

Research Article

# The Evolution of Bone Augmentation in Dentistry: A Bibliometric Analysis

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## Abstract

**Objectives:** This study aimed to map the scientific landscape of bone augmentation within oral and maxillofacial surgery using bibliometric methods, identify publication and citation trends and highlight the most influential contributions shaping current clinical practice.

**Methods:** Relevant articles were retrieved from the Web of Science Core Collection using a tailored search strategy. Bibliometric analyses were performed with the Bibliometrix R-package to assess publication trends, author collaboration networks, keyword co-occurrences and thematic structures. Co-citation analysis was conducted to explore the evolving intellectual framework, with emphasis on clinical relevance.

**Results:** Publications on bone augmentation have steadily increased since the mid-2000s, with a notable citation peak in 2006. Clinical Oral Implants Research and the International Journal of Oral and Maxillofacial Implants were identified as leading publication platforms. The 1997 study by Zitzmann NU received 114 local citations, achieving an LC/GC ratio of 26.21%. Key thematic trends revealed a balance between basic research and applied surgical innovations.

**Conclusion:** Bone augmentation remains a dynamic and growing area within oral and maxillofacial surgery. These bibliometric insights can guide future collaborations, inform research priorities and support the integration of evidence into clinical decision making for improved patient outcomes.

**Keywords:** Bone Augmentation; Bibliometrix R-Package; Key Thematic Trends

## Introduction

Alveolar bone loss is a common and significant clinical problem in dentistry. Although most frequently associated with periodontitis, it can also result from tooth extraction, trauma and other local factors, all of which contribute to dimensional changes in the alveolar ridge [1,2]. These alterations adversely affect tooth stability, function and esthetics and often necessitate the restoration of bone volume prior to dental implant placement [3]. To address this challenge, various bone augmentation techniques have been developed, including vertical, horizontal or combined approaches depending on the type of defect [4]. These procedures typically require the integration of autologous, allogeneic, xenogeneic or synthetic graft materials, along with barrier membranes and bioactive agents such as growth factors [5-7].

Although augmentation techniques and materials have been extensively studied, the field remains dynamic and continuously evolving. This ongoing development makes it increasingly challenging for researchers to keep pace with the expanding body of literature. Therefore, a comprehensive mapping of the scientific landscape and research trends in this area is of significant importance.

Bibliometric analysis has emerged as a valuable tool for assessing scientific output across various elements such as articles, authors, keywords, journals, institutions and countries within a given research field. It enables the examination of how a field has evolved over time based on the relationships and interactions among these components [8,9]. Such analyses allow for a

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comprehensive and systematic understanding of a field's current structure, the identification of research clusters, the detection of emerging trends and the mapping of core concepts along with their interconnections [10]. In this context, bibliometric approaches have been widely applied across various subfields of medicine and dentistry, proving to be an effective method for exploring the dynamics of domain-specific scientific production [11,12].

This study aims to conduct a bibliometric analysis of scientific publications on bone augmentation in dentistry published in the Web of Science (WoS) database between 1980 and 2025. By comprehensively evaluating publication trends, leading researchers and institutions, citation patterns and thematic developments, the study seeks to map the historical evolution of scientific output in the field of bone augmentation. The findings are intended to provide researchers working in this area with an integrated perspective for assessing the current knowledge structure, identifying future research opportunities and developing strategic directions.

## Material and Methods

This bibliometric study aimed to provide a comprehensive overview of research on bone augmentation procedures in dentistry. The search strategy was designed to capture a wide range of augmentation techniques in order to map the scientific landscape as broadly as possible. Including different augmentation approaches in a single dataset enabled the identification of shared research themes, overlapping biomaterials and methodological advances. Other regenerative indications, such as socket preservation and peri-implantitis defect grafting, were excluded because they represent distinct clinical scenarios with different objectives and evaluation criteria. The search strategy and methodological workflow are summarized in Supplementary Fig. 1. PRISMA-S (Preferred Reporting Items for Systematic Reviews and Meta-Analyses - Search extension) guidelines, which are internationally recognized for enhancing transparency and reproducibility in systematic reviews [11]. A completed PRISMA-S checklist is provided in Supplementary Fig. 1. The search parameters are summarized in Supplementary Table 1, detailing database selection, search date, full query, applied filters and number of retrieved records after each screening step. Since all data used in this study are publicly available, ethical approval was not required.

In this study, the Web of Science (WoS) database one of the most commonly used platforms for bibliometric analysis and literature searches was utilized. Different databases vary significantly in terms of journal coverage. WoS is among the most preferred academic sources due to its reliability and comprehensive indexing of high-quality scientific publications [12].

The data search was conducted on May 25, 2025, by Ş.Ç.B using the Web of Science (WoS) database. In the subsequent stage, the retrieved data were screened and filtered. A comprehensive search was performed in WoS using the following query: ("Bone Grafting Maxillary" OR "Bone Augmentation" OR "Alveolar Bone Grafting" OR "Alveolar Ridge Augmentation" OR "Bone Transplantation Maxillary" OR "Bone Regeneration" OR "Dental Bone Graft" OR "Block Graft" OR "Bone Graft Substitute" OR "Bone Substitute" OR "Bone Substitutes" OR "Bone Scaffold" OR "Bone Graft" OR "Bone Grafts" OR "Guided Bone Regeneration" OR "GBR" OR "Maxillary Sinus Lift" OR "Alveolar Bone" OR "Alveolar Bone Preservation" OR "Maxillofacial Bone Augmentation" OR "Hard Tissue Augmentation" OR "Vertical Ridge Augmentation" OR "Horizontal Ridge Augmentation" OR "Maxillary Bone Augmentation" OR "Mandibular Bone Augmentation" OR "Bone Augmentation Techniques" OR "Ridge Split" OR "Ridge Splitting" OR "Bone Splitting" OR "Ridge Expansion" OR "Autogenous Block Graft" OR "Bone Graft Materials" OR "Augmentation Techniques" OR "Khoury Bone Block Technique" OR "Sausage Technique" OR "Urban Technique" OR "Shell Technique" OR "Split-Crest Technique" OR "Bone Volume" OR "Split Bone Block Technique" OR "Tenting Screw Technique" OR "Titanium Mesh" OR "3D Mesh" OR "Collagen Membrane" OR "Narrow Ridge" OR "Sandwich Technique" OR "Sandwich Osteotomy" OR "Segmental Osteotomy" OR "Interpositional Graft" OR "Autograft" OR "Allograft" OR "Xenograft" OR "Resorbable Membrane" OR "Non-Resorbable Membrane" OR "PTFE Membrane" OR "Barrier Membrane" OR "Titanium-Reinforced Membrane"). This initial search yielded 62,502 records. After limiting the document types to "Article OR Review Article," 40,658 records remained. When the WoS indexes "SCI-EXPANDED, ESCI, CPCI-S" were selected, the number was reduced to 40,410. Further filtering by the subject category "Dentistry Oral Surgery Medicine" yielded 2,884 records. Restricting the language to English resulted in 2,819 publications. After excluding two retracted articles (document types: retracted publication), a total of 2,817 publications remained. Since new records are continually added to the database, publications from the year 2025 were excluded to ensure data stability and the final analysis was conducted on 2,722 publications.

