Application of 3D Printing Development in Dental Industry: Bibliometric Review

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Abstract. There have been many publications on 3D printing in the dental industry, but publications on bibliometric reviews are scarce. This forms the basis of this study, which aims to present a bibliometric review of the field of 3D printing in dental applications and related disciplines. All data analyzed was obtained from the Scopus database, covering the period from 2014 to August 16, 2024. Publication data was gathered using search terms related to "3D printing", "additive manufacturing", and "dental". These topics were applied to the title, abstract, and selected keywords. The Scopus dataset yielded a total of 2,700 publications from 2014 to August 16, 2024. The evolution of publication growth in these topics shows an increasing trend in developmental areas emerging from the analysis, such as dental materials, which have shown great potential for further research supported by structured collaborative networks. These findings suggest that international collaboration and a strong thematic focus will continue to be key drivers of progress in 3D printing technology and its applications.

Keywords: 3D Printing, Additive Manufacturing, Dental, Bibliometric Review, VOSviewer.

1 INTRODUCTION

3D printing technology has revolutionized the field of dentistry, bringing a new level of precision and efficiency to the creation of dental restorations [1]. As the technology has advanced, it quickly gained popularity for its ability to produce highly accurate and customized dental restorations [2]. Today, 3D printing is a standard practice in many dental offices, providing patients with faster and more affordable treatment options [3]. While 3D printing technology has certainly improved the creation of dental restorations, it is important to consider the potential limitations and risks associated with the use of this technology in dentistry, such as material safety concerns and quality control issues [4]. In addition, the cost of implementing and maintaining 3D printing technology in a dental practice may be prohibitive for some providers, limiting its widespread adoption [5]. Despite these challenges, the benefits of 3D printing in dentistry cannot be ignored. The ability to create custom-fit prosthetics and restorations with precision and efficiency has revolutionized the field, leading to improved patient outcomes and satisfaction [6]. With continued advancements in technology and materials, the future of 3D printing in dentistry looks promising, offering even more innovative solutions for dental care [7]. As the technology continues to evolve, it is

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critical for dental professionals to stay informed and educated on the latest developments in order to provide the best possible care for their patients.

Bibliometric reviews involve the systematic analysis of publications in a particular field or subject area to assess the impact and influence of research [8]. Different bibliometric methods can be used to answer different research questions, such as citation analysis, co-citation analysis, bibliographic coupling, co-author analysis, and co-word analysis [9]. These methods can provide a wide range of information about a research area, complementing traditional review methods. By analyzing citation patterns, publication trends, and collaborative networks, bibliometric reviews provide valuable insights into the growth and development of a particular research field [10]. In this section, we will discuss the key components of a bibliometric review and its importance in understanding the scientific landscape. For example, a bibliometric review of 3D printing research could track the number of publications related to different aspects of 3D printing over time, identify key researchers and institutions contributing to the field, and analyze citation networks to understand how knowledge in the field is disseminated [11]. By conducting such a review, researchers can better understand the global research landscape on 3D printing and identify gaps for future study [12]. In addition, a bibliometric review can help researchers identify emerging trends and potential collaborations in the field of 3D printing [13]. By analyzing publication patterns and citation networks, researchers can gain valuable insights into the current state of research and potential areas for innovation. This type of analysis can also help funders and policy makers make informed decisions about allocating resources and shaping future research agendas in the field of 3D printing. Ultimately, a bibliometric review can provide a comprehensive and systematic overview of the scientific landscape, enabling researchers to make evidence-based decisions and contribute to the advancement of knowledge in their respective fields [14].

Bibliometric reviews play a crucial role in mapping the intellectual structure of a particular research field [15]. By analyzing citation patterns and collaboration trends within the scientific literature, researchers can identify key players, emerging trends, and knowledge gaps that need to be addressed [16]. This information can help funding agencies, policymakers, and researchers make informed decisions about where to allocate resources and what areas to focus on in future research efforts. In essence, bibliometric reviews serve as a valuable tool for fostering innovation, promoting collaboration, and advancing the overall understanding of a given field [17].

