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From tradition to innovation: a bibliometric analysis of the evolution of periodontal plastic surgery

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No potential conflict of interest relevant to this article was reported.

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All data generated by this study are included in this manuscript.

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ABSTRACT

Purpose: The aim of this study was to conduct a bibliometric analysis of the periodontal plastic surgery literature to identify trends, research gaps, and key themes within the field and to establish a perspective on documented research.
Methods: This bibliometric study examined research outputs on mucogingival surgery indexed in the Web of Science database from 1990 to 2023. The Science Mapping Analysis Tool (SciMAT) software was used to visualize and predict research trends on this topic.
Results: An analysis of publication distribution by year revealed a decline in the number of publications between 1984 and 1995, followed by an overall upward trend after 1996 despite occasional decreases. The United States contributed the most with 593 publications, and Wang HL (n=74) was the most prolific author. The most frequently used keyword was "gingival recession" (n=625). Overall, the publications received 44,859 citations, averaging 25.49 citations per publication.
Conclusions: Researchers have made significant efforts to improve clinical practices and procedures in periodontal plastic surgery, resulting in an increase in studies over recent years. By analyzing thematic maps and clusters—using indicators such as frequency, citations, and centrality—researchers can identify the strengths, weaknesses, and gaps in current research.

Keywords: Bibliometrics; Connective tissue; Gingival recession; Journal impact factor; Periodontics

INTRODUCTION

Mucogingival surgery is a general term encompassing various periodontal treatments aimed at correcting defects in the position, size, and morphology of the soft tissues and underlying bone support structures around teeth and implants [1]. First introduced by Friedman in 1957 [2], this concept evolved into "periodontal plastic surgery" in 1993 [3]. Over the past 7 decades, periodontal plastic surgery has been increasingly integrated into clinical practice to increase tissue thickness, correct inadequate keratinized tissue width, and address various mucogingival deformities [4,5].

In recent years, patients' increasing aesthetic expectations have underscored the importance of periodontal plastic surgery. The demand for both aesthetically pleasing and functionally

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effective outcomes has spurred interest in aesthetic improvements and periodontal health. Therefore, new techniques and materials are being developed continuously, and scientific studies on periodontal plastic surgery are increasing [6].

Bibliometric mapping is a method used in many academic fields—including medicine, dentistry, econometrics, and social sciences—that involves the quantitative analysis of scientific documents (e.g., by author, topic, institution, citation, or country) using statistical and mathematical tools [7-9]. In other words, it aims to display the structural and dynamic characteristics of scientific research [9-11]. For this purpose, various science mapping software tools, such as VOSviewer, CiteSpace II, Science of Science Tool, UCINET, Cytospace, and CoPalRed, may be used [11-14].

The Science Mapping Analysis Tool (SciMAT) is one such scientific mapping tool that supports multiple bibliometric analysis workflows and facilitates the study of several bibliometric networks (including co-word, co-citation, journal co-citation, author co-citation, author collaboration, bibliographic coupling, journal bibliographic coupling, and author bibliographic coupling) [13]. It also offers advantages that are either limited or absent in other existing programs. SciMAT enables data preprocessing, segmentation by different periods, data reduction, and adjustments of analysis techniques, criteria, and algorithms at various stages [13,14].

Although bibliometric studies have been conducted on various periodontology topics, no specific scientific mapping analysis has focused on periodontal plastic surgery. This study aims to analyze the research development, key themes, and interdisciplinary interactions in periodontal plastic surgery using SciMAT software and to identify significant trends in the area.

MATERIALS AND METHODS

Ethics approval was not required for this study because the data used were publicly available through the Web of Science (WoS) Core Collection database. All publications included in the analysis were accessible without restrictions, and no personal data were collected or analyzed. The data were downloaded from the WoS Core Collection, and using the search criteria to filter relevant publications, 1,751 publications were identified (https://www.webofscience.com; **Supplementary Data 1)**. These records were downloaded in “plain text” format and uploaded to the SciMAT program (https://sci2s.ugr.es/scimat/index.html) (**Figure 1**). Data screening was carried out by Ş.Ç.B on 29.07.2024. In the next stage, the data were extracted and filtered, and 15 publications deemed irrelevant were excluded. The keywords from the remaining 1,736 publications were grouped while considering singular/plural forms, synonyms, and abbreviation usage. Due to a lack of keyword information in publications before 1990, the analyses were performed using data divided into 3 periods: 1990–1999, 2000–2009, and 2010–2023. The first period included 125 publications, the second 319, and the final period 1,207 publications.

A comprehensive literature review was conducted using WoS, a widely preferred database that hosts high-quality publications. In line with the objectives of this study, WoS was selected to provide an up-to-date and reliable source of multidisciplinary scientific publications. Additionally, the citation data and in-depth analytical capabilities offered by WoS provide a strong foundation for bibliometric analyses.

