Twenty years of clear aligner therapy: a bibliometric analysis (2002-2022)

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Introduction: Clear aligner (CA) therapy has become popular worldwide but there is little research in the area from the perspective of bibliometrics. The present study aimed to identify the most impactful studies on CA over its 20 years of publishing since 2002.
Methods: The Web of Science database was used to retrieve study records on CA for the period between 2002 and 2022. Two authors manually screened the related studies. CiteSpace was used to analyse the country and institutional co-operation, keywords and citations with the strongest 'burst'.
Results: The number of CA publications has increased and a total of 613 studies were included in the current analysis. The *American Journal of Orthodontics and Dentofacial Orthopedics* was the leading publishing journal reporting 79 published CA articles and 1627 total citations. Italy had the most significant productivity in this field (142/613, 23.16%). The United States of America was the leading country with the highest international collaboration. Based on the results of keyword analysis, orthodontic treatment, digital orthodontics, superimposition, and apical root resorption were previous research emphases.
Conclusions: The present analysis indicates that the treatment outcomes of CA therapy is the focus of current studies and provides developments for future research. The results provide an increased and comprehensive understanding of the state of the art of CA treatment.
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Introduction

The possibility of using a clear overlay orthodontic appliance was first introduced in 1946 by Kesling.[1] In 1999, Align Technology® (Santa Clara, California) integrated modern technology to develop the clear aligner treatment (CAT) protocol. Because of the improved aesthetics and comfort, increasing numbers of patients prefer CAT over conventional fixed appliances.[2,3] Since its introduction, clear aligner (CA) therapy has undergone continuous adjustment and progress, and worldwide, over 14 million patients have been treated using the Invisalign appliance.[4]

Recently, over 600 papers associated with clear aligner (CA) therapy have been published in the Web of Science Core Collection database. It is meaningful to categorise substantial evidence from massive databases so that researchers may establish innovative outlines of investigation. Bibliometrics has been commonly used to evaluate scientific research both quantitatively and qualitatively.[5]

In line with previous studies, the present review aims to perform a bibliometric analysis of CA therapy throughout its 20 years of publishing in the scientific literature. According to current knowledge and based on the collected evidence, this is the first bibliometric study of trends related to invisible appliance research. It is expected that the results will identify CA focused research and therefore benefit the development of national and institutional research strategies. In addition, the derived data or evidence can be used to examine the scientific history of investigative outputs and recognise potential future investigative pathways and prospects for collaboration.

Methods

The present study gathered original articles published on the Web of Science from 2002 to 2022. To avoid bias caused by daily database updates, the literature search was completed in a single day (2/12/2022), and two observers manually screened studies based on their titles and abstracts. The records were exported in plain text file format as "full record and cited references". Each record contained relevant analysis information, including title, author, keywords, abstract, and references.

The Web of Science results analysis and citation reports were used to evaluate different aspects of the publications, including the number of publications, the number of citations per year, output author/institution/country ranking, and the ranking of the most cited journal publications/literature/author. The downloaded data were imported into CiteSpace (version 5.7R5W; http://cluster.cis.drexel.edu/wchen/CiteSpace/) for further analysis, including author, institution, country/region collaboration network analysis and keyword co-occurrence analysis. Record screening results determined the final time span of the data (2002–2022). The 'time slice' was 3 years. Keywords were used for emergent analysis, while references were used for co-citation and emergent analysis.

Results

General information

The final analysis included 613 studies published by multiple authors from different countries/regions in the field related to clear aligners. As shown in Figure 1, there was an overall upward trend in the number of articles published per year from 2002 to 2022, increasing from 0 to 186 articles. In addition, the articles published from 2002 to 2022 were cited 7342 times. The frequency of citations increased from 0 in 2002 to 2705 in 2022. This indicates that CA and related studies have been expanding and further research is being conducted.

Distribution of discipline

All articles were classified into the 53 research area categories of the scientific core network, and the top 10 disciplines were ranked according to the number of published articles (Table I). Dentistry and Oral Surgery Medicine had the highest number of publications (430; 70.15%), the highest H-index, and the highest number of citations.

Journal analysis

The total of 613 articles were published in 102 journals. The current top three publishing journals were the *American Journal of Orthodontics and Dentofacial Orthopedics* (79/613, 12.89%), the *Angle Orthodontist* (62/613, 10.11%), and the *Progress in Orthodontics* (34/613, 5.55%) (Table II). These are accepted as excellent journals related to dentistry and orthodontics and have therefore published most of the articles.

The top 20 journals were selected based on the number of published studies (Table II). The highest citation frequency was closely related to the highest academic impact in each field. Table III provides details of the top 50 most cited articles. The *American Journal of Orthodontics and Dentofacial Orthopedics* was the journal which had the most relevant articles, the top 50 most cited articles, and the highest citation frequency. Kravitz et al. conducted the most cited studies (211 times) in the *American Journal of Orthodontics and Dentofacial Orthopedics.* The most cited review (221 times) was published in the *Angle Orthodontist* by Rossini et al.,[6] which reviewed studies from 2000 to 2014 to explore the tooth movement efficiency of clear aligners.

