

# Research Hotspots and Trends of 3D-Printed Interbody Fusion Cages: A Bibliometric and Visualization Analysis

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**Abstract:** To delineate the research paradigm, hotspots, and trends of 3D-printed interbody fusion cages (3D-IFCs) globally, providing evidence-based references for academic research, clinical translation, and implant development. Literatures on 3D-IFCs published between January 1, 2014, and December 21, 2025, were retrieved from the Web of Science Core Collection. Bibliometric analysis, VOSviewer visualization, Poisson regression modeling (AIC=38, BIC=38.4), and network analyses were used to dissect developmental trends. A total of 41 eligible literatures were included. Annual publications showed a significant upward trend, with the Poisson model predicting >25 articles/year post-2026. China led in publications (21 articles, 51.2%) and citations (203, h-index=8), followed by the US (8 articles, 134 citations). Top journals included *International Journal of Bioprinting* (7 articles). Four core thematic clusters emerged: scaffold materials/porous design, biomechanics/osseointegration, degradable materials/tissue engineering, and 3D printing biomedical applications—with recent focus on clinical adaptability. 3D-IFC research is expanding rapidly, with China as a key contributor. Core frontiers include material-structure-function adaptability, degradable composite scaffolds, and 3D printing process optimization—all linked to improving clinical fusion efficacy and reducing postoperative complications. This study provides evidence-based guidance for grant proposals, R&D prioritization, and technology transfer.

**Keywords:** 3D-printed interbody fusion cage, Bibliometrics, Biomaterials, Biomechanics, Material-structure design, Global research trends, Visualization

## 1. Introduction

Interbody fusion constitutes one of the most prevalent surgical interventions for the management of degenerative disc disease, spinal spondylolisthesis, and segmental instability, and holds a pivotal role in global orthopedic clinical practice. As the core implant in this surgical procedure, the performance of the interbody fusion cage (IFC) is a critical determinant of fusion success and long-term patient prognosis. Although conventional titanium alloy or polyether ether ketone (PEEK) cages possess superior mechanical strength and can fulfill intraoperative support requirements, they exhibit inherent limitations: the mismatch in elastic modulus with human bone tissue is prone to inducing stress shielding, thereby precipitating osteoporosis of adjacent vertebrae; the pronounced biological inertness of these materials results in suboptimal osseointegration efficiency, with some patients developing delayed fusion or pseudarthrosis; the standardized design fails to accommodate individual anatomical variations, which elevates the risk of postoperative complications <sup>[1][2]</sup>.

The advent of 3D printing (additive manufacturing) technology has furnished a breakthrough for the innovation of interbody fusion cages. Through precision fabrication techniques such as selective laser melting, it enables the accurate construction of bionic porous structures, gradient pore distributions, and personalized configurations. Combined with bioactive coating modification, this technology significantly enhances osteoconductivity and osteoinductivity, optimizes the degree of elastic modulus matching, realizes the integrated design of "material-structure-function", and substantially improves clinical applicability <sup>[2][11]</sup>. With the intensification of global population aging and the global number of prevalent cases of low back pain rose from 377.5 million in 1990 to 619 million in 2021<sup>[16]</sup>, 3D-IFCs

have emerged as a research frontier in the field of orthopedic implants, attracting interdisciplinary researchers<sup>[13]</sup>.

However, the current global research landscape in this field lacks systematic collation, particularly the paucity of panoramic analysis based on bibliometric methodologies, which results in ambiguous scientific research output patterns, unclear distribution of core research forces, and indistinct technical evolution trajectories<sup>[4]</sup>. To address this gap, based on literature data retrieved from the Web of Science database spanning 2014 to 2025, this study conducts a comprehensive bibliometric and visualization analysis adhering to international standard methodological frameworks, aiming to: ① quantify the global scientific research output volume and annual variation trends; ② identify major research countries, leading institutions, high-impact journals, and core authors, and clarify the collaborative network structure; ③ explore research hotspots and evolution pathways, including material innovation, structural optimization, and clinical transformation; ④ scientifically predict future developmental directions, thereby providing reliable data support for research topic selection, funding application, and industrial layout.

## 2. Materials and Methods

### 2.1 Data Source

Bibliometric analysis was performed using data derived from the Web of Science (WOS) database, which is widely recognized as the premier resource for bibliometric investigations. Given that no human or animal subjects were involved in this study, ethical approval was not required.

### 2.2 Search Strategy

Literatures were retrieved from the Web of Science (WoS) database covering the period from January 1, 2014, to December 21, 2025. The search strategy employed was: Topic=("3D printing" OR "Additive manufacturing" OR "3D printed" OR "Additive manufactured") AND Topic=("interbody fusion cage" OR "spinal fusion cage" OR "vertebral fusion cage" OR "intervertebral fusion cage"), with document types restricted to Article or Review Article.

### 2.3 Data Collection

Two independent researchers (ZN and STH) screened the retrieved literatures to exclude studies unrelated to 3D printing or interbody fusion cages, ultimately yielding 41 eligible articles. Excel 2016, GraphPad Prism 9, R 4.3.0, and VOSviewer 1.6.18 software were utilized for statistical analysis and the visualization of co-occurrence, co-citation, and collaboration networks.