The Bibliometrix software was used to perform the analysis of the retrieved data. Bibliometrix is a recent open-source R-based tool developed for conducting science mapping and bibliometric analysis [13].

In our study, a total of 2,722 articles were analyzed under four main sections: publication performance, keyword analysis, co-citation analysis and thematic analysis. During the keyword analysis, similar or synonymous terms were merged under a single keyword to prevent inflation of the total keyword count due to repetitive terms.

#### *Performance Analysis*

This section evaluated key bibliometric indicators, including the h-, m- and g-indices, Total Citations (TC), Publication Year (PY) and Number of Publications (NP). The h-index measures research impact; the m-index adjusts it by career length and the g-index emphasizes highly cited works [14-17].

Journal clustering based on Bradford's Law revealed that most literature is concentrated in a few core journals, while the rest is spread across many less frequent sources, following a structured distribution pattern [18].

A three-field graph was also used to visualize the relationships among authors, institutions and keywords, offering an integrated view of the bibliometric landscape [13].

#### *Keyword Analysis*

Keywords selected by authors are crucial for identifying research trends, as they reflect the core content of publications. Word cloud analysis was used to highlight the most frequently occurring terms, with word size proportional to frequency, thus revealing dominant and overlapping research themes over time [8,13].

#### *Co-Citation Analysis*

This method identifies the most frequently cited publications and their interconnections, offering insights into the intellectual foundations and developmental trajectory of the field [19].

#### *Thematic Analysis*

Thematic analysis was conducted to explore dominant topics and their evolution. Using thematic mapping, research themes were visualized across four quadrants in a strategic diagram:

Motor Themes: High centrality and density; core, well-developed topics.

Niche Themes: High density, low centrality; specialized but isolated.

Emerging/Declining Themes: Low density and centrality; either nascent or fading.

Basic Themes: Low density, high centrality; essential but underexplored.

This framework provides a static yet informative view of research structure and dynamics [20].

## **Results**

#### *Performance Analysis*

Statistical information regarding bibliometric data on bone augmentation between 1980 and 2024 is presented in Table 1. A total of 2,722 publications were analyzed, originating from 143 different sources. The average Annual Growth Rate (AGR) was 9.78%, indicating an accelerating trend in scholarly output. The AGR was calculated using the exponential growth model commonly applied in bibliometric studies. Growth rate =  $[(\text{number of documents in the last year} \div \text{number of documents in the first year})^{1/(\text{last year} - \text{first year})} - 1] \times 100$ . Exponential growth rate (r) =  $\ln W_2 - \ln W_1 \div T_2 - T_1$  where:  $\ln W_2$  = Natural log of the initial number of articles,  $\ln W_1$  = Natural log of the final number of articles after a specific period,  $T_2 - T_1$  = The unit difference between the initial time and the final time. The annual average growth rate was 9.78%, reflecting increasing academic interest in the field.

The mean age of the publications was 11.5 years, with an average of 30.29 citations per article. Overall, 42,242 references were cited.

A total of 8,776 authors contributed to the literature, with only 84 single author articles published. The average number of co-authors per article was 5.09 and international collaboration accounted for 26.63% of the publications. Regarding document types, 2,468 were research articles, 201 were reviews, 40 were conference proceedings and 13 were early access articles.

In total, 3,152 Keywords Plus and 3,436 author keywords were used, demonstrating the terminological diversity within the literature.

The annual publication trends presented in Figure 1 reveal a notable increase starting from the mid-2000s, reaching a peak of 182 publications in 2024. The year 2006 recorded the highest average citations per article, with 5.2 citations. However, despite the recent surge in publication numbers particularly between 2022 and 2024 a decline in citation rates has been observed. This trend likely reflects that newer publications have not yet had sufficient time to accumulate citations.

Supplementary Table 2 presents the top 20 most influential authors in the field of Bone Augmentation ranked by their h-index. Leading the list is Wang HL, who has published 56 articles since 2006, accumulating a total of 2,206 citations, with an h-index of 27 and a g-index of 49. He is followed by Jung R.E., who has published 45 articles since 2003 and received a total of 2,720 citations, with an h-index of 26 and a g-index of 52.

Supplementary Table 3 lists the top 20 journals in Bone Augmentation ranked by h-index, representing 66.05% of all publications (1,798 of 2,722). Key metrics include h-index, g-index, total citations, publication count, citations per article and starting year.

Clinical Oral Implants Research leads with 306 articles and 14,787 citations, averaging 48.3 citations per article. The International Journal of Oral and Maxillofacial Implants follows, with 178 articles, an h-index of 43 and an average of 40.8 citations per article.

Most publications appear in journals specializing in periodontology, oral implantology and maxillofacial surgery. Some journals with fewer articles still show high citation impact, highlighting the interdisciplinary and scientifically rich nature of the field.

Citation analysis identified the 20 most locally cited publications in bone augmentation, as shown in Supplementary Table 4. Key metrics include publication year, local and global citation counts, average citations per year and the ratio of local to global citations.

