

## Brief Communication

# Global research trends of peri-implantitis during the last two decades: a bibliometric and visualized study

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**Abstract:** Peri-implantitis is one of the most prevalent and impactful complications of dental implant prostheses. This study aimed to identify area focuses and emerging trends in peri-implantitis research. A literature search was conducted in the Web of Science Core Collection (WoSCC), employing a bibliometric approach for data evaluation. VOSviewer and CiteSpace software were used for identifying and analyzing research foci and trends. Between 2001 and 2020, there were 2,346 publications on peri-implantitis. Leaders in number of articles published and collaboration networks were USA and Europe. High-frequency keywords included periodontitis, treatment, prevalence, titanium, follow-up, survival, in vitro, and bone loss. Keyword burst detection analysis revealed epidemiology, outcomes, and impact as emerging research hotspots. The findings suggest a need for more international multicenter clinical studies on peri-implantitis, with future studies likely focusing on prevalence, treatment, and predisposing factors.

**Keywords:** Peri-implantitis, dental implants, disease hotspot, bibliometrics

## Introduction

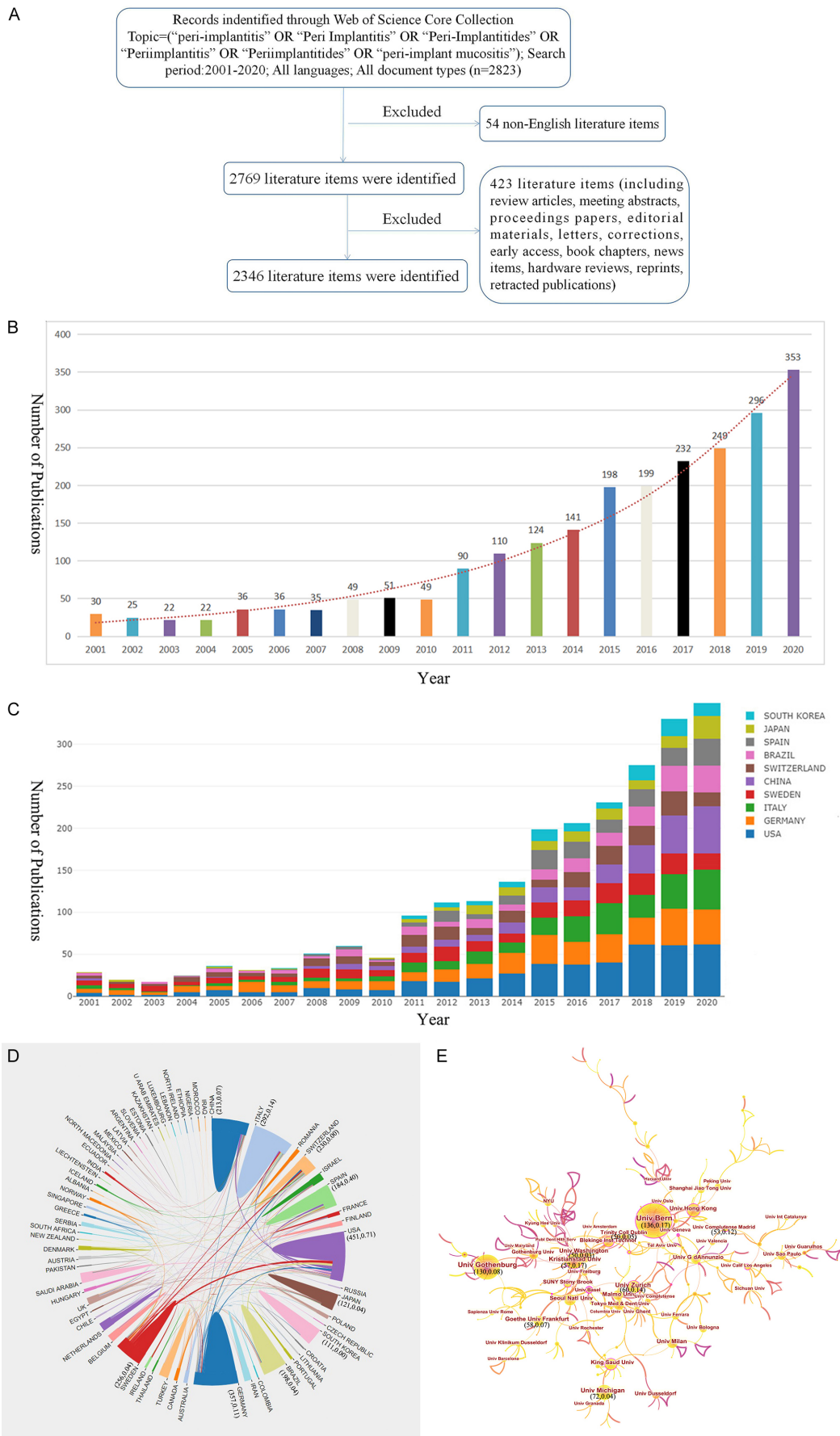
Peri-implantitis, inflammation that develops around implants with successful osseointegration and function, poses significant challenges following implant restoration [1]. This condition is classified into two types: peri-implant mucositis and peri-implantitis. A recent study revealed that over one-third of patients with dental implants and one-fifth of the implants themselves developed peri-implantitis [2], highlighting its severe threat to implant longevity and its role as a primary cause of implant failure. Without timely intervention and appropriate treatment, peri-implantitis can lead to the destruction of surrounding soft and hard tissues, potentially resulting in implant loosening and loss, which in turn causes considerable physical, psychological, and financial burdens for patients.

