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Review

Publication performance and trends in temporomandibular disorders research: A bibliometric analysis

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ABSTRACT

Background: Temporomandibular disorders (TMD) are common, can be both painful and non-painful, and encompass various conditions affecting the temporomandibular joint, the masticatory muscles or both TMD. Therefore, the purpose of this bibliometric analysis was to synthetically analyze citation performance in TMD, to address a more innovative method including details of article title, author keyword, *KeyWords Plus*, and abstracts.

Material and methods: Data used in this study were retrieved from the Clarivate Analytics Web of Science Core Collection, the online version of the Science Citation Index Expanded (SCI-EXPANDED) between 1992 and 2021. The distribution of key words in the article title and author-selected keywords were used to evaluate research trends.

Results: Of the 7,228 documents in SCI-EXPANDED, 6,138 documents met all inclusion criteria and were included in the final analysis, of which 4,945 were articles. The present bibliometric analysis of the articles published in the research filed of TMD revealed that orofacial pain, bruxism, chronic pain, and myofascial pain are the most commonly used keywords by the authors. Further, over the last 30 years 4,945 articles are published in the field of TMD, and the far most frequently cited study was published 8 years ago and handles the diagnostic criteria of TMD.

The USA and Brazil were top two ranking productive countries of publication on TMD. The most productive journal was Journal of Oral Rehabilitation, followed by Cranio-The Journal of Craniomandibular & Sleep Practice and Journal of Oral & Facial Pain and Headache. The most productive authors were P. Svensson, R. Ohrbach, and F. Lobbezooas. The most productive institutes were Sao Paulo University (Brazil), Malmo University (Sweden), and Washington university (USA)

Conclusion: Based on the outcome of this bibliometric study, the authors hope that both clinicians and researchers will have information to shape their future research focus, finding prominent institutions in their nearby area, or even to be stimulated to initiate new international or even multinational collaborations.

1. Introduction

The umbrella term temporomandibular disorders (TMD) encompass various conditions affecting the temporomandibular joint, the masticatory muscles or both [1,2]. TMD can be both painful and non-painful. Based on a recent systematic review the overall prevalence of TMD is approximately 31% for adults/elderly and 11% for children/adolescents, and the most prevalent TMD is the non-painful condition disk displacement with reduction [3]. The second most common TMD, affecting 10–15% of the general population, and up to 70% of all painful TMD-cases is pain from the masticatory muscles, i.e., myalgia [4–8]. Further, there is evidence that women are more susceptible to TMD than men [9]. Besides the sensory unpleasantness, painful TMDs are also emotionally disadvantageous, causing feelings such as anxiousness, stress, guilt, misery, isolation, even sleeping difficulties, which could lead to development of depression [10–12].

In order to quantify the quality of published papers for organizations, authors, and even countries as well as to identify the impact of publications and research groups in their field of research, bibliometrics are used [13,14]. This, since bibliometrics makes it simple to study and decode the developments on a subject, to pursue the dynamics and evolution of scientific knowledge. Bibliometrics is a powerful tool to comprehensively review research trends, investigate publication performances and providing future perspectives. Furthermore, the possibility to identify future research directions, based on a bibliometric analysis on the characteristics of available literature in a

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specific field, reduces the error margin and improves the decision-making [15,16]. Currently, research on TMD is published in peer-reviewed journals on a daily basis. The dilemma with the presence of such a huge amount of evidence is the ability to navigate in the jungle of publications finding the most important or influential publications.

Traditionally, the purpose of this bibliometric analysis is not just to synthetically analyze citation performance in TMD, but it will also address the more innovative method including details of including of article title, author keyword, *KeyWords Plus* [17], and abstracts should be included in the bibliometric analyses [18].

2. Methodology

Data used in this study were retrieved from the Clarivate Analytics Web of Science Core Collection, the online version of the Science Citation Index Expanded (SCI-EXPANDED) (data updated on 22 May 2022). Quotation marks (“ ”) and Boolean operator “or” were used which ensured the appearance of at least one search keyword in the terms of TOPIC (title, abstract, author keywords, and *KeyWords Plus*) from 1992 to 2021. The search keywords used were: “temporomandibular disorders”, “temporomandibular disorder”, “temporomandibular joint (TMJ) disorders”, “temporomandibular joint (TMJ) disorder”, “temporomandibular joint disorder”, “temporomandibular joint disorders”, “temporomandibular joints disorders”, “craniomandibular disorders”, “craniomandibular disorder”, “myogenous TMDs”, “myogenous TMD”, “temporomandibular dysfunction”, “temporomandibular joint disease”, “temporomandibular joint diseases”, “temporo- mandibular joint disorders”, “temporomandibular joint dysfunction”, “temporal mandibular disorder”, “temporomandibular diseases”, and “temporomandibular dysfunctions”. In addition, some misspelling keywords were also considered: “temporomandibulars disorders”, “temporomandibutar disorders”, “temporomandibular pain dzysfunction syndrome”, “arthrogenous TMD”, “arthrogenous TMDs”, “temporo mandibular jo in t dysfunction”, and “temporomanclibular disorder”. It resulted 7228 documents in SCI-EXPANDED. *KeyWords Plus* supplies additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes in the Institute of Science Information (ISI) (now Clarivate Analytics) database, and substantially augments title-word and author-keyword indexing [19]. It was pointed out that documents only searched out by *KeyWords Plus* are irrelevant to the search topic [20]. Ho’s group firstly proposed the ‘front page’ as a filter including the article title, abstract, and author keywords [13,21]. It has been reported that a big difference was found by using the ‘front page’ as a filter in bibliometric research topics published in medical related journals in SCI-EXPANDED, for example, *Chinese Medical Journal* [22], *World Neurosurgery* [23], *Annals of Translational Medicine* [24], and *BioMed Research International* [25]. This filter can avoid introducing unrelated publications for bibliometric analysis.

The full record in SCI-EXPANDED and the number of citations in each year for each document were checked and downloaded into Excel Microsoft 365, and additional coding was manually performed [26,27]. The functions in the Excel Microsoft 365, for example, Counta, Concatenate, Filter, Match, Vlookup, Proper, Rank, Replace, Freeze Panes, Sort, Sum, and Len were applied. Finally, 6138 documents (85% of 7228 documents) including search keywords in their ‘front page’ were defined as temporomandibular disorders research publications. The journal impact factors (IF_{2020}) were taken from the Journal Citation Reports (JCR) published in 2020.

