

## ORIGINAL ARTICLE

# Peri-implantitis: A bibliometric network analysis of top 100 most-cited research articles

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**Abstract**

**Background:** Over the past decades, there has been an increase in research publications focusing on peri-implantitis. When facing limited healthcare resources, bibliometric analyses can guide researchers and funding parties toward areas where reallocation or more focus on research activity is warranted. The main objective of this study was to identify the trends of the top 100 cited articles on peri-implantitis research as the first study of its kind.

**Methods:** A Web of Science search, using the keywords “peri-implantitis or periimplantitis” was built to create a database of the most-cited articles. Articles were ranked by citation count and screened by two independent reviewers. The bibliometric characteristics of the studies were gathered and analyzed using several bibliometric software. Author collaborations, author clusters, and keyword co-occurrence network analyses were also performed. The correlation between the citation count and the age of each article was tested.

**Results:** The top 100 cited papers were published from 1994 to 2018 and the total citation counts ranged from 119 to 972 with 244.5 citations/paper on average. There was no correlation between the age of the articles and the citation count ( $p$ -value = 0.67). 21% of the studies consisted of prospective clinical studies. 35% of the papers focused on treatment and prevention of peri-implantitis while 65% concerned epidemiology. The top three most prolific countries were Sweden ( $n = 31$ ), Germany ( $n = 15$ ), and Switzerland ( $n = 13$ ). We found 12 authors who had greater than five publications on the list. Also, the most published journal was *Clinical Oral Implants Research*.

**Conclusion:** This study provides insight into the characteristics and quality of the most highly cited peri-implantitis literature. This revealed a deficiency in terms of the number of studies on treatment strategies as well as a higher level of evidence studies among the most- impactful papers on peri-implantitis at the moment.

**KEYWORDS**

bibliometric analysis, bibliometrics, dental implants, peri-implantitis, web of science

**SUMMARY BOX****What is known**

There has been a growth in research publications focusing on peri-implantitis recently. Nonetheless, the literature lacks a bibliometric analysis revealing, the study types, topics, and author- and institution-collaborations.

### What this study adds

There is a lack of emphasis among the studies on treatment strategies as well as a shortage in the higher level of evidence studies among the most-impactful papers on peri-implantitis at the moment. Top 100 most-cited peri-implantitis articles were cited 244.5 times on average and there was no correlation between the age of the papers and the number of citations.

## 1 | INTRODUCTION

Dental implant therapy has become a well-established rehabilitation method for edentulism and yields superior evidence for its high success rate, proven by numerous studies.<sup>1-4</sup> This exponential increase in its use and popularity further necessitates understanding of its potential complications, disease occurrence, and methods to use when encountered. Peri-implantitis is one of the most challenging complications in dental implantology.<sup>1,3,5</sup> It has been proven that peri-implantitis has a microbial etiology and originates from an inflammatory response, which results in irreversible loss of peri-implant supporting compartments including alveolar bone.<sup>2-5</sup> In the epidemiological literature, a prevalence rate of 18.5% and 12.8% is indicated for the patient level and implant level, respectively.<sup>2,6-8</sup> Quantitative and qualitative evaluation of the current scientific literature in this field is crucial. Such assessments can play an effective role in research funding and grants and resource priority setting from the involved parties, as indicated in the Research Assessment Exercise.<sup>9,10</sup>

The bibliometric analysis presents a review process that allows a better description and evaluation of the published research on a specific topic. Fundamentally, it consisted mainly of bibliographic overviews of research publications or a selection of highly cited papers.<sup>10</sup> Moreover, it provides quantitative and visual processing in scientific papers to explore and define their unique characteristics and dynamics.<sup>10,11</sup> Bibliometric studies are often focused on evaluation or relations. Evaluation studies determine the total citations and the number of cited papers. Relational studies, on the other hand, elaborate on the structure of a research topic, research profiling of authors, institutional affiliations, new research avenues, and methodological techniques employed. The number of citations has been widely used as a measure of quality of research articles and, therefore, to evaluate the contribution and the scientific performance of scientists, research groups, departments, or institutions. Appropriate interpretation is utterly vital in bibliometric reviews. To the best of our knowledge, despite several bibliometric analyses on various topics of dentistry<sup>12,13</sup> and implantology,<sup>14-17</sup> a study with a primary focus on peri-implantitis is lacking. Therefore, the aim of this bibliometric analysis was to identify and analyze the top 100 most-cited papers in *peri-implantitis* using comprehensive data analysis and bibliometric tools. Furthermore, this study can help researchers and policymakers define policies with regard to the diagnosis and treatment of peri-implantitis and also define the focus of currently most-impactful literature in this field.

## 2 | MATERIALS AND METHODS

### 2.1 | Study protocol and data source

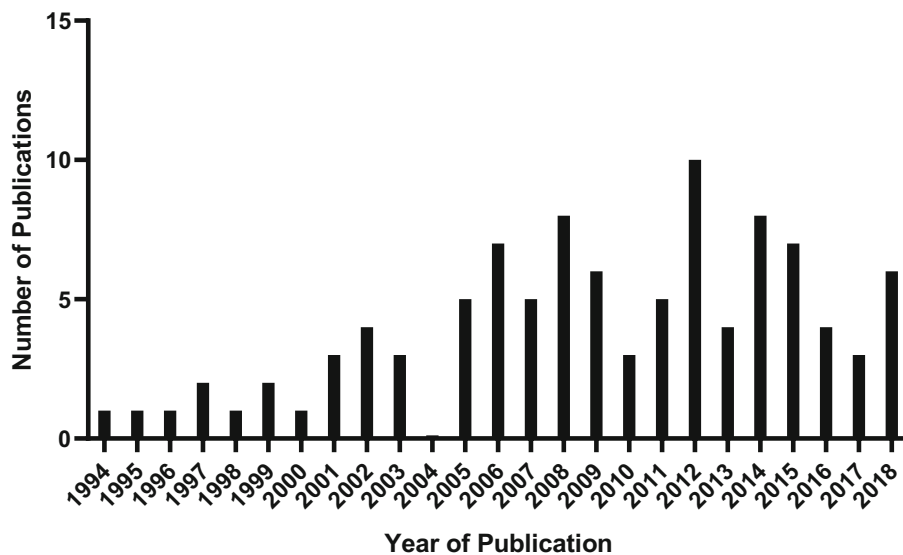
This bibliometric analysis was conceptualized with adherence to the latest methodological guidelines of this study design.<sup>18</sup> Moreover, the article was designed according to the Standards for Reporting Qualitative Research (SRQR) checklist<sup>19</sup> (Table S1). No Institutional Review Board approval was needed for this study since it was a retrospective evaluation of publicly available data.

### 2.2 | Bibliometric search strategy

The Web of Science Core Collection (WoS) database hosted by Clarivate Analytics (<https://clarivate.com/webofsciencegroup/solutions/web-of-science/> last accessed on 10/10/2022), was searched in October 2022 for all citations pertaining to peri-implantitis. The WoS database was selected to be utilized since it is the oldest available source of scientific papers.<sup>20</sup> The keyword “peri-implantitis OR periimplantitis” were entered and the WoS “topic search” tab was used to identify the articles with the main topic of peri-implantitis. We did not perform any limitations in terms of the category of the journals to prevent overlooking the evidence. Likewise, no restrictions were applied to the basis of abstract availability, study type, or non-human research subjects. Time restriction was also not imposed. To maintain a relevant and focused list of peri-implantitis articles, only articles with a primary focus on this topic were selected, thereby excluding other topics, such as peri-implant mucositis. All the journals were searched using both the print and electronic International Standard Serial Numbers. Following a comprehensive search, the results were sorted according to the “Times Cited” option in the WoS database and organized in descending order. Next, initially, the titles and abstracts were screened by one author (H.S) all of which were reviewed again and confirmed by the senior author (H.L.W).