Although peri-implantitis shares similar onset and progression patterns with periodontitis [3], it typically involves more teeth, progresses more rapidly, and often results in a worse prog-

nosis. The pathophysiology of peri-implantitis remains poorly understood, and the effectiveness of various treatments continues to be debated. Over the last two decades, significant progress has been made globally in understanding the epidemiology, diagnosis, pathogenesis, and therapy of peri-implantitis. However, comprehensive records to guide researchers in identifying study patterns in the field of peri-implantitis research are still lacking.

Bibliometric analysis can aid researchers in constructing the knowledge structure of the field, comparing changes in research hotspots over time, and predicting future research directions. CiteSpace [4] is a java-based information visualization program, and VOSviewer assists in creating network data maps [5]. By analyzing the literature published globally over the past 20 years, we aimed to uncover potential hotspots and research trends from various perspectives, thereby providing dentists with a deeper understanding of the macro and micro characteristics of the peri-implantitis field.

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**Figure 1.** A. Flow chart of literature screening. B. Trends in the number of publications on peri-implantitis research in 2001-2020. C. The top 10 countries/regions on peri-implantitis research in 2001-2020. D. Co-operation between countries/regions in peri-implantitis research (Frequency, Centrality). E. The network map of institutions involved in peri-implantitis research (Frequency, Centrality).

## Materials and methods

In this study, only original publications from 2001 to 2020 in the Web of Science Core Collection (WoSCC) database were included. **Figure 1A** displays the sample search strategy: Subject = (peri-implantitis) and Language = English. To avoid bias due to the continuously updated database, two researchers independently conducted the data analysis, completing all data downloads and literature searches by October 1, 2021.

The WoSCC data was downloaded and converted to text before being entered into the analysis tools. Analysis was performed using VOSviewer 1.6.16 (Leiden University, Leiden, The Netherlands), CiteSpace 5.7. R5, 64-bit (Drexel University, Philadelphia, USA), and a bibliometric online analysis platform (<http://bibliometric.com/>) to identify co-cited articles, keywords, countries, institution, journal, author, and network characteristics of keyword bursts. Metrics such as the H-index and centrality were calculated using the collected data.

## Results

Between 2001 and 2020, a total of 2,346 articles, excluding those from non-research journals and conference proceedings, were retrieved and included for analysis. The number of relevant research articles published in the last decade (1,992) was 5.6 times greater than those published from 2001 to 2010 (354), as shown in **Figure 1B**. Countries leading in publishing articles on peri-implantitis in the last decade were the USA, Germany, Italy, and China, with significant peaks in publication numbers occurring in 2011, 2015, and 2020, respectively (**Figure 1C**).

**Figure 1D** presents a map of the peri-implantitis research collaborative network in various countries. The USA had the highest number of publications and was central to the research collaboration network, with a centrality value of 0.71. This was followed by Spain (0.4), Italy (0.14), and Germany (0.11).