In the SCI-EXPANDED database, the corresponding author is labelled as reprint author, but in this study, we used the term corresponding author [13]. Single author in articles with unspecified authorship were both the first as well as corresponding author [28]. Similarly, in a single institutional article, the institution is classified as the first as well as the corresponding-author institution [28]. In multi-corresponding author articles, all the corresponding authors, institutes, and countries were considered. Articles with corresponding authors in SCI-EXPANDED, that had only address but not affiliation names were checked out and the addresses were changed to be affiliation names.

Affiliations in England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK) [29]. Affiliations in Hong Kong before the year ofg1997 were reclassified as in China [30].

Publications were assessed using following citation indicators:

C_{year}: the number of citations from Web of Science Core Collection in a particular year (e.g. C_{2021} describes citation count in 2021) [13].

TC_{year}: the total citations from Web of Science Core Collection received since publication year till the end of the most recent year (2021 in this study, TC_{2021}) [31].

CPP_{year}: citations per publication ($CPP_{2021} = TC_{2021}/TP$), *TP*: total number of publications [32].

Six publication indicators were applied to evaluate publication performance of countries and institutions [33].

TP: total number of articles

IP: number of single-country or single-institution articles

CP: number of internationally or inter-institutionally collaborative articles

FP: number of first-author articles

RP: number of corresponding-author articles

SP: number of single-author articles

Six citation indicators related to the six publication indicators (CPP_{2021}) were also applied to evaluate the publication impact on countries and institutes [34].

Y-index (*j, h*)was used to evaluate publication performance of authors, and defined as [13,35]:

j being a constant related to the publication potential, the sum of the first-author articles and the corresponding-author articles; and *h* being a constant related to the publication characteristics, polar angle about the proportion of *RP* to *FP*. The greater the value of *j*, the more the first- and corresponding-author contributes to the articles.

$h = \pi/2$, indicates an author that has only published corresponding-author articles, *j* is the number of corresponding-author articles;

$\pi/2 > h > 0.7854$ indicates that an author has more corresponding-author articles than first-author articles ($FP > 0$);

$h = 0.7854$ indicates that an author has the same number of first- and corresponding-author articles ($FP > 0$ and $RP > 0$);

$0.7854 < h < 0$ indicates an author with more first-author articles than corresponding-author articles ($RP > 0$);

$h = 0$, indicates that an author has only published first-author articles, *j* is the number of first-author articles.

3. Results and discussion

3.1. Characteristics of document-types

Ho and his group have identified the characteristics of document-type based on the citations per publication ($CPP_{year} = TC_{year}/TP$) and the number of authors per publication ($APP = AU/TP$) as basic information of document-type in a research topic [36]. Using TC_{2021} and CPP_{2021} is advantageous owing to invariability and ensured repeatability when compared to just number of citations from the Web of Science Core Collection [37].

A total of 6138 TMD documents published in SCI-EXPANDED were found among 15 document-types which are presented in Table 1. This publication count includes 4945 articles (81% of 6138 documents) with an *APP* (number of authors per publication) of 4.8. The percentage of articles regarding TMDs (81%) was higher than other medical-related topics, for example 77% in Q fever [38], 70% in Ebola [39], 69% in breast reconstruction [40], 68% in cisplatin-based chemotherapy for small-cell lung-cancer [32], 66% in acupuncture [41], 66% in insomnia [42], and 66% in keloid [24]. However, a higher percentage of articles (89%) was found in fracture nonunion [43].

Table 1
Citations and authors according to the document type.

Document type	*TP*	%	*TP**	*AU*	*APP*	TC_{2021}	CPP_{2021}
Article	4945	81	4935	23,600	4.8	106,534	22
Review	603	10	603	2564	4.3	22,281	37
Meeting abstract	328	5.3	327	1390	4.3	79	0.24
Editorial material	128	2.1	126	263	2.1	767	6.0
Proceedings paper	127	2.1	126	387	3.1	4911	39
Letter	87	1.4	86	196	2.3	81	0.93
Correction	18	0.29	17	60	3.5	19	1.1
Note	15	0.24	15	39	2.6	74	4.9
News item	8	0.13	5	5	1.0	9	1.1
Book chapter	4	0.065	4	14	3.5	94	24
Addition correction	3	0.049	3	8	2.7	0	0
Discussion	2	0.033	2	3	1.5	0	0
Data paper	1	0.016	1	7	7.0	4	4.0
Reprint	1	0.016	1	5	5.0	0	0
Retracted publication	1	0.016	1	1	1.0	19	19

TP: number of publications; *TP**: number of publications with author information; *AU*: number of authors; *APP*: number of authors per publication; TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; CPP_{2021}: number of citations (TC_{2021}) per publication (*TP*); N/A: not available.

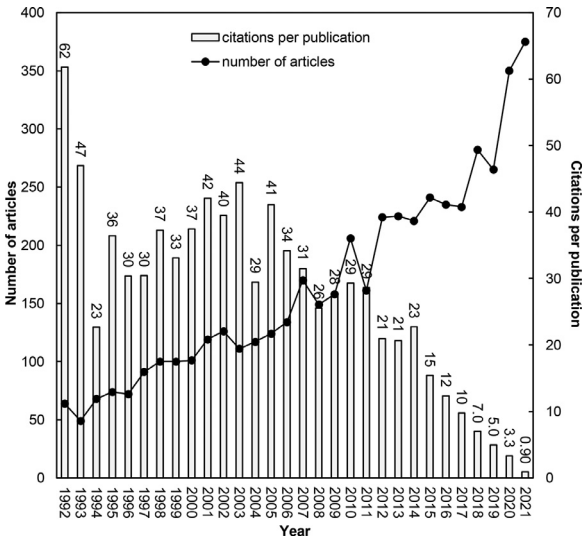

Fig. 1. Number of temporomandibular disorder articles and citations per publication by year.

A review entitled "Central sensitization: Implications for the diagnosis and treatment of pain"[44] was the most frequently cited document in the research field of TMD with a TC_{2021} of 2175. This review was also the only classic document with TC_{2021} of 1000 or more [45].

The document-type proceedings papers, including 127 documents, had the greatest CPP_{2021} value of 39. The CPP_{2021} of the document-type review articles was found to be 1.7 times of articles. Also this variable was higher than of other medical-related topics, for example, insomnia (1.4 times) [42], fracture nonunion (1.3 times) [43], and breast reconstruction (0.86 times) [40].

Since documents can be categorized in two difference document-types in Web of Science Core Collection [46], the cumulative percentages in Table 1 exceed 100%. Examples of documents that were categorized in two different document-types were the 127 proceedings papers, two book chapters, and one data paper.