The most cited paper by Zitzmann NU received 114 local citations and 435 global citations, with a local-to-global citation ratio of 26.21%, indicating significant impact both locally and internationally. Jensen SS's study followed closely with 108 local citations and the highest average local citations per year (6.75). Despite being more recent, Benic GI's publication also showed strong influence, with a 29.31% local to global citation ratio.

### *Funding Analysis*

Most frequent funding agencies in bone augmentation publications (1980-2024) show in Supplementary Table 5. Funding information was available for 914 of the 2,722 publications. According to the WoS "Funding Agency" field, the most frequent sponsors were:

- National Natural Science Foundation of China (NSFC)
- National Institutes of Health (NIH)
- European Commission (Horizon 2020)

These agencies have played a central role in shaping the research agenda in bone augmentation. Funding analysis offers important insights into the structural and geographic drivers of research activity, highlighting that bibliometric assessments should integrate funding patterns alongside citation-based indicators.

### *Word Analysis*

Supplementary Fig. 2 presents a word cloud illustrating the 50 most frequently used keywords in the bone augmentation literature, with the size of each term reflecting its frequency within the dataset. The most commonly used keyword in this field is “Bone Regeneration,” appearing 1,179 times. It is followed by “Dental Implant” (455), “Bone Augmentation” (232), “Alveolar Ridge Augmentation” (149) and “Alveolar Bone Grafting” (142).

Fig. 2 illustrates the changing trends in keyword usage over the years, highlighting emerging focal points within the field. According to the findings presented in Fig. 2, keywords such as “Bone Regeneration,” “Dental Implant,” “Bone Graft,” “Biomaterials,” and “Bone Substitutes” have been frequently used since the early 2000s and have maintained their significance to the present day. After 2010, terms related to technical and biological approaches, including “Cone Beam Computed Tomography,” “Tissue Engineering,” “Platelet-Rich Plasma,” and “Collagen,” became more prominent. From 2015 onwards, the use of multidisciplinary terms such as “Cleft Lip,” “Meta-Analysis,” “Inflammation,” and “Hyaluronic Acid” has notably increased.

### *Co-Citation Network Analysis*

Fig. 3 presents a Paper Co-citation Network analysis of bone augmentation literature, examining the co-citation relationships among publications. The analysis applied the Walktrap algorithm and included the top 25 most cited papers. As shown in Fig. 3, the co-citation network is divided into four clusters represented by red, blue, green and purple nodes.

The red cluster centers around seminal works by authors such as Dahlin C, Buser D and Dahlin C, which are frequently co-cited together. The blue cluster highlights studies by Araújo MG, Simion M and Zitzmann NU though with lower centrality and citation density compared to the red cluster. Smaller clusters are also observed in green and purple, representing other thematic groups within the literature.

Authors Co-Citation Network analysis revealed two main clusters in bone augmentation research, as illustrated in Fig.3. Buser D, emerged as the most central author, frequently cited both individually and in conjunction with Simion M, Dahlin C, Zitzmann NU and Becker W, who represent foundational contributors within the red cluster. In contrast, the blue cluster included notable figures such as Chiapasco M, Hämmerle CHF, Araújo MG, Jensen SS and Donos N.

Fig. 3 illustrates the Sources Co-citation Network analysis of journals publishing bone augmentation research. Node size represents the number of co-citations a journal receives, while edge thickness indicates the intensity of co-citation links between journals.

The blue cluster mainly includes journals focused on dentistry, particularly periodontology and dental implantology. Leading journals in this cluster with the largest nodes are *Clinical Oral Implants Research*, *Journal of Periodontology*, *International Journal of Oral and Maxillofacial Implants* and *Journal of Clinical Periodontology*.

The red cluster comprises journals primarily centered on oral and maxillofacial surgery and biomaterials research, with prominent titles including *Journal of Oral and Maxillofacial Surgery*, *International Journal of Oral and Maxillofacial Surgery*, *Plastic and Reconstructive Surgery*, *Biomaterials* and *Journal of Craniomaxillofacial Surgery*.

The smaller green cluster represents a distinct group, notably featuring the *Cleft Palate Craniofacial Journal*.

Fig. 4 shows the historical citation network of bone augmentation literature created using Bibliometrix. It visualizes citation links among the top 19 locally cited papers over time. The earliest work by Dahlin C, connects to subsequent studies by Hämmerle CHF and Retzepi M. Later publications by Benic GI, Rakhmatia YD and others form the more recent part of the network. Rocchietta I, is noted for its extensive connections within the network.

### *Thematic Analysis*

Fig. 5 shows a thematic map of bone augmentation research based on 500 frequently used author keywords clustered by the Louvain algorithm. Themes are divided into four groups by centrality and density:

Motor Themes: Well-developed and central topics like “Bone Regeneration” and “Biomaterials”.

Niche Themes: Specialized but less connected areas such as “Alveolar Bone Grafting” and “Peri-Implantitis”.

Emerging or Declining Themes: Peripheral and less developed topics like “Platelet-Rich Fibrin” and “Socket Preservation”.

Basic Themes: Fundamental but underexplored subjects including “Dental Implant,” “Bone Augmentation,” and “Tissue Engineering”.

Description	Results	Description	Results
Main Information About Data		Authors	
Timespan	1980:2024	Authors	8776
Sources (Journals, Books, Etc)	143	Authors Of Single-Authored Docs	84
Documents	2722	Authors Collaboration	
Annual Growth Rate %	9.78	Single-Authored Doc	97
Document Average Age	11.5	Co-Authors Per Doc	5.09
Average Citations Per Doc	30.29	International Co-Authorships %	26.63
References	42242	Document Types	
Document Contents		Article	2468
Keywords Plus (ID)	3152	Article; Early Access	13
Author's Keywords (DE)	3436	Article; Proceedings Paper	40
		Review	201

Table 1: Main information.