**Figure 1E** highlights that the University of Bern in Switzerland and the University of Gothenburg in Sweden were the two major universities contributing research papers on this topic within the research collaboration network. Notably, only one of the top ten universities in this field was located in the USA. A centrality score greater than 0.1 indicated a high level of inter-institutional collaboration.

The top three researchers in peri-implantitis, as identified in the VOSviewer visualization study author network, were Schwarz F (74 publications), Renvert S (59), and Wang HL (52). The work of Lang received the highest average citation rate (119.46). However, the centrality of all authors' research teams was less than 0.1, suggesting a lack of coordination among the teams (**Figure 2A**).

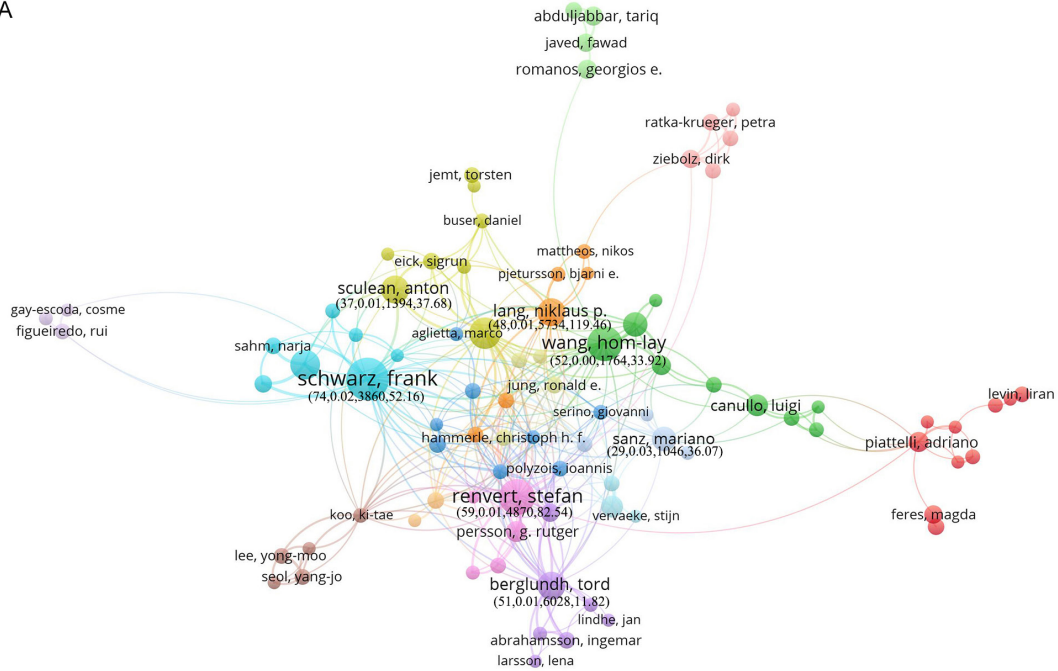
A high-frequency word analysis map of keywords was created by VOSviewer. The most frequently occurring words were 'peri-implantitis' (1,403 occurrences), followed by 'dental implant' (869), 'periodontitis' (341), 'diseases' (310), 'therapy' (283), and 'prevalence' (220). These words were categorized into directories, with the five main categories distinguished by different colors in **Figure 2B**: periodontitis, therapy, infection, follow-up, and European workshop. **Figure 2C** shows the chronological distribution of keywords, while **Figure 2D** displays the distribution of average frequency of keywords over time, with more yellow blocks indicating more recent research hits.

In the first decade, the primary research hotspots in peri-implantitis were animal experiments. In contrast, the past decade focused more on meta-analysis (7.82) and non-surgical treatment (6.28). The keywords 'outcome' and 'impact' began emerging as focal points in peri-implantitis research starting in 2018 (**Figure 2E**).