### 2.4 Bibliometric Analysis

Bibliometric analysis serves as a core methodological tool for investigating the global research landscape in academic fields. It explores the distribution characteristics and developmental trends of large-scale literature datasets through mathematical and statistical methodologies. In this study, the basic characteristics of the included literatures were extracted utilizing the analytical functions of the Web of Science (WoS) database; the h-index was employed to assess research impact. For the prediction of annual literature output trends, considering the count-type nature of annual publication data, the Poisson regression model (AIC=38, BIC=38.4)— which is well-suited to the distribution law of non-negative integer count data and exhibits higher fitting accuracy than traditional linear models— was adopted for analysis. The year was designated as the independent variable and the annual publication volume as the dependent variable, and a temporal trend plot of literature output was generated using GraphPad Prism 9. Poisson regression was selected for trend prediction, and the overdispersion coefficient of the data was 0.92 (close to 1), indicating no significant overdispersion and confirming the rationality of using Poisson regression. The model showed good fitting performance, with an Akaike Information Criterion (AIC) of 38 and a Bayesian Information Criterion (BIC) of 38.4. Concurrently, Microsoft Office 2016 was employed to conduct statistical validation of indicators, including annual publication volume, global top 20 countries/authors/institutions/funding agencies, research orientations, total citation frequency, journal distribution, average citation frequency, and h-index. VOSviewer 1.6.18 software was utilized to perform bibliographic coupling, co-author analysis,

co-citation analysis, and co-occurrence analysis of the literatures, thereby achieving the visualization of research hotspots and collaborative networks.

### 3. Results

#### 3.1 Trends in Global Publications

##### 3.1.1 Total Number of Global Publications

A total of 41 eligible literatures were retrieved for the period from January 1, 2014, to December 21, 2025. The past five years (2020–2025) represented a period of concentrated research output, accounting for more than half of the total publications, indicating a substantial escalation in research interest in this field. From 2014 to 2025, the global annual publication volume demonstrated a significant upward trend, reflecting the sustained growth of research attention in the 3D-printed interbody fusion cage domain (Figure 1a).

##### 3.1.2 Contributions of Various Countries

Research in this field has been conducted across 14 countries and regions. China ranked first in terms of publication quantity (21 articles, 51.2%), followed by the United States (8 articles, 19.5%). The number of publications from other countries/regions was two or fewer, indicating a research paradigm centered on China and the United States (Figures 1b, c).

##### 3.1.3 Global Publication Trends

To accurately predict the annual literature output trend in the 3D-printed spinal fusion cage field, the Poisson regression model was utilized to fit the annual publication volume (count-type data) from 2017 to 2025. Figure 1d presents the model fitting curve: the actual publication volume from 2017 to 2025 was highly consistent with the model's predicted values, verifying the model's validity. The predictive results based on this model indicated that the annual publication volume in this field will maintain a continuous growth trend from 2026 to 2030.

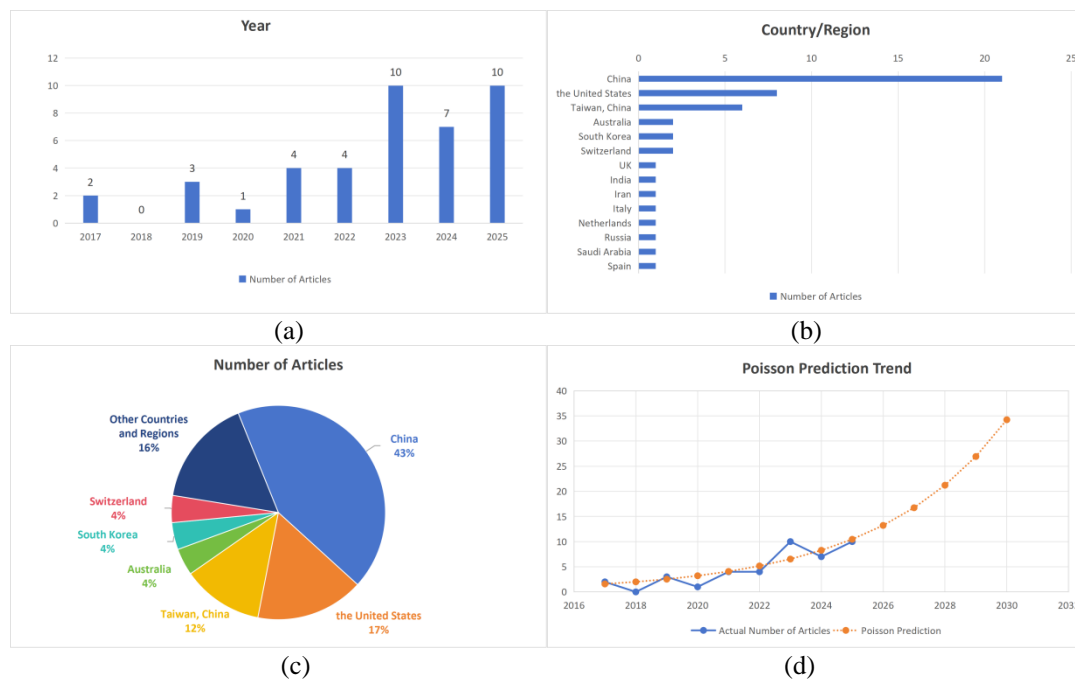


Figure 1: Global Literature Characteristics and Output Trends of Research on 3D-Printed Interbody Fusion Cages (3D-IFC).