The content of different document-types differs, and therefore only articles were used for the further analysis. This since articles generally contain introduction, methods, results, discussion, and conclusion. A total of 4945 TMD-related articles in 12 different languages were analyzed and are presented below. The most used language was English with 98% of the articles (4842 out of 4945 articles) followed distantly by German (37 articles), French (23), Spanish (13), and Turkish (13). Less the ten articles used other languages as follows: Portuguese (7), Hungarian (2), Korean (2), Serbian (2), and one for each of Czech, Italian, and Polish respectively. Finally, one article was bilingual (English and Estonian) and published in *Annals of Plastic Surgery*. A notable finding was that non-English articles had fewer citations, with a CPP_{2021} of 4.6, while English articles had a CPP_{2021} of 22. The same accounted for *APP* where non-English articles had an *APP* of 3.5, while English articles had an *APP* of 4.8.

3.2. Characteristics of publication outputs

Ho proposed in 2013 a correlation between annual number of articles (*TP*) and their citations ($CPP_{year} = TC_{year}/TP$) by year to understand the development trends and impacts of publications in a research topic [32]. In the last decade, it has been applied in several medical-related topics including dengue fever [37], Ebola [39], breast reconstruction [40], insomnia [42], fracture nonunion [43], keloid [24], and Q fever [25]. Between the years 1992 and 2021, 4945 articles associated to TMDs were published in SCI-EXPANDED. The mean value of TC_{2021} was 22 with 1980 as the maximal value for an article. Fig. 1 demonstrates the distribution of the annual number of articles and their CPP_{2021} by year, which was expressed as TC_{2021}/TP [32], where *TP* is number of articles published in that year. Fig. 1 is showing that the number of publications in the field of TMD is increasing rapidly and the number of citations declining drastically, and that it takes approximately ten years to reach a plateau of accumulated citations. This study together with previous studies evaluating the impact of articles in the fields of dengue fever [37], Ebola [39], breast reconstruction [40], insomnia [42], and Q fever[25] indicate that a decade has to pass before one can assess and evaluate the impact of articles.

3.3. Web of science category and journal

In 2020, Journal Citation Reports (JCR) indexed 9531 journals with citation references across 178 Web of Science categories in SCI-EXPANDED. In 2021, identify the characteristics of the Web of Science category based on their citations per publication ($CPP_{year} = TC_{year}/TP$) and the number of authors per publication ($APP = AU/TP$) as basic information of the Web of Science category in a research topic were presented [34,43]. Total 628 journals published articles related to temporomandibular disorders in 93 Web of Science categories in SCI-EXPANDED. Table 2 shows the top ten productive categories, mainly in the category of dentistry, oral surgery and medicine (contains 92 journals in the category) with 3136 articles (64% of 4945 articles). When

Table 2
The top 10 most productive Web of Science categories.

Web of Science category	No. Journals	*TP* (%)	*APP*	CPP_{2021}
dentistry, oral surgery and medicine	92	3171 (64)	4.5	21
clinical neurology	208	410 (8.3)	5.6	42
neurosciences	273	388 (7.8)	5.8	45
surgery	212	373 (7.5)	4.9	16
anesthesiology	33	206 (4.2)	5.4	60
general and internal medicine	169	201 (4.1)	5.3	13
radiology, nuclear medicine and medical imaging	134	141 (2.9)	5.1	20
rehabilitation	68	140 (2.8)	4.6	15
research and experimental medicine	140	132 (2.7)	5.4	11
biomedical engineering	90	95 (1.9)	5.5	14

TP: total number of articles;%: percentage of articles in all temporomandibular disorder articles; *APP*: number of authors per paper; CPP_{2021} citations per paper (TC_{2021}/TP).

comparing the top ten categories, articles published in the category of anesthesiology displayed the greatest CPP_{2021} reaching up to 60. Articles published in the category of neurosciences displayed the highest *APP* reaching up to 5.8. Since journals can be classified in more than one category in SCI-EXPANDED, the cumulative percentage of categories exceeds 100% in Table 2. For instance *Pain* was classified in categories of anesthesiology, clinical neurology, and neurosciences [35].

Recently, Ho (2021) proposed to display the characteristics of the journals based on their citations per publication ($CPP_{year} = TC_{year}/TP$) and the number of authors per publication ($APP = AU/TP$) as basic information of the journals in a research topic [34]. Table 3 shows the top 12 most productive journals with journal impact factors, CPP_{2021}, and *APP*. The *Journal of Orofacial Pain* with 228 articles and *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology* with 84 articles were not listed in SCI-EXPANDED after 2013 and 2011 respectively. In 2014, the official journal of the American Academy of Orofacial Pain, the European Academy of Orofacial Pain and Dysfunction, the Asian Academy of Craniomandibular Disorders, and the Australian and New Zealand Academy of Orofacial Pain, namely the *Journal of Orofacial pain* changed name to *Journal of Oral & Facial Pain and Headache.* Therefore, articles published in *Journal of Orofacial Pain* from 1998 to 2013 and *Journal of Oral & Facial Pain and Headache* from 2014 to 2021 were in this study merged to on group and called *Journal of Oral & Facial Pain and Headache*. Top productive journal was found to be the *Journal of Oral Rehabilitation* (IF_{2020} = 3.837) that published 487 articles representing 9.8% of the 4945 articles, followed by the *Cranio-The Journal of Craniomandibular & Sleep Practice* (IF_{2020} = 2.020) with 394 articles (8.0%) and the *Journal of Oral & Facial Pain and Headache* (IF_{2020} = 1.871) with 358 articles (7.2%). When comparing the top 12 productive journals, TMD articles published in *Pain* (IF_{2020} = 6.961) showed the highest CPP_{2021} reaching to 95 while articles in the *Cranio-The Journal of Craniomandibular & Sleep Practice* (IF_{2020} = 2.020) only reached a CPP_{2021} of 13. The *APP* ranged from 6.1 in *Pain* to 3.4 in the *Journal of Prosthetic Dentistry*. When it comes to impact factors, the journal with the highest IF_{2020} of 21.405 was the *American Journal of Respiratory and Critical Care Medicine* with one article published on TMD, followed by the *Annals of the Rheumatic Diseases* also with one article on TMD (IF_{2020} = 19.103), and the *Journal of Clinical Investigation* also with only one article on TMD (IF_{2020} = 14.808).

3.4. Publication performances: countries and institutions

It is widely recognized that two authors: the first and last author, of which one usually also is the corresponding author, are considered as the authors contributing most with the fist in writing of a research article and the last being the senior reaseacher [40,47]. At the institutional level, the determined institution of the corresponding author might be a home base of the study or origin of the paper [13]. There were 41 articles in the field of TMD (0.83% of 4945 articles) without affiliations in SCI-EXPANDED. A total of 4904 articles were published by authors affiliated from 91 countries. Among these, 3882 articles were single-country articles (79% of 4904 articles) published by authors from 63 countries with a CPP_{2021} of 21. The remaining 1022 were inter-/multi-national collaborative articles (21% of 4904 articles) published by authors from 85 countries with a CPP_{2021} of 25. The results demonstrated that inter-/multi-national collaborative raised citations in the research field of TMD.