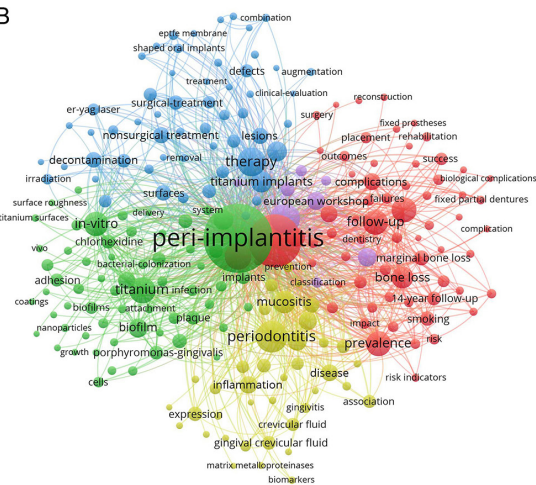
**Figure 3A** shows a visual network diagram of co-cited articles, featuring a total of 79 nodes and 80 links, each representing a citation relationship. The diameter of a node reflects its citation frequency. If a higher frequency of cita-

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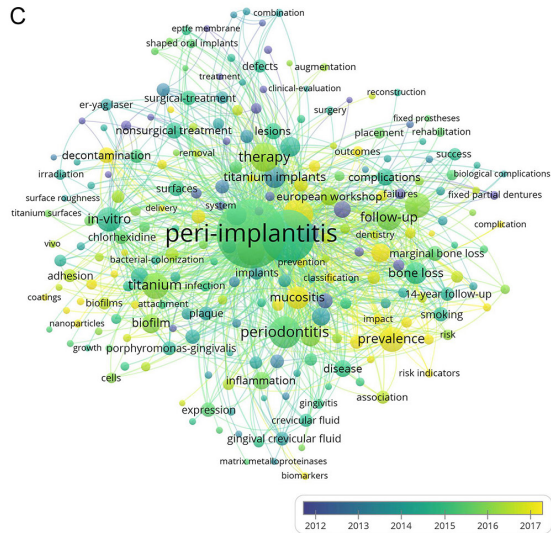
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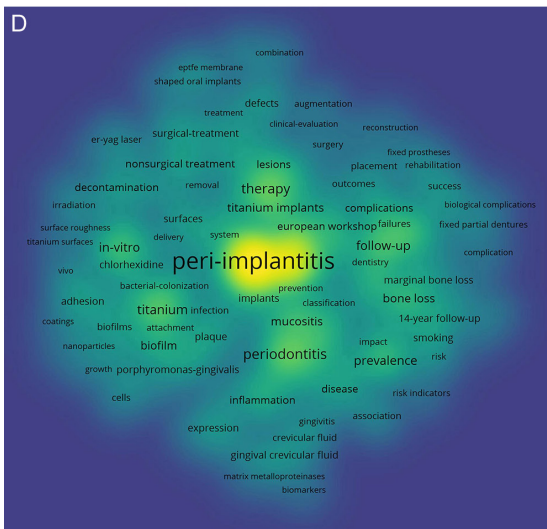
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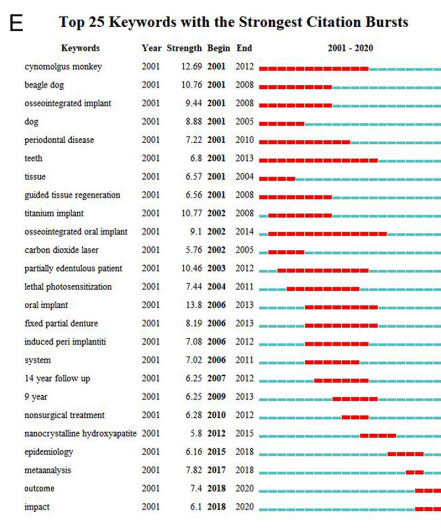
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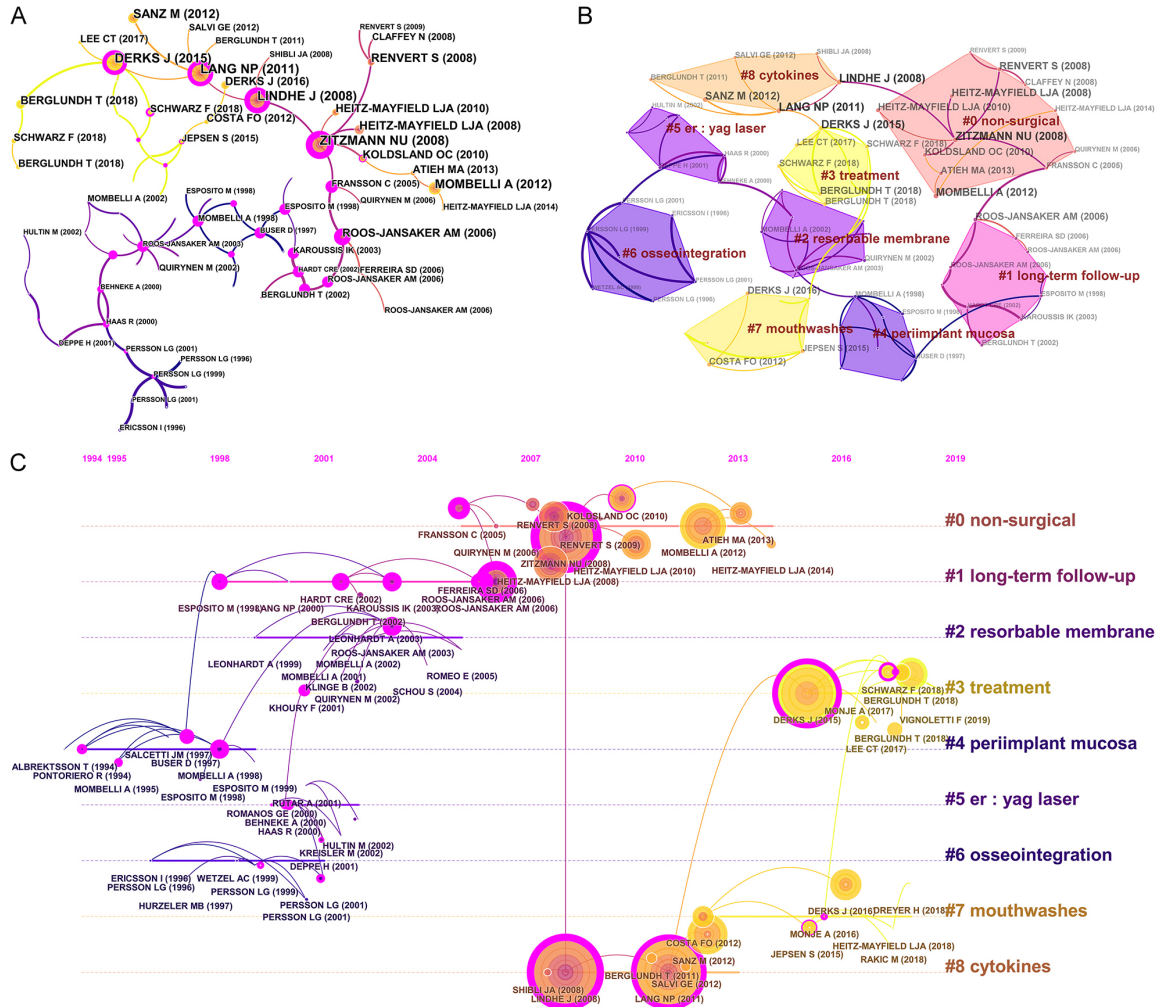
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**Figure 2.** A. Cooperation network of the productive authors in peri-implantitis research (Articles Counts, Centrality, Total Citations, Average Citations). B. Keywords co-occurrence analysis of global research on peri-implantitis based on the WoSCC (Web of Science Core Collection) database. C. Distribution of keywords regarding the chronological order of appearance. D. Distribution of keywords regarding the average frequency of appearance. E. Keywords with the strongest citation bursts in research on peri-implantitis from 2001 to 2020.



**Figure 3.** A. Co-citation map of references on peri-implantitis. B. Clustered network map of co-cited references on peri-implantitis. C. The timeline view of keyword clusters of publications on peri-implantitis.

tion occurs with other papers, the links between nodes are more prominent, indicating closer research content between the authors. A purple circle around a node indicates a stronger centrality relationship between the papers, suggesting a higher degree of collaboration, while a yellow circle indicates the extent of citation during that period.

