

Global Research Trends and Hotspots of Contrast-Enhanced Ultrasound in Tumor Diagnosis: A Bibliometric Analysis (2000–2025)

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Abstract: *Objective:* To systematically evaluate global research trends on contrast-enhanced ultrasound (CEUS) in tumor diagnosis using bibliometric methods. *Methods:* Publications from January 2000 to June 2025 were retrieved from the Web of Science Core Collection (SCI-EXPANDED). Only English-language articles and reviews were included. A total of 3,493 records were analyzed. VOSviewer 1.6.20 were used for bibliometric and visualization analyses, covering annual output, countries and institutions, authors, journals, keyword co-occurrence, collaboration networks, and co-citation patterns. *Results:* The number of publications demonstrated steady growth with acceleration after 2018, peaking in 2021 and 2023 (> 350 papers/year). Dietrich Christoph F. was the most productive and influential author, while Chinese scholars (e.g., Dong Yi, Wang Wen-Ping) and institutions such as Sun Yat-sen University and Fudan University emerged as leading contributors. European journals, particularly Ultrasound in Medicine and Biology and European Radiology, showed high academic influence. Keyword analysis revealed liver cancer, especially hepatocellular carcinoma, as the dominant research theme, with expanding applications in breast, renal, and prostate tumors. Collaboration networks highlighted strong partnerships between China and Europe, whereas North American participation remained limited. Co-citation analysis indicated that a small number of highly cited studies shaped the intellectual foundation of the field. *Conclusion:* CEUS research in tumor diagnosis has expanded rapidly, characterized by concentrated leadership, thematic diversification, and strengthening international collaboration. With advances in artificial intelligence, super-resolution imaging, and novel contrast agents, CEUS is expected to evolve from a diagnostic tool into an integrated platform for tumor detection, treatment monitoring, and personalized cancer care.

Keywords: Contrast-enhanced ultrasound; Tumor diagnosis; Bibliometrics; Research trends

Online publication: October 16, 2025

1. Introduction

Early diagnosis and accurate evaluation of tumors are crucial for improving patient survival and guiding individualized treatment strategies. Imaging techniques, as indispensable tools in oncology research and clinical practice, have significantly promoted the progress of precision oncology. Among them, ultrasound is widely applied due to its advantages of being noninvasive, safe, and capable of real-time imaging. However, conventional two-dimensional ultrasound is limited in spatial resolution and microvascular visualization, making it insufficient to fully capture tumor angiogenesis and tissue perfusion characteristics.

Contrast-enhanced ultrasound (CEUS), as a functional imaging technique, has developed rapidly in recent years. Through intravenous injection of microbubble contrast agents, CEUS enables real-time and dynamic monitoring of tumor blood perfusion, effectively compensating for the shortcomings of conventional ultrasound. Recent studies have demonstrated that CEUS plays an important role in the diagnosis, staging, and therapeutic assessment of various solid tumors, including those of the thyroid, breast, kidney, and liver.

For example, a recent meta-analysis by Gao et al. highlighted that CEUS exhibited significantly higher sensitivity, specificity, and area under the curve (AUC) compared with conventional ultrasound in detecting lymph node metastasis of thyroid cancer ^[1]. In the field of breast imaging, Zhu et al. reported that CEUS-based BI-RADS showed superior diagnostic efficacy over conventional BI-RADS, particularly for category 4 lesions, thereby reducing unnecessary biopsies ^[2]. Furthermore, Wu et al. (2024) demonstrated that high-frame-rate CEUS (H-CEUS) significantly improved the qualitative and quantitative characterization of solid renal tumors, providing better differentiation between benign and malignant masses ^[3].

Despite these promising advances, challenges remain in this field: research topics are fragmented, contributions vary across regions, and there is a lack of systematic global reviews to summarize research trends and frontiers. Bibliometric analysis offers a powerful approach to quantitatively map the knowledge structure of a discipline, identify influential scholars and institutions, and uncover emerging research hotspots. Such insights may facilitate a comprehensive understanding of the developmental trajectory of CEUS and provide valuable references for future innovations.