In this research paper, we aim to conduct a comprehensive bibliometric analysis of the academic literature in a given field, with the goal of identifying the most influential authors, institutions, and journals. We also seek to uncover emerging research trends and areas of collaboration within the field.

2 MATERIAL AND METHODS

All analyzed data were obtained from the Scopus database, published from 2014 to August 16, 2024. The publications data were obtained using formulas related to "3D printing," "additive manufacturing," and "dental". The keyword search applies the use of boolean operators such as AND and OR functions, it helps the data search process by linking the keywords into “dental” AND “Additive manufacturing” OR “3D

Printing". These keywords are applied to the title, abstract, and several other keywords. The resulting data will be visualized using a node-link diagram, a node-link diagram is used to describe the relationship between nodes (such as authors or articles) with edges (lines connecting them) [18]. Then, the data can be validated the results of bibliographic analysis are generally carried out by comparing statistical data with manual interpretations of academic publications [19].

The VOSviewer software is employed to identify the network of shared word attachments that are used as keywords to obtain up-to-date information and to study patterns that have been formed [20]. The functions that are applied to VOSviewer are the co-citation function and the co-occurrence function [21]. The co-citation function is employed to demonstrate the extent to which terms or references are mentioned over time. In contrast, the co-occurrence function is utilized to illustrate the frequency of occurrence of keywords or references over time [22]. The calculation method employed by VOSviewer involves two distinct approaches: full counting and fractional counting [23]. In full counting, the number of citations is calculated according to the document being tested. In fractional counting, the number of citations is influenced by the number of co-authors on a given document. In full counting, each entity is given full credit, which is more suitable for simple analysis [24]. Fractional counting, on the other hand, divides the credit according to the number of entities involved, providing a more proportional picture of each entity's contribution [25]. The development map of research publications is analyzed into two main parts: the co-authorship map and the co-occurrence map.

3 RESULT AND DISCUSSION

The collection of Scopus publication datasets yielded a total of 2,700 publications from 2014 to August 16, 2024. The growth of publications related to the topic of 3D printing and dentistry over this period demonstrates an increasing trend. The highest level of publication growth was observed in 2023, with a total of 480 publications. However, this figure may change, as 2024 is still ongoing, and there is a possibility of surpassing the previous year's total. In contrast, the lowest number of publications was recorded in 2015, with a total of 33 publications.

A reduction in the number of publications was observed in 2015, with a total of five fewer documents published compared to the previous year. Additionally, a similar decline in the number of publications was noted in 2024. A comparison with the preceding year reveals a reduction in the number of publications by 18 documents. However, the year 2024 is still ongoing and can still increase. Despite this decline, the advancement of 3D printing research in dental industry applications represents a subject of ongoing interest and continues to expand on an annual basis.

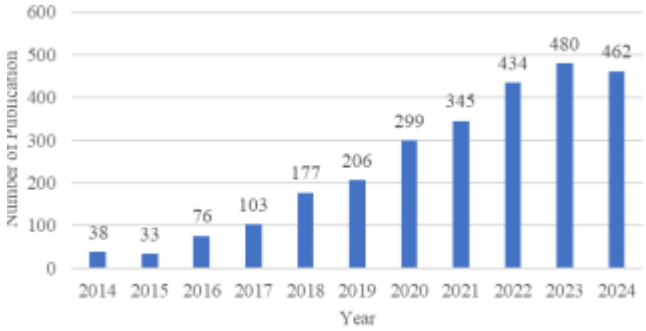

Fig. 1. The Advancement of Research Publications (Scopus, 2024)

3.1 The Development of Research Publications by Author (Co-Authorship)

The dataset obtained from Scopus is stored in RIS (Research Information Systems) format, and then analyzed using the VOSviewer application. The methods employed in the dataset are co-authorship and full counting [26].