### 2.3 | Data extraction

An electronic spreadsheet form was designed for data collection. After selecting the top 100 most-cited publications, remarkable key attributes were obtained from the included studies. The following bibliometric parameters were gathered: study title, author names, year of publication, journal, institution, country, publication types (original/review), publication language, keywords, number of citations until October 2022, and citations per year. Also, the main scope of each article was categorized manually



**FIGURE 1** Publication timeline of the top 100 most-cited articles with the main topic of peri-implantitis (See Table A1 for full records of the top 100 articles.)

based on the focused topic related to peri-implantitis: epidemiology/etiology/diagnosis, treatment, and prevention and similarly, the study design of each paper was detected by the full-text reading of the article.

Additionally, the journal's impact factor (IF) and quartile ranking (Q1–4) were extracted from Journal Citation Reports™ 2021, released in June 2022 by Clarivate Analytics.

## 2.4 | Statistical analysis

For citation analysis, the data were exported into HistCite™ software (American, Clarivate Analytics). The normal distribution of the data was tested using Kolmogorov–Smirnov test. The relationship between the impact factor of a journal and the citation count of top 100 cited articles was analyzed using the Pearson correlation coefficient. All data are presented in the form of median and inter-quartiles (IQ). For all cases, a *p*-value of less than 0.05 was considered significant. The statistical analyses of the data were performed by one author with experience in biostatistics (H.S) and using SPSS software (version 26.0, IBM Corp, Armonk, NY). In addition, R studio (Biblioshiny and ggplot packages) (Rstudio Version 1.1.383; RStudio, Inc., Boston, MA) and VOSviewer 1.6.9 were used to extract key information, create network maps for countries and keywords with high frequency, and for cluster analysis. The size of each circle (node) represented the number of occurrences, the more the occurrence times, the bigger the circle. In cluster analysis, different colors showed different fields or directions.

## 3 | RESULTS

### 3.1 | General characteristics

Initially, the search strategy detected 4030 records on WoS. Following the application of the mentioned filters and criteria, the

top 100 most-cited papers with the main topic of peri-implantitis were included in this study (Table A1 in Appendix A). Briefly, these studies were authored by 305 authors from 28 countries and published in 16 journals. These studies were published between 1994 and 2018. Figure 1 shows the chronological evolution of the included publications. All the included papers were published in English.

### 3.2 | Top 10 highly cited papers

Overall, the global citation score (GCS) was 24 454 (244.5 citations/paper on average) ranging from 119 to 972. The highest cited paper was “Peri-implant diseases: Consensus Report of the Sixth European Workshop on Periodontology” by Lindhe and Meyle (2008)<sup>21</sup> published in the Journal of Clinical Periodontology and was cited 972 times. The top 10 most-cited papers along with their conclusion bottom lines can be seen in Table 1.

### 3.3 | Year of publications and citations score

The average age of publications was  $12.8 \pm 5.9$  years. The highest production occurred in 2012 ( $n = 10$ ) followed by 2008 ( $n = 9$ ) and 2006 ( $n = 8$ ). The results of the Kolmogorov–Smirnov test revealed a non-normal distribution of the data ( $p$ -value = 0.001) therefore, the spearman correlation test was used to identify a possible correlation between the number of total citations and the age of the publication, however, there was no significant correlation between these two ( $p$ -value = 0.67) (Appendix B). Additionally, the annual scientific publication growth rate of the articles was 9.46%. Overall, 48% of the most-cited articles were published after 2010 (2010–2018).

**TABLE 1** Top 10 most-cited papers in peri-implantitis and their “one-sentence summary”

Ranking	Author	Title	Journal	TCC	Conclusion
1	Lindhe, J; Meyle, J, 2008 <sup>21</sup>	Peri-implant diseases: Consensus report of the sixth European workshop on periodontology	Journal of Clinical Periodontology	972	Peri-implantitis is caused by bacteria. A number of risk indicators were identified. The outcomes of non-surgical treatment were unpredictable.
2	Esposito, M, 1998 <sup>28</sup>	Biological factors contributing to failures of osseointegrated oral implants—(II). Etiopathogenesis	European Journal of Oral Sciences	905	Progressive chronic marginal infection (peri-implantitis) and overload in conjunction with the host characteristics are the major etiological agents causing late failures. It appears that implant surface properties may influence the failure pattern.
3	Esposito, M, 1998 <sup>29</sup>	Biological factors contributing to failures of osseointegrated oral implants (I). Success criteria and epidemiology	European Journal of Oral Sciences	871	Due to the limited number of literature, further clinical follow-ups and retrieval studies are required to achieve a better understanding of the mechanisms for failure of osseointegrated implants.
4	Zitzmann, NU, 2008 <sup>30</sup>	Definition and prevalence of peri-implant diseases	Journal of Clinical Periodontology	781	There is a limited evidence on the prevalence of peri-implant diseases. Peri-implantitis was found in 28% and more than 56% of subjects and in 12% and 43% of implant sites.
5	Lang, NP, 2011 <sup>25</sup>	Periimplant diseases: where are we now?—Consensus of the seventh European workshop on periodontology	Journal of Clinical Periodontology	655	The clinical and radiographic data should routinely be obtained after prosthesis installation on implants in order to establish a baseline for the diagnosis of peri-implantitis during maintenance of implant patients.
6	Derks, J; Tomasi, C, 2015 <sup>5</sup>	Peri-implant health and disease. A systematic review of current epidemiology	Journal of Clinical Periodontology	635	The review suggested future studies with considering application of consistent case definitions and assessing random patient samples of adequate size and function time to develop strategies for preventing peri-implantitis.
7	Caton, JG, 2018 <sup>31</sup>	A new classification scheme for periodontal and peri-implant diseases and conditions—Introduction and key changes from the 1999 classification	Journal of Clinical Periodontology	600	This paper presents the new consensus with regards to the new classification for periodontal and peri-implant diseases and presents changes to the 1999 classification.
8	Heitz-Mayfield, LJA, 2008 <sup>32</sup>	Peri-implant diseases: diagnosis and risk indicators	Journal of Clinical Periodontology	599	The review detected strong evidence supporting that poor oral hygiene, a history of periodontitis and smoking are risk indicators for peri-implant disease. However, future prospective studies are required to confirm this.
9	Berglundh, T, 2018 <sup>1</sup>	Peri-implant diseases and conditions: consensus report of workgroup 4 of the 2017 world workshop on the classification of periodontal and peri-implant diseases and conditions	Journal of Clinical Periodontology	517	A classification for peri-implant diseases was presented. The peri-implant health was described as the absence of bleeding on probing, swelling, erythema and suppuration. Peri-implantitis is a plaque induced pathological condition with presence of progressive loss of supporting bone.
10	Quirynen, M, 2002 <sup>33</sup>	Infectious risks for oral implants: a review of the literature	Clinical Oral Implants Research	480	Periodontitis enhancing factors such as smoking and poor oral hygiene also increase the risk of peri-implantitis.