Based on this, the present study utilized the Web of Science Core Collection to retrieve relevant publications from 2000 to 2025, and employed VOSviewer for systematic bibliometric analysis. The aim was to delineate the global research landscape, identify core authors and institutions, and explore research hotspots and emerging trends, thereby providing constructive references for the academic development and clinical applications of CEUS.

2. Methods

2.1. Data source and search strategy

The data for this study were retrieved from the Web of Science Core Collection (WoSCC), with the Science Citation Index Expanded (SCI-EXPANDED, 1900–present) selected as the citation index. The search strategy was defined as follows: TS = (“contrast-enhanced ultrasound” OR “CEUS”) AND (“tumor” OR “tumour” OR “cancer” OR “carcinoma” OR “neoplasm” OR “oncology” OR “malignant”) AND (“diagnosis” OR “diagnostic” OR “detection” OR “screening”). The time span was set from January 2000 to June 30, 2025. Only articles and reviews published in English were included, while conference proceedings, early access publications, editorials, and letters were excluded. A total of 3,853 records were initially retrieved. After independent screening of titles and abstracts by two researchers, duplicates and irrelevant studies were removed, resulting in 3,493 publications (2,832 articles and 661 reviews) included for analysis.

2.2. Data analysis

Bibliometric analyses were conducted using VOSviewer 1.6.20. The analyses covered the following aspects: annual publication trends, geographical distribution of countries and regions, contributions of authors and institutions, high-frequency keywords and emerging research hotspots, collaboration networks, and co-citation patterns. This comprehensive bibliometric approach was designed to systematically map the global research landscape of CEUS in tumor diagnosis and to elucidate its developmental trajectories and emerging themes.

3. Results

3.1. Top 10 authors by publication output

Among the top 10 authors ranked by publication output, Dietrich Christoph F. ranked first with 77 articles, which have been cited 1,864 times (average 24.21 citations per article), indicating a strong academic influence. He was followed by Dong Yi (72 articles, 894 citations, average 12.42) and Wang Wen-Ping (58 articles, 1,197 citations, average 20.64). In terms of average citations, Piscaglia Fabio achieved the highest impact, with 40 articles cited 1,760 times (average 44.00 per article), followed by Lu Ming-De (31.00) and Xu Hui-Xiong (28.80). Overall, authors with higher publication outputs generally also demonstrated relatively high citation rates, suggesting their central contributions to this research field (Table 1).

Table 1. Top 10 authors by publication output

Author name	Total number of articles	Total citations	Average citations
Dietrich, Christoph F.	77	1864	24.2078
Dong, Yi	72	894	12.4167
Wang, Wen-Ping	58	1197	20.6379
Lu, Ming-De	55	1705	31
Xie, Xiao-Yan	55	1568	28.5091
Wang, Wei	52	1020	19.6154
Xu, Hui-Xiong	49	1411	28.7959
Luo, Yan	44	596	13.5455
Piscaglia, Fabio	40	1760	44
Goerg, Christian	37	234	6.3243

3.2. Top 10 institutions by publication output

At the institutional level, Sun Yat-sen University ranked first with 172 publications and 3,626 citations (average 21.08 citations per article), demonstrating its leading academic position in this field. Fudan University (166 publications, 2,935 citations, average 17.68) and Shanghai Jiao Tong University (139 publications, 2,410 citations, average 17.34) followed closely behind. Notably, although Peking University ranked eighth with only 61 publications, it achieved the highest average citation count of 23.15 among all institutions, highlighting the high quality and strong impact of its research output. Overall, multiple top-tier Chinese universities have formed a concentrated research force in this field (Table 2).

Table 2. Top 10 institutions by publication output

Institution name	Total number of articles	Total citations	Average citations
Sun Yat-sen University	172	3626	21.0814
Fudan Univ	166	2935	17.6807
Shanghai Jiao Tong Univ	139	2410	17.3381
Sichuan Univ	101	1310	12.9703
Zhejiang Univ	88	1225	13.9205
Huazhong Univ Sci & Technol	75	1157	15.4267
Chinese Peoples Liberat Army Gen Hosp	74	1059	14.3108
Peking Univ	61	1412	23.1475
Tongji Univ	60	893	14.8833
Iuliu Hatieganu Univ Med & Pharm	55	797	14.4909

3.3. Top 10 journals by publication output

Table 3 presents the top 10 journals ranked by publication output on contrast-enhanced ultrasound (CEUS) in tumor diagnosis. Among them, Ultrasound in Medicine and Biology published the highest number of articles ($n = 186$), followed by Clinical Hemorheology and Microcirculation ($n = 167$) and the Journal of Ultrasound in Medicine ($n = 127$). These three journals collectively accounted for nearly one-third of all publications in this field, indicating their central role in disseminating CEUS-related research.