Inter-country distribution and cooperation

Figure 2 shows the global distribution of published literature in CA therapy and related research areas. Table IV lists the top 10 countries with the most
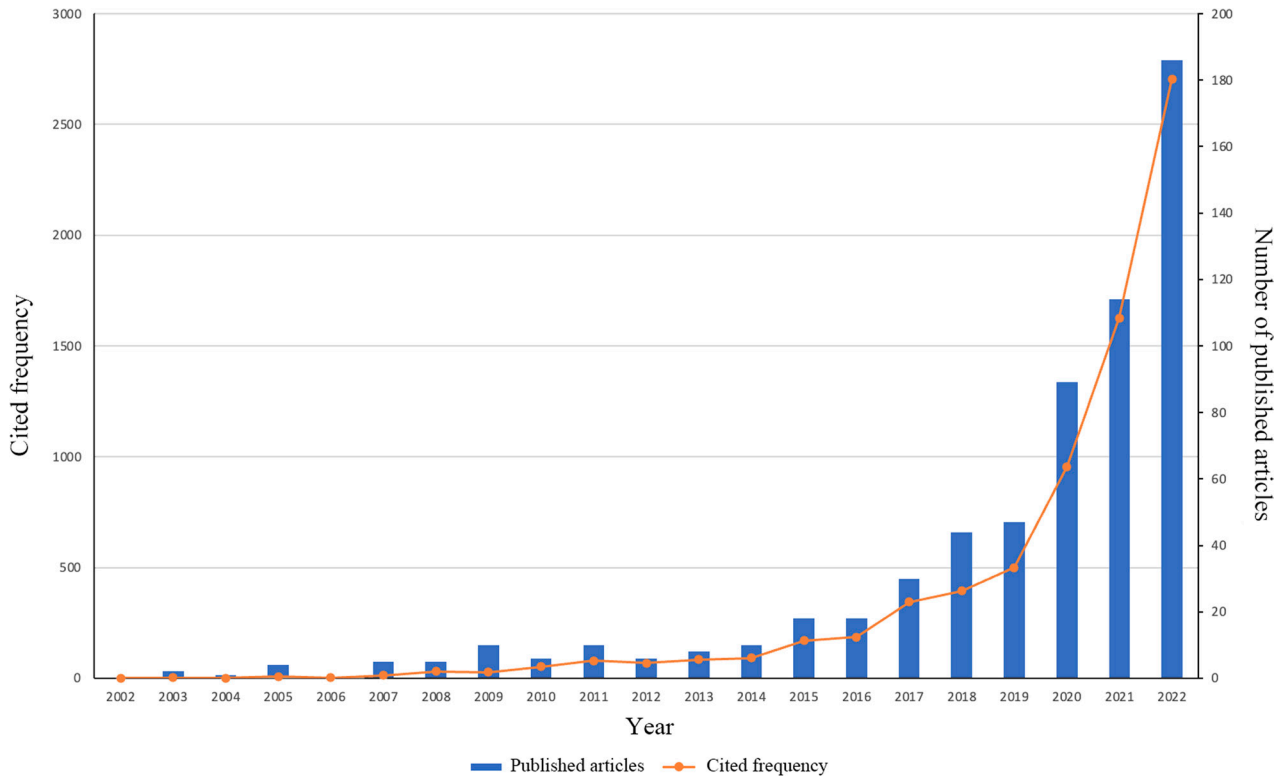
Figure 1. Citation frequency and number of published articles over time.

published literature from 1992 to 2022, with Italy, the United States of America and China accounting for 23.16% (142), 18.92% (116) and 16.31% (100) of all published literature, respectively. The top three total citation frequencies came from the United States (2132), Italy (1543) and China (987). The United States of America is the centre of co-operation between countries/regions, with the closest relationships occurring between Germany, Canada, and other countries (Figure 2).

Table I. Top 10 Disciplines ranked according to the number of published articles

Rank	Research area	Count	% Of 613	Sum of cited frequency	Average citations per article	H-Index
1	Dentistry & Oral Surgery Medicine	430	70.15%	6400	14.88	42
2	Materials Science Multidisciplinary	47	7.67%	246	5.23	8
3	Physics Applied	40	6.53%	177	4.43	8
4	Medicine General Internal	33	5.38%	186	5.64	8
5	Chemistry Multidisciplinary	22	3.59%	35	1.59	3
6	Engineering Multidisciplinary	22	3.59%	29	1.32	3
7	Medicine Research Experimental	22	3.59%	113	5.14	5
8	Metallurgy Metallurgical Engineering	19	3.10%	140	7.37	7
9	Chemistry Physical	17	2.77%	139	8.18	7
10	Physics Condensed Matter	17	2.77%	139	8.18	7

Table II. Top 20 Journal with the largest number of published articles

Number	Journal	Count	% of 613	H-Index	Sum of cited frequency	Rank	Average citations	Sum of top 50 most-cited articles	Impact factor (2021)
1	American Journal of Orthodontics and Dentofacial Orthopedics	79	12.89%	21	1627	1	20.59	12	2.711
2	Angle Orthodontist	62	10.11%	22	1504	2	24.34	12	2.684
3	Progress in Orthodontics	34	5.55%	15	559	3	16.56	4	3.247
4	Applied Sciences-Basel	21	3.43%	2	22		1.05		2.838
5	BMC Oral Health	20	3.26%	7	335	5	16.80	3	3.747
6	Materials	17	2.77%	8	138	9	8.12		3.748
7	Australasian Orthodontic Journal	16	2.61%	2	13		0.81		0.269
8	Journal of Orofacial Orthopedics	15	2.45%	8	278	6	18.50	2	2.341
9	European Journal of Orthodontics	14	2.28%	11	513	4	36.64	6	3.131
10	Korean Journal of Orthodontics	14	2.28%	6	181	8	12.93	1	1.361
11	Dentistry Journal	13	2.12%	4	51		12.75		0.81
12	Orthodontics & Craniofacial Research	13	2.12%	7	202	7	15.54	2	2.563
13	Journal of the World Federation of Orthodontics	10	1.63%	5	52		5.20		0.4
14	Seminars in Orthodontics	10	1.63%	5	100	10	10.00		1.34
15	Journal of Orthodontics	9	1.47%	2	13		1.44		0.5
16	International Journal of Environmental Research and Public Health	8	1.31%	3	34		4.25		4.614
17	Journal of Clinical Medicine	8	1.31%	4	49		6.13		4.964
18	APOS Trends in Orthodontics	7	1.14%	2	9		1.29		0.19
19	Biomed Research International	7	1.14%	3	55		7.86		3.246
20	Journal of Craniofacial Surgery	7	1.14%	2	20		2.86		1.172