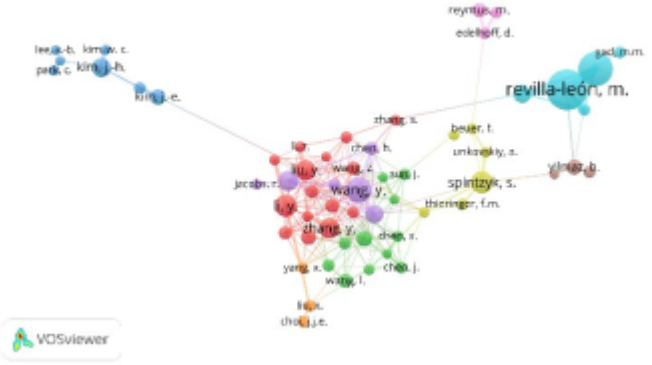

Fig. 2. Network Visualization by Co-Authorship

Network visualization is the process of creating a graphical representation of network data and the interconnections within it [27]. This technique is crucial for comprehending intricate structures, as it enables users to discern patterns, anomalies, and trends that are not readily apparent in raw data [28]. The transformation of data into a visual format facilitates more effective decision-making and enables a more profound comprehension of the interconnections between network elements [29]. Node-link diagrams are a common form of visualization that is frequently employed in various contexts [30]. In these diagrams, nodes are represented as points and edges as lines connecting those points [31]. While effective for small to medium-sized networks, the complexity of these diagrams can become a challenge when applied to larger networks [32].

In the field of bibliometrics, the visualization of networks can be employed to elucidate the interconnections between authors, publications, or concepts within the domain of scientific literature [33]. By rendering bibliometric data in a visual format, researchers can expeditiously discern collaboration patterns, research trends, and the impact of specific publications or authors within a given field [34]. To illustrate, a node-link diagram can delineate the principal authors in a given research domain and their collaborative relationships with other authors [35]. Fig. 2 shows a visualization of the collaboration network between different authors. Each node represents an author, while the lines or edges connecting the nodes show the collaboration between two authors in one or more publications. The larger the node size, the greater the influence or productivity of that author in the network, based on the number of publications or collaborations. The network in the middle of the figure shows a high concentration of collaborations, especially among authors such as "Wang Y", "Zhang Y", and "Liu Y". This indicates a close-knit research group around these individuals, suggesting the possibility of a laboratory or institution that is active in joint publications.

At the top right, we see a more isolated group of authors with key nodes such as "Özcan M" and "Revilla-León M". While they have fewer collaborations in the overall network, their position suggests that they play an important role in their own collaborative group, perhaps in a more specific research area. The left part of the figure shows a more isolated group of authors such as "Lee J" and "Kim J-E". Their focus appears to be on independent research or specialized subfields, as indicated by their lower frequency of interaction with the main network. Overall, this visualization illustrates that there are some groups of researchers that collaborate very closely, but there are also some groups that are more isolated, indicating variations in the level of collaboration between researchers in the field under study. Fig. 3 shows the co-authorship network colored based on the time dimension. The color of each node and edge indicates the time of publication, with different color gradients showing changes in collaborative activity from 2020 to 2024.

The portion of the network with blue and purple nodes in Figure 2 shows collaborations that occurred earlier in the 2020-2021 timeframe. For example, authors such as "Kim JE" and "Lee J" appear to be more active in their collaborations during this period, perhaps indicating that they are leading or involved in established projects. The more yellow and green colored nodes indicate more recent collaboration activity, occurring around 2022 to 2024. Authors such as "Wang Y", "Zhang Y", and "Özcan M" appear to be still active in recent collaborations, suggesting that they remain key players in the growing collaboration network.

The different color combinations in the middle of the figure indicate that some authors' collaborations were continuous from the beginning to the end of the study period. This may indicate stability and continuity of collaboration between authors in the field. The more yellow part on the right of the figure indicates that there has been a recent increase in collaborative activity in the field. Authors such as "Özcan M" and "Revilla-León M" seem to be involved in new or developing projects in recent years. Overall, this temporal mapping demonstrates the dynamics within the research collaboration network, showing how collaborations evolve and change over time, with some authors remaining at the center of activity while others may enter or leave the collaboration network.