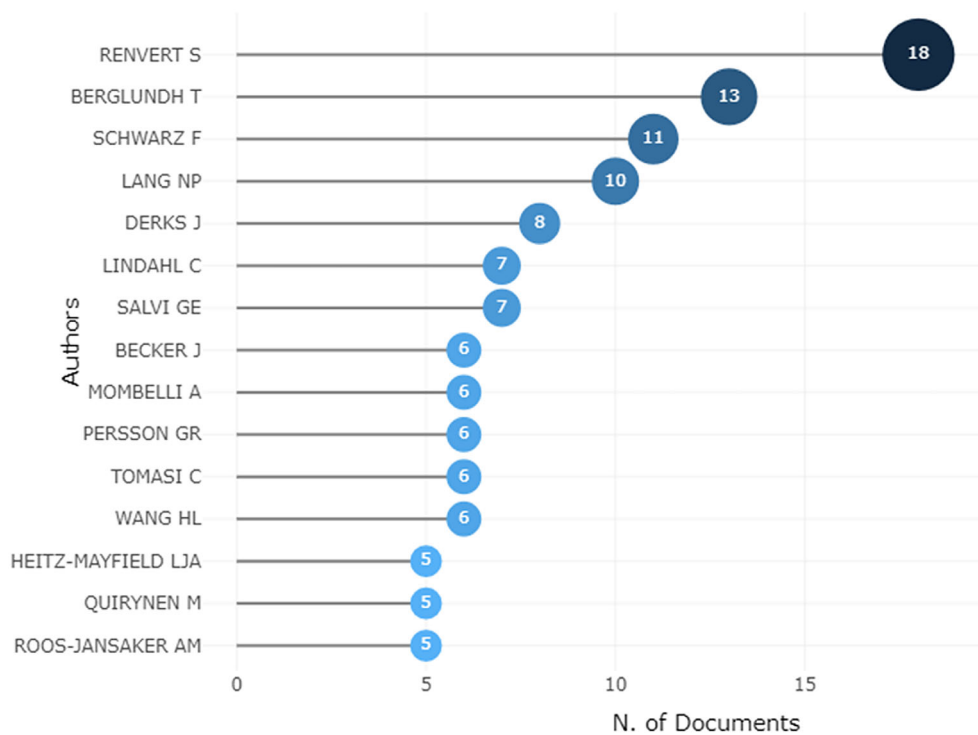
Abbreviation: TCC, total citation count.

### 3.4 | Leading authors, institutions, and journals

The most productive authors were Renvert S ( $n = 18$ ), Berglundh T ( $n = 13$ ), and Schwarz F ( $n = 11$ ) (Figure 2). Moreover, the most-cited authors were Berglundh T ( $n = 4166$ ), Renvert S ( $n = 3978$ ),

and Derks J ( $n = 2604$ ) based on the total global citation score (Table 2).

The institution with the highest number of publications was the University of Gothenburg ( $n = 24$ ), followed by the University of Bern ( $n = 21$ ) and Kristianstad University ( $n = 18$ ) as shown in Figure 3.



**FIGURE 2** Top 15 most-contributed authors to the top 100 most-cited peri-implantitis papers based on their H-index within the included articles

Ranking	Author	Number of records	TLCS	TGCS
1	Renvert S	18	108	3978
2	Berglundh T	13	79	4166
3	Schwarz F	11	45	2424
4	Lang NP	10	95	2558
5	Derks J	8	25	2604
6	Lindahl C	7	40	1424
7	Salvi GE	7	29	1592
8	Becker J	6	35	865
9	Mombelli A	6	67	1581
10	Persson GR	6	39	886
11	Tomasi C	6	21	2049
12	Wang HL	6	7	1780
13	Heitz-Mayfield LJA	5	1	1825
14	Quirynen M	5	30	1540
15	Roos-Jansaker AM	5	21	1397

**TABLE 2** Most published authors (more than four studies) and the corresponding number of records

Note: TLCS is the total number of being cited by the studies within this collection (the articles included in this study) whereas TGCS is the total number of citations for an author in WoS for their articles in this study.

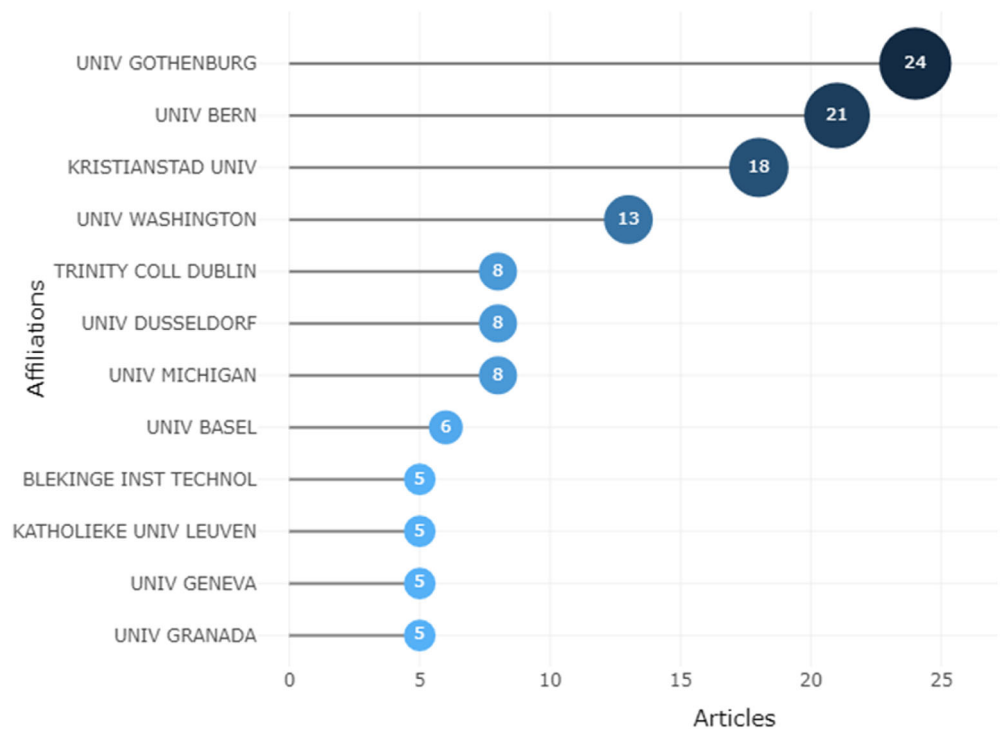
Abbreviations: TLCS, total local citation score; TGCS, total global citation score.

When it comes to the journals, the top three ranked journals based on the number of documents were “Clinical Oral Implants Research” ( $n = 35$ ), “Journal of Clinical Periodontology” ( $n = 29$ ), and “Journal of Periodontology” ( $n = 10$ ) whereas, the top most-cited journals were “Journal of Clinical Periodontology” ( $n = 9477$ ), “Clinical Oral Implants Research” ( $n = 6569$ ) and “Journal of Periodontology” ( $n = 2093$ ). The complete ranking of the published journals is presented in Table 3.

### 3.5 | Keywords and trending topics analysis

The results of topic determination revealed 65 articles (65%) within the category of epidemiology/etiology/diagnosis of peri-implantitis. Among the remaining, 35 (35%) and 5 (5%) belonged to the “treatment” and “prevention” topics, respectively. Figure 4 depicts the results of the topic analysis as a pie chart.