Six publication indicators and the six related citation indicators (CPP_{2021})[34] were applied to compare the top 16 productive countries (Table 4).

USA dominated as productive country in the six publication indicators with a *TP* of 1177 articles (24% of 4904 articles), an *IP* of 761 articles (20% of 3882 single-country articles), a *CP* of 416 articles (41% of 1022 inter-/multi-national collaborative articles), an *FP* of 909 articles (19% of 4904 first-author articles), an *RP* of 884 articles (18% of 4802 corresponding-author articles), and an *SP* of 98 articles (42% of 232 single-author articles).

However, when it came to the six related citation indicators CPP_{2021} among the top 16 productive countries, Denmark with 147 articles had the highest CPP_{2021} of 42 for their *TP*, 47 for their *IP*, 43 for their *FP*, and 41 for their *RP*. Australia and Sweden had, on the other hand, the highest CPP_{2021} of 53 for their *CP,* and 54 for their *SP*.

When it comes to development trends in number of published articles, the top five productive countries in 2021 are presented in Fig. 2. When countries such as USA (rank 1st), Brazil (rank 2nd) have been the most productive counties the last 15 years, countries like China, Italy, and Turkey are approaching. This study could show that they have published 44 articles (rank 7th), 38 (rank 5th), and 34 articles (rank 8th) in the year of 2021 (Fig. 2, Table 6).

Concerning institutions, 1886 articles in the field of TMD (38% of 4904 articles) originated from single institutions with a CPP_{2021} of 22, while 3018 articles (62%) were institutional collaborations with a CPP_{2021} of 21. The top 15 productive institutions and their characteristics are presented in Table 5. The University of Sao Paulo in Brazil ranked top in five of the six publication indicators with a *TP* of 255 articles (5.2% of 4904 articles), an *IP* of 81 articles (4.3% of 1886 single-institution articles), a *CP* of 174 articles (5.8% of 3018 inter-institutionally collaborative articles), an *FP* of 177 articles (3.6% of 4904 first-author articles), and an *RP* of 130 articles (2.7% of 4802 corresponding-author articles). The University of Washington and the

Table 3
The top 13 most productive journals with 82 articles or more.

Journal	*TP* (%)	IF_{2020}	*APP*	CPP_{2021}	Web of Science category
Journal of Oral Rehabilitation	487 (9.8)	3.837	4.7	20	dentistry, oral surgery and medicine
Cranio-The Journal of Craniomandibular & Sleep Practice	394 (8)	2.02	4.1	13	dentistry, oral surgery and medicine
Journal of Orofacial Pain	228 (4.6)	N/A	4.3	42	dentistry, oral surgery and medicine
Journal of Oral & Facial Pain and Headache	130 (2.6)	1.871	5.5	19	dentistry, oral surgery and medicine
Acta Odontologica Scandinavica	123 (2.5)	2.331	3.9	23	dentistry, oral surgery and medicine
Journal of Oral and Maxillofacial Surgery	118 (2.4)	1.895	4.3	23	dentistry, oral surgery and medicine
International Journal of Oral and Maxillofacial Surgery	111 (2.2)	2.789	4.9	19	dentistry, oral surgery and medicine surgery
Pain	100 (2.0)	6.961	6.1	95	anesthesiology clinical neurology neurosciences
Journal of Prosthetic Dentistry	97 (2.0)	3.426	3.4	30	dentistry, oral surgery and medicine
Dentomaxillofacial Radiology	84 (1.7)	2.419	4.9	20	dentistry, oral surgery and medicine radiology, nuclear medicine and medical imaging
Journal of Dental Research	84 (1.7)	6.116	5.8	37	dentistry, oral surgery and medicine
Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology	84 (1.7)	N/A	4.5	31	dentistry, oral surgery and medicine
American Journal of Orthodontics and Dentofacial Orthopedics	82 (1.7)	2.65	4.0	34	dentistry, oral surgery and medicine

TP: total number of articles;%: percentage of articles in all temporomandibular disorder articles; IF_{2020}: journal impact factor in 2021; *APP*: number of authors per article; CPP_{2021} citations per paper (TC_{2021}/TP).

Table 4
Top 16 productive countries with *TP*≥100.

Country	*TP*	*TP*		*IP*		*CP*		*FP*		*RP*		*SP*	
		R (%)	CPP_{2021}	*R* (%)	CPP_{2021}	*R* (%)	CPP_{2021}	*R* (%)	CPP_{2021}	*R* (%)	CPP_{2021}	*R* (%)	CPP_{2021}
USA	1177	1 (24)	37	1 (20)	37	1 (41)	36	1 (19)	39	1 (18)	39	1 (42)	27
Brazil	658	2 (13)	16	2 (13)	15	3 (14)	19	2 (12)	15	2 (13)	15	12 (1.7)	29
Japan	418	3 (8.5)	20	3 (8.0)	20	8 (10)	23	3 (7.7)	20	3 (7.8)	20	3 (4.7)	7.7
Sweden	379	4 (7.7)	30	6 (5.3)	26	2 (17)	35	5 (5.7)	25	5 (5.6)	25	5 (4.3)	54
Italy	375	5 (7.6)	22	4 (6.1)	19	4 (14)	28	4 (6.3)	19	4 (6.3)	20	16 (1.3)	7.0
Germany	300	6 (6.1)	25	8 (4.4)	16	6 (13)	36	7 (5.0)	21	7 (5.0)	21	2 (5.2)	11
China	268	7 (5.5)	11	7 (5.0)	10	10 (7.2)	12	6 (5.1)	11	6 (5.1)	10	21 (0.86)	16
Turkey	241	8 (4.9)	10	5 (5.7)	10	24 (2.1)	10	8 (4.8)	10	8 (4.9)	10	5 (4.3)	5.9
Canada	193	9 (3.9)	40	15 (1.6)	33	5 (13)	43	13 (2.3)	32	14 (2.2)	30	3 (4.7)	11
Netherlands	190	10 (3.9)	33	13 (2.3)	29	9 (10)	37	12 (2.3)	28	12 (2.5)	27	9 (2.2)	30
South Korea	162	11 (3.3)	13	9 (3.5)	10	21 (2.6)	28	9 (3.1)	11	9 (3.1)	11	9 (2.2)	2.6
UK	156	12 (3.2)	31	12 (2.4)	20	12 (6.3)	47	14 (2.2)	19	13 (2.2)	19	5 (4.3)	19
Finland	151	13 (3.1)	22	10 (3.0)	21	17 (3.2)	23	10 (2.7)	21	10 (2.6)	21	12 (1.7)	12
Denmark	147	14 (3.0)	42	19 (1.0)	47	7 (10)	40	16 (1.6)	43	16 (1.7)	41	12 (1.7)	52
Spain	141	15 (2.9)	16	11 (2.6)	13	14 (4.0)	23	11 (2.5)	17	11 (2.5)	17	25 (0.43)	12
Australia	109	16 (2.2)	39	18 (1.1)	17	11 (6.7)	53	18 (1.2)	21	18 (1.2)	22	8 (3.0)	24

