain field.[11] The aim of this bibliometric review was to identify and analyze the 116 most cited articles on clear aligners published in orthodontic journals in the last 10 years.

MATERIAL AND METHODS

SEARCH STRATEGY

Web of Science (WoS) Core Collection database with globally searched keywords and phrases related to clear aligners on January 28, 2024 (“clear aligner appliance”, “clear aligner”, “clear aligner therapy”, “removable thermoplastic orthodontic appliance”, “invisalign”) comprehensive electronic literature search was carried out without any restrictions. All published articles were independently identified by 2 authors (Ö.F.S and E.A) through a computerized database search. According to the results, 1,087 articles were listed. Among the articles, articles that were not yet cited were excluded from the review, leaving 749 articles. In order to create standardization, research articles were filtered and the search results were updated, resulting in 590 articles related to orthodontics and clear aligners. Among the remaining articles, filtering was done again to select those published in the last 10 years and they were sorted according to their highest citation status. As a result of filtering, 116 most cited articles related to orthodontics and clear aligners in the last 10 years were determined. This study was carried out in parallel with the principles of the Declaration of Helsinki. Written consent for publication was obtained from each participant.

ANALYSIS

Bibliometric parameters such as article title, number of citations, citation density, year of publication, authorship, country of authors, publishing institution and keywords were selected from the WoS Core Collection database. VOSwiever (025 Centre for Science and Technology Studies, Leiden University, The Netherlands) was used to analyze and visually retrieve relevant bibliometric data. Classification of topics was determined by reviewing titles and abstracts. It was analyzed and evaluated in terms of author and country, university, most used keywords, topics and trends.

RESULTS

According to the screening criteria, a total of 1,087 articles were initially found, and then the articles with at least 1 citation were identified and reduced to 749

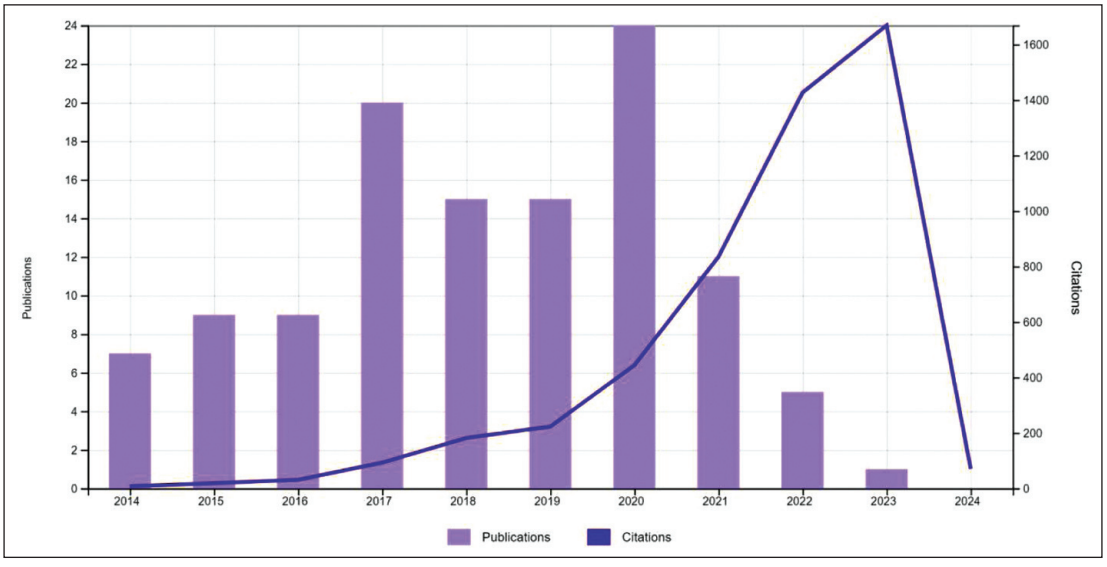

FIGURE 1: Publication and citation trends of the most cited articles in the last 10 years. Columns indicate the number of publications per year, and the line indicates the number of citations per year.

articles. Since only research articles were included in the review, 590 articles were identified after filtering. Afterwards, the filtered articles were sorted in descending order according to the number of citations and the most cited articles related to clear aligners in the last 10 years were determined in order to determine the current trend. Accordingly, the number of most cited articles in the last 10 years was found to be 116. The average number of citations per article was determined as 43.53. The publication and citation trends of the 116 identified articles are shown in Figure 1. Here, it is seen that there is an increasing trend in both the number of publications and the number of citations, especially in the 2017-2020 period. It is noteworthy that 44 of the 116 most cited articles in the last 10 years were published in 2020 and received 444 citations.

