Original Article

Ultrasound-guided thermal ablation therapy for papillary thyroid carcinoma: a bibliometric analysis from 2000 to 2023

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Background: Papillary thyroid cancer (PTC) is increasingly treated with procedures. However, there is a lack of relevant systematic evaluation articles. Therefore, this study aims to explore the research landscape of PTC thermal ablation through bibliometric analysis.

Methods: We searched publications related to PTC thermal ablation therapy from January 1, 2000 to December 31, 2023, from the Web of Science Core Collection (WoSCC). Subsequently, bibliometric analyses were then performed using the R package "bibliometrix", as well as VOSviewer and CiteSpace software, to visualize data on countries, institutions, journals, authors, keywords, and references.

Results: A total of 283 publications from 17 countries were retrieved, and the number of publications had shown a steady increase over the past decade, with China, the USA and South Korea being the top three contributing countries. The Chinese People's Liberation Army General Hospital was the most prolific institution, with the *International Journal of Hyperthermia* being the most frequent publisher. The author with the highest number of publications was Yukun Luo. "Radiofrequency ablation" was identified as the most commonly used keyword, indicating a potential research hotspot for the future.

Conclusions: This bibliometric study comprehensively analyzed publications on PTC thermal ablation, providing valuable insights into the history and current status of this research field, while also offering guidance for future research directions.

Keywords: Papillary thyroid carcinoma; thermal ablation; ultrasound; bibliometric analysis

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Introduction

Papillary thyroid cancer (PTC) constitutes the predominant form of thyroid malignancy, encompassing approximately 84% of cases (1). PTC is distinguished by its indolent growth pattern and generally favorable prognosis (2). Over the past two decades, there has been a persistent rise in the global prevalence of PTC. In 2000, age-standardized incidence rates for thyroid cancer were documented at 10.1 per 100,000 women and 3.1 per 100,000 men, with corresponding age-standardized mortality rates of 0.5 per 100,000 women and 0.3 per 100,000 men (3). This trend

has imposed substantial burdens on both socioeconomic factors and public health (4,5). Conventional therapeutic strategies have traditionally revolved around surgical management, typically involving total thyroidectomy followed by adjunctive radioactive iodine therapy, aiming at mitigating the risks of disease recurrence and metastasis (6). Nonetheless, these interventions carry inherent risks and may adversely impact patient well-being, necessitating careful consideration of potential complications and lifelong requirements for hormone replacement therapy (7,8).

In recent decades, the management paradigm of PTC has undergone profound evolution, driven by advancements in minimally invasive methodologies and precision medicine (9). Among these innovations, ultrasound-guided thermal ablation has emerged as a promising non-surgical approach for treating PTC. This technique utilizes ultrasound imaging to precisely deliver thermal energy, effectively ablating cancerous tissue within the thyroid gland (10). Thermal ablation encompasses diverse modalities such as radiofrequency ablation, microwave ablation, and laser ablation (11). Unlike conventional surgery, ultrasound-guided thermal ablation capitalizes on real-time imaging capabilities to target and treat malignant tissues accurately, while sparing adjacent healthy structures. This approach holds the potential for reduced complication rates and expedited recovery times (12-14). Typically performed on an outpatient basis without general anesthesia, thermal ablation minimizes hospitalization durations and appeals to patients seeking less invasive options or those unsuitable for surgery due to concurrent medical conditions (15,16).

The expanding literature on ultrasound-guided thermal ablation therapy for PTC underscores its growing adoption in clinical settings. However, there remains a paucity of comprehensive studies evaluating pertinent publications. This bibliometric analysis aims to scrutinize the scholarly output concerning thermal ablation for PTC from 2000 to 2023, offering a comprehensive synopsis of research trends, geographic distributions, and thematic focuses within this burgeoning area. This endeavor seeks to inform future therapeutic strategies and advance patient care in the coming years

Methods

Search strategies

This study utilized the Web of Science Core Collection (WoSCC) database to retrieve relevant literature and conduct bibliometric analysis, which covers a wide range of disciplines and provides accurate citation data. This database is extensively utilized in bibliometric analysis (17,18). The search strategy employed was as follows: TS (Topic) = ((papillary thyroid carcinoma) OR (thyroid papillary carcinoma) OR (thyroid papillary cancer) OR (papillary thyroid cancer) OR (papillary thyroid microcarcinoma) OR (thyroid papillary micro-carcinoma) OR (thyroid micropapillary carcinoma) OR (PTC) OR (PTMC)) AND TS = ((thermal ablation) OR (Radiofrequency Ablation) OR (Microwave ablation) OR (Laser ablation) OR (High-Intensity Focused Ultrasound Ablation)). Initially, two authors (J.Z. and S.L.) retrieved 311 records using this strategy, which was subsequently refined based on the following criteria to mitigate potential biases: (I) time span: from January 1, 2000 to December 31, 2023; (II) document type: article or review; (III) language: English. Ultimately, a total of 283 publications were included in the analysis, which output in "plain text" format with "full records and references". Details of the screening process are illustrated in Figure S1.