TP: number of total articles; *TP R* (%): total number of articles and the percentage of total articles; *IP R* (%): rank and percentage of single-country articles in all single-country articles; *CP R* (%): rank and percentage of internationally collaborative articles in all internationally collaborative articles; *FP R* (%): rank and the percentage of first-author articles in all first-author articles; *RP R* (%): rank and the percentage of corresponding-author articles in all corresponding-author articles; *SP R* (%): rank and the percentage of first-author articles in all first-author articles; CPP_{2021}: citations per publication ($CPP_{2021} = TC_{2021}/TP$); N/A: not available.

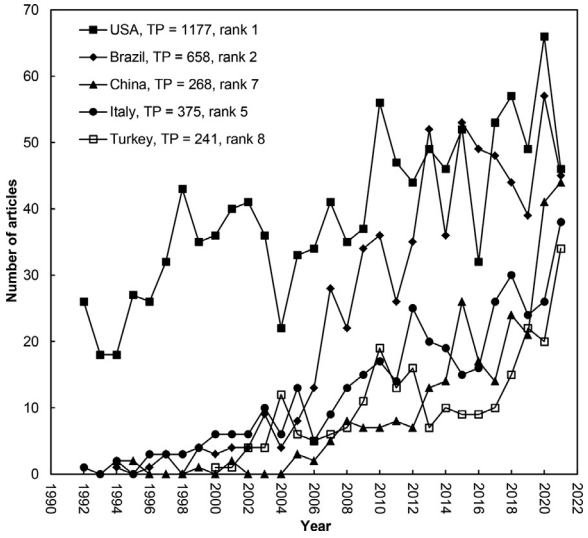

Fig. 2. Developments of the top five productive countries in 2021.

University of Michigan in the USA ranked top with an *SP* of six articles (2.6% of 232 single-author articles) respectively. Compared to the top 15 productive institutions in Table 5, the University of Washington had the greatest CPP_{2021} of 99 for their *TP*, 110 for their *CP*, 87 for their *FP*, and 85 for their *RP*. It shows that the University of Washington had not only high impact publications but also their independent research ability. The University of North Carolina in the USA had the greatest CPP_{2021} of 79 for their *IP*. The Malmo University in Sweden had the greatest CPP_{2021} of 79 for their *SP*.

3.5. Publication performances: authors

For articles related to TMD, the *APP* was 4.8 whereas the maximum number of authors was 41 in one article. Of the 4935 articles with author information, 90% articles were published by groups of one to seven authors, including 940 (19% of 4935 articles), 865 (18%), 741 (15%), 727 (15%), 517 (10%), 398 (8.1%), and 250 (5.1%) were written by groups of 4, 5, 3, 6, 2, 7, and 1 author respectively.

Table 6 lists the top 20 productive authors with four publication indicators, their citation indicators, and *Y*-index constants. P. Svensson was the most productive author with 106 articles including 13 first-author articles (ranked 4th), 22 corresponding-author articles (ranked 3rd), and three single-author articles (ranked 6th). D. Manfredini with 69 articles, the fourth most productive author, was the author with the most first-author articles (35 articles), and the most corresponding-author articles (49 articles). Although not among the top 20 productive authors, W.E. Shankland was the most productive single author (only publishing single author articles) with five published articles (ranked 1st). Finally, among the top 20 productive authors, W. Maixner was found to have the greatest CPP_{2021} of 191 for first-author articles, and corresponding-author articles respectively. On the other hand, S.F. Dworkin had the greatest CPP_{2021} for total articles with 178.

Only nine of the top 20 productive authors were also found to be top 20 publication potential authors as evaluated by the *Y*-index. These were D. Manfredini, P. Svensson, K. Sipila, R. Ohrbach, E. Winocur, G.D. Slade, A. Michelotti, C.M. Visscher, and M.T. John.

A total of 4819 articles in the field of TMD (97% of 4945 articles) had both first and corresponding author information in SCI-EXPANDED. Based on the *Y*-index, 4819 TMD related articles were contributed by 12,514 authors in which 8576 authors (69% of 12,514 authors) had no first- and/or no corresponding-author articles with *Y*-index (0, 0); 753 (6.0%) authors published only corresponding-author articles with $h = \pi/2$; 225 (1.8%) authors published more corresponding-author articles with $\pi/2 > h > 0.7854$ ($FP > 0$); 1634 (13%) authors published the same number of first- and corresponding-author articles with $h = 0.7854$ ($FP > 0$ and $RP > 0$); 132 (1.1%) authors published more first-author articles with $0.7854 > h > 0$ ($RP > 0$); and 1194 (9.5%) authors published only first-author articles with $h = 0$.

In the polar coordinates (Fig. 3), the distribution of the *Y*-index (*j*, *h*) of the leading 29 potential authors in the research field of TMJ with $j \geq 18$ was demonstrated. Every point has a coordinate *Y*-index (*j*, *h*) that could symbolize a single author or multiple authors, for example, J.C. Turp, D.R. Reissmann, K. Kaneyama, and T. Badel with the same *Y*-index (20, 0.7854). D. Manfredini with *Y*-index (84, 0.9505) and R. Emshoff with *Y*-index (54, 0.8593) showed to have a much higher publication potential than the other top 29 authors in research field of TMD. D. However, Manfredini had lower CPP_{2021} (Table 6). W. Maixner had higher CPP_{2021} but lower publication potential.

One can only speculate why D. Manfredini was found to have the greatest publication performance, but by analyzing his publications at one of the search engines PubMed (https://pubmed.ncbi.nlm.nih.

Table 5
Top 15 productive institutions.