MOST CITED ARTICLES AND CITATION CORRELATION ANALYSIS

The citation correlation analysis of the top 10 most cited articles on clear aligners in the last 10 years, sorted by the number of citations, is shown in Table 1. Among these articles, the most cited clear aligner article in the last 10 years is titled "Treatment outcome and efficacy of an aligner technique-regarding incisor torque, premolar derotation and molar distalization" written by Simon et al. In 2014, a total of 162 were cited.[12] Haouili et al.'s article titled "Has Invisalign improved? A prospective follow-up study on the effectiveness of tooth movement with Invisalign" published in 2020 achieved the highest average with 27.4 citations per year.[13] The full list of the 116 most cited articles of the last 10 years is provided in the supplementary file. The total number of citations for each article varies between 21 and 162, with a total of 5002. The number of citations, which was 8 in 2014, increased to 93 with increasing momentum in 2017 and reached its highest value of 444 citations in 2020.

AUTHOR PROFILE

The top 10 journals with the most cited articles in the field of clear aligners in the last 10 years and each publishing two or more articles are shown in Figure 2. Angle Orthodontist journal took the first place in this list with a total of 27 articles. It was followed by the American Journal of Orthodontics and Dentofacial Orthopedics with 21 articles.

AUTHOR AND INSTITUTION ANALYSIS

A total of 458 authors contributed to the 116 most cited articles on clear aligners in the last 10 years. Table 2 shows the top 10 authors who have published at least 4 articles and made significant contributions

TABLE 1: The 10 most cited articles on transparent plates (Web of Science).

No	Publication	Journal	Author	Year of publication	Number of citation	Number of citations per year
1	Treatment outcome and efficacy of an aligner technique - regarding incisor torque, premolar derotation and molar distalization	BMC Oral Health	Simon M.[12]	2014	162	14.73
2	Clear aligners in orthodontic treatment	Australian Dental Journal	Weir T.[14]	2017	139	17.38
3	Forces and moments generated by removable thermoplastic aligners: Incisor torque, premolar derotation, and molar distalization	American Journal of Orthodontics and Dentofacial Orthopedics	Simon M.[12]	2014	138	12.55
4	Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign	American Journal of Orthodontics and Dentofacial Orthopedics	Haouili[13]	2020	137	27.4
5	Braces versus Invisalign®: gingival parameters and patients' satisfaction during treatment: a cross-sectional study	BMC Oral Health	Azaripour A.[15]	2015	104	10.4
6	Efficiency, effectiveness and treatment stability of clear aligners: A systematic review and meta-analysis	Orthodontics&Craniofacial Research	Zheng M.[16]	2017	96	12
7	How accurate is Invisalign in nonextraction cases? *Are predicted tooth positions achieved?*	Angle Orthodontist	Grünheid T.[17]	2017	88	11
8	Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study	Progress in Orthodontics	Ravera S.[33]	2016	86	9.56
9	A comparison of treatment effectiveness between clear aligner and fixed appliance therapies	BMC Oral Health	Ke Y.[18]	2019	85	14.17
10	Accuracy of clear aligners: A retrospective study of patients who needed refinement	American Journal of Orthodontics and Dentofacial Orthopedics	Charalampakis O.[19]	2018	85	12.14