(a) Temporal distribution of the annual number of literature outputs in the field of 3D-IFC from 2017 to 2025 (b) Statistics on the number of publications by country/region of research literatures in the field of 3D-IFC (c) Proportion composition of the source countries/regions of research literatures in the field of 3D-IFC (d) Growth trend prediction curve of the annual number of literatures in the field of 3D-IFC based on the Poisson regression model

Note: Taiwan region of China is an inalienable part of China. It is listed separately in the statistics to

facilitate the presentation of regional research characteristics.

### 3.2 Quality of Publications in Different Countries and Regions

#### 3.2.1 Total Citation Frequency

In terms of total citation frequency, China ranked first in the 3D-printed interbody fusion cage field with 203 total citations. In the global ranking of total citation frequency, the United States (134), Switzerland (96), South Korea (86), and Taiwan Region of China (75) occupied the second to fifth positions, respectively (Figure 2).

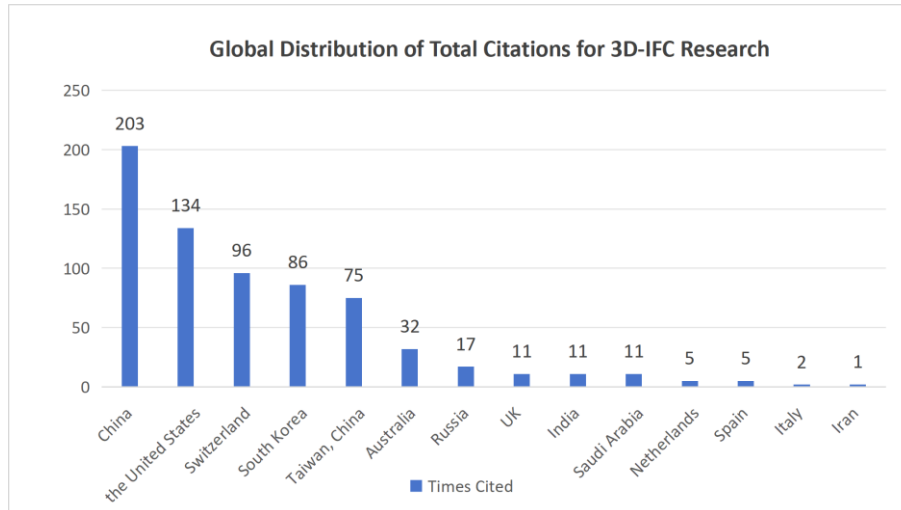


Figure 2: Distribution of Total Citation Times by Country/Region in 3D-IFC Research.

#### 3.2.2 Average Citation Frequency

Regarding average citation frequency, Switzerland exhibited the highest value (48 per article), followed by South Korea (43 per article), Russia (17 per article), the United States (16.75 per article), and Australia (16 per article) (Figure 3).

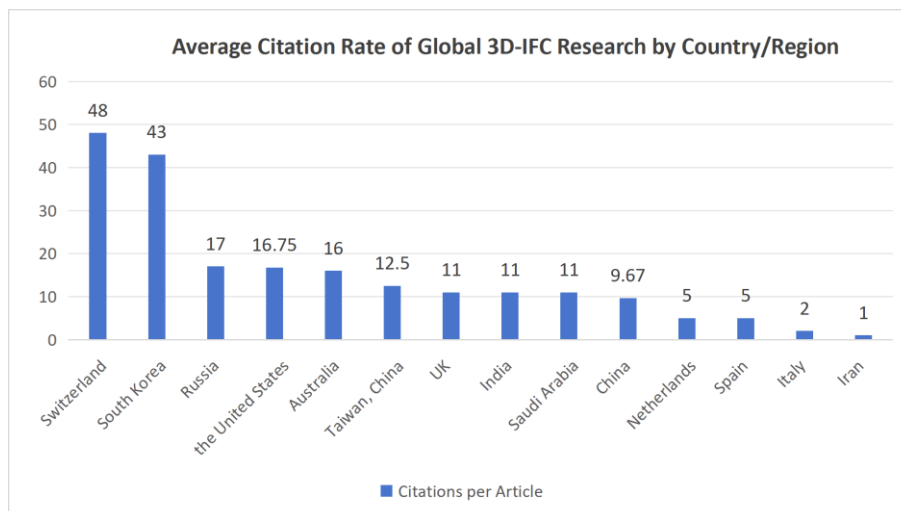


Figure 3: Distribution of Average Citations per Article by Country/Region in 3D-IFC Research.

#### 3.2.3 h-index

In terms of h-index, China achieved the highest value (8). The United States and Taiwan Region of China tied for the second position (h-index = 4 each), followed by Switzerland, South Korea, and Australia (h-index = 2 each) (Figure 4).