Institution	*TP*	*TP* *R* (%)	*CPP*	*IP* *R* (%)	*CPP*	*CP* *R* (%)	*CPP*	*FP* *R* (%)	*CPP*	*RP* *R* (%)	*CPP*	*SP* *R* (%)	*CPP*
Univ Sao Paulo, Brazil	255	1 (5.2)	17	1 (4.3)	19	1 (5.8)	16	1 (3.6)	17	1 (2.7)	17	37 (0.43)	75
Malmo Univ, Sweden	135	2 (2.8)	34	25 (0.69)	27	2 (4.0)	34	6 (0.92)	19	4 (0.94)	18	37 (0.43)	79
Univ Washington, USA	128	3 (2.6)	99	2 (2.2)	77	4 (2.8)	110	2 (1.2)	87	2 (1.2)	85	1 (2.6)	38
Univ N Carolina, USA	96	4 (2.0)	76	6 (1.2)	79	8 (2.5)	76	3 (1.2)	74	3 (1.0)	81	N/A	N/A
Karolinska Inst, Sweden	95	5 (1.9)	17	36 (0.53)	23	6 (2.8)	16	10 (0.80)	19	13 (0.75)	14	N/A	N/A
Aarhus Univ, Denmark	90	6 (1.8)	36	N/A	N/A	3 (3.0)	36	17 (0.67)	31	11 (0.77)	29	N/A	N/A
Univ Amsterdam, Netherlands	89	7 (1.8)	31	126 (0.16)	34	4 (2.8)	31	10 (0.80)	15	19 (0.60)	17	N/A	N/A
Univ Minnesota, USA	88	8 (1.8)	50	13 (0.85)	17	10 (2.4)	57	4 (1.0)	61	4 (0.94)	65	4 (1.7)	15
SUNY Buffalo, USA	83	9 (1.7)	66	46 (0.42)	32	7 (2.5)	70	40 (0.41)	50	31 (0.44)	56	10 (1.3)	13
Univ Maryland, USA	82	10 (1.7)	42	9 (1.1)	41	13 (2.1)	43	20 (0.61)	39	16 (0.65)	38	N/A	N/A
Univ Florida, USA	81	11 (1.7)	41	24 (0.74)	34	11 (2.2)	42	26 (0.53)	41	34 (0.40)	45	37 (0.43)	56
Univ Estadual Campinas, Brazil	81	11 (1.7)	19	17 (0.80)	24	12 (2.2)	18	5 (0.94)	19	7 (0.85)	19	N/A	N/A
Vrije Univ Amsterdam, Netherlands	74	13 (1.5)	36	261 (0.053)	47	9 (2.4)	36	279 (0.061)	28	63 (0.27)	12	N/A	N/A
Univ Michigan, USA	61	14 (1.2)	48	8 (1.1)	29	21 (1.3)	58	8 (0.82)	28	11 (0.77)	26	1 (2.6)	34
Seoul Natl Univ, South Korea	57	15 (1.2)	15	3 (1.3)	16	29 (1.1)	14	10 (0.80)	16	6 (0.87)	14	37 (0.43)	5.0

TP: total number of articles; *TP R* (%): total number of articles and percentage of total articles; *IP R* (%): rank and percentage of single-institute articles in all single-institute articles; *CP R* (%): rank and percentage of inter-institutionally collaborative articles in all inter-institutionally collaborative articles; *FP R* (%): rank and percentage of first-author articles in all first-author articles; *RP R* (%): rank and percentage of corresponding-author articles in all corresponding-author articles; *SP R* (%): rank and percentage of single-author articles in all single-author articles; *CPP*: citations per publication ($CPP_{2021} = TC_{2021}/TP$); N/A: not available.

gov/?term=Manfredini%2C+Daniele%5BAuthor%5D) there are some indicators. He has several publications on bruxism, one of the most common causes of TMD [48], as well as several studies on diagnostics and treatment approaches of TMD. By focusing on, perhaps, the most important aetiological risk-factor it is not far-fetched to understand why these studies are being well-cited. Further, the same search also indicated that he has published several systematic reviews on risk-factors, diagnostics, and treatment approaches of TMD, which are also studies resulting in several citations.

C.M. De Felicio (25, 1.131), E. Winocur (25, 1.058), K.G. Raphael (25, 0.8254), and A.G. Glaros (25, 0.8254) all had the same *j* of 25. All these authors are located on the same curve (*j* = 25) in Fig. 3, indicating that they had the same publication potential in the research field of TMD with a *j* of 25 but different publication characteristics [37]. De Felicio published more corresponding-author articles than first-author articles with an *h* of 1.131, followed by Winocur with an *h* of 1.058. Both of Raphael and Glaros published the same number of first-author articles and corresponding-author articles with an *h* of 0.8254, respectively. Similarly, A. Wanman (18, 1.204), H. Kurita (18, 0.7854), and C.S. Greene (18, 0.6747) are also located on the same curve with *j* of 18. Wanman had more corresponding-author articles with an *h* of 1.204. Kurita had the same number of first- and corresponding-author articles with an *h* of 0.7854. However, Greene had more first-author articles with an *h* of 0.6747 that indicated Yano still active to perform temporomandibular disorder research. Similar situations for authors located on *j* of 19, 20, 21, and 22 were found. G.D. Slade (22, 0.7854), R.J.M. Gray (22, 0.7854), J.C. Turp (20, 0.7854), D.R. Reissmann (20, 0.7854), K. Kaneyama (20, 0.7854), T. Badel (20,

Table 6
top 20 productive authors.

Author	*TP* rank (*TP*)	CPP_{2021}	*FP* rank (*FP*)	CPP_{2021}	*RP* rank (*RP*)	CPP_{2021}	*SP* rank (*SP*)	CPP_{2021}	*h*	rank (*j*)
P. Svensson	1 (106)	43	4 (13)	71	3 (22)	59	6 (3)	34	1.037	3 (35)
R. Ohrbach	2 (90)	64	4 (13)	67	10 (14)	68	36 (1)	26	0.8224	6 (27)
F. Lobbezoo	3 (89)	37	55 (6)	31	51 (8)	36	N/A	N/A	1.012	55 (13)
D. Manfredini	4 (69)	28	1 (35)	37	1 (49)	34	36 (1)	12	0.9505	1 (84)
W. Maixner	5 (64)	100	121 (4)	191	158 (4)	191	N/A	N/A	0.7854	136 (8)
T. List	6 (59)	71	13 (10)	52	43 (9)	58	N/A	N/A	0.9098	35 (16)
G.D. Slade	7 (56)	63	8 (11)	58	21 (11)	55	N/A	N/A	0.7854	11 (22)
M.T. John	8 (51)	82	13 (10)	97	21 (11)	94	36 (1)	5	0.8330	14 (21)
R.B. Fillingim	8 (51)	50	55 (6)	83	85 (6)	83	N/A	N/A	0.7854	65 (12)
P.C.R. Conti	10 (48)	19	55 (6)	47	85 (6)	45	36 (1)	75	0.7854	65 (12)
C.M. Visscher	11 (47)	47	13 (10)	39	21 (11)	24	N/A	N/A	0.8330	14 (21)
A. Michelotti	12 (46)	58	8 (11)	49	33 (10)	54	N/A	N/A	0.7378	14 (21)
L. Guarda-Nardini	13 (44)	32	8 (11)	28	769 (1)	52	N/A	N/A	0.09066	65 (12)
J.D. Greenspan	14 (42)	49	187 (3)	62	85 (6)	59	N/A	N/A	1.107	117 (9)
M. Ernberg	15 (41)	19	346 (2)	47	250 (3)	32	N/A	N/A	0.9828	302 (5)
M. Naeije	16 (39)	32	748 (1)	29	158 (4)	53	N/A	N/A	1.326	302 (5)
A. Wanman	17 (38)	19	79 (5)	25	12 (13)	23	6 (3)	29	1.204	27 (18)
S.F. Dworkin	17 (38)	178	29 (8)	108	43 (9)	113	6 (3)	59	0.8442	30 (17)
E. Winocur	19 (37)	25	23 (9)	36	8 (16)	21	N/A	N/A	1.058	7 (25)
K. Sipila	20 (35)	16	8 (11)	21	4 (19)	20	N/A	N/A	1.046	5 (30)