Fig. 4 shows a heat map of the density or intensity of collaboration between authors. Lighter areas indicate places where there is a high concentration of collaborative activity, while darker areas indicate a lack of collaborative activity.

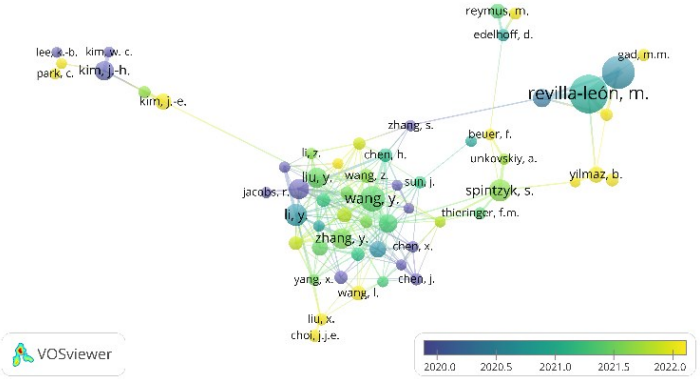

Fig. 3. Overlay Visualization by Co-Authorship

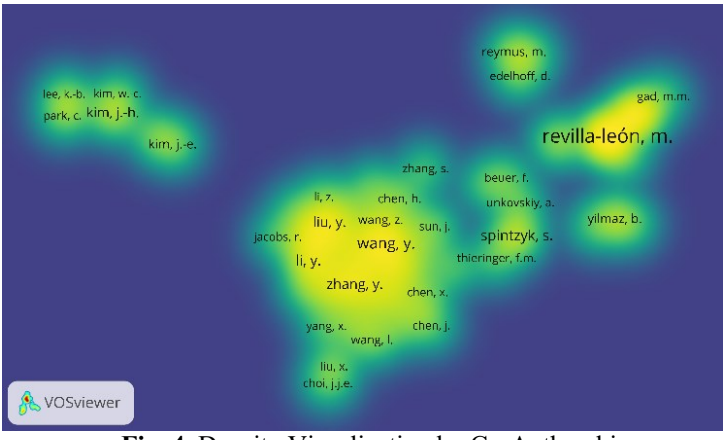

Fig. 4. Density Visualization by Co-Authorship

The highest concentration is seen in the central area, which includes authors such as "Wang Y", "Zhang Y", and "Liu Y". This area is bright yellow, indicating that a lot of collaboration is happening around these authors. This suggests that they may be at the center of the collaboration network, perhaps as research leaders or institutions that facilitate collaboration. Another prominent area is on the right, around authors like "Özcan M" and "Revilla-León M". Although not as bright as the central area, the yellow color around them indicates that they also play an important role in the research collaboration, although perhaps in a more limited or specific scope. The left part of the image shows less collaborative activity, especially around authors like "Lee J" and "Kim JE". The green color in this area indicates that while there is some collaboration, the activity is not as intense as in the central area. Their research is focused on a specific

subfield, as evidenced by the limited interaction with the main network. Other darker or blue areas indicate minimal or no collaboration between authors in that area. This could indicate the presence of independent researchers or small groups that are less involved in the larger collaborative network. This heat map provides a clear view of where collaboration is most intense within the network, as well as where there is potential to expand collaboration.

3.2 The Development of Research Publications by Keyword (Co-Occurrence)

Fig. 5 shows the co-occurrence visualization map generated by the VOSviewer software, illustrating the relationship between keywords that frequently co-occur in the literature published between 2014 to August 16, 2024. The map is divided into several color clusters, each representing a major theme of the study. The red, green, blue, and yellow clusters are the most dominant, indicating interrelated but differently focused areas of research.