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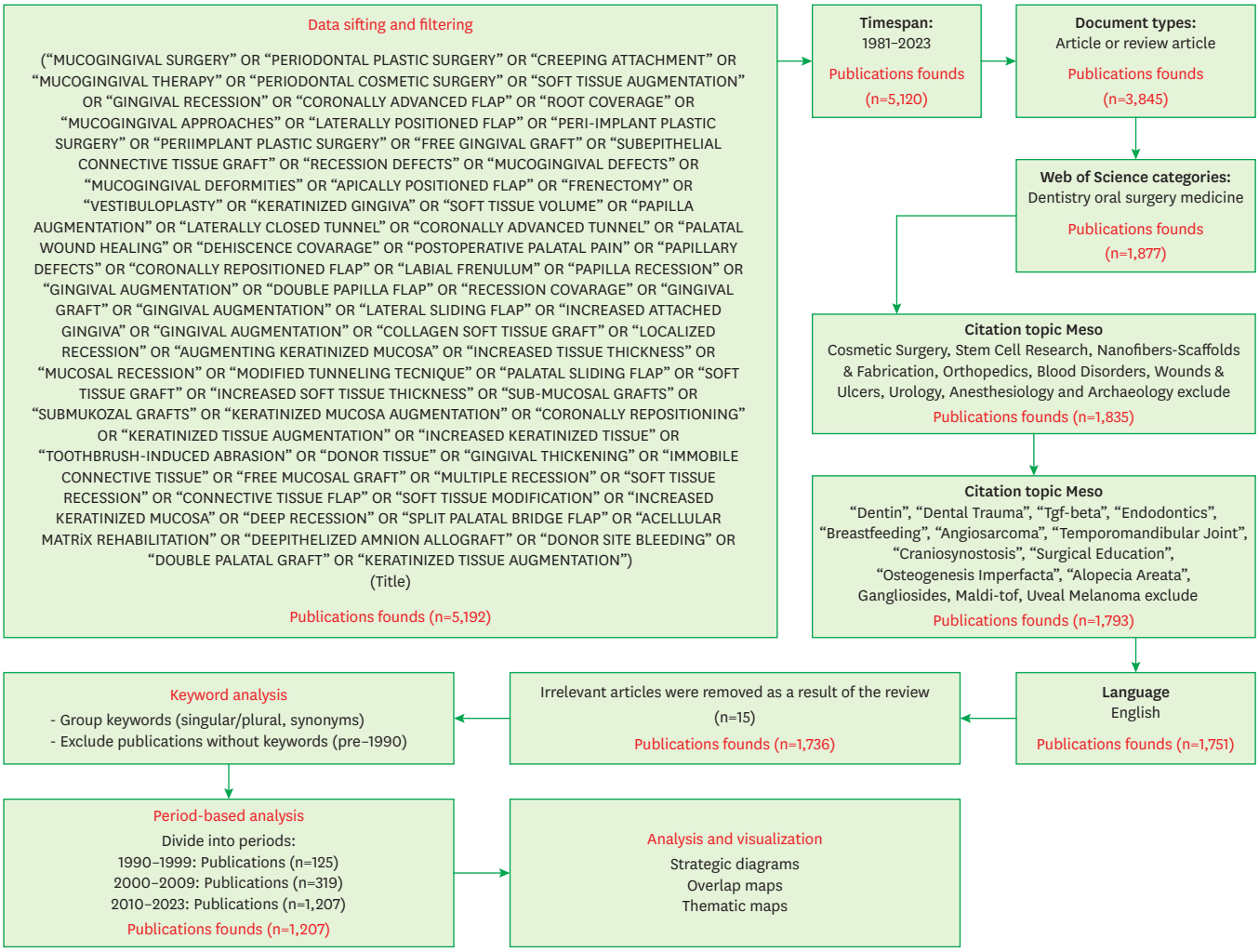


Figure 1. Workflow of data sifting, filtering, and analysis in Science Mapping Analysis Tool (SciMAT) for periodontal plastic surgery research.

The configuration settings of the SciMAT program used in the analyses are as follows:

[Unit of analysis: Words (authorRole=true, sourceRole=true, addedRole=true); Kind of network: Co-occurrence; Normalization measure: Equivalence index; Cluster algorithm: Simple centers; Max cluster size: 10; Min cluster size: 1; Evolution measure: Inclusion index; Overlap measure: Inclusion index]. The findings were reviewed, and it was decided to exclude the "Short Term" and "Masticatory Mucosa" keyword groups from the analysis. Results were presented with strategic diagrams, thematic networks, overlap maps, and thematic development maps. In the visuals, the size of each theme corresponds to the number of publications. The quality of each theme was evaluated based on publication counts, total citation counts, and h-index values. In the strategic diagrams, the positioning of themes was influenced by their centrality and density levels.

Themes with stronger external relations (i.e., higher centrality) were positioned on the right side of the diagram, while themes with stronger internal relations (i.e., higher density) appeared at the top. Based on these characteristics, themes were placed in 4 different areas: motor themes with high centrality and density (top-right), emerging or disappearing themes

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with low centrality and density (bottom-left), foundational and transformational themes with high centrality but low density (bottom-right), and advanced or isolated themes with low centrality and high density (top-left). The thematic networks illustrated the relationships between themes, with the thickness of the lines representing the strength of those relationships. The overlap map showed quantitative changes in the keywords used across the analysis periods. The thematic development map illustrated the horizontal relationships between themes over time, with thicker lines indicating stronger relationships. Solid lines indicate shared keywords between the theme names, whereas dashed lines indicate shared keywords other than the theme names [14,15].

Ethics statement

Since the data are publicly open, ethics approval was not required for this study. Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

RESULTS

Figure 2 shows the distribution of the analyzed publications by year. The graph indicates that publication numbers were low between 1984 and 1995; however, after 1996, an overall increasing trend was observed despite occasional decreases. **Figure 3** presents the distribution of publications by country. The United States ranked first with 593 publications, significantly outpacing other countries. Italy followed with 305 publications, Brazil ranked third with 227, and Turkey was seventh with 95 publications.