TP: total number of articles; *FP*: first-author articles; *RP*: corresponding-author articles; *SP*: single-author articles; CPP_{2021}: citations per publication ($CPP_{2021} = TC_{2021}/TP$); *j*: a *Y*-index constant related to the publication potential; *h*: a *Y*-index constant related to the publication characteristics; N/A: not available.

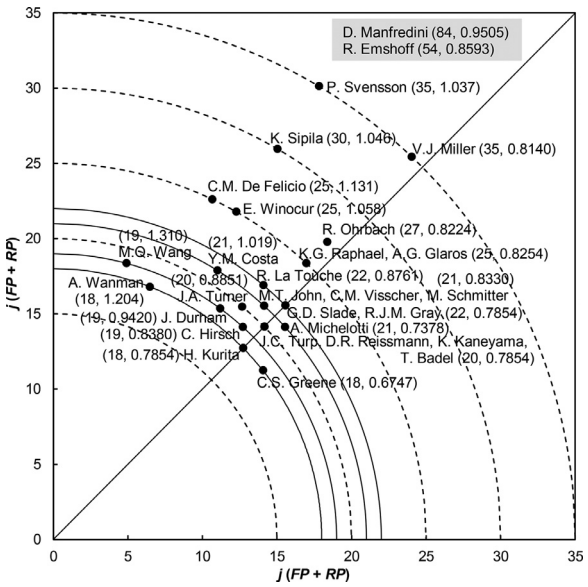

Fig. 3. Top 29 authors with *Y*-index ($j \geq 18$) Citations of a highly cited article are not always high [35]. Therefore, it is necessary to understand the citation history of a highly cited article. The citation histories of the TMD articles contain search keywords in their title or author keywords as shown in Fig. 4. (In the text Fig. 3 should be changed to Fig. 4.).

0.7854), and H. Kurita (18, 0.7854) are located on the diagonal line ($h = 0.7854$) indicating that they had the same publication characteristics but different publication potential. Slade and Gray had the greatest publication potential with a j of 22 followed by Turp, Kaneyama, and Badel with a j of 20, and Kurita with a j of 18. The location on the graph along with one of the curves or along a line from the origin represents different families of author publication potential or publication characteristics, respectively. A potential for bias in the analysis of authorship might attributes to different authors having the same name, or the same author using different names over time [49].

3.6. Citation histories of the ten most frequently cited articles

Total citations are updated from time to time on the Web of Science Core Collection. To improve bibliometric study, the total number of citations from the Web of Science Core Collection since publication year to the end of the most recent year of 2021 (TC_{2021}) was applied to avoid bias using data from the database directly [50]. A total of 2308 articles (47% of 4945 articles), 4135 articles (85% of 4876 articles with abstract in SCI-EXPANDED), and 2375 articles (65% of 3659 articles with author keywords in SCI-EXPANDED) were found to contain search keywords in their title, abstract, and author keywords respectively. Although it is recommended having search keywords in article title or author keywords rendering more hits in a search as well as in bibliometric studies [34], six of the top ten cited articles only contained search keywords in their abstracts. Table 7 shows the top 10 most frequently cited articles with search keywords in their title or author keywords.

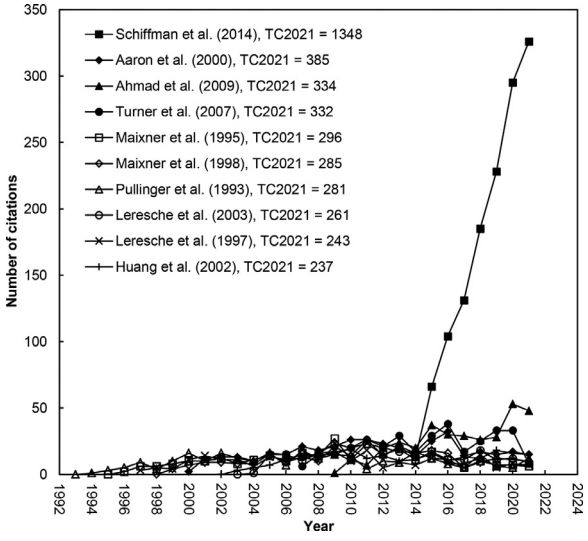

Fig. 4. The citation histories of the top ten highly cited articles with search keywords in their title or author keywords.

Citations of a highly cited article are not always high [35]. Therefore, it is necessary to understand the citation history of a highly cited article. The citation histories of the TMD articles contain search keywords in their title or author keywords as shown in Fig. 3. Green Giants are considered to be articles with sharply increasing citations for some years after publication when compared to others in the same research filed, and they quickly become high impact publications in few years with high C_{year} [51]. Green Giants were found in Web of Science category of environmental sciences and in pain research [51]. The Green Giant in the research field of TMD was the article entitled "Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: Recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group" (Schiffman et al., 2014) by 34 authors from USA, Canada, Sweden, Denmark, Netherlands, Italy, Switzerland, Germany, Belgium, Australia, France, and the UK.

It is not surprising that this article is the Green Giant in the research field of TMD since it is about and describes the internationally accepted and validated clinical examination (Axis I) and biopsychosocial evaluation (Axis II), including the diagnostic criteria for TMD. Based on this, all clinical and experimental trials, epidemiological, and aetiological studies including human participants are referring to this study. Therefore, it will continuously increase its citations since all new studies will refer to this, until these diagnostic criteria will be revised. This becomes even more obvious when looking at Table 7, since the third most cited article is one about image analysis in the previous article about diagnostic criteria [52].