**FIGURE 3** The institutions where contributed to more than three publications among the top 100

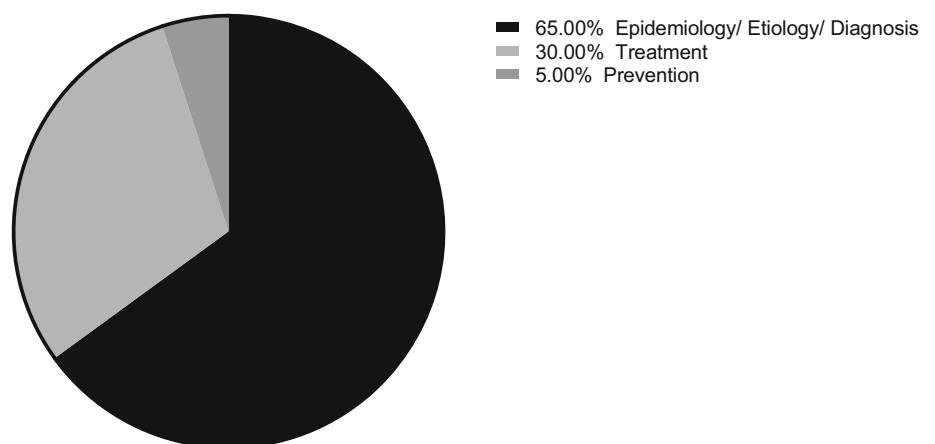


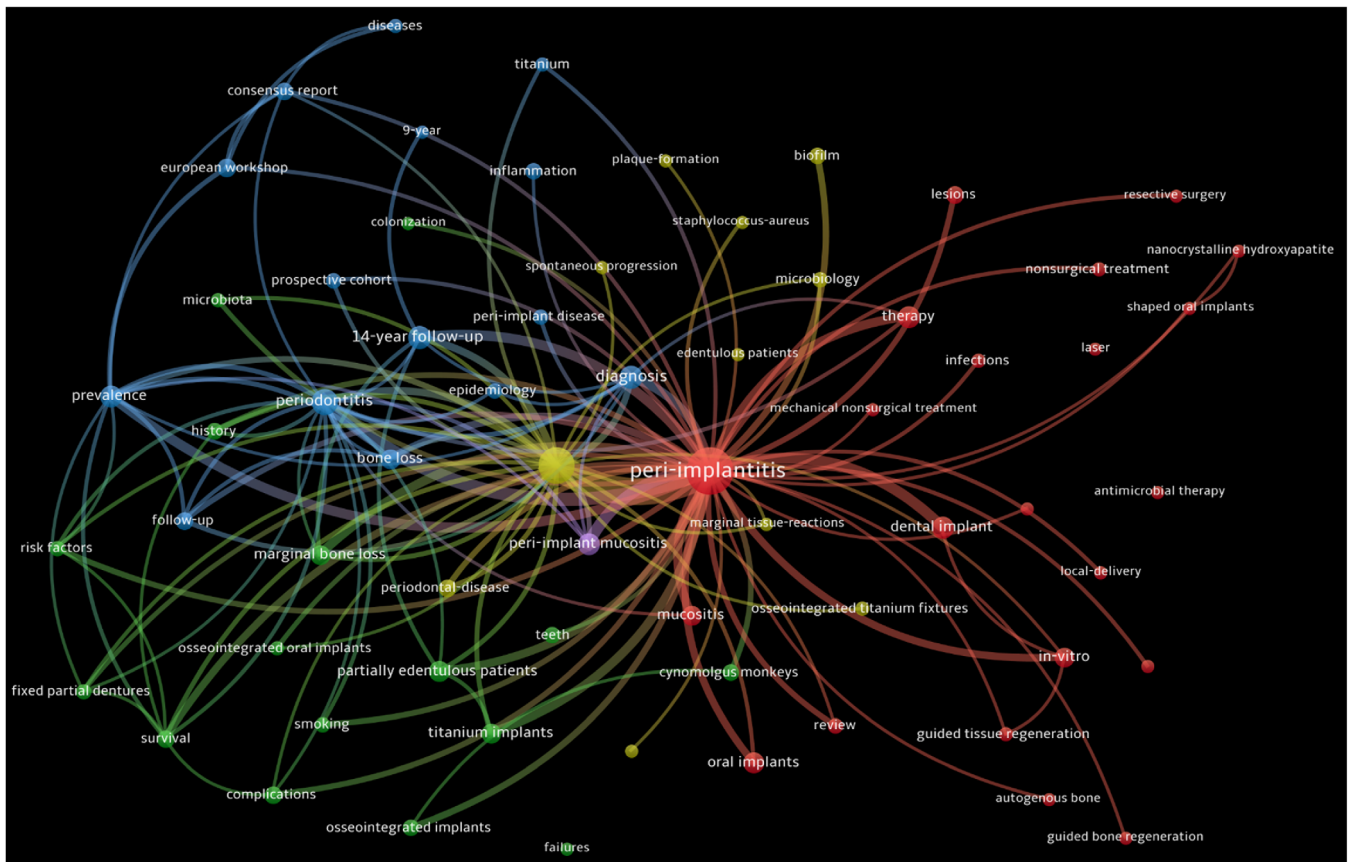
**TABLE 3** Journal analysis based on the latest reported data from Clarivate Journal Citation Reports™

Ranking	Journal	No. of the articles in the top 100	TGCS	Citation/article	IF 2021	Quartile	Category
1	Clinical Oral Implants Research	35	6569	182	5.021	Q1	Implant dentistry
2	Journal of Clinical Periodontology	29	9477	298.5	7.478	Q1	Periodontology
3	Journal of Periodontology	10	2093	193.1	4.49	Q1	Periodontology
4	International Journal of Oral & Maxillofacial Implants	4	666	169.5	2.91	Q2	Implant dentistry
5	Periodontology 2000	4	1100	274.7	12.23	Q1	Periodontology
6	Clinical Implant Dentistry and Related Research	3	477	196.5	4.25	Q1	Implant dentistry
7	Journal of Dental Research	3	619	187.5	8.92	Q1	Dentistry

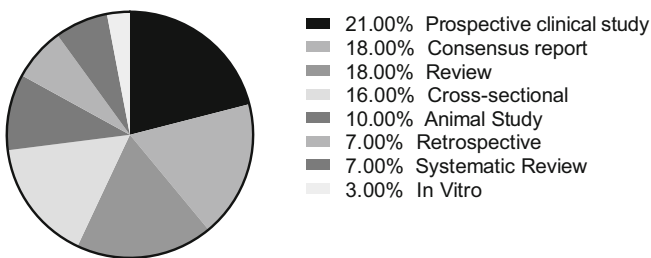
Abbreviations: TGSC, total global citation score; IF, impact factor.

**FIGURE 4** The main scope of the publications and the topic analysis pie chart. This revealed the majority of the publications being inclined towards epidemiology/etiology/diagnosis compared to prevention and treatment aspects at the moment.





**FIGURE 5** Keyword co-occurrence network of the included papers. The keywords occurring more than five times among the articles were considered. The size of the nodes represents the times one keyword repeated among the studies and the line connecting two nodes depicts the co-occurrence of the two keywords. The thickness of each line corresponds to the strength of the link between two keywords. Four clusters were formed (Cluster one, Red: Peri-implantitis. Cluster two, Yellow: Dental implants. Cluster three, Green: Marginal bone loss. Cluster four, Blue: Periodontitis.)



**FIGURE 6** The study designs of the included articles

For the keyword co-occurrence network analysis, all keywords (including author keywords and KeyWords Plus) were considered. The minimum number of occurrences of a keyword among the included studies was set at five times. Also, the minimum cluster size was set at five, meaning that the items below the minimum cluster size were added to the bigger cluster (appearing as a distinct color within the network graph) (Figure 5). Based on these thresholds, 64 keywords were detected (within four clusters); red color (cluster one, 22 items), green color (cluster two, 16 items), blue color (cluster three, 14 items), and yellow color (cluster four, 12 items) as presented in Figure 5. The

**TABLE 4** The country of authors contributed to the top 100 most-cited articles and their corresponding single-author and multiple co-author publications

Country	Total records	SCA	MCA
Sweden	31	16	15
Germany	15	8	7
Switzerland	13	8	5
USA	9	6	3
Brazil	6	4	2
Italy	3	3	0
United Kingdom	3	3	0
Australia	2	1	1
Belgium	2	1	1
Denmark	2	2	0
Spain	2	0	2