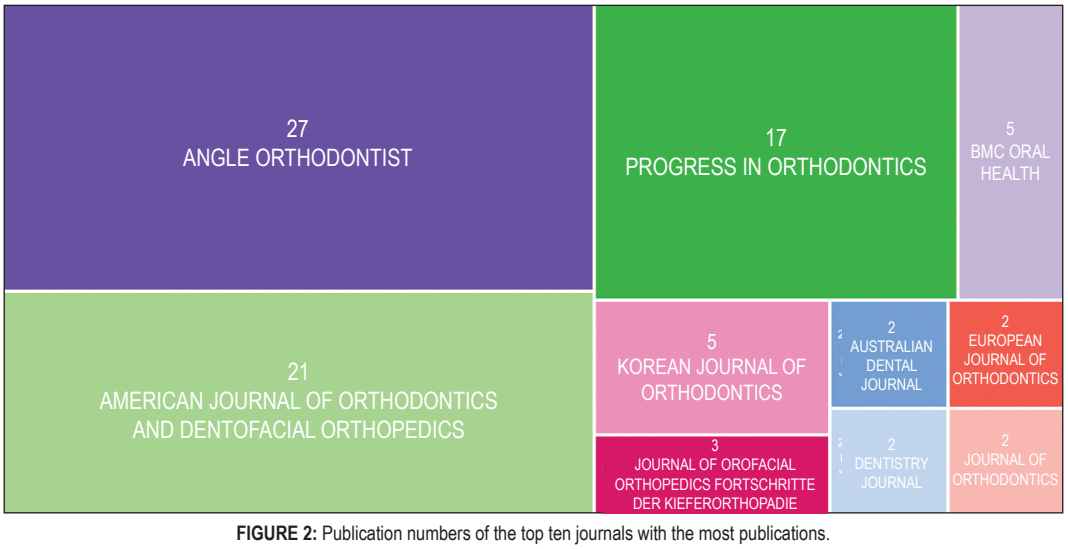

FIGURE 2: Publication numbers of the top ten journals with the most publications.

to this subject. In Figure 3, the connection network of these authors is schematized. The striking point here is that 9 of the top 10 authors with the most article publications have connections with institutions in Italy. A total of 156 universities contributed to the 116 published and most cited articles. Among these,

TABLE 2: Top 10 authors with the largest number of publications on clear aligner.

Author	Number of publications	Affiliation	Country
Castroflorio, Tommaso	7	University of Torino	Italy
Deregibus, Andrea	6	Università di Torino	Italy
Lombardo, Luca	5	Ferrara University	Italy
Siciliani, Giuseppe	5	Ferrara University	Italy
D'Anto, Vincenzo	5	Università degli Studi di Napoli Federico II	Italy
Razionale, Armando Viviano	5	University of Pisa	
Garino, Francesco	5	Self-employment	Italy
Eliades, Theodore	4	University of Zurich	Switzerland
Cugliari, Giovanni	4	European Institute of Oncology	Italy
Barone, Sandro	4	University of Pisa	Italy

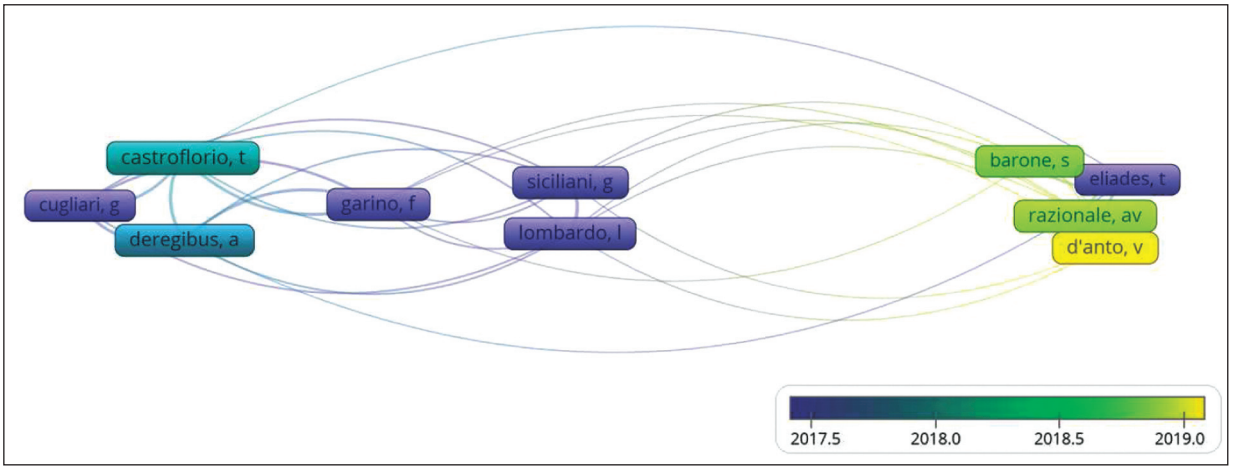

FIGURE 3: Authors with the most publications and their connections with each other.

the top 10 universities, each of which contributed at least four or more articles, are listed in Table 3. Here again, while it is seen that 6 of the top 10 universities are in Italy, it is noteworthy that China's Peking University ranks 2nd with Italy's Turin University with 7 publications.