Table III. Top 50 most cited articles on CAT from 2002 to 2022

Rank	Title	First author	Corresponding author(s)	Journal	Year	Total citations	Annual citations	Top 25 citation burst
1	Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review	Rossini, G	Rossini, G	Angle Orthodontist	2015	221	31.57	△
2	How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign	Kravitz, ND	Kravitz, ND	American Journal of Orthodontics and Dentofacial Orthopedics	2009	211	16.23	△
3	Intraoral aging of orthodontic materials: the picture we miss and its clinical relevance	Eliades, T	Eliades, T	American Journal of Orthodontics and Dentofacial Orthopedics	2005	165	9.71	
4	Outcome assessment of invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system	Djeu, G	Djeu, G	American Journal of Orthodontics and Dentofacial Orthopedics	2005	128	7.53	△
5	Treatment outcome and efficacy of an aligner technique - regarding incisor torque, premolar derotation and molar distalization	Simon, M	Simon, M	BMC Oral Health	2014	108	13.50	△
6	Forces and moments generated by removable thermoplastic aligners: Incisor torque, premolar derotation, and molar distalization	Simon, M	Simon, M	American Journal of Orthodontics and Dentofacial Orthopedics	2014	99	12.38	△
7	A comparison of treatment impacts between invisalign aligner and fixed appliance therapy during the first week of treatment	Miller, KB	McGorray, SP	American Journal of Orthodontics and Dentofacial Orthopedics	2007	91	6.07	
8	Clear aligners in orthodontic treatment	Weir, T	Weir, T	Australian Dental Journal	2017	83	16.60	
9	The treatment effects of invisalign orthodontic aligners - A systematic review	Lagravere, MO	Lagravere, MO	Journal of the American Dental Association	2005	82	4.82	

Table III. Top 50 most cited articles on CAT from 2002 to 2022

Rank	Title	First author	Corresponding author(s)	Journal	Year	Total citations	Annual citations	Top 25 citation burst
10	Braces versus Invisalign (R): gingival parameters and patients' satisfaction during treatment: a cross-sectional study	Azaripour, A	Azaripour, A	*BMC Oral Health*	2015	77	11.00	△
11	Clinical effectiveness of Invisalign (R) orthodontic treatment: a systematic review	Papadimitriou, A	Kloukos, D	*Progress in Orthodontics*	2018	74	18.50	
12	Periodontal health during clear aligners treatment: a systematic review	Rossini, G	Rossini, G	*European Journal of Orthodontics*	2015	71	10.14	△
13	Invisalign and traditional orthodontic treatment postretention outcomes compared using the American Board of Orthodontics Objective Grading System	Kuncio, D	Kuncio, D	*Angle Orthodontist*	2007	68	4.53	
14	Influence of attachments and interproximal reduction on the accuracy of canine rotation with invisalign - A prospective clinical study	Kravitz, ND	Kravitz, ND	*Angle Orthodontist*	2008	67	4.79	△
15	Invisalign® treatment in the anterior region: Were the predicted tooth movements achieved?	Krieger, E	Krieger, E	*Journal of Orofacial Orthopedics*	2012	66	6.60	△
16	Efficiency, effectiveness and treatment stability of clear aligners: A systematic review and meta-analysis	Zheng, M	Yu, Z	*Orthodontics & Craniofacial Research*	2017	65	13.00	
17	Effects of mechanical properties of thermoplastic materials on the initial force of thermoplastic appliances	Kohda, N	Iijima, M	*Angle Orthodontist*	2013	64	7.11	△
18	Adult patients' adjustability to orthodontic appliances. Part I: a comparison between Labial, Lingual, and Invisalign (TM)	Shalish, M	Shalish, M	*European Journal of Orthodontics*	2012	64	6.40	

	Title			Journal	Year			
19	Stress relaxation properties of four orthodontic aligner materials: A 24-hr in vitro study	Lombardo, L	Arreghini, A	*Angle Orthodontist*	2017	62	12.40	
20	Activation time and material stiffness of sequential removable orthodontic appliances. Part 1: Ability to complete treatment	Bollen, AM	Bollen, AM	*American Journal of Orthodontics and Dentofacial Orthopedics*	2003	61	3.21	
21	Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign	Haouili, N	Kravitz, ND	*American Journal of Orthodontics and Dentofacial Orthopedics*	2020	58	29.00	
22	Social perceptions of adults wearing orthodontic appliances: a cross-sectional study	Jeremiah, HG	Jeremiah, HG	*European Journal of Orthodontics*	2011	59	5.36	
23	A comparison of the periodontal health of patients during treatment with the Invisalign® system and with fixed lingual appliances	Miehke, RR	Miehke, RR	*Journal of Orofacial Orthopedics*	2007	59	3.93	
24	Esthetic orthodontic treatment using the invisalign appliance for moderate to complex malocclusions	Boyd, RL	Boyd, RL	*Journal of Dental Education*	2008	58	4.14	△
25	How accurate is Invisalign in nonextraction cases? Are predicted tooth positions achieved?	Grunheid, T	Grunheid, T	*Angle Orthodontist*	2017	57	11.40	
26	Management of overbite with the Invisalign appliance	Khosravi, R	Khosravi, R	*American Journal of Orthodontics and Dentofacial Orthopedics*	2017	57	11.40	
27	Evaluation of Invisalign treatment effectiveness and efficiency compared with conventional fixed appliances using the Peer Assessment Rating index	Gu, JF	Deguchi, T	*American Journal of Orthodontics and Dentofacial Orthopedics*	2017	57	11.40	
28	Initial Forces and Moments Delivered by Removable Thermoplastic Appliances during Rotation of an Upper Central Incisor	Hahn, W	Hahn, W	*Angle Orthodontist*	2010	57	4.75	△