Table 3. Top 10 journals by publication output

Journal Name	Total Number Of Articles	Total Citations	Average Citations
Ultrasound In Medicine And Biology	186	4301	23.1237
Clinical Hemorheology And Microcirculation	167	2821	16.8922
Journal Of Ultrasound In Medicine	127	2163	17.0315
Frontiers In Oncology	124	745	6.0081
Ultraschall In Der Medizin	96	5085	52.9688
European Radiology	92	3276	35.6087
Abdominal Radiology	89	1718	19.3034
European Journal Of Radiology	88	3035	34.4886
Medical Ultrasonography	74	854	11.5405
Diagnostics	70	606	8.6571

In terms of total citations, Ultraschall in der Medizin ranked first with 5,085 citations, despite contributing a smaller number of publications ($n = 96$). Its exceptionally high average citation rate (52.97 per article) highlights its strong academic influence and the high quality of its published works. Similarly, European Radiology (3,276 citations; average 35.61) and the European Journal of Radiology (3,035 citations; average 34.49) demonstrated significant impact, reflecting the leading position of European journals in radiological imaging research.

By contrast, some journals with relatively high output, such as Frontiers in Oncology ($n = 124$), showed

lower average citations (6.01), suggesting that while these journals contribute substantially to volume, their academic influence is relatively limited compared with specialized radiology or ultrasound journals.

Overall, the distribution pattern suggests that CEUS-related tumor diagnosis research is mainly disseminated in specialized ultrasound and radiology journals, with European journals demonstrating particularly strong academic impact. This reflects both the interdisciplinary nature of CEUS and the regional research advantages in Europe.

3.4. Co-occurrence analysis of keywords

Table 4 summarizes the top 10 keywords by co-occurrence frequency. The most frequent term was “contrast-enhanced ultrasound” ($n = 1024$), followed by its variant spelling “contrast-enhanced ultrasound” ($n = 847$). Other frequently co-occurring keywords included “hepatocellular carcinoma” ($n = 776$), “diagnosis” ($n = 722$), “ultrasonography” ($n = 593$), and “sonography” ($n = 452$). General oncological and imaging-related terms such as “cancer” ($n = 447$), “CT” ($n = 429$), “lesions” ($n = 425$), and the abbreviation “CEUS” ($n = 378$) also appeared among the top 10. These findings indicate that research on CEUS in tumor diagnosis is strongly linked to imaging modalities, clinical diagnosis, and liver cancer, especially hepatocellular carcinoma.

The co-occurrence network map (**Figure 1**) visualizes these relationships and highlights the clustering of keywords into distinct research themes. Four major clusters were identified:

The green cluster, centered on “contrast-enhanced ultrasound,” “diagnosis,” and “cancer,” emphasizes clinical diagnostic applications and differentiation between benign and malignant lesions. The blue cluster focuses on liver-related research, particularly hepatocellular carcinoma, intrahepatic cholangiocarcinoma, cirrhosis, and surveillance, reflecting the central role of CEUS in liver oncology. The yellow cluster is associated with comparative imaging modalities such as CT and MRI, highlighting CEUS as an alternative or complementary diagnostic tool.

The red cluster emphasizes technical aspects, including contrast agents, perfusion, microbubbles, angiogenesis, and breast cancer applications, representing the development of CEUS methodologies and therapeutic monitoring.

Together, the keyword analysis reveals that CEUS research in tumor diagnosis is dominated by studies on liver cancer and hepatocellular carcinoma, while also extending to breast, kidney, and prostate tumors, as well as broader applications in lesion characterization and differential diagnosis. Moreover, the interplay between technical development and clinical application underscores the interdisciplinary nature of CEUS research.