COUNTRY PROFILE AND CONNECTION NETWORK ANALYSIS

Authors from 27 different countries contributed to the 116 most cited articles about clear aligners in the last 10 years. As listed in Table 4, the most studies from these countries belong to Italy and the USA, with 32 publications each. China followed them with 25 articles. When we look at the citation/publication ratio, Germany stands out with the highest ratio of 79.16. Australia follows it with 54.4. The fact that Italy, USA and China come after Germany and Australia can be thought to be related to the excess number of

TABLE 3: Top 10 most cited university institutions.

University	Number of publications	Country
Peking University	7	China
University of Turin	7	Italy
A O U Citta Della Salute e Della Scienza di Torino	5	Italy
Sichuan University	5	China
University of Ferrara	5	Italy
University of L'Aquila	5	Italy
University of Naples Federico Ii	5	Italy
University of Pisa	5	Italy
National Kapodistrian University of Athens	4	Greece
Shanghai Jiao Tong University	4	China

TABLE 4: Number of citations and publication rates of countries (top 10 countries).

Country	Number of Publications	Number of Citation	Number of Citations/Publication ratio
USA	32	1.572	49. 125
Italy	32	1.188	37.125
China	25	963	38.52
Canada	8	320	40
England	6	136	22.66
Germany	6	475	79.16
Australia	5	272	54.4
Switzerland	5	177	35.4
Greece	4	149	37.25
Saudi Arabia	4	137	34.25

publications. In addition, the connection network between countries is visualized in Figure 4. Accordingly, there is a remarkable cooperation between Italy, USA and China.

ANALYSIS OF KEYWORDS AND STUDY TOPICS

The visual of the most used keywords in the 116 articles examined is presented in Figure 5. The most frequently referenced keywords are "Invisalign" and "clear aligner". These are followed by keywords such as "orthodontic tooth movement", "aligner", "orthodontics", "orthodontics appliance" and "orthodontic treatment". When the subject distribution of the study areas is examined, the majority of the studies at the macro level (108 articles) in the 116 most cited articles related to clear aligners in the last 10 years were conducted in the field of "Dentistry and Oral Medicine", and then in the field of "Health Literacy&Telemedicine" (5 articles) article was carried out (Table 5). When the review was carried out at the micro level, it was seen that the most articles were on "Orthodontic Treatment" (97 articles), followed by "Porphyromonas Gingivalis" (9 articles) and "Health Literacy". It was observed that the majority of the articles were related to orthodontic treatment and the health of oral structures. The number of studies on materials, mechanisms and microorganisms remained low.

DISCUSSION

With the introduction of clear aligners into the literature, there have been major developments in orthodontic practice. This development has also increased the interest in clear aligners from an academic perspective and has provided a significant increase in academic research applications in this field.