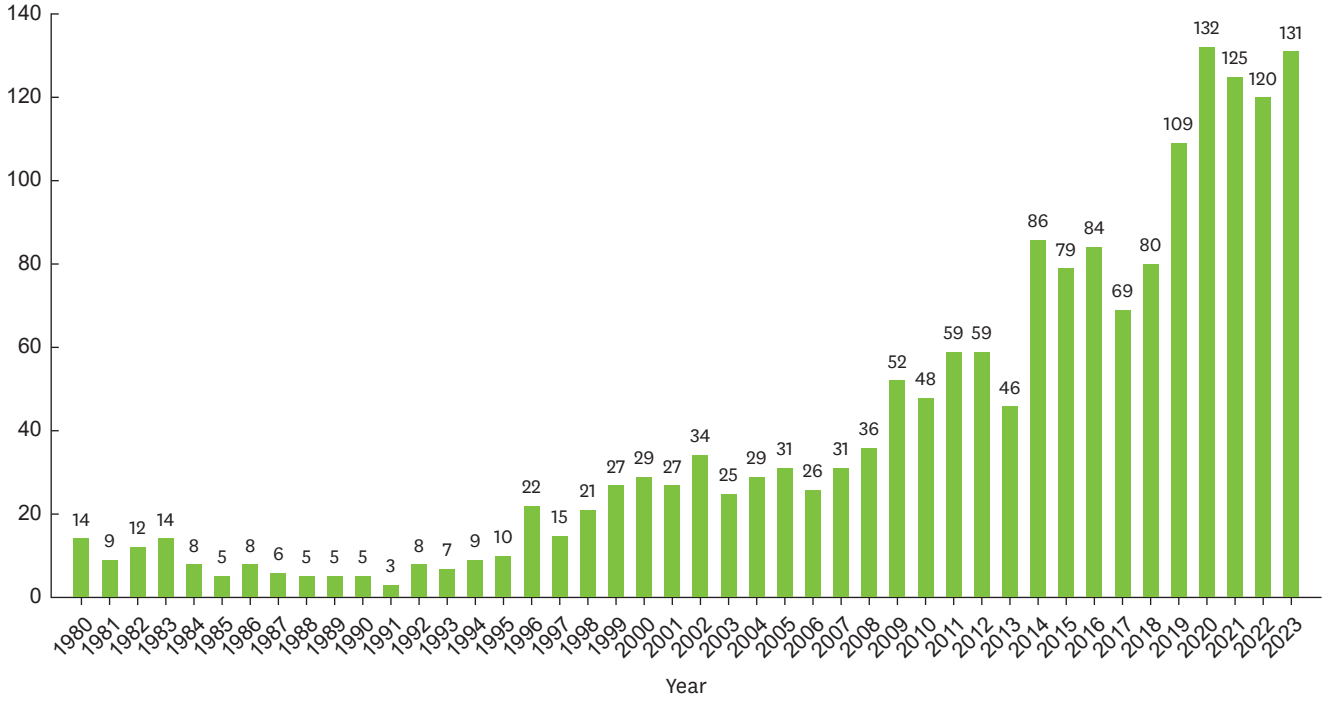


Figure 2. Distribution of articles by years.

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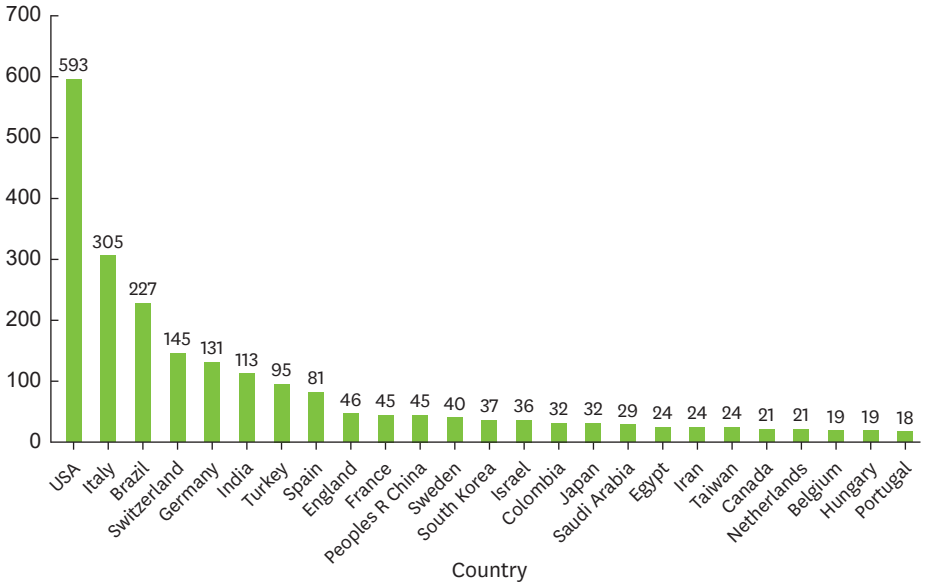


Figure 3. Distribution of articles by countries (top 25 countries).

The publications received a total of 44,859 citations, with an average of 25.49 citations per publication. When self-citations were excluded, the total number of citations decreased to 23,203, and the overall h-index of the publications was 95. **Table 1** provides information on the most cited publications. The top 5 most cited publications were produced by Langer and Langer (1985), Loe et al. (1992), Chambrone and Tatakis (2015), Kassab and Cohen (2003), and Serino et al. (1994). Notably, the publication by Langer and Langer (1985) received 588 citations, while the Chambrone and Tatakis (2015) publication garnered 296 citations in a relatively short time.