Further high-frequency cluster analysis revealed eight distinct clustered sections in the field of peri-implantitis. **Figure 3B** demonstrates that the key phrases and cited clusters

with high frequency from 1995 to 2000 were #4 peri-implant mucosa, #6 osseointegration, #1 long-term follow-up, and #2 resorbable membrane, while the main clusters from 2000 to 2013 were #0 non-surgical and #8 cytokines. The issue of #3 treatment has been in the spotlight for the last few years. Yellow circles indicate the heat of the clusters in the study article (**Figure 3C**).

The most frequently referenced paper, with 709 citations, was “Definition and prevalence of peri-implant disorders” by Zitzmann NU, pub-

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**Table 1.** Top 10 co-cited references on peri-implantitis research from 2001 to 2020

Rank	Title	Cited Frequency	Author	Year	Journal
1	Definition and prevalence of peri-implant diseases	709	Zitzmann NU	2008	<i>Journal of Clinical Periodontology</i>
2	A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years	691	Berglundh T	2002	<i>Journal of Clinical Periodontology</i>
3	Effect of material characteristics and/or surface topography on biofilm development	689	Teughels W	2006	<i>Clinical Oral Implants Research</i>
4	A systematic review of the 5-year survival and complication rates of implant-supported single crowns	642	Jung RE	2008	<i>Clinical Oral Implants Research</i>
5	Peri-implant diseases: where are we now? - Consensus of the Seventh European Workshop on Periodontology	593	Lang NP	2011	<i>Journal of Clinical Periodontology</i>
6	Peri-implant diseases: diagnosis and risk indicators	533	Heitz-Mayfield LJA	2008	<i>Journal of Clinical Periodontology</i>
7	Peri-implant health and disease. A systematic review of current epidemiology	507	Derks J	2015	<i>Journal of Clinical Periodontology</i>
8	Periodontal diseases	489	Kinane DF	2017	<i>Nature Reviews Disease Primers</i>
9	A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years	466	Pjetursson BE	2012	<i>Clinical Oral Implants Research</i>
10	Nine- to fourteen-year follow-up of implant treatment. Part II: presence of peri-implant lesions	431	Roos-Jansåker AM	2006	<i>Journal of Clinical Periodontology</i>

lished in *Journal of Clinical Periodontology* in 2008 [6]. “Periodontal disorders”, published in *Nature Reviews Disease Primers* in 2017 by Kinane DF, et al., was the most recent highly referenced article among the top 10 cited publications with high citation frequency (**Table 1**) [7].

### Discussion

To the best of our knowledge, this study represents the first application of both quantitative and qualitative bibliometric methods in the field of peri-implantitis. Our bibliometric analysis of global publications from 2001 to 2020 in peri-implantitis revealed a notable upward trend in research output, particularly an exponential increase in the last decade. This trend signifies a growing interest among researchers in peri-implantitis.

Among the top 10 contributing countries, the USA led with 19.2% of all published papers and demonstrated the most extensive international engagement, as indicated by the highest centrality level. In the last decade, the number of articles from China, Japan, and Brazil has increased significantly. However, these countries appeared to be less collaborative with other nations, as reflected by their lower centrality. The 10 institutions with the most publications in peri-implantitis studies were relatively evenly distributed between Europe and the

USA, with a clear regional dimension, which is mainly influenced by the prevalence of implants, research conditions, and technical competence. We recommend that countries and universities with lower levels of international collaboration, particularly those in emerging areas of peri-implantitis research, consider enhancing their international collaborations to accelerate their progress in this field.

According to the WoSCC database, Schwarz F was the most prolific author in peri-implantitis research, while Berglundh T had the highest total citations. Lang NP stood out with the highest average citations and H-index. The tendency of university hospitals to contribute more significantly to the literature compared to institutes or labs may be attributed to their greater access to tissue specimens and clinical data.

Analysis of the top 10 co-cited references during 2001-2020 indicates a focus on consensus guidelines for peri-implantitis. The definition of peri-implantitis was first proposed by Albrektsson T and Isidor F in 1994 [7]. With the evolution of implant dentistry, the increasing incidence of peri-implantitis has garnered significant research attention. Since human trials were not available and retrospective studies were the only way to identify problems and find solutions, systematic reviews of articles with over five years of post-implant prosthetic observation were more frequently cited and refer-

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enced by scholars from 2002 to 2015 [8-10]; these systematic reviews represented further exploration of the mechanisms, diagnosis, and treatment of peri-implantitis.