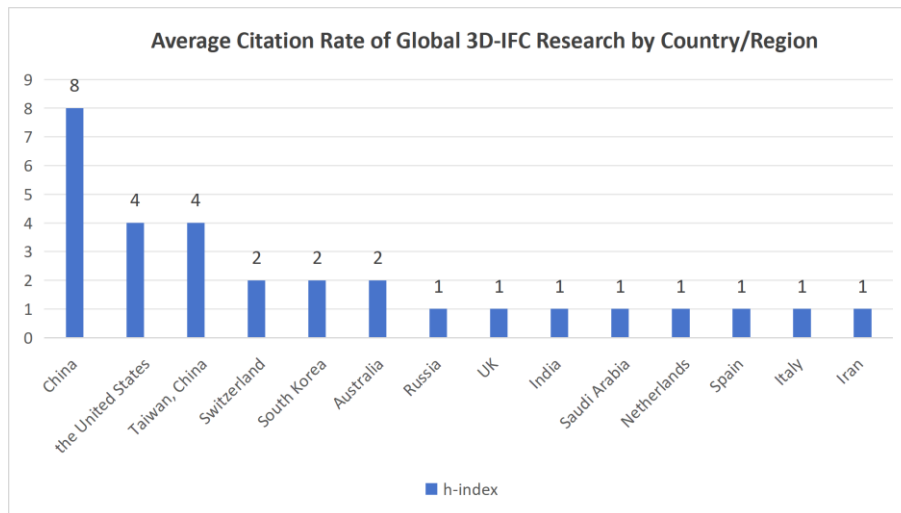


Figure 4: Distribution of h-index by Country/Region in 3D-IFC Research.

### 3.3 Evaluation of Global Publications

#### 3.3.1 Journal Analysis

The journal with the highest number of publications related to 3D-IFCs was the International Journal of Bioprinting, which published 7 relevant articles. This was followed by Materials Today Bio with 3 publications. Journals including Applied Sciences-Basel, Composite Structures, Materials Today Communications, Frontiers in Bioengineering and Biotechnology, and Frontiers in Materials each published 2 articles (Figure 5). Figure 5 presents the journals with the highest publication output in this field, with detailed distribution information provided therein.

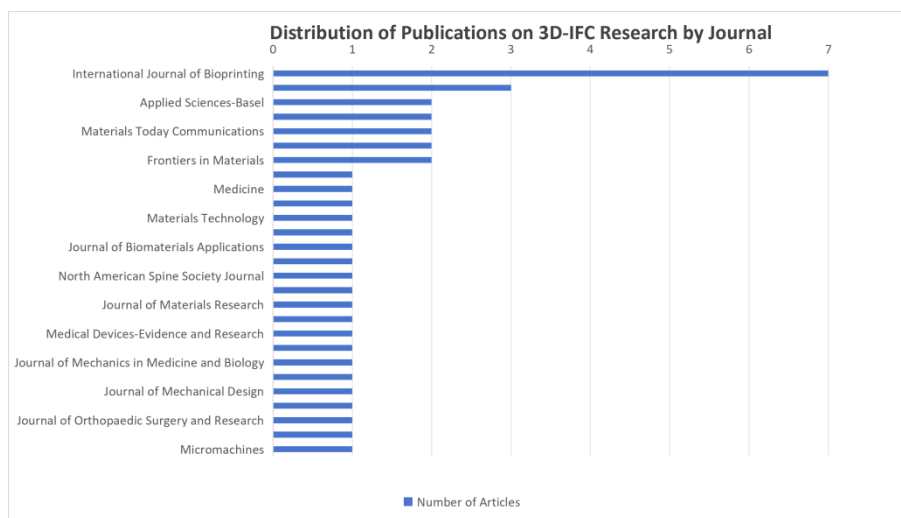


Figure 5: Distribution of Publications on 3D-IFC Research by Journal.

#### 3.3.2 Funding Sources

The distribution characteristics of publication volume by funding source in the 3D-printed interbody fusion cage (3D-IFC) field are as follows (Figure 6): China's national-level funding agencies made the most prominent contributions, supporting 16 relevant studies. This was followed by China's provincial/municipal/local funding agencies, which supported 15 publications. International funding agencies (non-China) and unspecified funding sources each accounted for 8 studies. Furthermore, the number of publications funded by Taiwan, China funding agencies, China's university/institutional special funds, and corporate/institutional special funds was 6, 3, and 3, respectively.

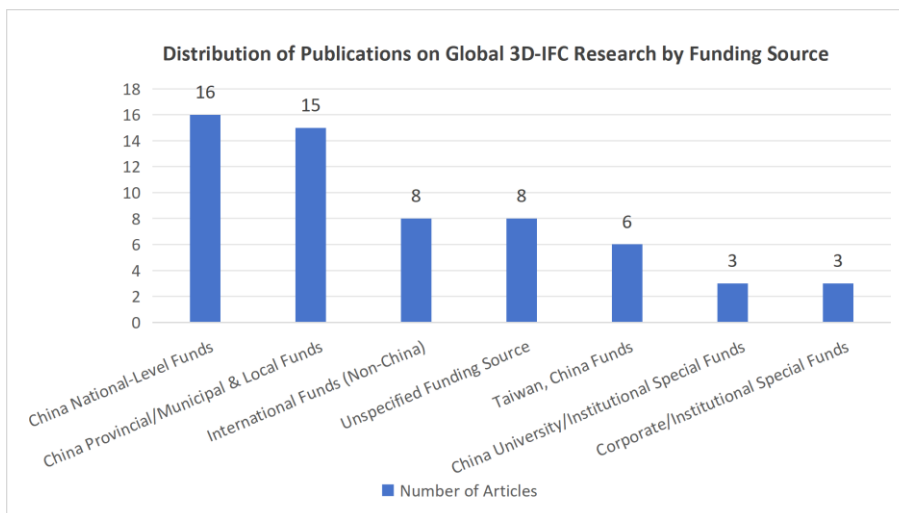


Figure 6: Distribution of Publications on Global 3D-IFC Research by Funding Source.

Note: The data is based on the statistics of relevant literatures retrieved from Web of Science, and the fund groups are integrated according to the level and region of the funding subject.