Data analysis

The study utilized VOSviewer 1.6.20, CiteSpace 6.3.1, and the "bibliometrix" package of R (v4.3.1) for scientometric and visual analysis. VOSviewer, developed by Professors Nees Jan van Eck and Ludo Waltman in 2009 (19), visualizes citation, collaboration, and co-occurrence relationships among journals, references, countries, and institutions through imported data. The resulting network graph sizes nodes based on publication counts, with connections representing relationships between nodes. Nodes closely related are grouped into clusters of the same color. Citespace, an information visualization and analysis software based on Java developed by Professor Chaomei Chen (20), analyzes keywords and references displaying significant citation bursts. The "bibliometrix" package in R (v4.3.1) is an open-source tool for visual scientific literature analysis (21), highlighting dynamic changes in publications across countries and international collaboration. Ethical approval from the ethics committee was not required as the study utilized data from public databases.

Results

Growth trend of publications

This study identified a total of 283 publications that met the

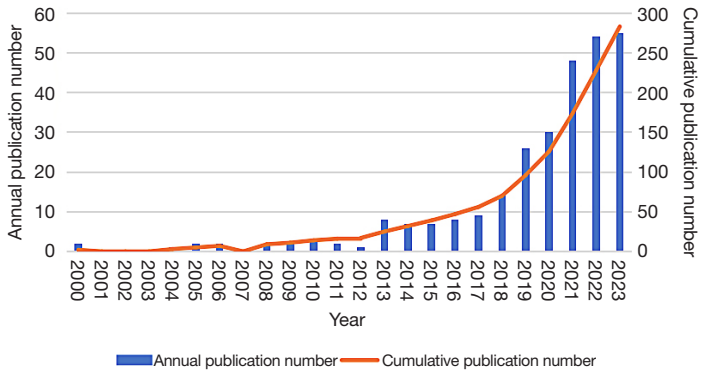

Figure 1 Annual and cumulative growth trends of publications.

inclusion criteria related to PTC thermal ablation, including 219 articles and 64 reviews. The annual publication trends in this research field are illustrated in *Figure 1*. There were fewer publications in the early stages, but since 2014, the number of publications per year has increased rapidly. Approximately 91.17% of the publications were concentrated in the past decade, reflecting an increasing focus among researchers on the field of PTC thermal ablation therapy.

Countries and institutions

Figure 2A, a world map, clearly shows the overall distribution of publications by country/region, with darker colors indicating higher publication numbers in those areas. The number of publications from each country is shown in *Figure 2B*. China leads significantly with 167 publications, followed by the United States (n=32), South Korea (n=32), and Italy (n=22). Other countries have published fewer than 10 articles each. In terms of citations, Chinese publications have the highest number of citations (n=2,587), but the average number of citations per article is only 15.5, much lower than France's 39.6 (Table S1). *Figure 2C* illustrates international collaboration among countries, with China participating in the most collaborations, followed by South Korea, the United States, and France.

In addition, a total of 290 institutions conducted PTC thermal ablation studies. *Figure 2D* shows the top 10 institutions with the highest number of publications, seven of which are located in China. Among them, the Chinese People's Liberation Army General Hospital leads the way with 49 publications. Meanwhile, the network of collaboration map between institutions were shown in Figure S2.

Journals and authors

A total of 111 journals published studies on the thermal ablation of PTC. *Table 1* lists the top 10 journals based on the number of publications, with 70% of them categorized in Q2. The *International Journal of Hyperthermia* led with 42 publications, followed by *Frontiers in Endocrinology* (n=27) and *European Radiology* (n=17). However, *Thyroid* received the highest number of citations (1,666 times), followed by *International Journal of Hyperthermia* (816 times) and *Journal of Clinical Endocrinology & Metabolism* (628 times) (Table S2). Additionally, *Figure 3* illustrates the collaborative network map of journals and co-cited journals, respectively.

A total of 1,156 authors have contributed to research in the PTC thermal ablation field. *Table 2* lists the top 10 authors by publication count. The most productive author was Luo YK, with 36 articles (*h*-index =14), followed by Zhang Y (28 articles, *h*-index =13), Yan L (27 articles, *h*-index =12), Zhang MB (25 articles, *h*-index =13), and Xiao J (21 articles, *h*-index =8). A map of the collaboration network between the authors is shown in Figure S3. The colors indicate clusters, where close communication and similar research directions exist between nodes in the same cluster.