Table 2 lists the authors with the most publications. The top 3 authors were Wang HL (n=74), Zucchelli G (n=62), and Tavelli L (n=45).

Table 1. Most-cited publications (top 10)

Rank	Title	Authors	Year	Total citations
1	Subepithelial connective-tissue graft technique for root coverage	Langer, B; Langer, L	1985	588
2	The natural-history of periodontal-disease in man - prevalence, severity, and extent of gingival recession	Loe, H; Anerud, A; Boysen, H	1992	322
3	Periodontal soft tissue root coverage procedures: a systematic review from the AAP Regeneration Workshop	Chambrone, Leandro; Tatakis, Dimitris N.	2015	296
4	The etiology and prevalence of gingival recession	Kassab, MM; Cohen, RE	2003	296
5	The prevalence and distribution of gingival recession in subjects with a high standard of oral hygiene	Serino, G; Wennstrom, JL; Lindhe, J; Eneroth, L	1994	276
6	Postoperative complications following gingival augmentation procedures	Griffin, Terrence J.; Cheung, Wai S.; Zavras, Athanasios I.; Damoulis, Petros D	2006	275
7	Coronally advanced flap procedure for root coverage. Is flap thickness a relevant predictor to achieve root coverage? A 19-case series	Baldi, C; Pini-Prato, G; Pagliaro, U; Nieri, M; Saletta, D; Muzzi, L; Cortellini, P	1999	275
8	Patient morbidity and root coverage outcome after subepithelial connective tissue and de-epithelialized grafts: a comparative randomized-controlled clinical trial	Zucchelli, Giovanni; Mele, Monica; Stefanini, Martina; Mazzotti, Claudio; Marzadori, Matteo; Montebugnoli, Lucio; de Sanctis, Massimo	2010	273
9	Treatment of multiple recession-type defects in patients with esthetic demands	Zucchelli, G; De Sanctis, M	2000	269
10	The interproximal clinical attachment level to classify gingival recessions and predict root coverage outcomes: an explorative and reliability study	Cairo, Francesco; Nieri, Michele; Cincinelli, Sandro; Mervelt, Jana; Pagliaro, Umberto	2011	261

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Table 2. Most prolific authors

Rank	Name	No. of documents
1	Wang HL	74
2	Zucchelli G	62
3	Tavelli L	45
4	Sculean A	42
5	Chambrone L	40
6	Cortellini P	38
7	Barootchi S	37
8	Santamaria MP	36
9	Tatakis DN	35
10	Cairo F	35

Table 3 presents the most frequently used keyword groups in the analyzed publications. "Gingival recession" was the most common keyword (n=625), followed by "root coverage" (n=443) and "connective tissue Graft" (n=393).

The strategic diagram for the period 1990–1999 (**Figure 4**) illustrates key research themes and their relationships based on conceptual density and interaction levels. A total of 12 themes were identified during this period and were categorized by strategic significance. Five themes were classified as motor themes ("recession," "guided tissue regeneration," "citric acid," "gingival recession," "root coverage"); 2 as isolated and advanced themes ("healing response," "toothbrushing/adverse effects"); 2 as basic and transformational themes ("clinical evaluation," "attached gingiva"); and 3 as emerging or disappearing themes ("dogs," "periodontal repair," "periodontal disease"). The diagram visually organizes these themes, with central themes representing critical areas of focus and peripheral themes denoting less interconnected but still relevant domains.

Table 4 shows that during the 1990–1999 period, the theme "guided tissue regeneration" had the highest number of publications (n=41), a total of 2,727 citations, and an h-index of 32. The "gingival recession" theme, with 15 publications, accumulated 1,281 citations and an h-index of 14.

Table 3. Most frequently used words (top 20)

Sequence No.	Word group	Number
1	Gingival recession	625
2	Root coverage	443
3	Connective tissue graft	393
4	Coronally advanced flap	318
5	Defects	284
6	Connective tissue	254
7	Graft	216
8	Surgery	157
9	Dental implants	154
10	Guided tissue regeneration	144
11	Root coverage procedures	143
12	Outcomes	143
13	Thickness	143
14	Acellular dermal matrix	143
15	Regeneration	140
16	Surgical flaps	134
17	Mucogingival surgery	130
18	Prevalence	124
19	Gingival recession/Surgery	120
20	Periodontal plastic surgery	116

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Table 4. Findings related to the themes (1990–1999)

Name	No. of documents	No. of citations	h-index	Centrality	Density
Guided tissue regeneration	41	2,727	32	215.78	58.06
Citric acid	16	970	14	104.61	36.99
Recession	10	753	10	35.04	81
Gingival recession	15	1,281	14	66.9	32.47
Root coverage	11	825	10	101.61	17.41
Clinical evaluation	13	687	11	89.89	11.48
Attached gingiva	4	193	3	17.77	9.26
Healing response	3	149	3	13.27	50
Toothbrushing/Adverse effects	2	96	2	2.55	33.33
Dogs	3	198	3	14.54	16.07
Periodontal repair	2	92	2	9.55	13.33
Periodontal disease	2	335	2	14.18	7.41

The strategic diagram for the period 2000–2009 (**Figure 5**) reflects the strategic priorities of that period. Themes are positioned according to their centrality and intensity, with a greater concentration of emerging themes at the center and peripheral themes supporting the overall strategic ecosystem. In this period, 16 themes emerged. Of these, 6 were motor themes ("bioabsorbable membrane," "longitudinal evaluation," "root coverage," "tooth root/surgery," "acellular dermal matrix," "smoking"); 3 are isolated and advanced themes ("glass ionomer cement," "12 case reports," "dental implants"); 3 were basic and transformational themes ("histologic evaluation," "collagen/therapeutic use," "thickness"); and 4 were emerging or disappearing themes ("gingiva/anatomy and histology," "localized gingival recessions," "gingival recession defects," "monkeys").