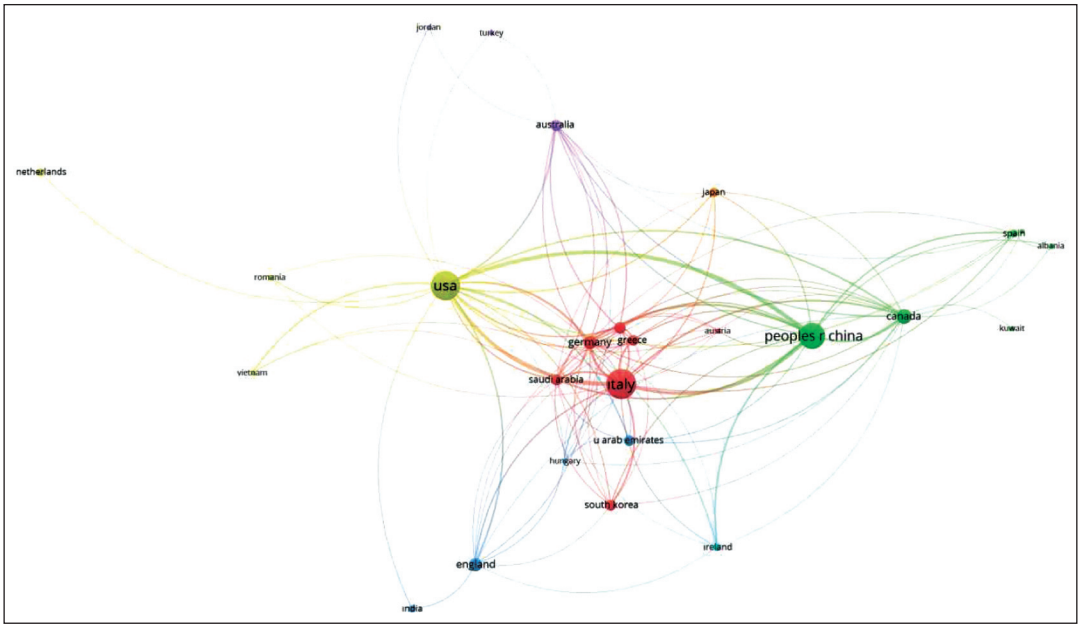

FIGURE 4: The countries with the most publications and their connections with each other.

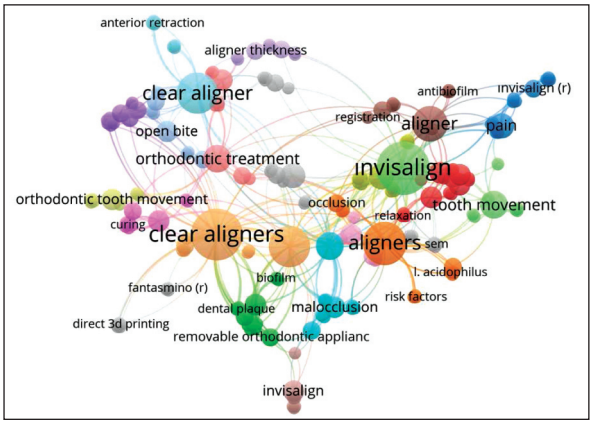

FIGURE 5: The most used keywords and their connections with each other.

TABLE 5: Distribution of the most cited publications on clear aligner in the last 10 years by subject.

Macro	Number of publications	Micro	Number of Publications
Dentistry&Oral Medicine	108	Orthodontic Treatment	97
Health Literacy&Telemedicine	5	Porphyromonas Gingivalis	9
Bone Diseases	1	Health Literacy	4
Polymers&Macromolecules	1	Dentin	2
Nanoparticles	1	Telemedicine	1
		Osteoclast	1
		Climbing Robot	1
		Silver Nanoparticles	1

It has also become one of the most debated topics. Therefore, the primary benefit of the current analysis study is to reveal the basic orientation of academic activities.[2]

Additionally, it was conducted to show researchers emerging trends and to assist in identifying areas that require further effective research. The aim of this bibliometric study is to identify and evaluate the 116 most cited articles in the field of orthodontics indexed in the "orthodontics and clear aligner" category in WoS in the last 10 years. The bibliometric analysis method is a valid tool for this study as it makes it possible to perform reliable searches in the Science Citation Index database and include all potentially valid articles.[6]

The quality of the article is determined by its recognition by scientific academic communities and how it creates changes in clinical practice.[20] The fact that an article is included in the list of most cited articles in its field of science may indicate that it has played an important role in the development of this field of science. As seen in Figure 1, there has been a significant increase in clear vinyl versions, especially in 2017 and 2020. As the total number of publications increased, the number of citations also increased proportionally in the following years (Figure 1). Developments in clear plate biomechanics and the increase in demand for aesthetic treatments have also increased academic interest. Quotations for the year 2024 are not included in Figure 1 because they may be misleading. Although the number of publications decreased between 2020 and 2024, the increase in the number of citations can be considered an indicator confirming that academic interest in clear records is increasing. The articles included in this analysis were studies published between 2014 and 2024. On average, a scientific article starts to receive citations 1 or 2 years after it is published, and it is known to reach its maximum number of citations within 10 years.[21] In this case, the potential effectiveness of recently published articles can often be overlooked. To evaluate an article as a classic, 100 citations are taken as a reference point in medical fields with limited research activity.[22] Additionally, publications with earlier publication dates have higher citation counts. However, it is necessary to take into account that other factors such as research topic(s), authors, institutions and journal may also affect the number of citations. Among the 116 most cited articles in the last 10 years, Angle Orthodontist is the journal that published the most articles with 27 articles. This success can be explained by the indexing level of the journal and its important position in the field of orthodontics. At this point, Angle Orthodontist journal has surpassed the American Journal of Orthodontics and Dentofacial Orthopedics in publishing the most cited article about clear aligners in the last 10 years. This situation shows that the increasing interest in clear aligners will help to focus and increase the direction of studies and articles in this field.