Table III. Top 50 most cited articles on CAT from 2002 to 2022

Rank	Title	First author	Corresponding author(s)	Journal	Year	Total citations	Annual citations	Top 25 citation burst
29	Structural conformation and leaching from in vitro aged and retrieved Invisalign appliances	Schuster, S	Bradley, TG	American Journal of Orthodontics and Dentofacial Orthopedics	2004	52	2.89	
30	Effectiveness of clear aligner therapy for orthodontic treatment: A systematic review	Robertson, L	Mir, CF	Orthodontics & Craniofacial Research	2020	52	26.00	
31	A comparison of treatment effectiveness between clear aligner and fixed appliance therapies	Ke, YY	Zhu, YF; Zhu, M	BMC Oral Health	2019	52	17.33	
32	Predictability of orthodontic movement with orthodontic aligners: a retrospective study	Lombardo, L	Arreghini, A	Progress in Orthodontics	2017	52	10.40	
33	Discomfort associated with Invisalign and traditional brackets: A randomized, prospective trial	White, DW	Buschang, PH	Angle Orthodontist	2017	52	10.40	△
34	Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study	Ravera, S	Ravera, S	Progress in Orthodontics	2016	52	8.67	
35	Dynamic stress relaxation of orthodontic thermoplastic materials in a simulated oral environment	Fang, DY	Bai, YX	Dental Materials Journal	2013	46	5.11	
36	Torquing an upper central incisor with aligners-acting forces and biomechanical principles	Hahn, W	Hahn, W	European Journal of Orthodontics	2010	47	3.92	
37	A novel pressure film approach for determining the force imparted by clear removable thermoplastic appliances	Barbagallo, LJ	Darendeliler, MA	Annals of Biomedical Engineering	2008	47	3.36	△
38	Accuracy of interproximal enamel reduction during clear aligner treatment	De Felice, ME	Grassia, V	Progress in Orthodontics	2020	46	23.00	

| #	Title	Author 1	Author 2	Journal	Year			
39	Accuracy of clear aligners: A retrospective study of patients who needed refinement	Charalampakis, O	Kim, KB	*American Journal of Orthodontics and Dentofacial Orthopedics*	2018	46	11.50	
40	A systematic review of the accuracy and efficiency of dental movements with Invisalign®	Galan-Lopez, L	Galan-Lopez, L	*Korean Journal of Orthodontics*	2019	45	15.00	
41	The predictability of transverse changes with Invisalign	Houle, JP	Pinheiro, FHSL	*Angle Orthodontist*	2017	44	8.80	
42	Clinical limitations of invisalign	Phan, X	Phan, X	*Journal of the Canadian Dental Association*	2007	42	2.80	
43	Treatment outcome with orthodontic aligners and fixed appliances: a systematic review with meta-analyses	Papageorgiou, SN	Eliades, T	*European Journal of Orthodontics*	2020	42	21.00	
44	Effects of variable attachment shapes and aligner material on aligner retention	Dasy, H	Kwak, JH	*Angle Orthodontist*	2015	42	6.00	
45	Initial forces generated by three types of thermoplastic appliances on an upper central incisor during tipping	Hahn, W	Hahn, W	*European Journal of Orthodontics*	2009	42	3.23	
46	Comparative time efficiency of aligner therapy and conventional edgewise braces	Buschang, PH	Buschang, PH	*Angle Orthodontist*	2014	41	5.13	
47	Periodontal health during orthodontic treatment with clear aligners and fixed appliances A meta-analysis	Jiang, Q	Li, H	*Journal of the American Dental Association*	2018	40	10.00	
48	Variables affecting orthodontic tooth movement with clear aligners	Kuroda, S	Kuroda, S	*American Journal of Orthodontics and Dentofacial Orthopedics*	2014	38	4.75	△
49	Twitter analysis of the orthodontic patient experience with braces vs Invisalign	Noll, D	Shroff, B	*Angle Orthodontist*	2017	38	7.60	
50	Preparation and characterization of thermoplastic materials for invisible orthodontics	Zhang, N	Bai, Y	*Dental Materials Journal*	2011	37	3.36	
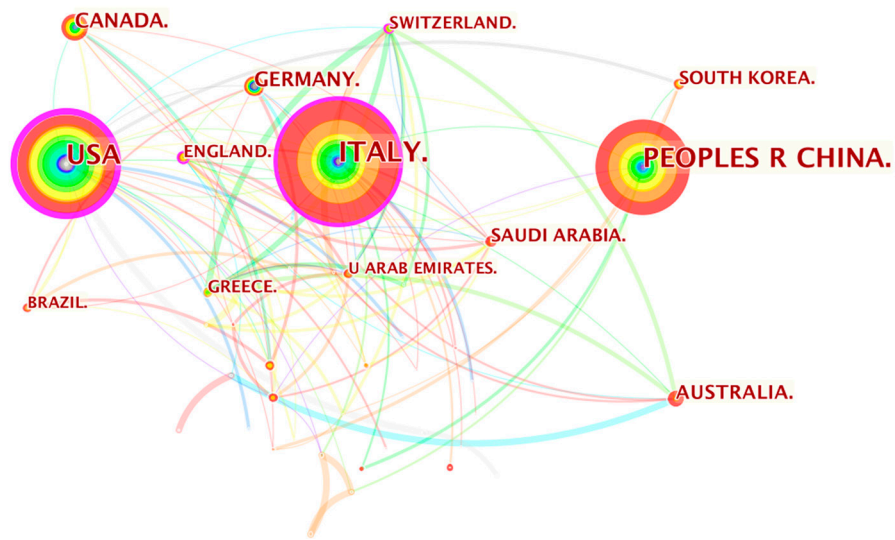
Figure 2. Co-occurrence network map of countries/regions.

Inter-institutional distribution and cooperation

There is a significant level of collaboration between institutions. The University of Ferrara, University of L'Aquila, University of Turin, Sichuan University, University of Roma Tor Vergata, University of Alberta, University of Queensland, and Capital Medical University were the most productive, influential, and central institutions in the field based on the number of published studies, citation frequency and collaborations (Figure 3).