By analyzing the citation network and keywords, we can observe the trends of research hotspots during a specific period. High-frequency keywords included 'periodontitis', 'treatment', 'prevalence', 'titanium', and 'follow-up' showing a comparison of peri-implantitis with periodontitis, having keywords 'follow-up time', 'incidence', 'choice of implant material', 'selection of treatment', and 'evaluation of outcome'; all being hot topics in peri-implantitis research. Analysis of top keywords using burst detection revealed that the concentration of research on peri-implantitis has shifted from etiology and pathogenesis to population incidence and prevalence, and from therapeutic options to outcome assessment and prevention strategies.

Understanding the population prevalence of peri-implantitis is crucial for its improvement and prevention. However, the prevalence of peri-implant disease remains a controversial topic, with studies showing prevalence ranging from 1% to 47% [11]. Salvi GE, et al. [12] explored this variation and identified several factors: (a) Varying thresholds for peri-implant bone loss were employed, with the lowest incidence study (1%) using a threshold of over 5 mm [13], and the highest (47%) using a 0.4 mm threshold [14]. Some scholars recommended that bone levels extending at least 3 mm apical to the implant platform constituted a lesion [15]; (b) Meaningful studies were all no less than five years. Studies also showed a 45% morbidity rate after nine years of rehabilitation [16]; (c) Rather than multicenter randomized controlled research, studies relied on a small sample size, primarily from universities or private clinics, which could lead to selection bias. Therefore, establishing consensus criteria is expected to standardize peri-implantitis diagnosis and significantly influence prevalence research.

Our findings indicate that peri-implantitis research was fragmented and irrelevant until 2007, based on the timing of the clustering diagram. From 2007 to 2010, non-surgical treatment was a popular issue in research. Between 2007 and 2013, there was a surge in basic

research on inflammatory cytokines. As treatment techniques and dental consensus have improved, research on treatment decisions has emerged as a new focus in the last five years. Renvert S et al. [17] at the consensus conference emphasized that when clinical and imaging tests suggest the feasibility of retaining an implant, priority should be given to infection management and non-surgical treatment. This includes techniques like sandblasting, Er:YAG laser, metal (titanium) curettes, and plastic-tipped ultrasonic curettes. Additionally, several non-surgical adjunctive treatments were proposed, such as antibiotics with or without microbicides, laser-assisted therapies, and probiotic treatments. The conference also highlighted the importance of regular maintenance check-ups, including peri-implant bleeding on probing (BOP) assessments, radiographs, oral hygiene assessment, and treatment, as well as oral hygiene instruction (OHI) and home care procedures. In cases of severe peri-implantitis, implant loosening was deemed a critical factor for considering implant removal, although no consensus exists on this issue. Wang WC et al. [18] concluded that the decision to remove an implant should be based on the degree of loosening, extent of bone loss, prosthetic design, type of implant, therapeutic prognosis, and patient preference. Thus, combining non-surgical and surgical treatments as needed can effectively manage peri-implant mucositis; early non-surgical intervention is ideal for peri-implantitis, but surgical treatment remains vital, and the maintenance phase of treatment holds significant value.

However, our study has certain limitations. Although the WoSCC database is the world's largest comprehensive academic information resource covering the largest number of disciplines, is the most classic and authoritative citation database in the scientific community, and often chosen for bioinformatics research [19, 20], the quality of papers within it varies, potentially leading to some unavoidable analysis errors. Additionally, our current visualization software can only process one database at a time, and the exclusion of reviews, books, and chapters may introduce a bias in the statistical results.

### Conclusion

Over the past two decades, the field of peri-implantitis has seen a steady increase in

research publications, with the USA and Europe leading contributions. Our study has identified key authorities, compiled a list of highly cited literature, and evaluated the current hotspots and future directions in peri-implantitis research. This analysis will aid researchers in seeking academic collaborations with leading figures in the field. Peri-implantitis remains a promising research area, with epidemiology and therapeutic policy currently at the forefront of research efforts.

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### Disclosure of conflict of interest

None.

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