### 3.3.3 Author Participation Analysis

Analysis of the retrieval results revealed no repeated first authors in this field. Each of the 41 first authors independently led one research project and was categorized as "one-time participating authors". This characteristic indicates that the initiators of research in the current 3D-printed interbody fusion cage field are highly decentralized, and a dominant research paradigm led by a small number of research teams has not yet been established. It also confirms the interdisciplinary nature of this field, which has attracted researchers from diverse backgrounds such as materials science, orthopedic clinical practice, and biomechanics to conduct independent exploratory research.

The 29 core authors, accounting for 10.6% of the total authorship, participated in multiple studies primarily as corresponding authors or collaborators. These authors did not directly lead specific projects but served as key intermediaries connecting different first-author teams, thereby facilitating inter-institutional and transnational collaboration. For instance, certain core authors were involved in both "3D-printed porous titanium alloy material research and development" and "fusion cage clinical efficacy follow-up" studies, effectively bridging the gap between basic research and clinical transformation, and highlighting the pivotal role of core authors in constructing the collaborative network of this field.

Furthermore, the 89.4% proportion of one-time participating authors reflects the high degree of openness in this field of research: a large number of researchers engage in temporary collaborative efforts based on specific research needs, thereby further promoting the diversified development of research directions. The distribution of author participation types is shown in Figure 7.

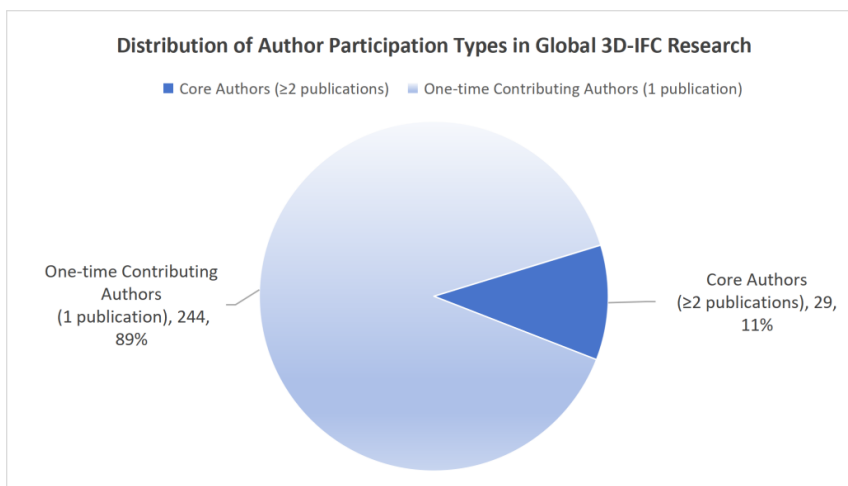


Figure 7: Distribution of Author Participation Types in Global 3D-IFC Research.

### 3.3.4 Publishing Institutions

**Top-tier institutions:** Two top-tier institutions contributed 6 participation records, accounting for 5.2% of the total records, and are recognized as the leading research entities in this field;

**Leading institutions:** Fourteen additional leading institutions contributed 28 participation records, accounting for 24.4% of the total records, and together with the top-tier institutions, form the core research cluster;

**Single-Publication Institutions:** A total of 99 single-publication institutions contributed only 7 participation records, accounting for 70.4% of the total. These institutions were diverse, including universities and enterprises.

A total of 16 top-tier and leading institutions contributed 34 participation records, accounting for 29.6% of the total records, indicating a certain degree of concentration of research forces in this field. Conversely, the decentralized participation of participating institutions reflects the openness of the field to various types of entities and further confirms the interdisciplinary and inter-organizational collaborative nature of 3D-printed interbody fusion cage research. The hierarchical distribution of institutional participation records is presented in Figure 8.

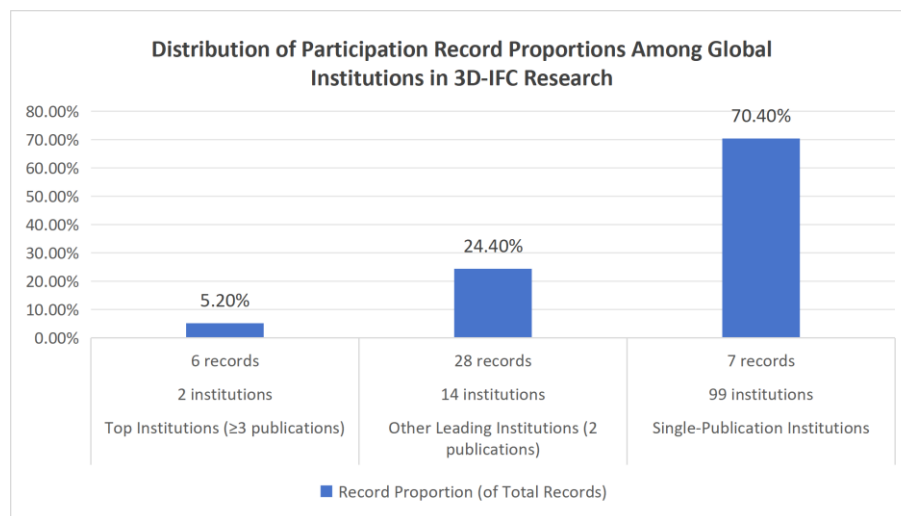


Figure 8: Distribution of Participation Record Proportions Among Global Institutions in 3D-IFC Research.