Table 4. Top 10 keywords by co-occurrence frequency

Rank	Frequency	Centrality	Time	Keyword
1	1024	0	2005	contrast-enhanced ultrasound
2	847	0.01	2006	contrast enhanced ultrasound
3	776	0	2005	hepatocellular carcinoma
4	722	0.01	2005	diagnosis
5	593	0.01	2007	ultrasonography
6	452	0.02	2005	sonography
7	447	0.01	2007	cancer
8	429	0.02	2005	ct
9	425	0.01	2005	lesions
10	378	0.01	2010	ceus

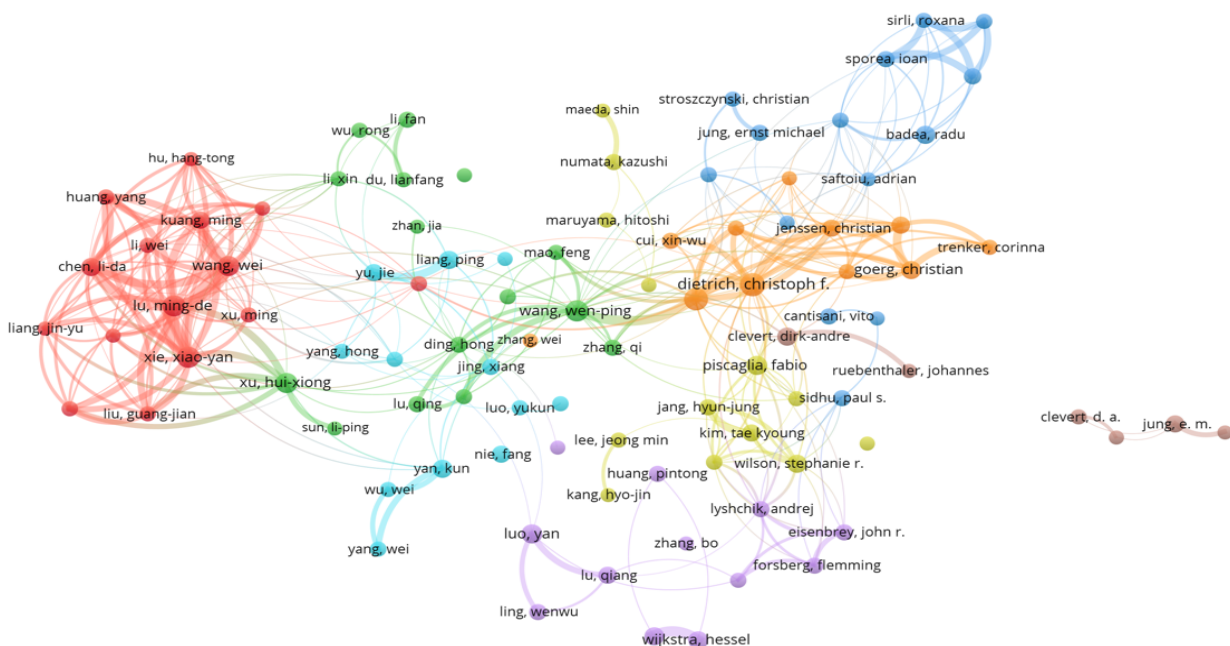


Figure 2. Author collaboration network.

3.6. Institutional collaboration network

The institutional collaboration network reflects patterns of academic cooperation at the organizational level. Chinese universities such as Fudan University, Shanghai Jiao Tong University, Sun Yat-sen University, and Zhejiang University occupy central positions in the network, underscoring their importance in both research output and collaborative capacity. Western institutions, including Stanford University, the University of California system, and several European medical centers, also demonstrate high node weights, indicating their substantial international influence. The clustering of different colors reveals the formation of several tightly connected groups, with collaborations among Chinese universities being the most frequent, highlighting the characteristics of regional academic alliances. In contrast, cross-national collaborations are more concentrated between international medical research institutions and leading Chinese universities. This collaborative model not only promotes the diversification and internationalization of research but also facilitates the bidirectional exchange of clinical experience and experimental techniques (**Figure 3**).

