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Image-Guided Implant Planning and Surgery: A Radiology-Focused Bibliometric Analysis

Menduh Sercan KAYA
Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Dicle University

ABSTRACT: Image-guided implant planning and surgery is a field that integrates digital planning with three-dimensional imaging techniques for the rehabilitation of missing teeth. The aim of the present study was to evaluate the scientific productivity, conceptual structure, research trends, and thematic evolution of the radiology-focused scientific literature on image-guided implant planning and surgery using bibliometric analysis methods. The dataset was compiled from articles and review papers published in English between 2005 and 2025 in the Web of Science Core Collection database. A total of 424 publications were analyzed using the bibliometrix package through R, RStudio, and Biblioshiny. Annual scientific production, trend topics analysis, keywords co-occurrence network analysis, thematic map analysis, and thematic evolution analysis were performed. The findings demonstrated an increasing trend in scientific production, with a marked acceleration after 2018. The highest scientific output was observed in 2025. Digital planning technologies, cone-beam computed tomography, and dynamic navigation systems were identified as the principal research topics in this field. The thematic evolution analysis revealed that early studies primarily focused on computer-assisted surgery and three-dimensional imaging technologies, whereas more recent research has shifted toward implant placement accuracy and dynamic navigation systems. In conclusion, scientific production in the field of image-guided implant planning and surgery has increased substantially in recent years, and research trends have evolved toward digital technologies and real-time navigation systems.

KEYWORDS: Bibliometric analysis, Computer-assisted implant surgery, Cone-beam computed tomography, Dental implant, Dynamic navigation, Guided implant surgery.

I. INTRODUCTION

One of the most widely used treatment modalities for the functional and esthetic rehabilitation of missing teeth is dental implant therapy. Although implant therapy is considered a highly successful long-term treatment option, its success depends on several factors, including adequate bone volume, sufficient bone quality, accurate assessment of the surrounding anatomical structures, and proper implant positioning. Therefore, surgical planning plays a critical role in the overall success of implant therapy (1-3). Radiological evaluation plays a pivotal role in implant surgery. For implant treatment planning, radiological assessment is primarily performed using two-dimensional and three-dimensional imaging modalities. Two-dimensional imaging techniques have several limitations, including superimposition, magnification, distortion, and the inability to provide volumetric assessment. In contrast, three-dimensional imaging modalities enable the evaluation of bone quality, bone volume, and cortical bone morphology in the region of interest. Furthermore, the relationships between the planned implant site and adjacent anatomical structures can be assessed in multiple planes, providing highly accurate diagnostic information. Volumetric assessment also allows precise determination of the surgical safety margins between the implant and surrounding anatomical structures during implant surgery, thereby minimizing the risk of potential complications (3-6).

Advances in three-dimensional imaging technologies and digitalization have marked a turning point in image-guided implant planning and surgery. As a result of these developments, three-dimensional imaging modalities have been integrated with intraoral scanning systems and computer-aided design/computer-aided manufacturing technologies. This integration has enabled the implementation of virtual implant planning models. Consequently, these technological advancements have led to the development of static surgical guides and dynamic navigation systems that provide real-time guidance during implant planning and placement. These systems have made it possible to place implants in their planned positions with greater accuracy. In recent years, advances in three-dimensional imaging systems, digital planning software, intraoral scanners, and computer-aided design/computer-aided manufacturing technologies have made image-guided implant surgery an increasingly active area of research (7-12). The number of scientific publications in this field has been increasing steadily, making it increasingly difficult to comprehensively evaluate its conceptual structure. Therefore, an assessment of the conceptual framework and research trends in this field is warranted.

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Bibliometric analysis is a quantitative method that enables the evaluation of the conceptual structure, research trends, and scientific productivity within a specific research area. By applying annual scientific production, keywords co-occurrence network analysis, trend topics analysis, thematic map analysis, and thematic evolution analysis, bibliometric analysis provides a comprehensive quantitative overview of the development and intellectual structure of a research field (13-15).

The aim of this study was to examine the radiology-focused scientific literature on image-guided implant planning and surgery using bibliometric analysis methods and to evaluate the scientific productivity, conceptual structure, research trends, and thematic evolution in this field.

II. MATERIALS and METHODS

This study was designed as a radiology-focused bibliometric analysis of the literature on image-guided implant planning and surgery. Therefore, no human or animal subjects were involved, and ethical approval was not required.