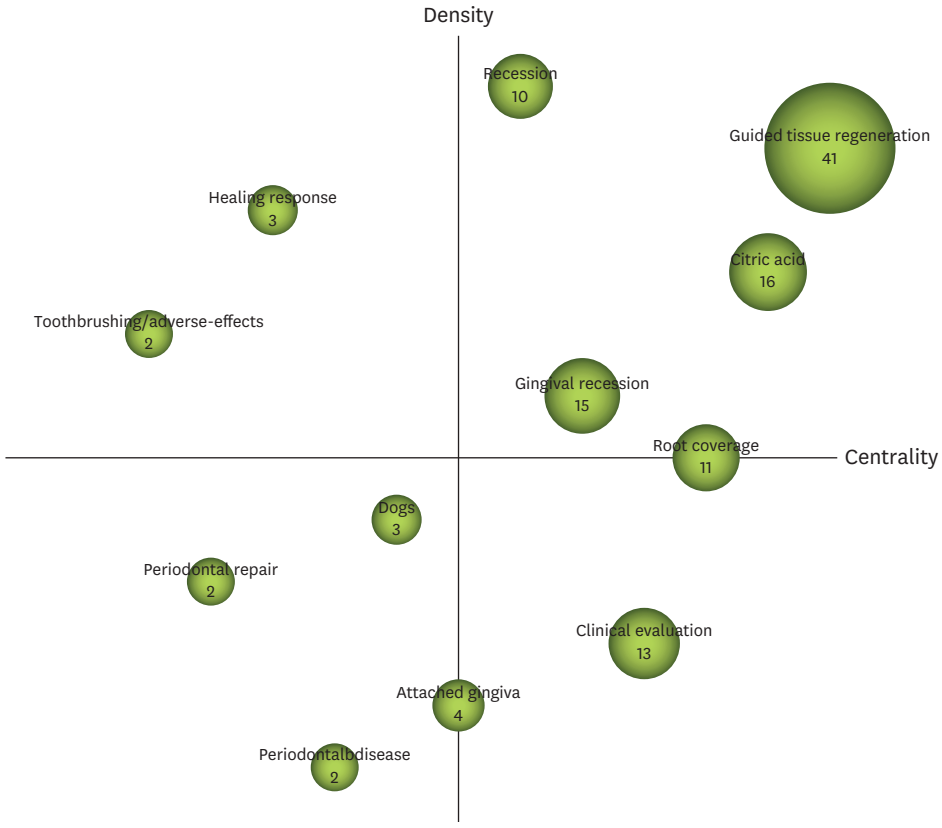


Figure 4. Strategic diagram (1990–1999).

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Figure 5. Strategic diagram (2000–2009).

Table 5 indicates that for the 2000–2009 period, the "root coverage" theme had the highest number of publications (n=11) with 8,527 citations and an h-index of 56. The "Bioabsorbable Membrane" theme had 113 publications, 5,970 citations, and an h-index of 47.

The strategic diagram for the period 2010–2023 (**Figure 6**) maps research areas according to centrality and density. In this period, 24 themes were identified. Among these, 9 were motor themes ("coronally advanced flap," "width," "esthetic zone," "modified coronally advanced tunnel," "patient morbidity," "prevalence," "soft tissue augmentation," "consensus report," "multicenter"); 4 were isolated and advanced themes ("proclination," "glass ionomer restoration," "zone," "laser"); 4 were basic and transformational themes ("connective tissue," "allograft," "matrix," "regeneration"); and 7 were emerging or disappearing themes ("dental," "beta-tricalcium phosphate," "bone graft," "vestibuloplasty," "sites," "randomized clinical trial," "recession"). Topics such as "coronally advanced flap," "width," and "connective tissue" in the upper right corner stand out as the most important and well-studied, being both central and mature. In contrast, themes like "Matrix" and "Allograft" on the bottom right are central but open to further research and development, while themes in the left sections are either specific and isolated (top left) or less studied niche areas (bottom left).

The findings regarding the themes for the 2010–2023 period are given in **Table 6**. The theme with the highest number of publications (n=573) and citations (n=12,424) in this period was

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Figure 6. Strategic diagram (2010–2023).

Table 5. Findings related to the themes (2000–2009)

Name	No. of documents	No. of citations	h-index	Centrality	Density
Bioabsorbable membrane	113	5,970	47	187.31	60.02
Root coverage	170	8,527	56	186.48	27.59
Tooth root/Surgery	46	2,882	33	114.99	23.05
Longitudinal evaluation	20	1,606	16	37.16	31
Acellular dermal matrix	30	1,947	23	70.43	10.16
Histologic evaluation	24	1,000	17	65.43	9.71
Smoking	22	1,143	18	41.11	9.89
Thickness	23	1,275	17	50.4	4.4
Dental implants	9	414	6	5.65	12.52
Localized gingival recessions	6	377	5	16.76	7.56
Glass ionomer cement	4	222	4	8.86	64
12 Case report	4	75	4	16.18	13.7
Gingiva/Anatomy and histology	4	90	3	9.1	8.15
Collagen/Therapeutic use	3	97	3	19.72	7.76
Monkeys	3	47	3	3.86	5.54
Gingival recession defects	2	143	2	11.87	5.71

"coronally advanced flap" with an h-index value of 55. The "width" theme, which ranked second in terms of the number of publications (n=129), had a total number of citations of 2,335 and an h-index value of 25. It is noteworthy that the total number of citations of the "connective tissue" theme, which had 111 publications and an h-index value of 25, was 2,376.