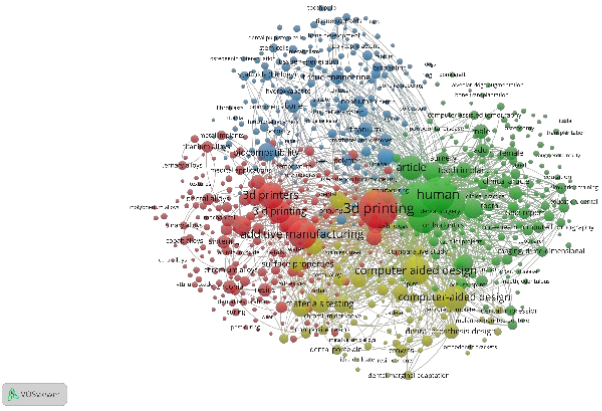

Fig. 5 Network Visualization by Co-Occurrence

The red cluster focuses on topics related to "additive manufacturing" and "3D printing. Keywords such as "biocompatibility", "dental alloys", and "titanium alloys" indicate that the focus of this cluster is on materials used in 3D printing, particularly in the context of biocompatibility for medical and dental applications. This indicates an increase in research into the use of 3D printing technology to produce medical devices and materials that are compatible with the human body.

The green cluster emphasizes the relationship between people and technology, as represented by the keywords "people", "processes" and "computer-aided design". This reflects attention to the application of 3D printing technology to medical and surgical procedures, as well as the development of computer-aided design for prosthetic and reconstructive applications. Research in this cluster appears to be focused on the direct application of these technologies to humans, with the goal of improving medical outcomes.

The blue cluster focuses on "tissue engineering", "bone regeneration" and "biomaterials", indicating a focus on regenerative research and biotechnology. This shows the strong link between 3D printing technology and the development of scaffolds for tissue regeneration, as well as the application of biomaterials in the restoration and reconstruction of biological tissues. This technology plays an important role in biomedicine, especially in supporting tissue growth and regeneration.

The yellow cluster contains terms related to “dental materials,” “materials testing,” and “surface properties.” This focus signifies significant research on the development and testing of materials used in dentistry, including strength and reliability testing of materials used in dental prosthetics. This shows that the field of dentistry is one of the main beneficiaries of 3D printing technology. Fig. 6 is a visualization map of the co-occurrence of various topics related to 3D printing and additive manufacturing, created with VOSviewer software. The time span of this analysis is from 2014 to August 16, 2024, as indicated by the color scale at the bottom of the figure. In this visualization, the size and color of the nodes or dots represent the frequency of occurrence as well as the average time of the related publications, while the connecting lines show the relationship or interconnection between the topics.

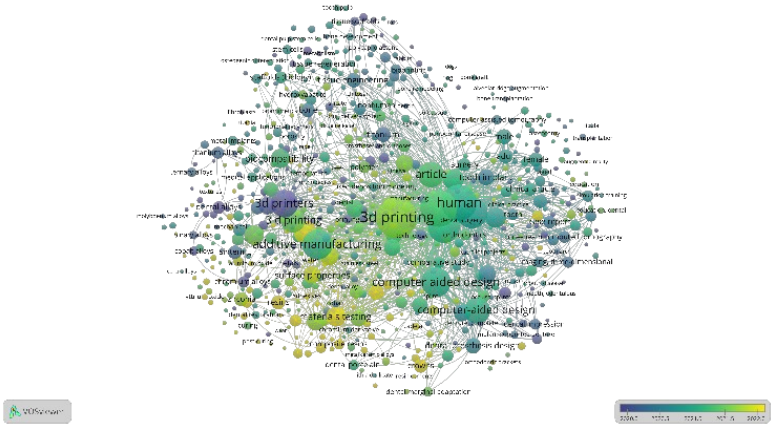

Fig. 6 Overlay Visualization by Co-Occurrence

From the map, "3D printing" and "additive manufacturing" appear as central topics with large node sizes, indicating that these two topics dominate the scientific and technical discussions in the field. Other related topics such as "biocompatibility", "human", and "computer-aided design" also have significant nodes, indicating that these topics are often discussed along with the main topics. This indicates that research in this area is not only focused on the 3D printing technology itself, but also on its practical applications and biomedical consequences. The temporal analysis shown by the colors of the nodes illustrates the evolution over time. Nodes with a yellow color indicate newer topics, such as "zirconia" and "composite resins", which are likely to be emerging areas of research in the recent past. Meanwhile, turquoise nodes, such as "biocompatibility" and "tissue engineering," indicate topics that have been the focus of