The dataset was retrieved from the Web of Science Core Collection (WoSCC) database using the Advanced Search option with the following search query: (("image-guided implant surgery" OR "guided implant surgery" OR "computer-guided implant surgery" OR "computer guided implant surgery" OR "computer-assisted implant surgery" OR "computer assisted implant surgery" OR "computer-guided implant placement" OR "computer guided implant placement" OR "guided implant placement" OR "template-guided implant surgery" OR "template guided implant surgery" OR "static guided surgery" OR "dynamic guided surgery" OR "dynamic navigation" OR "computer-aided implant surgery" OR "computer aided implant surgery" OR "navigated implant surgery" OR "navigation-guided implant surgery") AND ("dental implant*" OR "oral implant*" OR "implant dentistry" OR "implant placement") AND (radiolog* OR imaging OR "diagnostic imaging" OR "dental imaging" OR "oral radiology" OR "maxillofacial radiology" OR CBCT OR "cone beam computed tomography" OR CT OR "computed tomography" OR MDCT OR MSCT OR "multidetector computed tomography" OR "multislice computed tomography" OR MRI OR "magnetic resonance imaging" OR "panoramic radiography" OR orthopantomograph* OR OPG OR "periapical radiography" OR "intraoral radiography" OR "digital planning" OR "virtual planning" OR "three-dimensional imaging" OR "3D imaging")).

The search covered the period from 2005 to 2025. Only articles and review papers published in English were included. Conference proceedings, editorial letters, publications in languages other than English, and studies not focused on the radiological aspects of implant surgery were excluded to ensure the homogeneity of the dataset.

The analyses were performed using the bibliometrix package (version 5.3.0) through R (version 4.6.0), RStudio, and Biblioshiny. annual scientific production was conducted to evaluate scientific productivity. To investigate the conceptual structure of the literature, keywords co-occurrence network analysis, trend topics analysis, thematic map analysis, and thematic evolution analysis were performed.

Author-provided keywords were used for the keywords co-occurrence network analysis. The conceptual structure of the literature was examined using a network-based clustering approach. In the resulting network, different colors represented distinct thematic clusters, node size indicated the frequency of keyword occurrence, and edge thickness reflected the strength of keyword co-occurrence. Thematic map analysis was performed to explore the thematic structure of the literature. The identified themes were classified as motor themes, basic themes, niche themes, and emerging or declining themes. To investigate the thematic evolution of the research field over time, thematic evolution analysis was conducted using 2018 as the cut-off year separating the two time periods.

III. RESULTS

The final dataset consisted of 424 articles published between 2005 and 2025. According to the annual scientific production analysis, scientific output in the field of image-guided implant planning and surgery remained relatively low until 2018, followed by a marked increase thereafter. The highest level of scientific production was observed in 2025 (Figure 1).

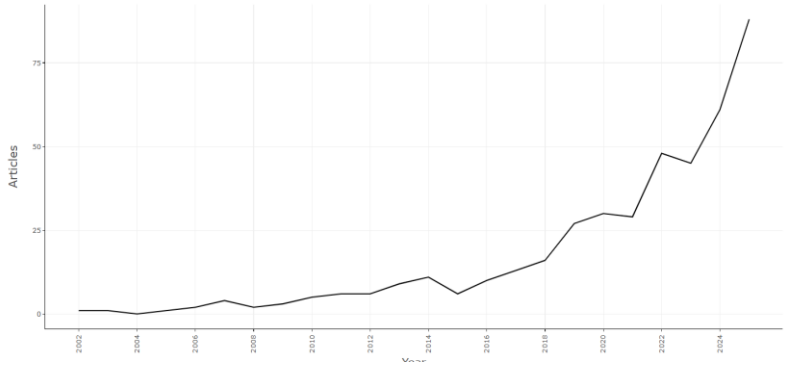

Figure 1. Annual scientific production in image-guided implant planning and surgery.

According to the trend topics analysis, the terms "flapless surgery", "template", "surgical template", and "reliability" were the most prominent topics during the earliest period. In the subsequent years, "technology", "stereolithographic surgical guides", "computer technology applications", "tomography", "computed tomography", "system", and "dentistry" emerged as the dominant research topics. In recent years, "placement", "surgery", "accuracy", "implant", "implant placement", and "dynamic navigation system" have become the most prominent terms (Figure 2).