Distribution and cooperation among authors

The top 10 authors are listed in Table V and are ranked according to the number of published articles and citations. The authors who produced the most published articles were Castroflorio (21 articles; 3.42% of the total number of published articles). The authors whose articles had been cited more than 400 times were Castroflorio (cited 535 times in total; cited 25.48 per study), Deregibus (480; 30.00), and Eliades (475, 36.54).

Table IV. Top 10 Countries ranked by the number of published articles

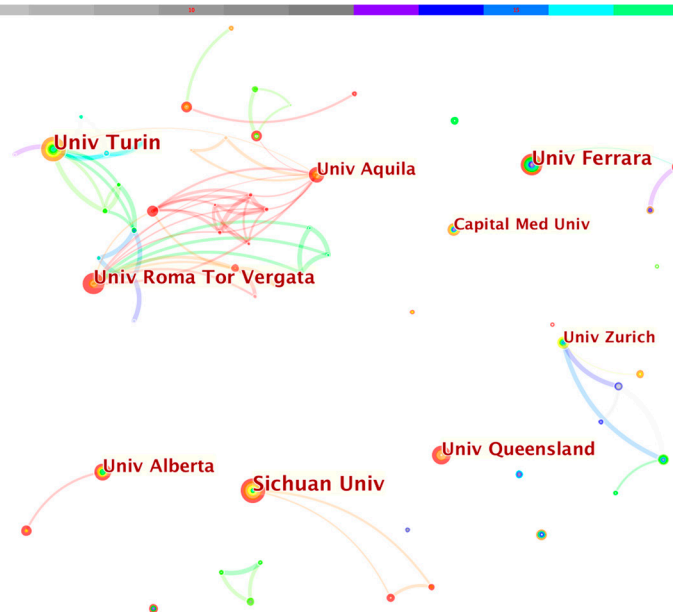| Number	Country	Count	% of 613	Sum of times cited	Average citation per article	H-Index
1	Italy	142	23.16%	1543	10.87	22
2	U. S. A	116	18.92%	2132	18.38	26
3	People R China	100	16.31%	987	9.87	19
4	Canada	40	6.53%	538	13.45	13
—	Germany	35	5.71%	958	27.37	16
6	Australia	32	5.22%	265	8.28	6
7	Saudi Arabia	29	4.73%	111	3.83	5
8	Greece	24	3.92%	582	24.25	12
—	India	23	3.75%	125	5.43	5
—	Switzerland	22	3.59%	337	15.32	10

Figure 3. Co-occurrence network map of institutions.

Research focuses

Emerging trends

Citation 'bursts' are articles that have seen a significant increase in citations over a short period and may reflect the focus of research at that time. The top 25 studies with the highest burst values are shown in Figure 4. Nine of the articles reported on the comparison between clear aligners and traditional fixed orthodontic appliances (2, 12, 14, 15, 18, 20, 21, 22, 25). Seven studies focused on the accuracy of clear aligners (4, 5, 8, 10, 13, 14, 17), while five

studies reported the periodontal health of patients treated with clear aligners (12, 18, 19, 20, 22). Other topics included orthodontic force, attachments, material science and clear aligner generations.

Keywords burst

Keywords can accurately reflect the research focus of a certain period. Therefore, detecting emergent keywords can help summarise the development of research frontiers and explore new topics. The nine most frequently cited keywords are provided

Table V. The Top 10 authors with the largest number of published articles and citation (December 31, 2022)

Number	Author	Count	% of 613	Number	Author	Sum of times cited	Average citation per article
1	Castroflorio T	21	3.42%	1	Castroflorio T	535	25.48
2	Deregibus A	16	2.61%	2	Deregibus A	480	30.00
—	Siciliani G	16	2.61%	3	Eliades T	475	36.54
4	Weir T	15	2.45%	4	Rossini G	396	39.60
5	Vaid NR	14	2.28%	5	Parrini S	369	36.90
6	Eliades T	13	2.12%	6	Kravitz ND	358	71.60
—	Lombardo L	13	2.12%	7	Siciliani G	271	16.94
7	Parrini S	10	1.63%	8	Lombardo L	259	19.92
—	Cozza P	10	1.63%	9	Simon M	207	41.4
—	D'anto V	10	1.63%	10	Bai Y	154	25.67

in Figure 5. The keywords with the longest use include orthodontic treatment, digital orthodontics, superimposition, and apical root resorption.

Discussion

General and global characteristics of CA therapy

The present study shows that CA therapy and related studies have received greater attention and that the total number of published papers has increased over time. Table II lists the journals that have the more relevant articles, are most cited, and have a greater impact. It is recommended that scholars read relevant journal articles and that authors submit manuscripts on relevant topics to these journals.

There is a rich collaboration between different countries/regions, especially between Western countries (Figure 2). Italy ranks first in the number of published articles and has the top 3 most productive institutions involved in CA research. In addition, the U.S.A. ranks first in the frequency of citations and has a high centrality, indicating that it is at the forefront of the field and at the centre

of international collaboration (Table IV). Seven of the top 10 producing countries are non-English speaking, indicating a global trend in the distribution of research in this field (Table IV). Moreover, three of the top 10 publishing countries are from Asia where clinical research may benefit from a relatively large patient population.

The most influential and productive institutions and authors correspond to the countries/regions with the most published literature and most frequent citations. Collaborations and consultants from the institutions that publish the most literature and cite most frequently is encouraged. Collaboration between institutions is common but is mainly regional (Figure 3).

Research hotspots on CA

Citations of key literature were based on centrality value, citation frequencies, and burst value. By analysing the labels, keyword bursts, and key literature for each cluster, it was found that the most popular and recent research focus in the field included the following areas.