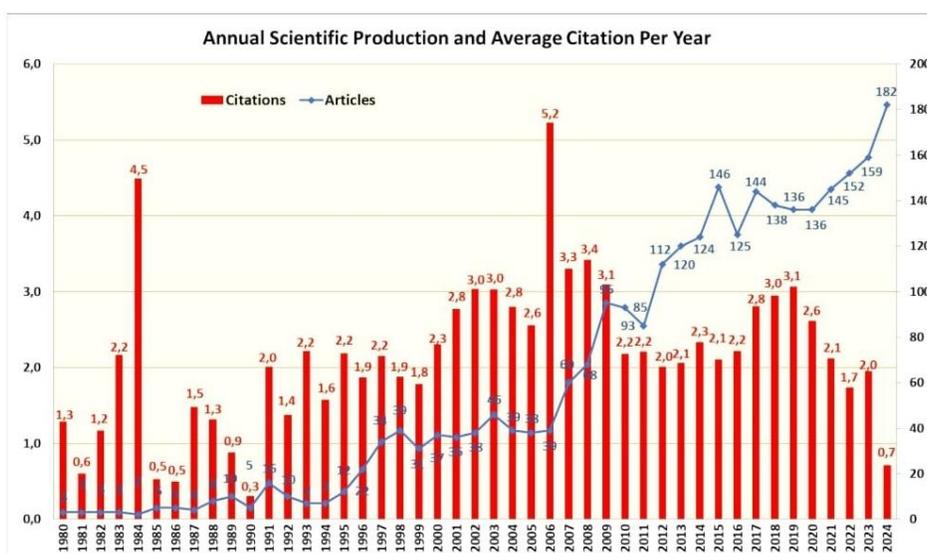


Figure 1: Annual scientific production and average citation per year.

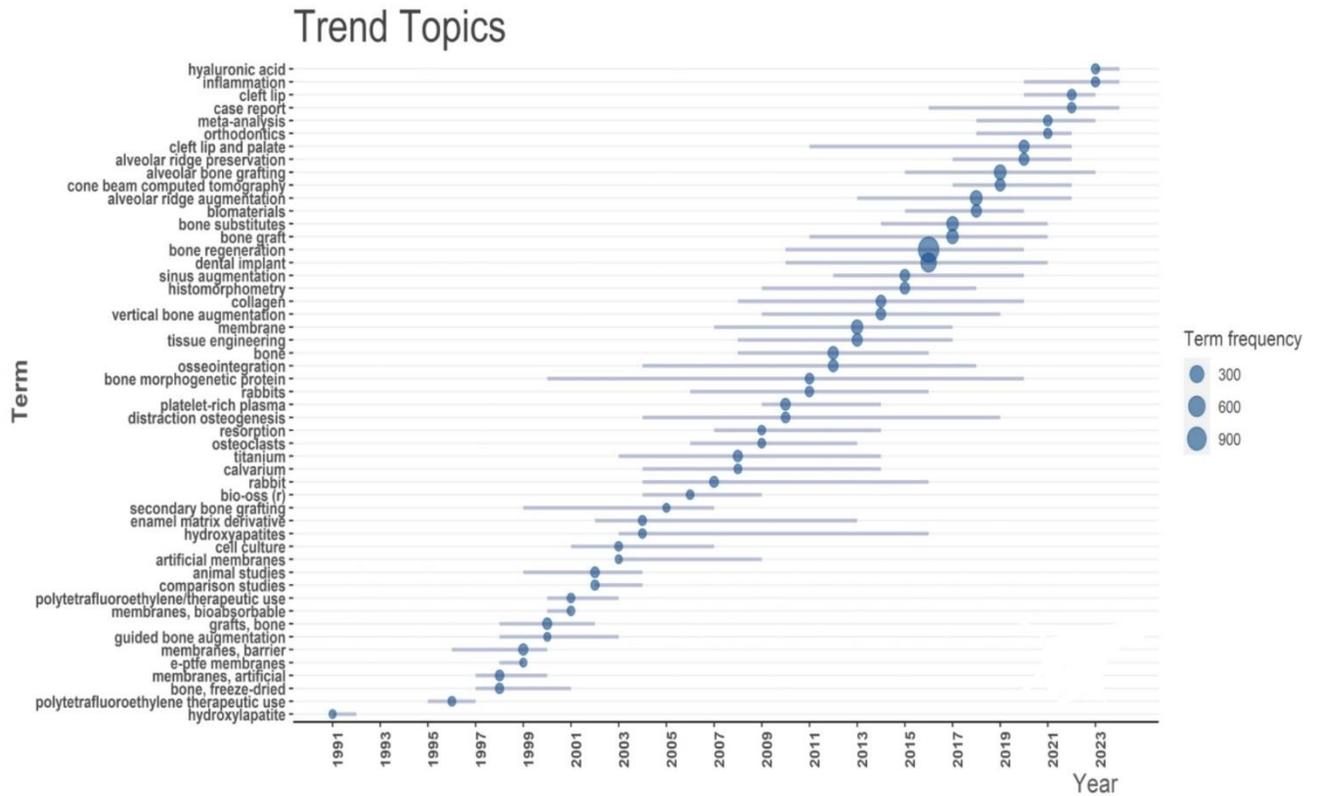


Figure 2: Trend topics.

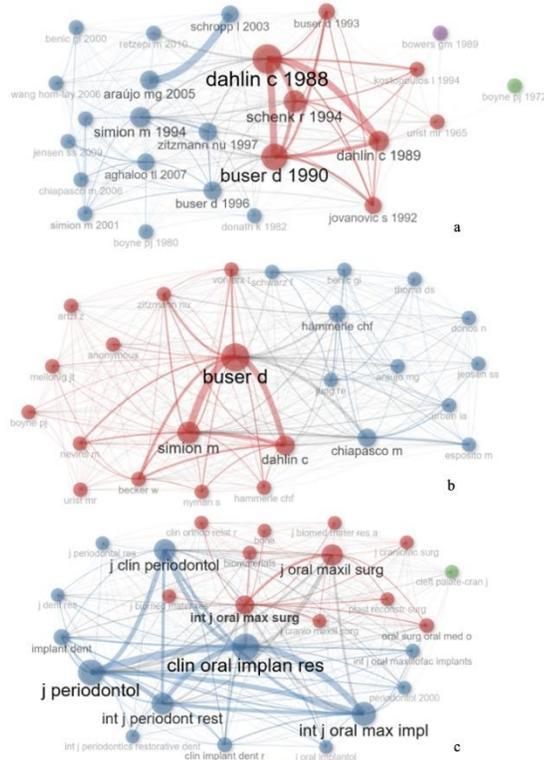


Figure 3: Papers, authors and sources co-citation network.