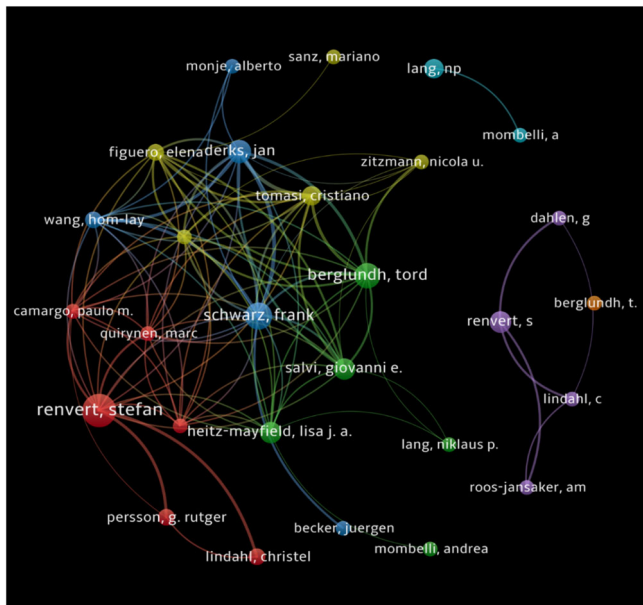
Abbreviations: SCA, single corresponding author; MCA: multiple corresponding authors.

top five most repeated keywords were: peri-implantitis ( $n = 75$ ), dental implants ( $n = 42$ ), periodontitis ( $n = 22$ ), diagnosis ( $n = 16$ ), and

prevalence ( $n = 15$ ). The size of the nodes in Figure 5 corresponds to the number of occurrences in each keyword and the thickness of the connecting lines represents the strength between two keywords.

### 3.6 | Study designs and methodology

Figure 6 depicts the pie chart corresponding to the study designs of the included articles. This analysis revealed approximately 40% of the



**FIGURE 7** The author's collaboration network map. The authors published more than five records were included to this network analysis. The size of each node corresponds to the number of published documents.

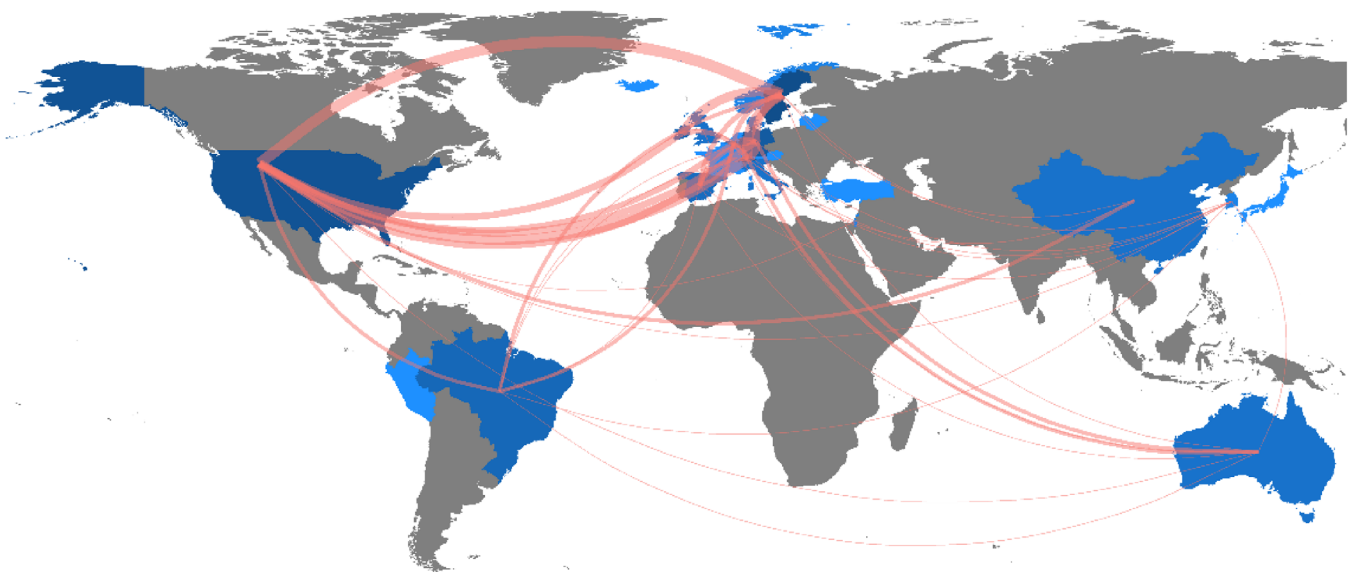
top-cited articles being non-systematic reviews and consensus reports (including commentaries). Moreover, 21% of the evidence were prospective clinical studies (either randomized or non-randomized trials) while 7% consisted of systematic reviews.

### 3.7 | Corresponding author's country and collaboration network analysis

Based on the country of the corresponding authors, the most productive country was Sweden ( $n = 31$ ) followed by Germany ( $n = 15$ ) and Switzerland ( $n = 13$ ) (Table 4). Furthermore, Sweden had both the most single-country ( $n = 16$ ) and multiple-country ( $n = 15$ ) co-authorship. Table 4 and Appendix C depict the data regarding co-author's characteristics.

The results of author collaboration network analysis revealed five clusters (indicating five different teams of authors) when set to authors who published more than five articles on this topic (Figure 7). Two of the clusters (red and green) formed a collaboration network between the authors. Within the red cluster, Berglundh T had the highest collaboration strength ( $n = 36$ ) and within the green cluster Derks J, and Schwarz F had the highest collaboration strengths.

Lastly, the analysis of worldwide collaboration revealed the most collaborating countries in the production of the top 100 most-cited papers. Figure 8 represents the results of this analysis. The lines connecting two countries indicate their collaboration. We set the minimum number of collaborations at two papers. Additionally, the thickness of the lines corresponds to the higher number of collaborations, and similarly, the darker the blue color of each map, the higher number of the publications from each country. The top five collaborations were between (Sweden–USA,



**FIGURE 8** Country collaboration map. The thickness of each line represents the number of collaborations. The darkness of blue color corresponds to the number of publications from each country.



$n = 14$ ), (Sweden–Switzerland,  $n = 12$ ), (USA–Switzerland,  $n = 11$ ), (Sweden–Ireland,  $n = 10$ ), and (Sweden–Germany,  $n = 8$ ).

## 4 | DISCUSSION

In this study, we combined the bibliometric analysis with network visualizations using several tools to characterize the top 100 most-cited articles on the main topic of peri-implantitis. This analysis is the first of its category when peri-implantitis is considered and emphasizes significant findings for future research in dental implantology. Due to its increasing prevalence, it is crucial for the dental research community to identify and evaluate the most influential papers in the field of peri-implantitis.<sup>2</sup> The outcomes of this study comprised the most prolific authors, most published journals, most contributed institutions and countries, keywords and topic analysis as well as the citations count.

Several bibliometric studies have been published in the field of implant dentistry.<sup>14–17,22–24</sup> Fardi and colleagues,<sup>24</sup> conducted a bibliometric analysis on the top 100 papers in implant dentistry. Likewise, Antonio Alarcon and colleagues,<sup>14</sup> reported the 300 most-cited articles in implant dentistry. Both articles were published in 2017 and within their results, it can be noted that only a very limited number of articles were related to peri-implantitis. This was also in accordance with our study which determined that the impactful evidence for peri-implantitis is still growing due to the majority of the papers being consensus reports and reviews with a gap in the amount of well-designed original articles.

The journal analysis revealed that “Clinical Oral Implants Research” being the most published peri-implantitis topic journal followed by “Journal of Clinical Periodontology” and “Journal of Periodontology.” Also, three out of top seven mostly published journals were periodontology journals. This indicates a higher research production and impact of periodontology journals compared to miscellaneous or oral surgery journals when peri-implantitis is considered. Also, the fact that “Clinical Oral Implants Research” had a higher publication number but a lower impact factor, indicates that the relevancy of a journal has a bolder role in publications.