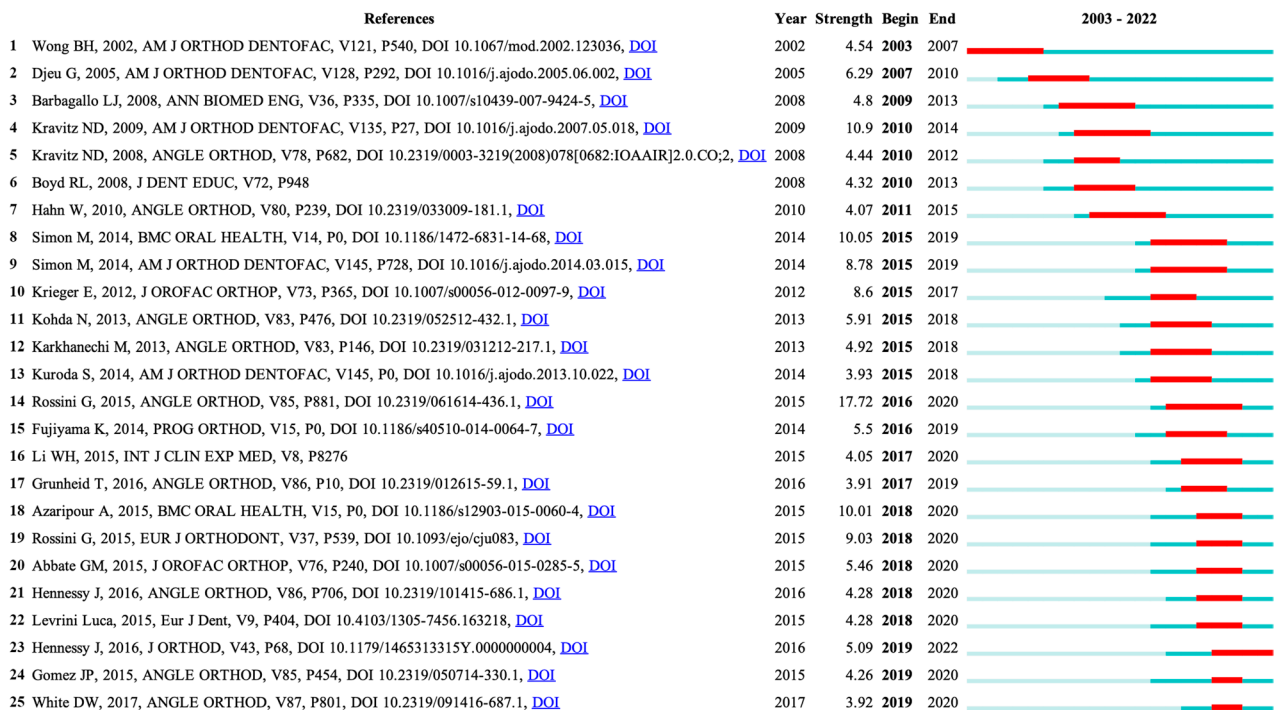**Top 25 References with the Strongest Citation Bursts**

	References	Year	Strength	Begin	End	2003 - 2022
1	Wong BH, 2002, AM J ORTHOD DENTOFAC, V121, P540, DOI 10.1067/mod.2002.123036, DOI	2002	4.54	**2003**	2007	
2	Djeu G, 2005, AM J ORTHOD DENTOFAC, V128, P292, DOI 10.1016/j.ajodo.2005.06.002, DOI	2005	6.29	**2007**	2010	
3	Barbagallo LJ, 2008, ANN BIOMED ENG, V36, P335, DOI 10.1007/s10439-007-9424-5, DOI	2008	4.8	**2009**	2013	
4	Kravitz ND, 2009, AM J ORTHOD DENTOFAC, V135, P27, DOI 10.1016/j.ajodo.2007.05.018, DOI	2009	10.9	**2010**	2014	
5	Kravitz ND, 2008, ANGLE ORTHOD, V78, P682, DOI 10.2319/0003-3219(2008)078[0682:IOAAIR]2.0.CO;2, DOI	2008	4.44	**2010**	2012	
6	Boyd RL, 2008, J DENT EDUC, V72, P948	2008	4.32	**2010**	2013	
7	Hahn W, 2010, ANGLE ORTHOD, V80, P239, DOI 10.2319/033009-181.1, DOI	2010	4.07	**2011**	2015	
8	Simon M, 2014, BMC ORAL HEALTH, V14, P0, DOI 10.1186/1472-6831-14-68, DOI	2014	10.05	**2015**	2019	
9	Simon M, 2014, AM J ORTHOD DENTOFAC, V145, P728, DOI 10.1016/j.ajodo.2014.03.015, DOI	2014	8.78	**2015**	2019	
10	Krieger E, 2012, J OROFAC ORTHOP, V73, P365, DOI 10.1007/s00056-012-0097-9, DOI	2012	8.6	**2015**	2017	
11	Kohda N, 2013, ANGLE ORTHOD, V83, P476, DOI 10.2319/052512-432.1, DOI	2013	5.91	**2015**	2018	
12	Karkhanechi M, 2013, ANGLE ORTHOD, V83, P146, DOI 10.2319/031212-217.1, DOI	2013	4.92	**2015**	2018	
13	Kuroda S, 2014, AM J ORTHOD DENTOFAC, V145, P0, DOI 10.1016/j.ajodo.2013.10.022, DOI	2014	3.93	**2015**	2018	
14	Rossini G, 2015, ANGLE ORTHOD, V85, P881, DOI 10.2319/061614-436.1, DOI	2015	17.72	**2016**	2020	
15	Fujiyama K, 2014, PROG ORTHOD, V15, P0, DOI 10.1186/s40510-014-0064-7, DOI	2014	5.5	**2016**	2019	
16	Li WH, 2015, INT J CLIN EXP MED, V8, P8276	2015	4.05	**2017**	2020	
17	Grunheid T, 2016, ANGLE ORTHOD, V86, P10, DOI 10.2319/012615-59.1, DOI	2016	3.91	**2017**	2019	
18	Azaripour A, 2015, BMC ORAL HEALTH, V15, P0, DOI 10.1186/s12903-015-0060-4, DOI	2015	10.01	**2018**	2020	
19	Rossini G, 2015, EUR J ORTHODONT, V37, P539, DOI 10.1093/ejo/cju083, DOI	2015	9.03	**2018**	2020	
20	Abbate GM, 2015, J OROFAC ORTHOP, V76, P240, DOI 10.1007/s00056-015-0285-5, DOI	2015	5.46	**2018**	2020	
21	Hennessy J, 2016, ANGLE ORTHOD, V86, P706, DOI 10.2319/101415-686.1, DOI	2016	4.28	**2018**	2020	
22	Levrini Luca, 2015, Eur J Dent, V9, P404, DOI 10.4103/1305-7456.163218, DOI	2015	4.28	**2018**	2020	
23	Hennessy J, 2016, J ORTHOD, V43, P68, DOI 10.1179/1465313315Y.0000000004, DOI	2016	5.09	**2019**	2022	
24	Gomez JP, 2015, ANGLE ORTHOD, V85, P454, DOI 10.2319/050714-330.1, DOI	2015	4.26	**2019**	2020	
25	White DW, 2017, ANGLE ORTHOD, V87, P801, DOI 10.2319/091416-687.1, DOI	2017	3.92	**2019**	2020	