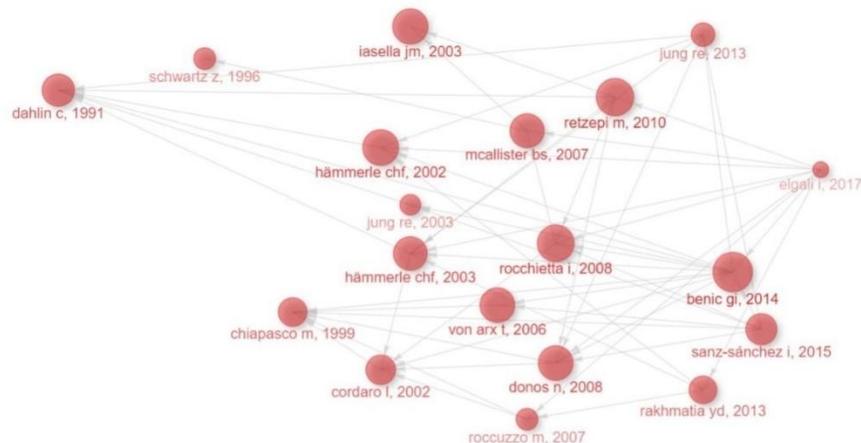


Figure 4: Historigraph.

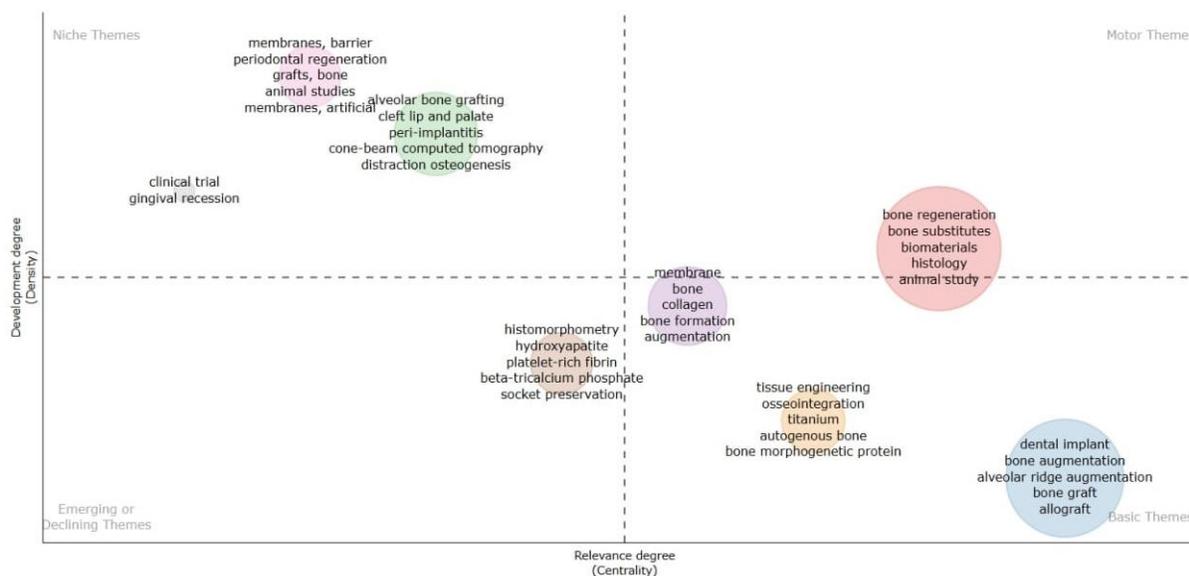


Figure 5: Thematic map.

## Discussion

Bibliometric analyses, applied across various disciplines, provide strategic insights by revealing the developmental trajectory of the literature, research trends and directions of scientific output, thereby informing future studies [22]. In this context, our study obtained scientific publications on bone augmentation from the Web of Science (WoS) database and conducted a comprehensive analysis. WoS is one of the most frequently used academic sources for bibliometric studies, offering a unique journal coverage compared to other databases [23]. Data analysis was performed using the open-source R-based Bibliometrix software, with visualizations supported through its user-friendly interface, Biblioshiny. This analysis systematically examines the global

scientific output in bone augmentation between 1980 and 2024, elucidating the current structure of the literature and emerging research trends.

A total of 8,776 unique authors have contributed to the bone augmentation literature. However, only 84 authors published single-authored articles, reflecting a strong culture of collaboration within the field. The average number of authors per article was 5.09 and the rate of international co-authorship stood at 26.63%. These figures highlight the global significance and interdisciplinary nature of the topic.

The marked increase in publication numbers since the mid-2000s reflects growing interest in bone regeneration techniques, driven by advances in dental implantology, biomaterials science and surgical innovations. The peak publication count in 2024 (n=182) and the rising number of contributing authors demonstrate that bone augmentation is a dynamic and rapidly evolving research area. The relatively low citation averages for recent publications are likely due to the insufficient time these studies have been available in the literature. Therefore, it is recommended to consider alternative metrics, such as citation density, which are time-independent indicators, to better assess the impact of studies published in recent years.

Authors such as Jung RE, Wang HL and Mellonig JT demonstrate significant productivity and scientific impact in the field, as reflected by their high h- and g-index values. Researchers active post-2000, including Thoma DS and Jung UW, stand out with high m-index scores despite their relatively short careers. This suggests an increase in impactful early-career contributions, which may be associated with improvements in training quality or funding availability. Another notable observation is that some authors who began publishing in earlier years (e.g., Mellonig JT, Dahlin C and Buser D.) have relatively low m-index values. This indicates that their productivity was not evenly distributed over time or that their influence was concentrated in specific periods.

Evaluation of the sources publishing articles on Bone Augmentation reveals that Clinical Oral Implants Research stands out as the most influential scientific platform in terms of local impact. Journal of Periodontology and International Journal of Oral and Maxillofacial Implants also rank among the key journals in the field, exhibiting high average citation rates. Although some newly established journals currently have lower impact factors, they hold potential to contribute to the development of the field. These findings highlight the importance for researchers to consider not only publication frequency but also the scientific impact level of journals when selecting target outlets for their work.