When it comes to the topics and keywords analysis, it can be interpreted that the main focus of the most impactful articles was epidemiology/etiology/diagnosis rather than treatment and management of peri-implantitis. Taking into consideration the fact that we analyzed the top-cited papers which technically can be considered as “classic landmarks” on the topic and the vast majority of the treatment-focused papers were at the lower rankings among the top 100 based on their citation count, it can be mentioned that the therapeutic concept of peri-implantitis has been gaining more focus recently. Furthermore, the fact that peri-implantitis is a relatively new condition, it can be justified why most of the citations belong to the “epidemiology/etiology/diagnosis” category and the recently increasing therapeutic focus of the research studies on the topic will possibly shift this trend in the foreseeable future.

Several consensus reports and guideline papers<sup>1,21,25</sup> were among the top-cited papers. This can potentially cause a tendency for other

authors to cite these papers more frequently as they are considered agreement papers. Therefore, causing a citation bias within the literature and shifting focus from the latest research trends toward more classical articles. The results of study design analysis in our study revealed that only 21% of the articles belonged to the prospective clinical studies. This dropped even more to only 7% for systematic reviews and meta-analyses. Ideally, the most-impactful articles in a discipline should consist of the highest level of evidence articles, such as meta-analyses or randomized controlled trials. This limitation in publication has also been brought up by Antonio Alarcon and colleagues,<sup>14</sup> in a similar study on implant dentistry articles.

Sweden ( $n = 31$ ), Germany ( $n = 15$ ), and Switzerland ( $n = 13$ ) were the top three locations of science production in our study. In other bibliometric studies in the field of dentistry,<sup>12,13,26</sup> USA, China, Brazil, and the United Kingdom were among the most productive countries. More specifically, in a more recent bibliometric report on peri-implant diseases by Tarazona-Álvarez,<sup>17</sup> the authors reported USA, Germany, and Sweden being the top three. In that study, they evaluated both peri-implantitis and peri-implant mucositis considering all publications in general. Therefore, it can be concluded that authors from Switzerland published more impactful papers despite the fewer number of publications. In the same study, it is mentioned that Schwarz F ( $n = 81$  publications), Lang NP ( $n = 67$ ), Renvert S ( $n = 62$ ), and Wang HL ( $n = 62$ ) were the top three most productive authors when all publications in peri-implant diseases are considered. This was slightly different with the author rankings in our results, although all collaborating authors were similar in both datasets but with different rankings. This indicates that the most-impactful publication network is occupied by the same authors however, the ranking can differ based on the “defined period of publication year” and “major topic” of the articles.

In a similar study designed by Shi and colleagues,<sup>27</sup> in the field of psychology and depression, the statistical analysis revealed a significant correlation between the age of a publication and the number of citations. Conversely, our data analysis failed to support this statement. This can be due to the fact that their included articles had been published within a 34-year time frame in contrast to that of 24 years in our study.

With that being mentioned, this study was not exempted from having limitations. First and foremost, with all advances in technology and especially with the era of social media, other sophisticated metrics, such as download statistics, bookmarking tools, and sharing times on social media are available nowadays.<sup>10</sup> And it is suggested for future research to take these into account as well. Another limitation would be the fact that we focused only on the top 100 most-cited papers which provided a thorough overview for the readers regarding the most impactful articles in the field of peri-implantitis, however, in order to digest the general information a bibliometric study on all published peri-implantitis papers would also be beneficial.

## 5 | CONCLUSIONS

Within its limitations, in this bibliometric study, the top 100 most-cited papers on peri-implantitis were analyzed. 48% of the papers

were published after 2010 and the annual scientific publication growth rate was 9.46%. The age of publication did not have a statistically significant correlation with the number of citations. A substantial deficiency was detected in terms of methodological quality of the top cited articles with only less than 30% fitting into the level of evidence 1 or 2. Sweden, Germany, and Switzerland were top three most productive countries. 65% of the articles were in the epidemiology/etiology/diagnosis category while 30% focused on treatment and 5% on prevention.

#### AUTHOR CONTRIBUTIONS

Hamoun Sabri: Conceptualization, statistical analysis, data presentation, and manuscript draft writing. Hom-Lay Wang: Conceptualization, critical review of the manuscript and final approval.

#### FUNDING INFORMATION

None.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest regarding this research article.

#### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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## APPENDIX A

**TABLE A1** Full records of top 100 cited articles with the topic of peri-implantitis

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
1	Lindhe, J; Meyle, J	Peri-implant diseases: consensus report of the sixth European workshop on periodontology	2008	Journal of Clinical Periodontology	972	Epidemiology	Consensus report
2	Esposito, M	Biological factors contributing to failures of osseointegrated oral implants—(II). Etiopathogenesis	1998	European Journal of Oral Sciences	905	Epidemiology	Review
3	Esposito, M	Biological factors contributing to failures of osseointegrated oral implants (I). Success criteria and epidemiology	1998	European Journal of Oral Sciences	871	Epidemiology	Review
4	Zitzmann, NU	Definition and prevalence of peri-implant diseases	2008	Journal of Clinical Periodontology	781	Epidemiology	Review
5	Lang, NP	Periimplant diseases: where are we now?—Consensus of the seventh European workshop on periodontology	2011	Journal of Clinical Periodontology	655	Epidemiology	Consensus report
6	Derks, J; Tomasi, C	Peri-implant health and disease. A systematic review of current epidemiology	2015	Journal of Clinical Periodontology	635	Epidemiology	Systematic review
7	Caton, JG	A new classification scheme for periodontal and peri-implant diseases and conditions—Introduction and key changes from the 1999 classification	2018	Journal of Clinical Periodontology	600	Epidemiology	Consensus report
8	Heitz-Mayfield, LJA	Peri-implant diseases: diagnosis and risk indicators	2008	Journal of Clinical Periodontology	599	Epidemiology	Systematic review
9	Berglundh, T	Peri-implant diseases and conditions: consensus report of workgroup 4 of the 2017 world workshop on the classification of periodontal and peri-implant diseases and conditions	2018	Journal of Clinical Periodontology	517	Epidemiology	Consensus report
10	Quirynen, M	Infectious risks for oral implants: a review of the literature	2002	Clinical Oral Implants Research	480	Epidemiology	Review
11	Roos-Jansaker, AM	Nine- to fourteen-year follow-up of implant treatment. Part II: presence of peri-implant lesions	2006	Journal of Clinical Periodontology	456	Epidemiology	Cross-sectional
12	Mombelli, A; Lang, NP	The diagnosis and treatment of peri-implantitis	1998	Periodontology 2000	440	Treatment	Consensus report
13	Isidor, F	Loss of osseointegration caused by occlusal load of oral implants—A clinical and radiographic study in monkeys	1996	Clinical Oral Implants Research	431	Epidemiology	Animal study
14	Mombelli, A	The epidemiology of peri-implantitis	2012	Clinical Oral Implants Research	409	Epidemiology	Consensus report
15	Sanz, M; Chapple, IL	Clinical research on peri-implant diseases: consensus report of Working Group 4	2012	Journal of Clinical Periodontology	371	Epidemiology	Consensus report
16	Schwarz, F	Peri-implantitis	2018	Journal of Clinical Periodontology	369	Epidemiology	Consensus report
17	Oh, TJ;	The causes of early implant bone loss: Myth or science?	2002	Journal of Periodontology	368	Epidemiology	Review

(Continues)

TABLE A1 (Continued)