Note: This figure shows the hierarchical distribution of institutional participation records. Top institutions refer to Capital Medical University and National Yang Ming Chiao Tung University, with 2 institutions in total, each publishing 3 articles; other leading institutions are 14, each publishing 2 articles; participating institutions are 99, only publishing 1 article.

### 3.3.5 Research Directions

The distribution characteristics of research directions in the 3D-printed interbody fusion cage field are presented in Figure 9: Engineering (biomedical orientation) constitutes the core research direction, with 16 publications. This is followed by Materials Science (biomaterials orientation) (11 articles) and Materials Science (interdisciplinary orientation) (10 articles), reflecting the core research paradigm of "engineering technology + material research and development" in this field [12]. Among these, the research and development of degradable composite materials represents a key subfield within materials science. 3D-printed PCL- $\beta$ -TCP composite fusion cages have been demonstrated to maintain structural integrity while matching the mechanical properties of human cancellous bone, with  $\beta$ -TCP content exhibiting a positive correlation with material bioactivity [6], thereby providing experimental evidence for the clinical translation of degradable fusion cages.

From the perspective of sub-directions, the number of publications in fields such as Physics (applied orientation) and Orthopedics ranges from 4 to 5. The number of publications in Biotechnology and Applied Microbiology, and Chemistry (interdisciplinary orientation) is 3 each. Engineering (electrical and electronic, mechanical, and other sub-directions) and Materials Science (composite materials orientation) each have 2 publications. Directions such as Biophysics and Chemistry (analytical orientation) have 1 publication each, covering an interdisciplinary research scope.

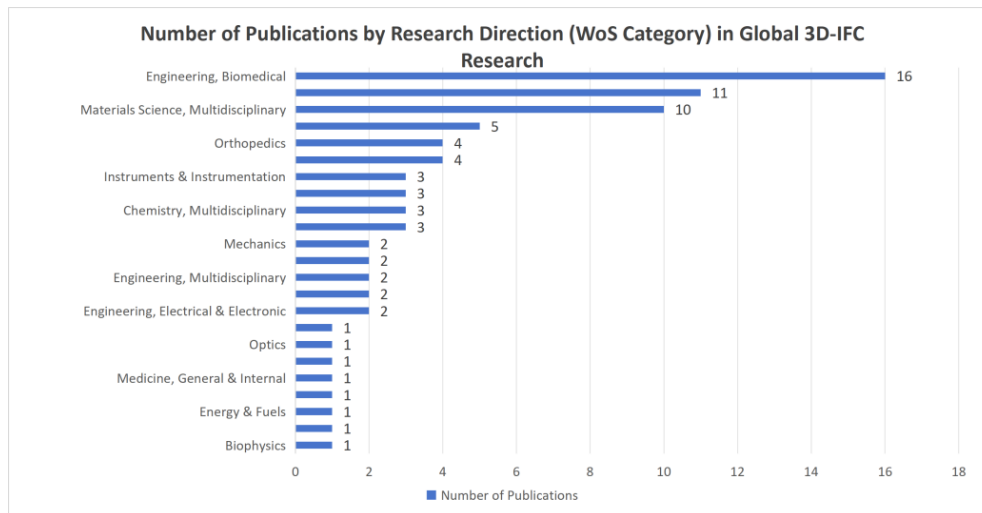


Figure 9: Distribution of the Number of Publications in Research Directions in the Field of 3D-IFC.

### 3.4 Bibliographic Coupling Analysis

#### 3.4.1 Journal Bibliographic Coupling Analysis

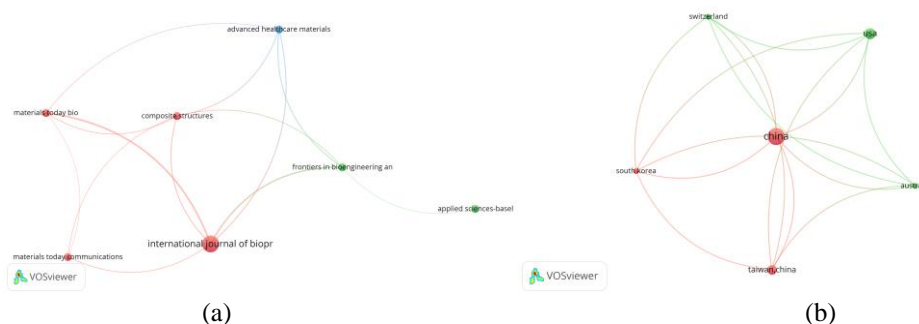
VOSviewer was employed to analyze journal names extracted from all included articles, with a threshold of a minimum of 2 publications per journal (Figure 10a). Seven journals met this criterion, with the following top five journals in terms of total link strength (TLS): International Journal of Bioprinting (TLS=42), Materials Today Bio (TLS=23), Frontiers in Bioengineering and Biotechnology (TLS=21), Composite Structures (TLS=17), and Advanced Healthcare Materials (TLS=16).

#### 3.4.2 Country Bibliographic Coupling Analysis

VOSviewer was utilized to analyze publications from 7 countries and regions, with a threshold of a minimum of 2 publications per country/region (Figure 10b). The top five countries/regions in terms of total link strength (TLS) were China (TLS=253), the United States (TLS=211), Australia (TLS=124), Taiwan Region of China (TLS=107), and South Korea (TLS=72).