3.7. Research foci

The article title, abstract, author keywords, and KeyWords Plus convey the most important information about the research. Therefore, word distribution analysis is very useful for evaluating research focuses and their development trends in a specific research topic [53]. In the last decade, Ho and his group proposed distributions of words in article titles and abstracts, author keywords, and *KeyWords Plus* to determine research focuses and their trends [18,53]. These analyses can minimize various limitations: the incomplete meaning of individual words in article titles and abstracts, the small sample size of author keywords, and the indirect relationship between *KeyWords Plus* and research topics[54] Therefore, the article title, article abstract, author keywords, and words in *KeyWords Plus* were analyzed during the research period to show rough trends [53]. The 20 most frequently used author keywords in TMD related research, and their distribution in three sub-periods (1992–2001, 2002–2011, and 2012–2021) are listed in Table 8.

The most frequently used author keywords, except for the search words, were not surprising: 1) orofacial pain; 2) bruxism; 3) chronic pain, and 4) myofascial pain. This since painful TMDs are not just common, but they are also affecting the patients emotionally, triggering feelings of anxiousness, stress, guilt, misery, isolation, even sleeping difficulties, which in turn often results in depression [10–12]. Bruxism is, as mentioned before, one of the most important factors of

Table 7
Top 11 most frequently cited articles.

Rank(TC_{2021})	Rank(C_{2021})	Title	Country	Reference
2 (1348)	1 (326)	Diagnostic criteria for temporomandibular disorders (DC/TMD) for clinical and research applications: Recommendations of the international RDC/TMD consortium network and orofacial pain special interest group	USA, Canada, Sweden, Denmark, Netherlands, Italy, Switzerland, Germany, Belgium, Australia, France, UK	Schiffman et al. (2014)
7 (385)	41 (15)	Overlapping conditions among patients with chronic fatigue syndrome, fibromyalgia, and temporomandibular disorder	USA	Aaron et al. (2000)
8 (334)	5 (48)	Research diagnostic criteria for temporomandibular disorders (RDC/TMD): Development of image analysis criteria and examiner reliability for image analysis	USA	Ahmad et al. (2009)
9 (332)	219 (8)	Mediators, moderators, and predictors of therapeutic change in cognitive-behavioral therapy for chronic pain	USA	Turner et al. (2007)
10 (296)	407 (6)	Sensitivity of patients with painful temporomandibular disorders to experimentally evoked pain	USA	Maixner et al. (1995)
11 (285)	134 (10)	Sensitivity of patients with painful temporomandibular disorders to experimentally evoked pain: Evidence for altered temporal summation of pain	USA	Maixner et al. (1998)
12 (281)	85 (12)	A multiple logistic-regression analysis of the risk and relative odds of temporomandibular disorders as a function of common occlusal features	USA	Pullinger et al. (1993)
14 (261)	171 (9)	Changes in temporomandibular pain and other symptoms across the menstrual cycle	USA	LeResche et al. (2003)
17 (243)	293 (7)	Use of exogenous hormones and risk of temporomandibular disorder pain	USA	LeResche et al. (1997)
19 (237)	41 (15)	Risk factors for diagnostic subgroups of painful temporomandibular disorders (TMD)	USA	Huang et al. (2002)

TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; C_{2021}: number of citations of an article in 2021 only.

Table 8
The 20 most frequently used author keywords.

Author keywords	*TP*	1992–2021Rank (%)	1992–2001Rank (%)	2002–2011Rank (%)	2012–2021Rank (%)
temporomandibular disorders	1117	1 (31)	1 (27)	1 (35)	1 (29)
temporomandibular joint	572	2 (16)	2 (20)	2 (15)	2 (15)
temporomandibular joint disorders	417	3 (11)	7 (5.3)	6 (6.8)	3 (14)
temporomandibular disorder	322	4 (8.8)	6 (5.9)	4 (7.7)	4 (10)
orofacial pain	258	5 (7.1)	16 (3.2)	3 (8.0)	5 (7.2)
pain	254	6 (6.9)	4 (6.8)	5 (7.2)	6 (6.8)
TMD	188	7 (5.1)	16 (3.2)	7 (4.8)	7 (5.6)
bruxism	158	8 (4.3)	8 (4.7)	9 (4.0)	9 (4.4)
chronic pain	151	9 (4.1)	19 (2.9)	10 (3.7)	8 (4.5)
myofascial pain	147	10 (4.0)	23 (2.4)	8 (4.6)	10 (4.0)
magnetic resonance imaging	143	11 (3.9)	3 (7.4)	11 (3.4)	12 (3.6)
facial pain	123	12 (3.4)	12 (4.1)	23 (2.0)	11 (3.9)
electromyography	120	13 (3.3)	10 (4.4)	16 (2.5)	14 (3.5)
temporomandibular joint disorder	112	14 (3.1)	29 (1.8)	18 (2.4)	13 (3.6)
headache	107	15 (2.9)	10 (4.4)	20 (2.3)	16 (3.0)
depression	96	16 (2.6)	56 (0.88)	15 (2.6)	17 (2.9)
epidemiology	95	17 (2.6)	21 (2.7)	12 (3.3)	23 (2.2)
osteoarthritis	94	18 (2.6)	23 (2.4)	30 (1.5)	15 (3.1)
masseter muscle	87	19 (2.4)	26 (2.1)	20 (2.3)	22 (2.5)
TMJ	83	20 (2.3)	43 (1.2)	25 (1.9)	19 (2.6)

TP: number of articles;%: percentage in each period.

painful TMDs[48] and as many as 10–15% of the general population, and up to 70% of all painful TMD-cases is chronic pain from the masticatory muscles, i.e., myofascial pain or myalgia [4–8].

4. Conclusion

The present bibliometric analysis of the articles published in the research filed of TMD revealed that orofacial pain, bruxism, chronic pain, and myofascial pain are the most commonly used keywords by the authors. Further, over the last 30 years 4945 articles are published in the field of TMD, and the far most frequently cited study was published 8 years ago and handles the diagnostic criteria of TMD. Further, the most productive authors as well as those with the highest performance share some common features. They have several national and international collaborations, they have a wide range of article types spanning from causes to treatments, from risk-factors to how TMD conditions affect sensory, emotional, and mechanical function, to systematic reviews. Based on the outcome of this bibliometric study, the authors hope that both clinicians and researchers will have information to shape their future research focus, finding prominent institutions in their nearby area, or even to be stimulated to initiate new international or even multinational collaboration.

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