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Table 6. Findings related to the themes (2010–2023)

Name	No. of documents	No. of citations	h-index	Centrality	Density
Proclination	45	899	17	21.14	45.27
Coronally advanced flap	573	12,424	55	149.1	38.66
Esthetic zone	55	980	19	37.5	26.04
Width	129	2,335	25	51.97	27.78
Modified coronally advanced tunnel	55	1,723	22	48.48	20.88
Prevalence	59	1,366	18	31.92	13.59
Glass ionomer restoration	34	751	14	21.74	22.09
Soft tissue augmentation	72	1,770	22	46.42	7.84
Patient morbidity	63	1,341	19	27.91	14.77
Connective tissue	111	2,376	25	49.72	4.96
Consensus report	66	1604	23	45.11	7.77
Multicenter	41	1,526	21	35.66	5.72
Regeneration	46	1,484	19	37.01	1.51
Allograft	40	758	15	34.56	3.37
Matrix	38	575	13	30.63	1.7
Recession	33	288	8	20.94	1.59
Sites	12	269	8	10.28	1.62
Laser	6	82	5	2.92	6.91
Vestibuloplasty	6	257	4	2.8	1.98
Zone	5	71	4	8.28	8.68
Dental	5	48	3	3.78	5.25
Beta tricalcium phosphate	4	59	4	3.75	2.96
Bone graft	3	0	0	0.63	2.14
Randomized clinical trial	3	135	3	3.11	1.61

The overlap map (**Figure 7**) reveals that out of 309 keywords used in the first period, 146 (47%) continued to be used in the second period. The keyword count increased to 795 in the second period, with 439 (55%) of these keywords also appearing in the final period, which saw a total of 2,019 keywords.

Figure 8 presents the thematic development map showing relationships between themes across the analysis periods. The map reveals that the "bioabsorbable membrane" theme was associated with "guided tissue regeneration" and "clinical evaluation" in the first period and with "connective tissue" in the final period. Furthermore, the "root coverage" theme in the first 2 periods was linked to "coronally advanced flap" in the final period. The "longitudinal evaluation" theme was connected with "recession," "attached gingiva," and "periodontal disease" in the first period and with "width" in the final period. The "smoking" theme in the second period exhibited a strong relationship with "healing response" and "periodontal disease" from the first period. Additionally, the "dogs" theme from the first period was related to "dental implants" in the second period, and "periodontal repair" from the first period was linked to "localized gingival recessions" in the second period. Finally, the "gingival recession

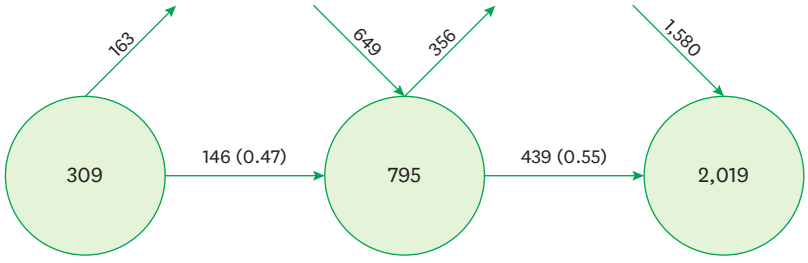


Figure 7. Overlap map.

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defects" theme from the second period was associated with "citric acid" from the first period and "multicenter" from the final period.



Figure 8. Thematic evaluation map (1990–2023).

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DISCUSSION

Bibliometrics involves a structured analysis of large data sets to identify prevailing research themes and trends over time. It provides a "big picture" of current research, facilitating the recognition of conceptual developments and shifts in disciplinary boundaries [16]. This study offers a comprehensive analysis of the literature on periodontal plastic surgery using the bibliometric tool SciMAT, thereby reflecting the evolution of research in this field and highlighting the most influential studies and authors. The findings are visualized through thematic networks, co-occurrence maps, thematic evolution maps, and strategic diagrams. The WoS database, one of the most comprehensive and widely used sources for literature reviews and bibliometric analyses [17], served as the basis for this study.

A total of 1,736 publications related to periodontal plastic surgery were retrieved from the WoS Core Collection between 1980 and 2023. The annual number of publications began to increase after 2013, with a significant rise observed after 2018. This trend may be attributed to patients' growing consciousness of periodontal health and heightened aesthetic expectations in recent years.

The USA and Italy emerged as the leading countries in periodontal plastic surgery research. The research ecosystems, institutional networks, and funding structures in these countries are key drivers of development in this field. The USA benefits from a strong infrastructure with large universities and research hospitals, robust private-sector collaborations, and substantial research budgets that facilitate innovative projects in biotechnology and biomaterials [18]. Italy, while conducting smaller-scale research, produces high-quality studies. Italian universities and research institutes possess deep expertise in biomaterials and clinical research, supported by European Union funding and local support. This strong, focused network fosters the development of innovative projects, and the regulation of biotechnology and genetics research in both countries accelerate scientific discovery while maintaining ethical standards [19].