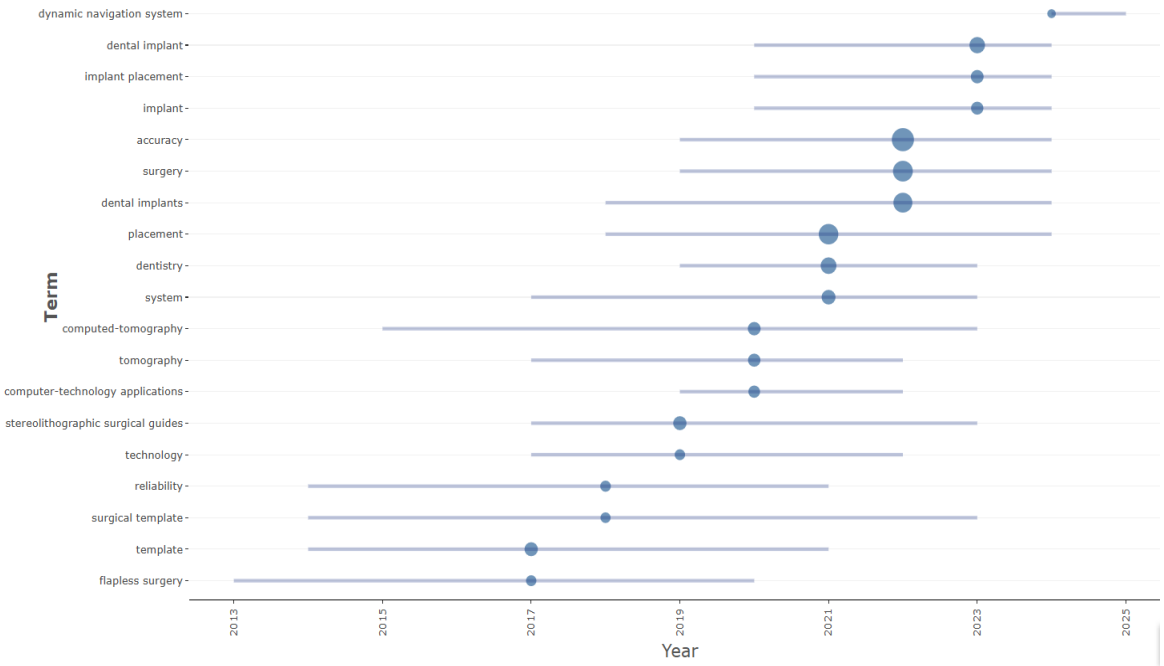

Figure 2. Trend topics in image-guided implant planning and surgery.

According to the keywords co-occurrence network analysis, four distinct thematic clusters were identified. In the red thematic cluster, the term "dental implant" had the largest node size and exhibited strong connections with the other themes. The remaining terms in this cluster were "dynamic navigation", "guided surgery", "implant surgery", "cbct", "cone beam computed tomography", "3D printing", "digital dentistry", "computer-assisted implant surgery", and "surgical template". The blue thematic cluster included the terms "surgery", "computer-assisted", and "computer-aided surgery". The green thematic cluster comprised "implants", "computer-assisted surgery", "navigation", and "dental", whereas the purple thematic cluster contained "guided implant surgery" and "digital workflow" (Figure 3).

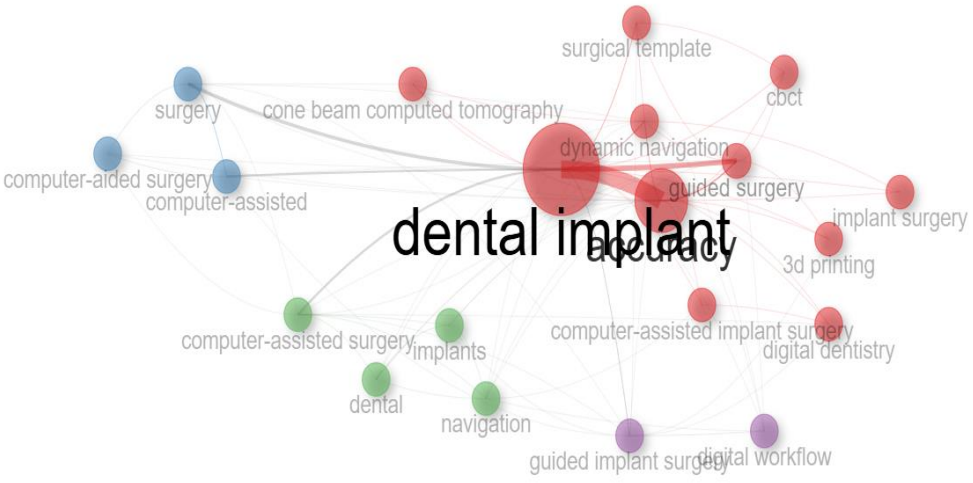

Figure 3. Keywords co-occurrence network in image-guided implant planning and surgery.