3.7. National collaboration network

The national collaboration network reveals the global distribution of research power and patterns of cooperation. In the network, countries such as China, the United States, and Germany exhibit larger nodes, reflecting their central roles in publication output and international influence. The collaboration between China and the United States is particularly strong, with both also maintaining close ties with Germany, Italy, and Japan, thereby forming a tightly connected international network. European countries constitute a regional collaboration circle characterized by frequent intra-regional partnerships. Notably, several emerging countries, including Romania, India, and South Korea, have become increasingly active in recent years. Although their overall publication volume remains limited, collaboration with core countries has enhanced their research visibility. Overall, the structure of international collaboration is characterized by a small number of core countries driving the field while

This network graph illustrates the complex web of international trade relationships. The nodes represent countries, and the edges represent trade flows between them. The graph is highly interconnected, with many countries having multiple trade partners. The nodes are colored in various shades, and the edges are thin lines connecting them. The graph shows a dense network of trade relationships, with many countries having multiple trade partners. The nodes are labeled with country names, and the edges represent trade flows between them. The graph is highly interconnected, with many countries having multiple trade partners. The nodes are colored in various shades, and the edges are thin lines connecting them.

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3.8. Annual publication trends

The annual publication trend reflects the overall developmental trajectory of this field. From 2005 to the present, the number of publications has shown a steady upward trend, with an accelerated increase observed after 2018, reaching stage-specific peaks in 2021 and 2023, with more than 350 articles published annually. The close fit between cumulative publications and the exponential growth model ($R^2 = 0.9488$) indicates that the development of this field follows an exponential growth pattern. This trend suggests that the field has not only maintained continuous academic attention but has also achieved new breakthroughs in methodological innovation, clinical application, and interdisciplinary integration. In light of the growing global demand for medical imaging and precision diagnostics in recent years, it can be anticipated that research activity in this area will remain at a high level, with continued growth in scientific output (**Figure 5**).

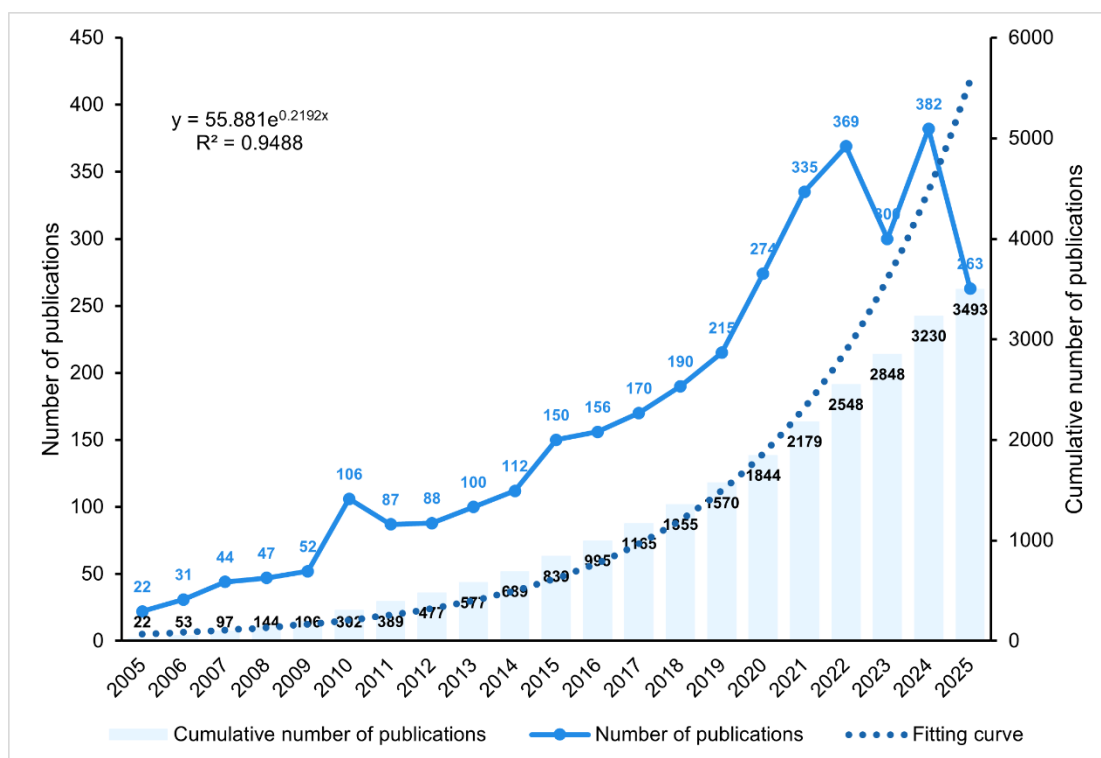


Figure 5. Annual publication trends.