research for a long time but are still relevant today. The "Human" theme, also large and at the center of the visualization, shows that much of the research in this area is focused on applications directly related to humans, especially in a medical context. This is consistent with the appearance of other themes, such as "Bone", "Surgery" and "Dental Materials", which highlight the focus of research on clinical and medical applications, especially in terms of tissue regeneration and prostheses. Fig. 7 shows a density map of the same topic, highlighting areas of high intensity based on keyword frequency. The bright yellow color in the center indicates areas with the highest concentration of research, while the darker color indicates areas with lower concentration. This helps to identify the most frequently researched topics in that time period.

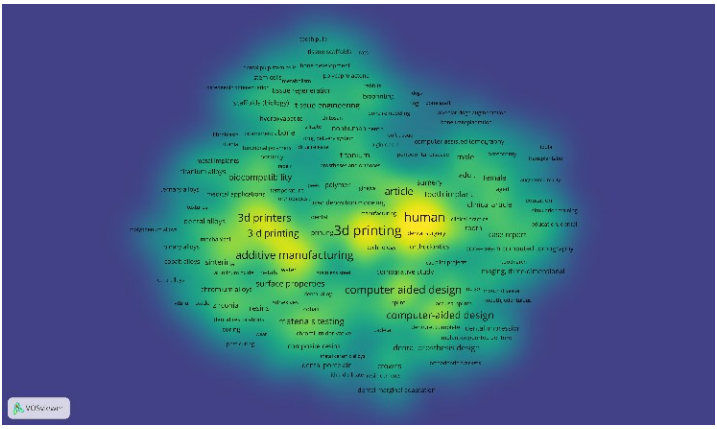

Fig. 7 Density Visualization by Co-Occurrence

The center of the density map, which is bright yellow, focuses on "3D Printing," "Additive Manufacturing,", “3d printers” and "Humans." This confirms that research into 3D printing technology and its applications in medical procedures are the areas of greatest interest over the past decade. This density shows that this technology is not only attracting a lot of attention, but is also becoming a center of innovation in scientific and medical research. The medium density region around the center includes keywords such as "tissue engineering," "bone regeneration," and "biocompatibility. This indicates that these areas, while not as popular as the main centers, remain a significant focus of related research, particularly in biotechnology and tissue regeneration. This indicates a continuing effort to explore how new technologies can be applied to improve medical outcomes.

The low to medium density regions, which include keywords such as "dental materials" and "surface properties", show that dentistry is a growing field but has a more specific volume of research. This suggests that while dentistry is a beneficiary of 3D printing technology, research in this area may be more segmented and specialized compared to broader medical applications. The density map provides insight into how much attention has been paid to different research topics over the past decade. From this map, it is clear that 3D printing technology and its applications in medical and regenerative engineering are the main focus, with applications in dentistry and specialty materials as growing but more segmented areas.

4 CONCLUSION

The conclusion of this study highlights the crucial role of research collaboration in driving the development of key themes in "3D printing" or "additive manufacturing", particularly in dental applications. The co-authorship and co-occurrence analysis reveal that the emergence of new research areas, such as "dental materials", is strongly supported by well-established collaborative networks among researchers. Furthermore, the findings suggest that international collaboration and a clear thematic focus will continue to be significant drivers of progress in this field.

These insights have important implications for the future of 3D printing, indicating that expanding and strengthening collaborative networks will unlock opportunities to explore new research topics that may become critical areas of study. The promising potential of dental materials research also demonstrates how collaboration can fuel innovation and clinical applications of 3D printing technology.

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