According to the thematic map analysis, the basic themes cluster included the terms "dentistry", "guided surgery", and "template". The motor themes cluster consisted of "dental implant", "surgery", and "bone". The niche themes cluster comprised "accuracy", "placement", and "dynamic navigation", whereas the emerging or declining themes cluster included "beam computed tomography", "technology", and "3D printing" (Figure 4).

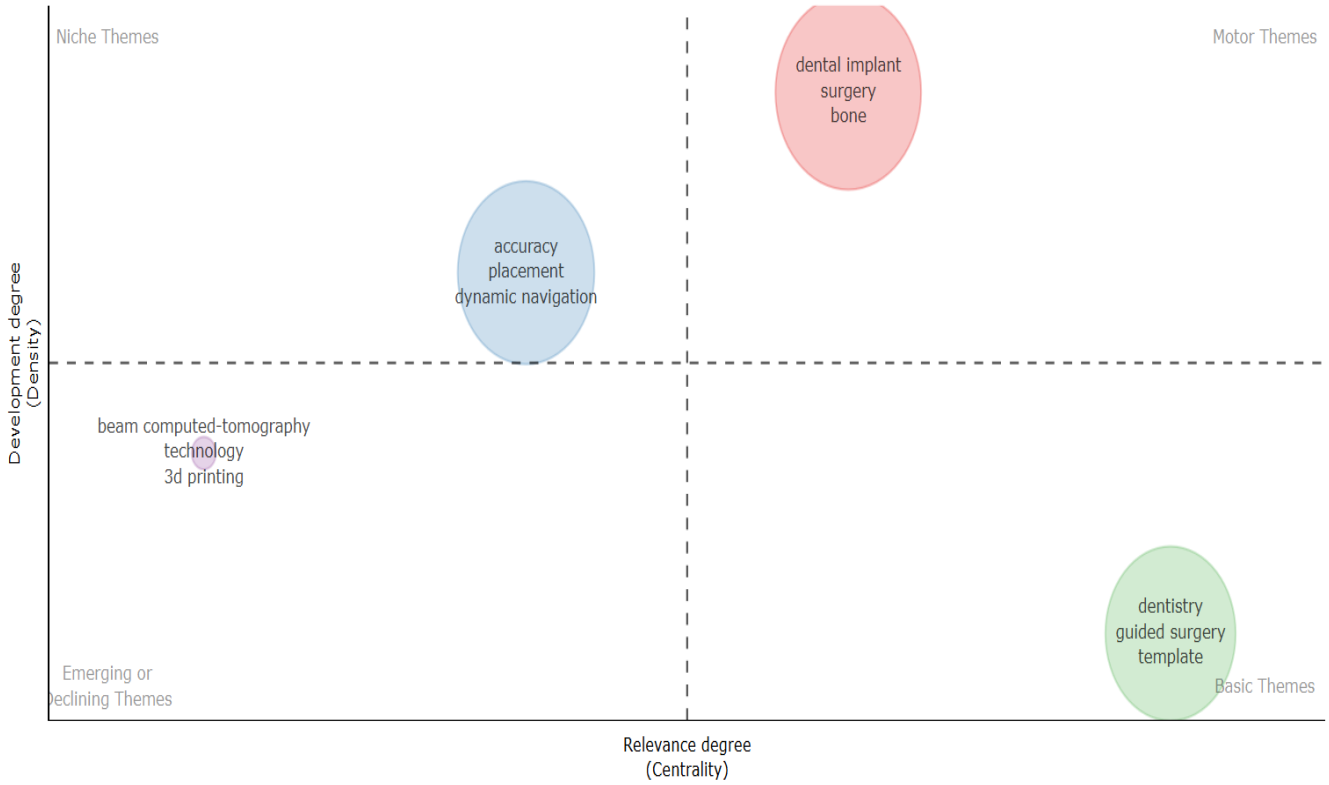

Figure 4. Thematic map of image-guided implant planning and surgery.