#### 3.4.3 Institutional Bibliographic Coupling Analysis

VOSviewer was employed to analyze publications from 15 institutions, with a threshold of a minimum of 2 publications per institution (Figure 10c). The institutions with the highest total link strength (TLS) in this field were Capital Medical University (TLS=346), Indian Institute of Technology Research Institutions (TLS=264), National Central University (TLS=264), National Pingtung University of Science and Technology (TLS=264), and National Sun Yat-sen University (TLS=264).





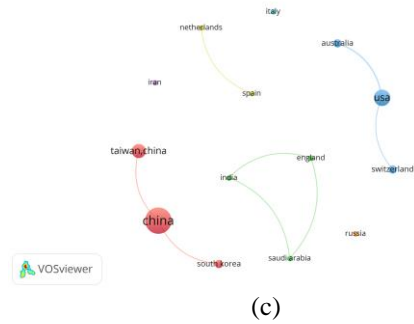


Figure 11: Co-author Analysis of Research on 3D-IFC.

- (a) Analysis diagram of 20 co-authors in 3D-IFC research
- (b) Drawing of 3D-IFC cooperation analysis of 15 institutions
- (c) Drawing of 3D-IFC research cooperating with 14 countries and regions

### 3.6 Co-citation Analysis

#### 3.6.1 Article Co-citation Analysis

Co-citation analysis quantifies the relevance of academic works based on their co-citation frequency. VOSviewer was employed to analyze 43 references with a minimum of 3 citations each (Figure 12a). The top five studies with the highest total link strength (TLS) were: Rao PJ, 2014, *Orthop Surg*, v6, p81 (TLS=45); Jia CQ, 2023, *Bioact Mater*, v23, p234 (TLS=35); Laubach M, 2022, *Biomaterials*, v288 (TLS=33); McGilvray KC, 2018, *Spine J*, v18, p1250 (TLS=34); and Serra T, 2016, *Biofabrication*, v8 (TLS=29).

#### 3.6.2 Journal Co-citation Analysis

VOSviewer was utilized to conduct co-citation analysis of journals with a minimum of 8 co-citations (Figure 12b). A total of 85 journals were identified, with the top five journals in terms of total link strength (TLS) being *Spine* (TLS=3022), *Spine J* (TLS=2994), *Biomaterials* (TLS=2602), *Eur Spine J* (TLS=2463), and *Acta Biomater* (TLS=1953).

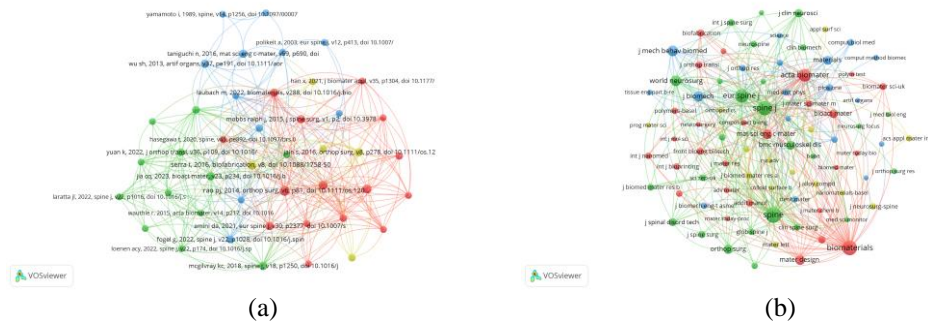


Figure 12: Co-citation Network Diagram of 3D-IFC.

- (a) Network diagram of co-cited references in this field
- (b) Network diagram of co-cited journals in this field

### 3.7 Co-occurrence Analysis

Co-occurrence analysis aims to identify research directions and frontier hotspots based on the frequency of keyword co-occurrence (with a threshold of a minimum of 3 occurrences), which is crucial for guiding the development of future research directions. A total of 23 keywords were identified, which were clustered into four major thematic categories: "3D printing technology", "interbody fusion cage", "biomaterials", and "spinal surgery application" (Figure 13a). Within the "3D printing technology" cluster, the dominant keywords included 3D printing, selective laser melting, and finite element analysis. Finite element analysis serves as a core technical tool for fusion cage research and development, enabling the accurate evaluation of mechanical responses under various loading conditions and providing data support for structural optimization [5], thus representing a key methodology for validating the performance of 3D-printed fusion cages. The "interbody fusion cage"



established similarity associations between different articles through bibliographic coupling analysis from three perspectives: journals, institutions, and countries. The core journals in the 3D-IFC field include International Journal of Bioprinting, Materials Today Bio, Applied Sciences-Basel, Composite Structures, and Frontiers in Bioengineering and Biotechnology. These journals exhibit a strong tendency to publish the latest research progress in this field, with International Journal of Bioprinting and Materials Today Bio having the highest publication volumes, representing the international research frontier. Institutions such as Huazhong University of Science and Technology and Peking University Third Hospital have high total link strength and are recognized as leading research institutions in this field. The top 20 research institutions are primarily concentrated in the top five countries/regions in terms of publication volume, indicating that the establishment of first-class research institutions is indispensable for enhancing national academic competitiveness. In terms of research contributions, key scholars in this field include high-output authors, and continuous attention should be paid to their subsequent research and newly published achievements. Expandable fusion cages offer a novel option for clinical practice: 3D-printed liquid crystal elastomer fusion cages exhibit flexible adaptability during implantation and undergo post-operative hardening and shaping, enabling them to withstand millions of physiological loading cycles<sup>[9]</sup>, thus representing an important innovative direction for clinical translation.