Keyword analyses reveal the content-based trends within the bone augmentation literature and illustrate how these trends have evolved over time. The keywords selected by researchers reflect the primary focus of each study and contribute to understanding the structural dynamics of the field [23]. The term "Bone Regeneration," as the most frequently used keyword, clearly represents the core focus of this field. Following this, terms such as "Dental Implant" and "Bone Augmentation" emphasize the critical importance of adequate bone volume for implant success and illustrate the inseparable relationship between augmentation procedures and implantology. The frequent occurrence of terms like "Membrane," "Collagen Membrane," and "Tissue Engineering" reflects strong interest in Guided Bone Regeneration (GBR) techniques and biomaterial based approaches. Furthermore, the widespread use of graft types such as allografts, xenografts, autologous grafts and beta-tricalcium phosphate indicates that material selection remains a significant research topic in clinical practice.

In recent years, there has been a noticeable increase in interest towards biological modulation strategies. The prominence of biological agents such as "Stem Cells," "Growth Factors," "Platelet-Rich Plasma," and "Platelet-Rich Fibrin" indicates the growing incorporation of regenerative medicine approaches within bone augmentation applications. However, more randomized controlled trials are needed to evaluate the long-term clinical effects of these biological supports. On the other hand, the widespread use of methodological terms like "Animal Study," "Histology," and "Clinical Trials" reflects that the field is being intensively investigated at both preclinical and clinical levels. Additionally, the emergence of the term "Systematic Review" highlights a trend toward synthesizing existing data to guide evidence-based practice.

Temporal analyses reveal a steady rise in core concepts such as "Bone Regeneration," "Dental Implant," and "Biomaterials" since the early 2000s. Notably, after 2010, terms like "Cone Beam Computed Tomography," "Alveolar Ridge Augmentation," and "Tissue Engineering" have gained prominence, reflecting the integration of digital technologies and regenerative biology into

clinical practice. From 2015 onwards, the increased usage of terms such as "Cleft Lip," "Inflammation," "Meta-Analysis," and "Hyaluronic Acid" indicates the field's evolution toward a multidisciplinary structure and an emphasis on evidence-based synthesis studies.

The findings derived from the historical citation network visualize the temporal development and knowledge flow within the bone augmentation literature. According to the citation network analysis, the study by Dahlin C, located on the left side of the network, stands out as one of the pioneering publications in the field. Its strong connections with works such as Hämmerle CHF and McAllister BS reflect the foundational methodological frameworks in the literature. Positioned centrally, the publication by Rocchietta I occupies a pivotal role in the theoretical and practical knowledge base, bridging earlier studies with subsequent research. More recent publications, such as those by Benic GI, Rakhmatia YD and Elgali I, appearing on the right side of the graph, contribute to advancing the field through modern surgical techniques and biomaterials research. However, the relatively smaller node sizes of these studies indicate that they have received fewer citations to date, suggesting potential for increased impact over time.

The results of the thematic map align with and further reinforce the findings obtained from the other analyses, offering additional insight into the structural and temporal evolution of research themes in the bone augmentation literature. Concepts such as "bone regeneration," "bone substitutes," and "biomaterials," located in the upper-right quadrant, exhibit both high centrality and density, representing the motor themes within the literature. In contrast, topics like "alveolar bone grafting," "cleft lip and palate," and "peri-implantitis" are positioned as niche themes due to their high density but limited centrality. The identification of concepts such as "tissue engineering," "osseointegration," and "bone morphogenetic protein" as basic themes indicates that these areas may become subjects of more extensive research in the future.

According to the authors' knowledge and the existing literature review, this study represents one of the comprehensive bibliometric analyses focusing on bone augmentation, aiming to provide a holistic overview of the literature. In contrast, the bibliometric study by Anjos, et al., evaluated only the top 100 most cited articles and primarily focused on singular metrics [24]. Their approach aimed to identify leading publications in the field by examining highly cited papers specifically. However, such methods may fall short of capturing the overall trends and collaboration dynamics within the literature comprehensively. In comparison, our study encompasses a broader dataset (n=2722). While Anjos, et al., concentrated on a specific clinical theme centered around "bone grafting," our analysis includes a wider range of terminology and applications under the general heading of "bone augmentation." This broader scope allows for an expanded thematic coverage and enables the analysis of a larger number of subfields. Additionally, whereas Anjos, et al., incorporated citation density metrics, our study emphasizes performance indicators focused more on total citations and productivity. Therefore, it can be concluded that different bibliometric approaches in the literature are complementary to each other.

It is important to acknowledge certain limitations regarding the scope of this bibliometric study. This research is based solely on the Web of Science database and therefore does not encompass literature indexed in other sources such as Scopus or PubMed. However, the comprehensive analytical framework employed and the use of the R-based Bibliometrix software allow for a robust depiction of the overall landscape and key trends within the field. Additionally, only articles published in English were included, which may have led to the exclusion of some publications in other languages that hold significant national-level impact. The inclusion of both ridge augmentation and Sinus Floor Elevation (SFE) procedures was a deliberate methodological choice to ensure a comprehensive mapping of bone augmentation research. This approach enabled the identification of shared research themes, common biomaterials and methodological overlaps between these domains, while excluding other regenerative indications such as socket preservation and peri-implantitis defect grafting that represent distinct clinical scenarios. However, combining these anatomically and procedurally different interventions may have also blended some procedure-specific nuances. Future studies could address this by performing separate analyses for each augmentation type to explore these distinctions in greater depth. Another limitation of this study is the absence of an evidence-level mapping of the included publications. Each record was not categorized according to study design (e.g., randomized controlled trial, cohort study, animal experiment, *in-vitro* study) and thus temporal trends in the level of evidence could not be evaluated. Incorporating such an analysis in future research would provide clinicians with a clearer understanding of the robustness and clinical applicability of the existing literature. Lastly, due to the inherent time-dependent nature of citation analysis, the impact of recently published studies may

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not be fully captured. Therefore, future research should consider alternative metrics that assess scientific impact independently of time.