According to the thematic evolution analysis, the themes "computed tomography", "computer-assisted", "computer-aided surgery", and "immediate loading" were the most prominent during the period from 2002 to 2018. In contrast, during the 2019–2025 period, the themes "accuracy", "dynamic navigation", and "surgery" became prominent. The terms "dental implant", "computer-assisted surgery", and "guided implant surgery" were found to persist across both periods, indicating their continued importance throughout the evolution of the research field (Figure 5).

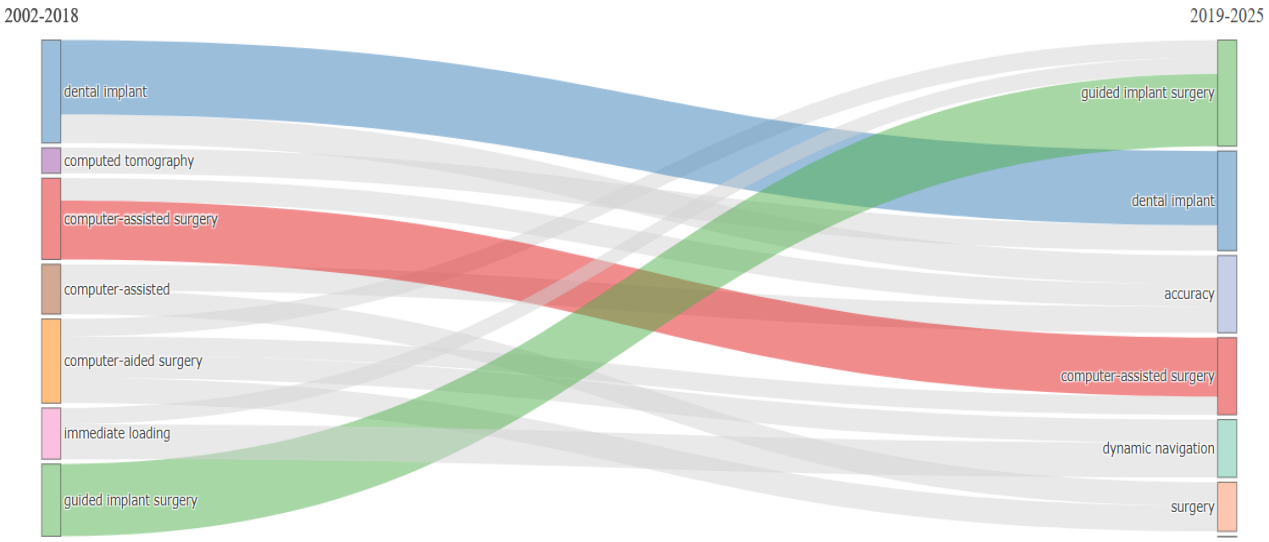

Figure 5. Thematic evolution in image-guided implant planning and surgery.

IV. DISCUSSION

Image-guided implant planning and surgery involves the digital planning of implant placement by integrating data obtained from three-dimensional imaging modalities with planning software and subsequently transferring this plan to implant surgery using either static surgical guides or dynamic navigation systems. In this workflow, cone-beam computed tomography plays a central role. cone-beam computed tomography enables three-dimensional evaluation of bone volume, bone quality, regional morphology, and anatomical structures such as the maxillary sinus, mandibular canal, and mental foramen through multiplanar imaging. The acquired three-dimensional imaging data are then integrated with intraoral scan data or digital models. This integration facilitates the development of a surgical plan associated with a lower risk of complications. Consequently, implant placement can be performed more accurately using minimally invasive surgical approaches. By improving the precision and predictability of implant surgery, this approach also contributes to more favorable prosthetic rehabilitation (6, 10, 11, 16-20). In recent years, numerous studies have been conducted on image-guided implant planning and surgery. However, information regarding the conceptual structure, research trends, scientific productivity, and thematic development of this field remains limited. Therefore, it is necessary to evaluate the current status, research trends, and temporal evolution of this topic using bibliometric analysis methods (14, 15).

From this perspective, the annual scientific production analysis demonstrated that scientific output in the field of image-guided implant planning and surgery increased markedly after 2018, reaching its highest level in 2025. This finding indicates that the field has attracted increasing academic interest in recent years. The observed increase may be attributed to the widespread adoption of implant therapy and cone-beam computed tomography. Furthermore, the integration of intraoral scanners, digital planning software, and computer-aided design/computer-aided manufacturing technologies into the clinical workflow may have further stimulated research on image-guided implant planning and surgery. In addition, the development of static surgical guides and dynamic navigation systems providing real-time guidance may have contributed to establishing this field as a major focus of contemporary research (3, 7, 10, 12).