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
18	Renvert, S	Non-surgical treatment of peri-implant mucositis and peri-implantitis: a literature review	2008	Journal of Clinical Periodontology	355	Treatment	Review
19	Leonhardt, A	Microbial findings at failing implants	1999	Clinical Oral Implants Research	343	Epidemiology	Case series
20	Heitz-Mayfield, LJA	Comparative biology of chronic and aggressive periodontitis vs. peri-implantitis	2010	Periodontology 2000	340	Epidemiology	Consensus report
21	Derks, J	Effectiveness of implant therapy analyzed in a Swedish population: prevalence of peri-implantitis	2016	Journal of Dental Research	312	Treatment	Cross-sectional
22	Roos-Jansaker, AM	Nine- to fourteen-year follow-up of implant treatment. Part III: factors associated with peri-implant lesions	2006	Journal of Clinical Periodontology	307	Epidemiology	Cross-sectional
23	Jepsen, S	Primary prevention of peri-implantitis: Managing peri-implant mucositis	2015	Journal of Clinical Periodontology	302	Prevention	Consensus report
24	Koldslund, OC	Prevalence of peri-implantitis related to severity of the disease with different degrees of bone loss	2010	Journal of Periodontology	302	Epidemiology	Cross-sectional
25	Ferreira, SD	Prevalence and risk variables for peri-implant disease in Brazilian subjects	2006	Journal of Clinical Periodontology	302	Epidemiology	Cross-sectional
26	Atieh, MA	The frequency of peri-implant diseases: a systematic review and meta-analysis	2013	Journal of Periodontology	297	Epidemiology	Systematic review
27	Serino, G	Peri-implantitis in partially edentulous patients: association with inadequate plaque control	2009	Clinical Oral Implants Research	276	Epidemiology	Cross-sectional
28	Costa, FO	Peri-implant disease in subjects with and without preventive maintenance: a 5-year follow-up	2012	Journal of Clinical Periodontology	274	Prevention	Cross-sectional
29	Pye, AD	A review of dental implants and infection	2009	Journal of Hospital Infection	274	Epidemiology	Review
30	Mombelli, A	The characteristics of biofilms in peri-implant disease	2011	Journal of Clinical Periodontology	252	Epidemiology	Review
31	Shibli, JA	Composition of supra- and subgingival biofilm of subjects with healthy and diseased implants	2008	Clinical Oral Implants Research	244	Epidemiology	Cross-sectional
32	Hultin, M	Microbiological findings and host response in patients with peri-implantitis	2002	Clinical Oral Implants Research	242	Epidemiology	Cross-sectional
33	Quirynen, M	Dynamics of initial subgingival colonization of "pristine" peri-implant pockets	2006	Clinical Oral Implants Research	236	Epidemiology	Prospective split-mouth
34	Lang, NP	Biological complications with dental implants: their prevention, diagnosis and treatment	2000	Clinical Oral Implants Research	235	Epidemiology	Consensus report
35	Sbordone, L	Oral microbial biofilms and plaque-related diseases: microbial communities and their role in the shift from oral health to disease	2003	Clinical Oral Investigations	232	Epidemiology	Review

TABLE A1 (Continued)

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
36	Norowski, PA	Biomaterial and antibiotic strategies for peri-implantitis: a review	2009	Journal of Biomedical Materials Research Part B- Applied Biomaterials	229	Treatment	Review
37	Claffey, N	Surgical treatment of peri-implantitis	2008	Journal of Clinical Periodontology	227	Treatment	Review
38	Heitz-Mayfield, LJA	The therapy of peri-implantitis: a systematic review	2014	International Journal of Oral & Maxillofacial Implants	225	Treatment	Systematic Review
39	Leonhardt, A	Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man	2003	Journal of Periodontology	223	Treatment	Cross-sectional
40	Berglundh, T	Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 world workshop on the classification of periodontal and peri-implant diseases and conditions	2018	Journal of Periodontology	218	Epidemiology	Consensus report
41	Kumar, PS	Pyrosequencing reveals unique microbial signatures associated with healthy and failing dental implants	2012	Journal of Clinical Periodontology	214	Epidemiology	Cohort
42	Schwarz, F	Peri-implantitis	2018	Journal of Periodontology	212	Epidemiology	Consensus report
43	Berglundh, T	Are peri-implantitis lesions different from periodontitis lesions?	2011	Journal of Clinical Periodontology	211	Epidemiology	Review
44	Warrer, K	Plaque-induced peri-implantitis in the presence or absence of keratinized mucosa- an experimental-study in monkeys	1995	Clinical Oral Implants Research	205	Epidemiology	Animal Study
45	Lee, CT	Prevalences of peri-implantitis and peri-implant mucositis: systematic review and meta-analysis	2017	Journal of Dentistry	202	Epidemiology	Systematic review
46	Karoussis, IK	Effect of implant design on survival and success rates of titanium oral implants: a 10-year prospective cohort study of the ITI (R) dental implant system	2004	Clinical Oral Implants Research	197	Epidemiology	Cohort
47	Smeets, R	Definition, etiology, prevention and treatment of peri-implantitis—a review	2014	Head & Face Medicine	194	Epidemiology	Review
48	Rocuzzo, M	Ten-year results of a three-arm prospective cohort study on implants in periodontally compromised patients. Part 1: implant loss and radiographic bone loss	2010	Clinical Oral Implants Research	187	Epidemiology	Cohort
49	Salcetti, JM	The clinical, microbial, and host response characteristics of the failing implant	1997	International Journal of Oral & Maxillofacial Implants	186	Epidemiology	Cohort

(Continues)

TABLE A1 (Continued)

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
50	Mombelli, A	Microbiology and antimicrobial therapy of peri-implantitis	2002	Periodontology 2000	184	Treatment	Consensus report
51	Figuro, E	Management of peri-implant mucositis and peri-implantitis	2014	Periodontology 2000	182	Treatment	Consensus report
52	Linkevicius, T	Does residual cement around implant-supported restorations cause peri-implant disease? A retrospective case analysis	2013	Clinical Oral Implants Research	182	Epidemiology	Retrospective
53	Persson, GR	Cluster of bacteria associated with peri-implantitis	2014	Clinical Implant Dentistry and Related Research	177	Epidemiology	Prospective in vivo
54	Qian, J	Reasons for marginal bone loss around oral implants	2012	Clinical Implant Dentistry and Related Research	177	Epidemiology	Review
55	Renvert, S	Infection at titanium implants with or without a clinical diagnosis of inflammation	2007	Clinical Oral Implants Research	175	Epidemiology	Cross-sectional
56	Daubert, DM	Prevalence and predictive factors for peri-implant disease and implant failure: a cross-sectional analysis	2015	Journal of Periodontology	170	Epidemiology	Cross-sectional
57	Renvert, S	Peri-implant health, peri-implant mucositis, and peri-implantitis: case definitions and diagnostic considerations	2018	Journal of Clinical Periodontology	169	Epidemiology	Consensus report
58	Dortbudak, O	Lethal photosensitization for decontamination of implant surfaces in the treatment of peri-implantitis	2001	Clinical Oral Implants Research	168	Treatment	Prospective in vivo
59	Dreyer, H	Epidemiology and risk factors of peri-implantitis: a systematic review	2018	Journal of Periodontal Research	165	Epidemiology	Systematic review
60	Carcuac, O; Berglundh, T	Composition of human peri-implantitis and periodontitis lesions	2014	Journal of Dental Research	163	Epidemiology	Prospective in vivo
61	Berglundh, T	Spontaneous progression of ligature induced peri-implantitis at implants with different surface roughness: an experimental study in dogs	2007	Clinical Oral Implants Research	162	Epidemiology	Animal Study
62	Monje, A	Impact of maintenance therapy for the prevention of peri-implant diseases: a systematic review and meta-analysis	2016	Journal of Dental Research	161	Prevention	Systematic review
63	Romeo, E	Therapy of peri-implantitis with resective surgery—A 3-year clinical trial on rough screw-shaped oral implants. Part I: clinical outcome	2005	Clinical Oral Implants Research	161	Treatment	Prospective clinical trial
64	Duske, K	Atmospheric plasma enhances wettability and cell spreading on dental implant metals	2012	Journal of Clinical Periodontology	160	Epidemiology	In vitro
65	Schwarz, F;	Clinical evaluation of an Er: YAG laser for nonsurgical treatment of peri-implantitis: a pilot study	2005	Clinical Oral Implants Research	160	Treatment	Prospective clinical trial