Figure 4. Top 25 References with the Strongest Citation Burst Value.

0# orthodontic treatment
1# digital orthodontics
2# superimposition
3# apical root resorption
4# pain
5# color stability
6# root resorption
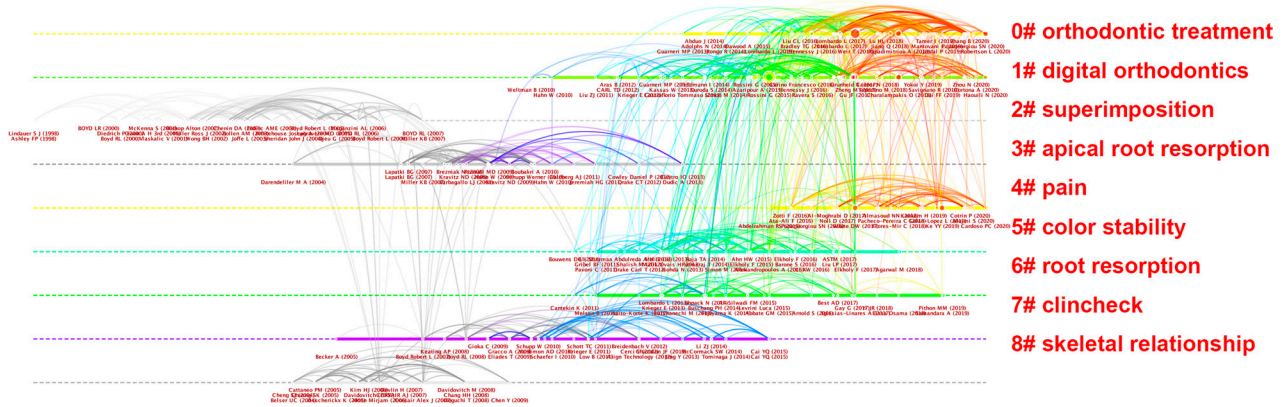7# clincheck
8# skeletal relationship

Figure 5. Top 9 most frequently cited keywords.

Orthodontic treatment

Clear aligners have been considered as an alternative to fixed orthodontics appliances (FOA). Since the introduction of a tooth positioning appliance to refine the final stages of orthodontic treatment, Kesling foresaw that more ambitious tooth movement could be achieved with a series of aligners. Later, Ponitz (1971) and Sheridan (early 1990s) proposed the "Invisible Retainer" producing minor tooth movements with individual aligners, after learning from Kesling's concept of pre-positioning teeth on a master study model. The major limitation of the described treatment methods is that only minor tooth movements could be achieved because of the technical difficulty of dividing larger overall movement into smaller and precise stages.[7] The Invisalign® system was released by Align technology in 1998 and was the first orthodontic appliance to use computer-aided design (CAD) and computer-aided manufacturing (CAM) in conjunction with laboratory techniques. This development made Kesling's early idea a reality. Since their advent, the aligner systems have grown rapidly to achieve improved tooth alignment and occlusion.[8] In the early 21st century, most clinicians considered the technique only suitable for simple cases such as Angle Class I malocclusion, the improvement of mild crowding, and 3 to 6 mm of space closure.[7,9] With continuous advances in attachments, materials, and orthodontic force, clear aligners have been applied to a variety of more complex malocclusions.[10,11]

Several top clusters (ranks 1, 4, 8, 9, 11, 13, 16, 20, 24, 26, 30, 31, 34, 40, 42, 43, 46) were associated with the clinical scope and the limitations of CA therapy in orthodontic treatment.[6,12–23] The most-cited article on orthodontic treatment (rank 1) by

Rossini[6] reported that CA therapy is effective in anterior tooth intrusion, posterior buccolingual tooth inclination, and upper molar bodily movements of about 1.5 mm. Ravera et al.[21] reported that CA therapy associated with composite attachments and class II elastics can distalise maxillary first molars by 2.5 mm. Buschang et al.[24] reported that CA therapy required significantly ($P < 0.01$) more visits (approximately 4.0), a longer treatment duration (5.5 months), more emergency visits (1.0), greater emergency chair time (7.0 minutes), and greater total chair time (93.4 minutes), but less material costs and less total doctor times than FOA. However, several studies have also reported that CA therapy is associated with a worse treatment outcome compared to FOA.[22,23] The outcome and limitation of CA therapy remain to be further explored.