The publication year undoubtedly affects the number of citations a work receives. The true influence of a research article is often best assessed at least 20 years post-publication, which means older research typically accumulates more citations, while more recent articles have had less time to do so [20]. Nonetheless, some recent studies have garnered more citations than many older works; this may be because 58.4% of the articles were published within the last 10 years, and increased interest in the topic has amplified the impact of newer research.

The top 3 researchers with the highest publication counts are from the USA and Italy, which is consistent with the leading publishing status of these countries. Moreover, co-authorship among these researchers underscores the collaborative nature of research in this field [21,22].

The analysis identified "gingival recession" as the most commonly used keyword (n=625), followed by "root coverage" (n=443) and "connective tissue graft" (n=393). Most cited articles were related to root coverage, indicating that clinical research in periodontal plastic surgery places particular emphasis on root coverage procedures [4].

During the 1990–1999 period, research focused on fundamental topics such as guided tissue regeneration and gingival recession. High h-index values and citation counts during this period underscore the growing importance of regenerative treatments in periodontal

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therapy and surgery. In the 1990s, the widespread use of guided tissue regeneration and the successful outcomes achieved with various membrane types established its effectiveness and safety, solidifying its role as a key treatment modality [23]. The first surgical approaches to GR emerged in the 1980s and by the 1990s, guided tissue regeneration methods and connective tissue grafts had become popular, leading to significant clinical successes [24]. These thematic connections illustrate how closely linked gingival recession and guided tissue regeneration are within periodontal treatment.

In the 2000–2009 period, "root coverage" and "bioabsorbable membranes" emerged as the most cited themes. By 2000, advances in biomaterials had led to significant progress in periodontal therapy, focusing on treatments that improved both aesthetics and function. For larger defects, guided tissue regeneration treatments using bioabsorbable membranes yielded more favorable results than open flap debridement. Unlike traditional membranes, bioabsorbable membranes naturally resorb during healing, eliminating the need for a second surgery, and have demonstrated superior stimulation of cellular proliferation compared to non-resorbable membranes. The combination of increasing aesthetic demands and innovative techniques contributed to more research on root coverage treatments during this period, resulting in higher citation rates [25].

The increase in themes between 2010 and 2023 can be attributed to advancements in clinical practices, rising demands for aesthetic and functional treatments, the development of biomaterials, enhanced international collaborations, and the standardization of treatment methods [26]. During this period, the "coronally advanced flap," "width," and "connective tissue" themes emerged as prominent motor themes, supported by high citation counts. The coronally advanced flap (CAF) technique is widely recognized as one of the most reliable options for root coverage due to its long history and continuous development; it is often used as a control in clinical trials. Additionally, the fact that alternative treatment approaches do not have a comparable volume of literature to CAF, it becomes challenging to definitively establish the superiority of one technique over another in various clinical scenarios [27]. Another key motor theme, "width" is critical for achieving aesthetic improvements and successful treatment of gingival recession, as increased gingival width enhances both appearance and healing outcomes [28]. The third important motor theme, "connective tissue," is considered the most successful type of graft for treating gingival recession. The use of connective tissue grafts enhances both aesthetic and functional healing. According to the 2015 American Academy of Periodontology Regeneration Workshop [27], subepithelial connective tissue grafts (SCTG)+CAF is regarded as the optimal approach for root coverage. A review by Chambrone et al. [29] showed that CAF combined with SCTG remains the gold standard for single gingival recession defects. In addition to connective tissue grafts (e.g., SCTG), alternative grafting materials are also available. According to a meta-analysis by Chambrone et al. [30], both platelet-rich fibrin+CAF and emdogain+CAF provide lower root coverage and keratinized tissue width gains compared to SCTG+CAF, which is still considered the gold standard for root coverage treatment. A study by Tonetti et al. [31] compared combines collagen matrix+CAF with SCTG+CAF, and while no differences were found in patient-reported outcomes, SCTG+CAF was more successful in terms of root coverage. In a meta-analysis by Cairo et al. [32], connective tissue graft procedures showed the highest overall aesthetic performance for root coverage and higher patient satisfaction. These reasons underscore why CAF and connective tissue emerged as key motor themes in the discussion of root coverage techniques.

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The overlap map analysis shows that 146 out of 309 keywords from the first period (47%) continued into the second period, highlighting the persistent relevance of core topics. The increase to 795 keywords in the second period indicates an expansion of the field with the emergence of topics such as biomaterials, new treatment methods, and technological advancements. In the third period, 439 keywords (55%) persisted, reflecting both the sustained importance of these themes and the introduction of new ones. The total keyword count reaching 2019 by 2023 signifies the diversification and growth of research, with an increased focus on aesthetics, biomaterials, and minimally invasive surgical approaches.