TABLE A1 (Continued)

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
66	Schwarz, F	Impact of defect configuration on the clinical outcome following surgical regenerative therapy of peri-implantitis	2010	Journal of Clinical Periodontology	159	Treatment	Prospective clinical trial
67	Schwarz, F	Comparison of naturally occurring and ligature-induced peri-implantitis bone defects in humans and dogs	2007	Clinical Oral Implants Research	157	Epidemiology	Animal study
68	Vargas-Reus, MA	Antimicrobial activity of nanoparticulate metal oxides against peri-implantitis pathogens	2012	International Journal of Antimicrobial Agents	156	Treatment	In vitro
69	Schwarz, F	Impact of the method of surface debridement and decontamination on the clinical outcome following combined surgical therapy of peri-implantitis: a randomized controlled clinical study	2011	Journal of Clinical Periodontology	154	Treatment	Randomized controlled trial
70	Miyata, T	The influence of controlled occlusal overload on peri-implant tissue. Part 3: a histologic study in monkeys	2000	International Journal of Oral & Maxillofacial Implants	154	Epidemiology	Animal study
71	Renvert, S; Quirynen, M	Risk indicators for peri-implantitis. A narrative review	2015	Clinical Oral Implants Research	152	Epidemiology	Review
72	Rinke, S	Prevalence of periimplant disease in partially edentulous patients: a practice-based cross-sectional study	2011	Clinical Oral Implants Research	149	Prevention	Cross-sectional
73	Roos-Jansaker, AM	Treatment of peri-implant infections: a literature review	2003	Journal of Clinical Periodontology	149	Treatment	Review
74	Pjetursson, BE	Peri-implantitis susceptibility as it relates to periodontal therapy and supportive care	2012	Clinical Oral Implants Research	147	Prevention	Cross-sectional
75	Persson, LG	Re-osseointegration after treatment of peri-implantitis at different implant surfaces - An experimental study in the dog	2001	Clinical Oral Implants Research	145	Treatment	Animal study
76	Mombelli, A	Treatment of peri-implantitis by local delivery of tetracycline—clinical, microbiological and radiological results	2001	Clinical Oral Implants Research	145	Treatment	Prospective clinical trial
77	Schwarz, F	Healing of intrabony peri-implantitis defects following application of a nanocrystalline hydroxyapatite (Ostim (TM)) or a bovine-derived xenograft (Bio-Oss (TM)) in combination with a collagen membrane (Bio-Gide (TM)). A case series	2006	Journal of Clinical Periodontology	144	Treatment	Case series
78	Renvert, S	Topical minocycline microspheres versus topical chlorhexidine gel as an adjunct to mechanical debridement of incipient peri-implant infections: a randomized clinical trial	2006	Journal of Clinical Periodontology	144	Treatment	Randomized clinical trial

(Continues)



TABLE A1 (Continued)

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
79	Galindo-Moreno, P	Marginal bone loss as success criterion in implant dentistry: beyond 2 mm	2015	Clinical Oral Implants Research	143	Epidemiology	Retrospective
80	Maximo, MB	Short-term clinical and microbiological evaluations of peri-implant diseases before and after mechanical anti-infective therapies	2009	Clinical Oral Implants Research	143	Treatment	Prospective clinical trial
81	Romeo, E	Therapy of peri-implantitis with resective surgery. A 3-year clinical trial on rough screw-shaped oral implants. Part II: radiographic outcome	2007	Clinical Oral Implants Research	143	Treatment	Prospective clinical trial
82	Renvert, S	Treatment of peri-implantitis using an Er:YAG laser or an air-abrasive device: a randomized clinical trial	2011	Journal of Clinical Periodontology	142	Treatment	Randomized clinical trial
83	Mouhyi, J	The peri-implantitis: implant surfaces, microstructure, and physicochemical aspects	2012	Clinical Implant Dentistry and Related Research	141	Epidemiology	Consensus report
84	Salvi, GE	One-year bacterial colonization patterns of <i>Staphylococcus aureus</i> and other bacteria at implants and adjacent teeth	2008	Clinical Oral Implants Research	139	Epidemiology	Cohort
85	Renvert, S	Mechanical non-surgical treatment of peri-implantitis: a double-blind randomized longitudinal clinical study. I: clinical results	2009	Journal of Clinical Periodontology	137	Treatment	Randomized clinical trial
86	Bassetti, M	Anti-infective therapy of peri-implantitis with adjunctive local drug delivery or photodynamic therapy: 12-month outcomes of a randomized controlled clinical trial	2014	Clinical Oral Implants Research	136	Treatment	Randomized clinical trial
87	Dalago, HR	Risk indicators for peri-implantitis. A cross-sectional study with 916 implants	2017	Clinical Oral Implants Research	133	Epidemiology	Cross-sectional
88	Albouy, JP	Spontaneous progression of peri-implantitis at different types of implants. An experimental study in dogs. I: clinical and radiographic observations	2008	Clinical Oral Implants Research	133	Epidemiology	Animal study
89	Renvert, S	Mechanical and repeated antimicrobial therapy using a local drug delivery system in the treatment of peri-implantitis: a randomized clinical trial	2008	Journal of Periodontology	132	Treatment	Randomized clinical trial
90	Hayek, RRA	Comparative study between the effects of photodynamic therapy and conventional therapy on microbial reduction in ligature-induced peri-implantitis in dogs	2005	Journal of Periodontology	132	Treatment	Animal study
91	Pier-Francesco, A	Titanium surface modification and its effect on the adherence of <i>Porphyromonas gingivalis</i> : an in vitro study	2006	Clinical Oral Implants Research	131	Epidemiology	In vitro
92	Derks, J	Peri-implantitis—onset and pattern of progression	2016	Journal of Clinical Periodontology	130	Epidemiology	Cross-sectional

TABLE A1 (Continued)

Ranking	First author(s)	Article title	Publication year	Source title	Times cited	Category	Study design
93	Kozlovsky, A	Impact of implant overloading on the peri-implant bone in inflamed and non-inflamed peri-implant mucosa	2007	Clinical Oral Implants Research	129	Epidemiology	Animal study
94	Karring, ES	Treatment of peri-implantitis by the Vector (R) system—a pilot study	2005	Clinical Oral Implants Research	129	Treatment	Prospective clinical study
95	Klinge, B	Peri-implant tissue destruction. The Third EAO Consensus Conference 2012	2012	Clinical Oral Implants Research	127	Epidemiology	Consensus report
96	Hanisch, O	Bone formation and reosseointegration in peri-implantitis defects following surgical implantation of rhBMP-2	1997	International Journal of Oral & Maxillofacial Implants	126	Treatment	Animal study
97	Oliveira, MN	Can degradation products released from dental implants affect peri-implant tissues?	2018	Journal of Periodontal Research	123	Epidemiology	Review
98	Schwarz, F	Nonsurgical treatment of moderate and advanced periimplantitis lesions: a controlled clinical study	2006	Clinical Oral Investigations	122	Treatment	Prospective clinical study
99	Belibasakis, GN	Microbiological and immunopathological aspects of peri-implant diseases	2014	Archives of Oral Biology	121	Epidemiology	Review
100	Wilson, TG	Foreign bodies associated with peri-implantitis human biopsies	2015	Journal of Periodontology	119	Epidemiology	Cross-sectional

APPENDIX B

The scatter plot presenting the number of citations and age of publication for each paper. There was not any statistically significant correlation between age and the citation count.