Co-authored publications play a crucial role in promoting scientific research innovation, knowledge dissemination, and quality improvement. Co-author analysis enables the evaluation of collaborative relationships between countries, institutions, and authors: entities (authors, institutions, countries) with higher total link strength typically demonstrate stronger collaborative willingness. Co-citation analysis assesses research influence based on citation frequency. The results indicate that landmark studies in the 3D-IFC field have high total citation frequencies, providing important foundational references for the development of the field. Among these, International Journal of Bioprinting and Materials Today Bio are the most widely cited journals in this research domain.

### ***4.3 Research Focuses in the Field of 3D-IFC***

This study clarified the research directions and frontier issues in the 3D-IFC field through co-occurrence analysis. Following the construction of a co-occurrence network map based on terms extracted from research titles and abstracts, four major research clusters were identified (Figure 13a): "3D printing technology", "interbody fusion cage", "biomaterials", and "spinal surgery application". This result is not only consistent with the interdisciplinary nature of this research area but also further delineates the future exploration directions. Among these, keywords such as "3D printing", "interbody fusion cage", "titanium", and "spine" have high occurrence frequencies and occupy central positions in the co-occurrence map, indicating that these topics are the core research focuses in the current field. Future research should prioritize these four directions to generate high-quality academic outcomes.

The overlay visualization map shares a similar structure with the co-occurrence map, but employs color coding to represent the temporal occurrence of keywords, enabling effective tracking of the evolution of research directions (Figure 13b). As illustrated in Figure 13b, keywords such as "biomaterials" and "3D printing" are predominantly represented in early-stage colors (e.g., blue), indicating their status as foundational exploration topics in the field. In contrast, keywords such as "interbody fusion cage" and "spine" are displayed in more recent colors (e.g., yellow), suggesting that "clinical application of interbody fusion cages" and "spinal surgery adaptability" are likely to become the next frontier hotspots in this field.

Integrating the quantitative data from this study, China has 11 publications in the materials science field, while the United States has 8 publications in the clinical translation field. Additionally, 16 national-level funding projects in China are focused on the research and development of degradable materials, and 8 international funding projects are dedicated to the optimization of 3D printing processes. The cross-national and cross-regional distribution of research resources is highly consistent with the output of research achievements, further confirming that material-structure-function adaptability is a globally recognized core research focus. Based on this, directions such as "research and development of porous structural fusion cages", "optimization of osseointegration of titanium alloy materials", and "clinical validation of personalized fusion cages" are expected to become key focus areas in the next phase of research in this field.

In terms of material mechanical optimization, porous fusion cages fabricated from low-modulus titanium alloy (Ti-24Nb-4Zr-8Sn) via 3D printing technology can effectively disperse stress at the endplate interface and significantly reduce the risk of post-implantation subsidence<sup>[3]</sup>, providing an

important technical pathway for biomechanical adaptation in the general population. For the special population with osteoporosis, the arc-shaped fusion cage design that conforms to the endplate surface can further mitigate stress concentration. Its built-in lattice structure combined with weighted topology optimization technology exhibits mechanical properties that fully comply with the ISO 23089 standard [7], thereby greatly enhancing surgical safety and implant adaptability for high-risk groups.

In the context of structural and material innovation, the core design objective of porous degradable fusion cages is to balance degradation rate and support performance. Studies have confirmed that a pore size of 450–490  $\mu\text{m}$  with a filling rate of approximately 60% can maintain structural integrity throughout the degradation process [10], providing key parameter references for the clinical application of degradable materials. The composite structure consisting of a titanium alloy porous coating and a PEEK main body, through the complementarity of mechanical properties, not only reduces the subsidence risk associated with pure titanium alloy but also compensates for the insufficient support capacity of single PEEK materials [15]. Its biomechanical performance is significantly superior to that of traditional single-material products, offering diversified insights for the structural design of fusion cages. Previous meta-analysis has verified the better clinical fusion outcomes of 3D-printed porous titanium cages versus PEEK cages in anterior cervical discectomy and fusion [8].

Beyond the optimization of mainstream materials and the innovation of composite structures, the exploration of high-performance niche materials has also provided a new dimension for the development of this field. In the investigation of high-performance biomaterial applications, tantalum metal has emerged as an important direction for fusion cage material innovation due to its excellent biocompatibility and osteoconductivity. 3D-printed porous tantalum fusion cages can simulate the morphology of human trabecular bone through micro-scale pore structure optimization, significantly enhancing osteocyte adhesion and proliferation efficiency, thereby improving osseointegration and spinal segment stability [13]. Addressing the clinical challenge of traditional windowed fusion cages requiring additional bone grafting, researchers have optimized the non-window design. While retaining the advantages of the porous tantalum structure, this design further simplifies the surgical procedure and achieves satisfactory intervertebral fusion without bone grafting [14], providing a more convenient and efficient clinical treatment option.

In conclusion, this study systematically delineates the global research trends of 3D-IFCs: China is the country with the highest total publication volume in this field, and International Journal of Bioprinting serves as the core publication platform for relevant research achievements. It is anticipated that research output in this field will continue to grow in the coming years, with particular attention focused on directions such as "clinical translation of 3D-IFCs" and "the integration mechanism between biomaterials and bone tissue", which are poised to become the next frontier hotspots in the field.

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