The thematic development map (**Figure 8**) reveals not only how periodontal plastic surgery research has evolved but also how some older treatment modalities have been replaced by newer approaches. For example, the "bioabsorbable membrane" theme was initially linked to "guided tissue regeneration" and "clinical evaluation" but is now associated with "connective tissue," reflecting advancements in regenerative techniques. Bioabsorbable membranes, designed as physical barriers to support the regeneration of connective tissue and bone by preventing epithelial downgrowth, have been improved over time in terms of biocompatibility, controlled degradation, and tissue integration. Their combination with connective tissue grafts has enhanced both aesthetic and functional outcomes while improving tissue stability. This evolving relationship between biomaterials and surgical methods demonstrates how the field is adapting to meet higher aesthetic demands and achieve more predictable treatment outcomes. Future research may further improve membrane properties and foster innovative combinations with connective tissue techniques [33]. Root coverage procedures remain among the most frequently performed operations in periodontal plastic surgery. Since the 1980s, various techniques and materials have been employed for this purpose [27]. The CAF technique, noted for its continuous development, high patient satisfaction, and excellent aesthetic outcomes, has gained prominence—particularly after 2010—and is frequently used as the control in clinical trials [32]. Initially, the "longitudinal evaluation" theme was associated with fundamental issues such as "recession," "attached gingiva," and "periodontal disease," suggesting that early mucogingival surgery primarily addressed basic clinical problems [6]. Today, its association with more specific parameters (e.g., "width") indicates that clinical research and practice are adopting more detailed and individualized approaches [28]. This shift reflects a growing interest not only in clinical outcomes but also in patient satisfaction, aesthetic results, and overall periodontal function. The map also shows that the "Smoking" theme had a strong association with "healing response" and "periodontal disease" in the early years, underscoring smoking's significant negative impact on periodontal healing and surgical outcomes. This relationship, well documented in earlier research, remains an important area of study given smoking's adverse effects on microvascular circulation and tissue healing [34]. Furthermore, the prominence of the "laser" theme in the post-2010 period highlights the increasing focus on minimally invasive treatment approaches. Lasers offer benefits such as tissue biomodulation, accelerated healing, and reduced postoperative discomfort, and are expected to become a standard component of clinical protocols [35]. "Beta-tricalcium phosphate" (β-TCP) has also gained importance as a biocompatible graft material for bone regeneration. Its controlled resorption and osteoconductive properties have expanded its use in periodontal regenerative surgery, presenting a promising area for future research in biomaterial customization. For example, Okubo et al. [36] found that combining β-TCP with type I collagen for alveolar ridge preservation effectively maintained peri-implant soft and hard tissue stability, and Shujaa Addin et al. [37] demonstrated that β-TCP combined with recombinant basic fibroblast growth factor enhanced periodontal wound healing and regeneration in extraction defects in canine teeth.

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The bibliometric findings of this study are particularly valuable for practitioners in periodontal plastic surgery. By identifying emerging research trends and key themes, clinicians can stay informed about the latest advances in surgical techniques and patient-centered outcomes. Understanding the evolution of both aesthetic and functional approaches enables practitioners to adopt evidence-based practices that align with current developments. Furthermore, the growing emphasis on integrating advanced technologies such as regenerative medicine and minimally invasive techniques offers opportunities to improve patient outcomes through more personalized and effective treatments [38]. This study, therefore, provides valuable insights that can inform clinical practice, enhance decision-making, and encourage innovation in treatment modalities.

It is important to acknowledge the limitations of bibliometric analyses. This study used the WoS database, which may have overlooked some relevant publications or research areas. Other major databases, such as Scopus and Google Scholar, offer different datasets and may include newer or lesser-known publications on specific topics. Consequently, relying solely on WoS might miss some literature; however, WoS's robust dataset covers much of the high-quality literature targeted in our study, so this limitation minimally affects the overall scope. Citation bias is another limitation, as older studies typically accumulate more citations over time, potentially overshadowing newer research. Furthermore, an over-reliance on publication counts does not always reflect research quality, and variations in journal impact factors may lead to certain studies being overrepresented [39]. Language and geographical biases should also be considered because this study analyzed only English-language articles and reviews, potentially neglecting important research published in other languages or regions. Nevertheless, the large volume of publications analyzed and the comprehensive assessment of emerging trends mitigate these limitations. Finally, citation counts do not fully capture the context of the studies, and interdisciplinary advancements may be underrepresented. Recognizing these limitations is essential for a balanced interpretation of the analysis [40].

To the best of our knowledge, this study is the first bibliometric analysis to comprehensively evaluate the field of periodontal plastic surgery. It provides a structured and detailed overview of research trends, key themes, and influential authors in this field. The analysis highlights several critical themes in periodontal plastic surgery, emphasizing significant advancements in the development and evolution of these themes, the integration of surgical techniques, and an increasing focus on aesthetic outcomes. Additionally, this study serves as a valuable resource for understanding the current state of periodontal plastic surgery research and lays the groundwork for future studies.

Future research in periodontal plastic surgery can benefit from emerging technologies and personalized medicine. Advances in artificial intelligence, 3D printing, and personalized therapies have the potential to revolutionize surgical procedures by making them more accurate, minimally invasive, and tailored to individual patient needs. Furthermore, the integration of tissue engineering and regenerative medicine will play an important role in restoring lost periodontal structures, offering new solutions beyond traditional procedures. Underexplored areas—such as the treatment of periodontal conditions in specific patient populations (e.g., individuals with systemic diseases or rare conditions)—could provide valuable insights for future research. Collaborative efforts among periodontists, orthodontists, biomaterials scientists, and engineers will be crucial in developing multidisciplinary approaches that address both the aesthetic and functional needs of

patients. As digital health technologies and artificial intelligence continue to advance, the potential for more effective diagnostic tools and personalized treatment plans will grow. Ensuring accessibility to advanced treatments for diverse populations will be essential for creating equitable solutions and overcoming geographical limitations. These emerging trends, combined with new methodologies in precision medicine, promise to define the future of periodontal plastic surgery and offer transformative opportunities for both research and clinical practice.

SUPPLEMENTARY MATERIAL

Supplementary Data 1

Periodontal plastic surgery search strategy

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