According to the trend topics analysis, a distinct shift in research trends was observed over time. During the early period, the prominence of the terms "flapless surgery", "reliability", and "surgical template" suggests that research on image-guided implant planning and surgery primarily focused on the development and application of surgical templates, as well as on their major advantages, including the reduction of surgical complications and the facilitation of minimally invasive implant surgery (21-23). During the subsequent period, the terms "technology", "stereolithographic surgical guides", "computer technology applications", "tomography", "computed tomography", and "system" became prominent. This finding suggests that research shifted toward image-guided implant planning using different imaging modalities and the fabrication of surgical guides through more advanced manufacturing technologies (24-26). In the most recent period, the prominence of the term "dynamic navigation system" indicates that the application of real-time navigation technologies has become a major focus of academic research. This trend may be attributed to the integration of digital planning, three-dimensional imaging, and dynamic navigation systems, which has shifted implant surgery from conventional approaches toward fully digital workflows (27-29).

According to the keywords co-occurrence network analysis, the prominence of the terms "digital dentistry", "digital workflow", "computer-assisted", "computer-aided surgery", and "computer-assisted implant surgery" suggests that implant surgery has become increasingly integrated with digital workflows. Likewise, the prominence of the terms "cbct" and "cone beam computed tomography" indicates that cone-beam computed tomography has become a major imaging modality in the field of image-guided implant planning and surgery. The prominence of the term "dynamic navigation" may further suggest that recent studies have increasingly focused on real-time navigation systems in implant surgery. Finally, the co-occurrence of the terms "3D printing", "cbct", "dynamic navigation", "digital workflow", and "guided surgery" within the same network indicates that multiple digital technologies are being integrated into a unified workflow in this field (10, 28, 30-32).

According to the thematic map analysis, the placement of the terms "dental implant", "surgery", and "bone" within the motor themes cluster indicates that bone assessment in dental implant surgery represents a current and intensively investigated research topic. The inclusion of "guided surgery" and "template" in the basic themes cluster suggests that the development and application of surgical guides constitute one of the fundamental research areas in image-guided implant surgery and play a central role in shaping the literature. Furthermore, the presence of "accuracy" and "dynamic navigation" within the niche themes cluster suggests that the effect of dynamic navigation systems on implant placement accuracy is a specialized research topic investigated by a relatively limited research community (2, 33-35).

According to the thematic evolution analysis, the prominence of the terms "computed tomography", "computer-assisted", and "computer-aided surgery" during the 2002–2018 period indicates that early research primarily focused on the integration of three-dimensional imaging modalities into implant planning and the development of computer-assisted surgical approaches. In addition, the presence of the term "immediate loading" during this period suggests that image-guided implant planning and surgery was also investigated in relation to implant loading protocols. During the 2019–2025 period, the terms "accuracy", "dynamic navigation", and "surgery" emerged as the dominant research themes. This finding suggests that research has shifted toward more specialized

topics, particularly the evaluation of implant placement accuracy and the application of dynamic navigation systems. Furthermore, the continued prominence of the terms "dental implant", "computer-assisted surgery", and "guided implant surgery" across both periods indicates that these concepts have consistently represented the core research themes of the field.

The present study has several limitations. First, the dataset was constructed exclusively from the WoSCC database, and only articles published in English were included in the analysis. Nevertheless, the high indexing standards of WoSCC and the fact that English is the predominant language of scientific publication enhance the reliability of the present study. Finally, by its nature, this bibliometric study evaluates the quantitative characteristics and conceptual structure of the literature in this field but does not directly assess the methodological quality or the level of clinical evidence of the included studies.

V. CONCLUSIONS

In conclusion, scientific production in the field of image-guided implant planning and surgery has shown an overall increasing trend, with a more pronounced rise in recent years. Research in this field has primarily focused on digital technologies. Cone-beam computed tomography has emerged as the most prominent imaging modality in this area. Furthermore, research trends have gradually evolved toward more specialized topics, particularly real-time dynamic navigation systems. Future studies should be designed to include publications in different languages and from multiple databases to provide a more comprehensive understanding of the field.

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