### Conclusion

This bibliometric analysis provides a comprehensive overview of the evolving landscape of bone augmentation research. The field is characterized by strong interdisciplinary collaborations, a consistent increase in scientific output and the growing integration of regenerative techniques with digital technologies. Although significant progress has been made, further investigation into emerging research areas is needed to improve clinical outcomes and support translational applications. Capturing future trends and identifying evidence-based research priorities are essential to advancing patient care and innovation in bone regeneration therapies. It is anticipated that this bibliometric study will serve as a valuable guide in these endeavors.

### Conflict of Interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

### Financial Disclosure

This study was self-funded. No external financial support was received.

### Ethics Statement

Since the data is publicly open ethics approval was not required for this study.

### Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to privacy and ethical restrictions, the data are not publicly available.

### Author Contributions

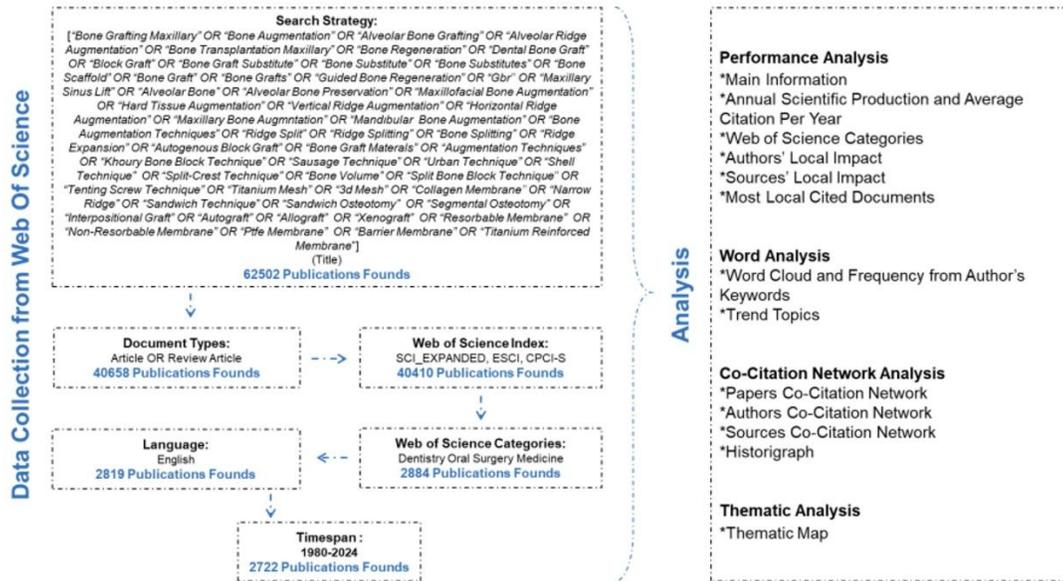
YILDIZ, Zeynep Hazan conceived the study and designed the research. USTAOĞLU, Gülbahar and ÇARDAKCI BAHAR, Şeyma conducted the measurements and collected the data. USTAOĞLU, Gülbahar and ÇARDAKCI BAHAR, Şeyma analyzed the data. USTAOĞLU, Gülbahar, ÇARDAKCI BAHAR, Şeyma and KOCA, Oğuz drafted the manuscript. YILDIZ, Zeynep Hazan served as the corresponding author.

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Supplementary Files



Supplementary Figure 1: Workflow of science mapping.



Terms	Frequency	Terms	Frequency
bone regeneration	1179	cone beam computed tomography	51
dental implant	455	osseointegration	50
bone augmentation	232	xenograft	49
membrane	154	alveolar ridge preservation	46
alveolar ridge augmentation	149	collagen	46
alveolar bone grafting	142	stem cells	45
bone substitutes	131	wound healing	45
bone graft	122	histomorphometry	44
allograft	77	sinus augmentation	44
alveolar bone loss	71	vertical bone augmentation	44
bone	67	tooth extraction	42
biomaterials	64	hydroxyapatite	42
cleft lip and palate	64	osteogenesis	42
tissue engineering	64	platelet-rich plasma	42
histology	62	collagen membrane	41
bone transplantation	54	ridge augmentation	40
animal study	51	growth factors	37
		systematic review	33
		bone formation	31
		titanium	31
		titanium mesh	31
		peri-implantitis	30
		periodontal regeneration	30
		grafts bone	29
		platelet-rich fibrin	29
		augmentation	27
		autogenous bone graft	25
		cone-beam computed tomography	24
		beta-tricalcium phosphate	23
		clinical trials	22
		mandible	21
		rabbit	21
		bone healing	20

Supplementary Figure 2: Word cloud and frequency from author's keywords.

Item	Description
Information specialist consulted?	No. The search was conducted by the study team.
Database(s) searched	Web of Science Core Collection (WoS)
Additional sources	None
Search date	June 24, 2024
Full search strategy	Boolean operators combining various synonyms (e.g., "Bone Grafting Material*" OR "Bone Augmentation" etc.). Detailed syntax in Supplementary Figure 1.
Language restriction	English only
Document type restriction	Article and review article
Year range	1980–2024
Initial search results	62,520 records
Updated search strategy?	No
Duplicate records removed?	Not applicable (each WoS record unique)

Supplementary Table 1: PRISMA-S search strategy summary.

Element	H-Index	G-Index	M-Index	TC	NP	PY-start
WANG HL	27	43	1,08	1901	56	2001
JUNG RE	26	52	1,083	2720	52	2002
MELLONIG JT	26	28	0,578	2206	28	1981
HÄMMERLE CHF	24	41	0,923	2896	41	2000
DONOS N	23	29	0,958	2088	29	2002
SCHWARZ F	21	35	1,05	1537	35	2006
BECKER J	19	26	0,95	1216	26	2006
THOMA DS	18	30	1	973	36	2008
MEALEY BL	17	21	0,586	822	21	1997
BUSER D	16	18	0,457	1995	18	1991
SIMION M	16	19	0,533	1308	19	1996
DAHLIN C	15	22	0,429	1604	22	1991
SANZ M	15	22	0,714	914	22	2005
JUNG UW	14	18	0,933	410	31	2011
COCHRAN DL	13	15	0,433	1048	15	1996
ITO K	13	21	0,464	479	22	1998
KHOJASTEH A	13	14	0,722	625	14	2008
ROHRER MD	13	15	0,448	907	15	1997
SATO S	13	19	0,619	406	26	2005
WIKESJÖ UME	13	13	0,52	708	13	2001