Our findings reveal that the most active international collaborations are seen between the USA, Italy and China. In a different analysis study con-

ducted similar to our study, intense cooperation between the USA, China and South Korea was observed.[23] The occurrence of collaboration between different countries may be explained by differences in research interests, language differences, or funding sources, as suggested by previous studies.[24] In the bibliometric study conducted by Bruni et al. on clear aligners, it was stated that the most publications were made from the USA, Italy and Germany. The reason for the different indicators in this study may be that only research articles were included in our study.[25]

The cited articles were found to be research articles. The most common field of study is dentistry and oral medicine at the macro level (108 articles), and at the micro level is fixed orthodontic treatment of existing irregularities in the teeth (97 articles). The minimum topics were nanoparticles, polymers and macromolecules (1 article each) at the macro level, and silver nanoparticles (1 article) at the micro level. The topics and density of the most cited articles in the field of clear aligners have also changed over time. In 2004, 1 article discussed the material properties of clear aligners, and in 2005, 3 articles discussed the technology and clinical effects of clear aligners.[26-29] The number of publications, which was static until 2008, started to rise rapidly after 2008, and as of 2017, the most cited articles reached 40 or more. The reason for the increase here can be shown as the increase in studies and research on this subject as a result of clear aligners becoming increasingly popular among clinicians and an orthodontic method demanded by patients.

When evaluated on a subject basis, issues related to orthodontic treatment and the technological development of clear aligners have been discussed in the last 10 years. It was observed that 185 of the 229 publications related to clear aligners in 2023 were related to dentistry and oral health at the macro level and the orthodontic treatment process at the micro level, and it was stated that the article with the highest number of citations among these received 33 citations.[30]

Network relationship analysis between keywords is a method used to map research specific to a specific field of science by detecting the connections between keywords.[31] In our study, the words shown in Table 5 were used, especially the most frequently used words for searching in WoS, namely “invisalign” and “clear aligner”. The articles were then ranked by the number of citations and detailed criteria were added during selection as suggested by other authors.[32] In the keyword relationship map, the larger and central networks consist of words such as invisalign, orthodontic tooth movement and clear aligner. One of the keywords, Invisalign, had a high number of usage in the keyword map; this may be due to Invisalign being the brand name of the clear aligner system with the highest usage worldwide. Nowadays, many companies produce clear aligners and their number is increasing day by day. The term orthodontic tooth movement is a keyword used in many studies predicting the consequences of certain orthodontic tooth movements, such as distalization, intrusion, and extrusion.[33] The mechanics of intermittent forces applied with clear aligners are attuned to the physiology of the periodontium and appear to have the ability to trigger biomarkers of orthodontic tooth movement at higher concentrations.[34]

Although this study was planned to minimize its shortcomings, it is very important to mention the current limitations. Possible shortcomings in the articles included in this study can be taken into account: no comprehensive search was conducted, only 1 citation database was used. The most commonly used citation count tracking databases include WoS, Scopus, and Google Scholar. The number of citations may vary depending on the database used. It may directly affect bibliometric measurements, as each database indexes different content and only considers citations from its own collection. Not considering other databases and literature could potentially limit the comprehensiveness of our search results.[35] Future studies addressing these limitations are recommended. A more extensive study through multiple databases and literature would be desirable. A statistical test to determine potential correlations between analyzed variables would also be interesting and useful.

CONCLUSION

The 116 most cited articles in the field of clear aligners in the last 10 years were written by 458 researchers from 156 institutions in 27 different countries.

This bibliometric analysis study identified the most cited articles and provided valuable information about trends in clear aligner research. This analysis contributes to the development of more effective treatment methods in the field of clear aligners and to the identification of methods to increase patient comfort.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Hilmi Büyükçavuş;* ***Design:*** *Ömer Faruk Sarı;* ***Control/Supervision:*** *Hilmi Büyükçavuş;* ***Data Collection and/or Processing:*** *Elif Albayrak;* ***Analysis and/or Interpretation:*** *Ömer Faruk Sarı;* ***Literature Review:*** *Elif Albayrak;* ***Writing the Article:*** *Elif Albayrak;* ***Critical Review:*** *Hilmi Büyükçavuş.*

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