3.9. Co-citation analysis

The co-citation analysis reveals the intellectual foundation of the field and the clustering of core references. In the network, nodes of different colors represent groups of publications with high co-citation frequencies, reflecting several relatively independent yet interconnected research themes. The green and blue clusters are mainly centered on imaging methodologies and clinical diagnostic studies, whereas the red cluster focuses on emerging applications and methodological refinements. Node size indicates citation frequency, while the thickness of the connecting lines reflects co-citation strength. For example, seminal works such as Claudon (2013) and Dietrich (2020) occupy central positions, underscoring their pivotal roles in advancing theoretical frameworks and methodological development in this field. The overall network demonstrates a core-periphery structure, suggesting that research hotspots are driven by a limited number of highly influential references, gradually diffusing and branching into diverse directions. This pattern implies that future investigations are likely to continue building upon these highly

cited works, leading to further deepening and expansion of the field (**Figure 6**).

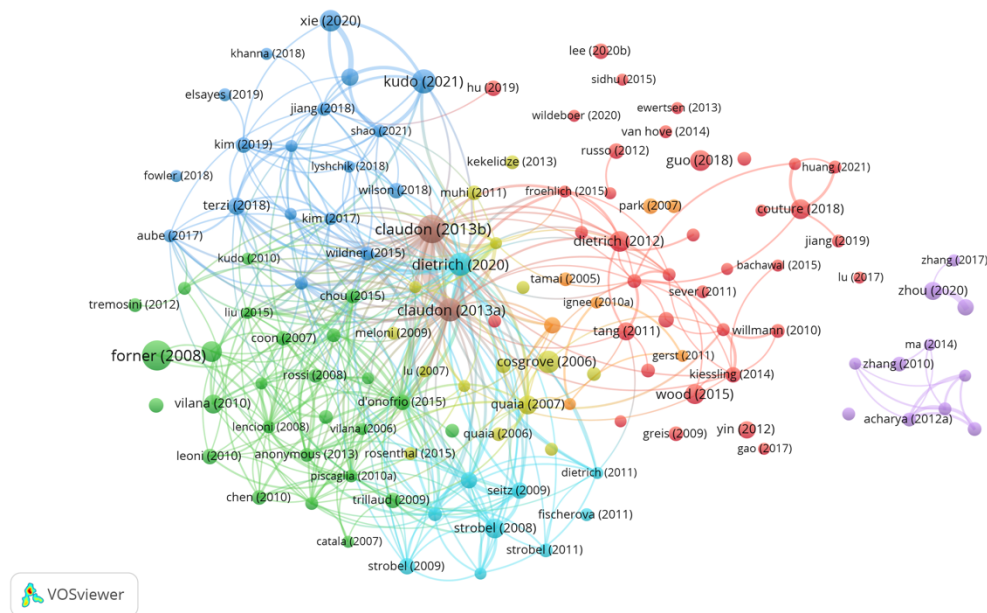


Figure 6. Co-citation analysis.

4. Discussion

This bibliometric study provides a comprehensive evaluation of the global research landscape of contrast-enhanced ultrasound (CEUS) in tumor diagnosis, highlighting key drivers, dissemination practices, collaboration patterns, thematic evolution, and future directions. A select group of authors and institutions has profoundly shaped the field. Christoph F. Dietrich has consistently contributed highly productive and influential work, with his most recent leadership in updating dynamic contrast-enhanced ultrasound (DCE-US) oncology monitoring guidelines in 2023 further underscoring his central role ^[4]. Similarly, Chinese institutions such as Sun Yat-sen University, Fudan University, and Shanghai Jiao Tong University have rapidly ascended as global leaders in CEUS research, while Peking University demonstrates high average citation impact despite modest output. At the same time, Fabio Piscaglia's high-impact studies on CEUS safety remain influential, showing that academic impact depends not only on publication volume but also on methodological rigor and clinical relevance.