Digital orthodontics

Digital orthodontic technology allows three-dimensional (3D) image manipulation through computer software and 3D printing of custom devices made of different materials. Of the orthodontic applications, a series of custom-made clear aligners that move the teeth throughout the entire treatment period are supported by three pillars: digital image acquisition of the patient's dental arch, visualisation and processing of the images using specific software, and the 3D printing of files.[25]

A conventional study model is based on the acquisition of a physical impression and the subsequent casting of plaster models. Compared to a conventional impression, intraoral scanning directly captures optical impressions, offering shorter

chair time, a reduction of consumables costs, greater patient comfort and a high digital accuracy. Like other 3D scanners, the intraoral scanner captures images through the projection of a laser light source or structured light without interacting with biological tissue.[26] These devices provide specific software for processing data and generating 3D virtual images of the dental arches.

The arch surface morphology data is usually saved on the computer as a Standard Triangular Language (STL) format file. The virtual dental casts allow clinicians to quickly obtain diagnostic information related to arch width and perimeter, model discrepancies, a Bolton discrepancy, overjet, and overbite. Several studies[27–31] (ranks 15, 32, 38, 41, 48) used an electronic digital calliper to make measurement on STL-generated dental casts. Moreover, an optical impression makes patients feel more involved in their treatment and is a powerful tool to establish more effective communication.[32,33]

The most common use of technical processes in orthodontics is the digital setup and fabrication of clear aligners. Traditionally, an orthodontic setup from crown separation to repositioning in wax, are performed on plaster models. With the help of digital technology, orthodontic treatment simulation processes have become faster and more practical. The model for the reference treatment phase can be automatically generated by the setup software and used for orthodontic appliance production.[34]

Applying digital technology in orthodontics aims to reduce the professional's chair and laboratory time, as well as make treatment faster, predictable, aesthetic, and more comfortable for patients. It may be concluded that the advent of digital orthodontic technology is a unique evolutionary milestone in orthodontic history, as it offers great possibilities for use in clinical practice, with potential benefits for both patients and practitioners.

Superimposition

It is noteworthy that, unlike actual biological dental movements, virtual movements are infinite and often the results may not be realistic.[35] The ability to measure the amount of tooth movement is important for assessing orthodontic treatment outcomes. An analysis of tooth movement allows clinicians to better understand orthodontic biomechanics, the speed and type of movement, as well as the efficiency of therapeutic interventions. The use of 3D scanners in dentistry provides a non-invasive method for measuring dental changes because it does not expose the patient to radiation.[36] In addition, 3D-model rendering by most scanners is considered accurate and reliable. Of the most-cited publications (ranks 2, 5, 14, 21, 25, 39), there were several studies using superimposition to calculate the mean accuracy of tooth movement. The most cited article (overall rank 2) was by Kravitz,[37] who measured the mean movement accuracy of 401 anterior teeth by the overlay of the virtual models.

Digital maxillary study casts are more commonly used to measure tooth movement because the palatal vault is considered stable throughout treatment for the evaluation of tooth positional change.[38,39] Several investigators have suggested using the medial point[38,40] or the medial two-thirds of the third palatal fissure[41,42] as a reference landmark for maxillary cast superimposition.[41] However, the mandibular arch lacks stable landmarks, and requires the use of a combination of cone-beam computed tomography (CBCT) images to digitally align the surface superimposition of the model on the mandibular basal bone structure.[43]

Apical root resorption

Root resorption is an unavoidable sequela of orthodontic tooth movement. In addition to genetic influences and trauma, orthodontic treatment is a factor that may lead to partial resorption of the root apices of the teeth,[44] generally called external apical resorption (EARR). Age, the force applied during treatment, extraction or non-extraction conditions, treatment duration, the distance of tooth movement and the level of pre-treatment root resorption are factors that impact on root resorption.[45] Because EARR is irreversible and may affect tooth longevity, it is important for the clinician to determine changes in root resorption during orthodontic treatment. Several studies have examined the effect of CA therapy on EARR, but there is disagreement regarding the level of EARR. Gandhi et al.[46] concluded that the mean root resorption for the permanent maxillary incisors was in the range of 0.25 mm to 1.13 mm (overall: 0.49 mm; 95% confidence interval [CI] = 0.24 to 0.75 mm). Previous studies have reported that root resorption associated with CA therapy for the

maxillary permanent incisors was less than for fixed orthodontic appliances, but was not statistically significant, except for tooth 12. This effect may result from the decreased magnitude of force delivered by CA therapy compared to FOA or due to discontinuous force application with CA therapy.[47,48]

Pain

Pain complaints are a common feature of the orthodontic treatment process[49] and directly affect patient satisfaction.[50] It has also become a principal topic in the field and clusters 7, 18, 33 were found to be related to this issue.[51–53] During orthodontic treatment, it is common to feel pain and discomfort, reaching a peak at 24 hrs after force application but imperceptible after 7 days. However, removable appliances produce intermittent forces, which allow the tissues to re-organise before compressive forces are reapplied[48] and have a reduction in the level of pain and discomfort reported by patients.[54] Most studies found that patients treated by CA therapy experienced less pain than those treated by FOA during the first week of orthodontic treatment.[55]

Limitations

Like other bibliometric analyses, the present study had limitations. The first relates to the time delay as recently published high-quality studies and highlights may have been excluded because of insufficient citation. Secondly, although the analysis was conducted objectively by software, there is an inherent subjective bias in the interpretation of the results.

Despite the limitations, the study has relevance in the field as it systematically analysed the developments, priorities, and trends in CA therapy. New research should carefully consider the most popular and recent clusters and read references applying high median centroids, citation frequencies, and citation burst values.

Conclusion

Over time, research in CA therapy and its related fields has been gaining popularity and expanding globally. The present analysis indicates that the treatment outcomes of CA therapy and adverse factors are the focus of current studies and the direction of future research. Further, this bibliometric analysis may provide a valuable reference on critical issues and help researchers efficiently and effectively explore the CA therapy field.

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Conflict of interest

The authors declare that there is no conflict of interest.

Authors' contributions

BG and ZL authors contributed equally to this study.

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