NP, Number of publications; TC, Total citations; PY-start, Publication year starting

**Supplementary Table 2: Authors local impact.**

Source	H-Index	G-Index	TC	NP	TC/NP	PY-start
CLINICAL ORAL IMPLANTS RESEARCH	66	104	14787	306	48,3	1991
JOURNAL OF PERIODONTOLOGY	58	93	11078	206	53,8	1981
INTERNATIONAL JOURNAL OF ORAL and MAXILLOFACIAL IMPLANTS	43	79	7258	178	40,8	1997
JOURNAL OF CLINICAL PERIODONTOLOGY	40	69	4960	90	55,1	1985
INTERNATIONAL JOURNAL OF PERIODONTICS and RESTORATIVE DENTISTRY	37	57	4538	210	21,6	1995
JOURNAL OF ORAL AND MAXILLOFACIAL SURGERY	36	63	4467	121	36,9	1983
JOURNAL OF CRANIO-MAXILLOFACIAL SURGERY	30	53	2985	74	40,3	1988
CLINICAL IMPLANT DENTISTRY AND RELATED RESEARCH	29	41	2272	105	21,6	2007
INTERNATIONAL JOURNAL OF ORAL AND MAXILLOFACIAL SURGERY	29	49	2735	88	31,1	1986
IMPLANT DENTISTRY	25	39	1876	86	21,8	2007
CLEFT PALATE-CRANIOFACIAL JOURNAL	23	40	1705	49	34,8	1994
JOURNAL OF DENTAL RESEARCH	21	30	2052	30	68,4	1980
ORAL SURGERY ORAL MEDICINE ORAL PATHOLOGY ORAL RADIOLOGY AND ENDODONTOLOGY	20	33	2563	33	77,7	1989
CLINICAL ORAL INVESTIGATIONS	17	23	737	52	14,2	2007
ARCHIVES OF ORAL BIOLOGY	15	22	575	22	26,1	1996
EUROPEAN JOURNAL OF ORAL IMPLANTOLOGY	15	17	1108	17	65,2	2009
JOURNAL OF ORAL IMPLANTOLOGY	15	26	860	66	13,0	2009
PERIODONTOLOGY 2000	15	19	1386	19	72,9	1998
JOURNAL OF PERIODONTAL RESEARCH	14	24	632	24	26,3	1981
ORAL SURGERY ORAL MEDICINE ORAL PATHOLOGY ORAL RADIOLOGY	14	22	549	22	25,0	2012

NP, Number of publications; TC, Total citations; TC/NP, Citations per paper; PY-start, Publication year starting

**Supplementary Table 3: Sources local impact.**

Document	YP	LC	LC/YYP	GC	GC/YYP	LC/GC Ratio%
ZITZMANN NU, 1997, INT J ORAL MAX IMPL	1997	114	4,071	435	15,54	26,21
JENSEN SS, 2009, INT J ORAL MAX IMPL	2009	108	6,750	483	30,19	22,36
BENIC GI, 2014, PERIODONTOL 2000	2014	102	9,273	348	31,64	29,31
RETZEPI M, 2010, CLIN ORAL IMPLAN RES	2010	94	6,267	482	32,13	19,50
ROCCHIETTA I, 2008, J CLIN PERIODONTOL	2008	92	5,412	369	21,71	24,93
HÄMMERLE CHF, 2002, J CLIN PERIODONTOL	2002	89	3,870	276	12,00	32,25
IASELLA JM, 2003, J PERIODONTOL	2003	87	3,955	531	24,14	16,38
CHIAPASCO M, 2009, INT J ORAL MAX IMPL	2009	86	5,375	570	35,63	15,09
VON ARX T, 2006, CLIN ORAL IMPLAN RES	2006	85	4,474	343	18,05	24,78
DONOS N, 2008, J CLIN PERIODONTOL	2008	85	5,000	236	13,88	36,02
MCALLISTER BS, 2007, J PERIODONTOL	2007	83	4,611	538	29,89	15,43
HÄMMERLE CHF, 2003, PERIODONTOL 2000	2003	82	3,727	295	13,41	27,80
DAHLIN C, 1991, CLIN ORAL IMPLAN RES	1991	78	2,294	229	6,74	34,06
ZITZMANN NU, 2001, INT J ORAL MAX IMPL	2001	77	3,208	247	10,29	31,17
SANZ-SÁNCHEZ I, 2015, J DENT RES	2015	75	7,500	212	21,20	35,38
CORDARO L, 2002, CLIN ORAL IMPLAN RES	2002	71	3,087	338	14,70	21,01
CHIAPASCO M, 1999, CLIN ORAL IMPLAN RES	1999	69	2,654	241	9,27	28,63
RAKHMATIA YD, 2013, J PROSTHODONT RES	2013	67	5,583	400	33,33	16,75
BUSER D, 1995, INT J PERIODONT REST	1995	64	2,133	206	6,87	31,07
CHOUKROUN J, 2006, ORAL SURG ORAL MED O	2006	63	3,316	1439	75,74	4,38

YP, Year of Publication; YY, Year 2025-Year of Publication; GC, Global Citations; LC, Local Citations

**Supplementary Table 4:** Most local cited documents.

Rank	Funding Agency	Count
1	Geistlich Pharma AG	16
2	University of Michigan Periodontal Graduate Study	13
3	Geistlich Pharma AG, Wolhusen, Switzerland	8
4	University Complutense of Madrid	6
5	Clinic of Fixed and Removable Prosthodontics and Dental Material Science, Center for Dental and Oral Medicine, University of Zurich	6
6	University of Zurich	5
7	National Natural Science Foundation of China (NSFC)	5
8	Projekt DEAL	5
9	Institut Straumann AG, Basel, Switzerland	4
10	Basic Science Research Program of the National Research Foundation of Korea (NRF)	4

**Supplementary Table 5:** Most frequent funding agencies in bone augmentation publications (1980–2024).

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