Journal distribution indicates that CEUS research is concentrated in specialized ultrasound and radiology journals. European journals such as *Ultraschall in der Medizin* and *European Radiology* continue to demonstrate strong influence, whereas emerging outlets publish more volume but with lower academic impact, underscoring the importance of novelty and clinical utility in shaping academic visibility.

Thematic evolution highlights CEUS's expanding role in oncology. Early studies validated diagnostic utility, particularly in liver nodules, while more recent research has focused on hepatocellular carcinoma. CEUS is now increasingly applied to other tumor types. Recent work has demonstrated its value in differentiating breast lesion subtypes ^[5] and in breast cancer management more broadly ^[6]. Similarly, advances have been made in renal imaging, with updated EFSUMB recommendations supporting CEUS for the evaluation of solid renal lesions ^[7].

Beyond oncology, new applications have been explored in the urinary system, from kidneys to bladder ^[8]. These developments reflect the cross-cancer and multi-organ potential of CEUS.

Technological innovation has further expanded CEUS capabilities. The 2023 update of DCE-US standards emphasized its use for treatment monitoring in oncology ^[4]. In parallel, super-resolution CEUS techniques are enabling microvascular analysis at unprecedented resolution, providing novel insights into liver tumor vascularity and therapeutic monitoring ^[9]. Collectively, these advances demonstrate that CEUS is evolving beyond a diagnostic modality toward an integrated platform for diagnosis, therapy monitoring, and potentially therapeutic delivery.

Collaboration networks illustrate the global and regional dynamics of CEUS research. Chinese and European scholars, often anchored by leaders such as Dietrich, form the backbone of international collaboration, while North American integration remains limited. National collaborations are driven by China and the United States, complemented by Germany, Italy, and Japan, whereas emerging countries such as India, South Korea, and Romania are improving visibility through collaborations with core nations. This model of a few core countries driving the field while engaging broader global participation fosters both knowledge dissemination and standardization.

The upward trend in publications, particularly post-2018, signals strong academic momentum and reflects growing clinical relevance. The exponential growth trajectory suggests CEUS research is in an accelerated development phase, with its findings increasingly influencing guidelines and clinical practice.

Several limitations must be acknowledged. This study relied on a single database, which may exclude regional or non-English publications. Moreover, bibliometric indicators such as publication and citation counts measure academic impact but do not necessarily capture clinical utility or translational outcomes. As artificial intelligence, deep learning, and molecular imaging converge with CEUS, future evaluations will require methods that better reflect interdisciplinary integration.

Looking forward, CEUS research offers broad opportunities. New contrast agents and molecular probes may extend their role into theranostics ^[4,9]. Artificial intelligence-driven image analysis will likely enhance reproducibility and diagnostic precision. Clinically, CEUS has strong potential for early tumor detection, therapy response monitoring, and long-term surveillance, particularly in resource-limited settings where it offers a cost-effective solution. High-quality multicenter prospective studies and global collaborative frameworks will be essential to strengthen the evidence base and promote guideline adoption.

In conclusion, CEUS research in tumor diagnosis is undergoing rapid expansion, characterized by concentrated leadership, thematic diversification, and strengthened collaboration. With ongoing technological innovation, clinical translation, and global cooperation, CEUS is expected to play an increasingly central role in oncologic imaging and personalized cancer care.

5. Conclusion

This study provides a comprehensive overview of the global research landscape of CEUS in tumor diagnosis. The field has grown rapidly over the past two decades, with China emerging as a major contributor. Research themes highlight both technological innovation and clinical application, particularly in hepatocellular carcinoma, while extending to other tumor types. Looking ahead, advances in artificial intelligence, novel contrast agents, and strengthened multicenter collaborations are expected to drive CEUS from a diagnostic modality toward a

comprehensive imaging tool, playing an increasingly important role in personalized cancer management.

Disclosure statement

The authors declare no conflict of interest.

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