Keywords co-occurrence and bursts

Figure 4A shows the top 10 keywords with the highest frequency in the field of PTC thermal ablation, with "radiofrequency ablation" ranking first (n=79), followed by "thermal ablation" (n=60) and "ultrasound" (n=58). VOSviewer software was used to visualize the frequency of keyword occurrence, and 70 keywords with a frequency of 3 or more were analyzed, as shown in *Figure 4B*. The

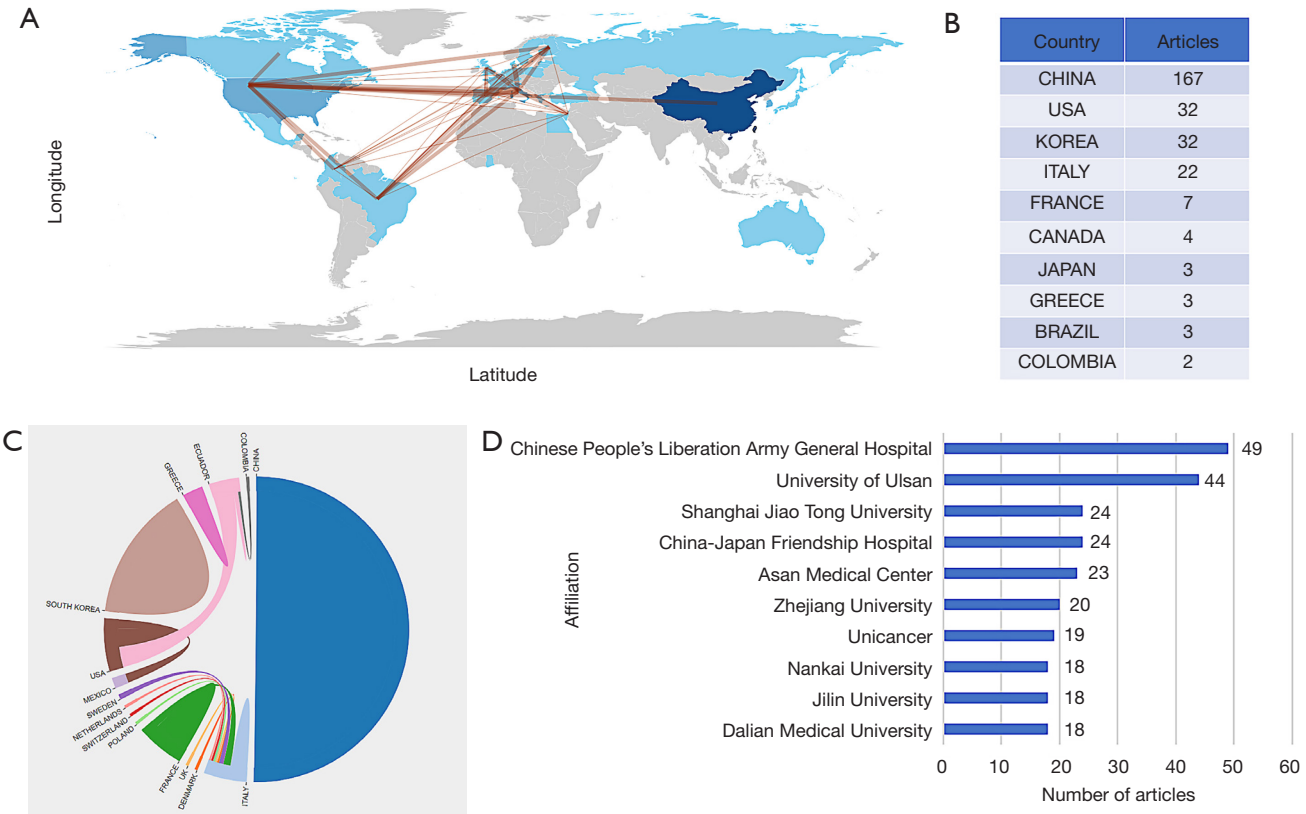

Figure 2 The field of thermal ablation of PTC. (A) World map of the distribution of country publications. (B) Number of publications from top 10 countries. (C) International collaboration between countries. (D) Number of publications from top 10 institutions. PTC, papillary thyroid cancer.

Table 1 Top 10 journals with the most publications in the field of thermal ablation of PTC

Rank	Journals	Counts	IF (2023)	JCR (2023)
1	*International Journal of Hyperthermia*	42	3	Q2
2	*Frontiers in Endocrinology*	27	3.9	Q2
3	*European Radiology*	17	4.7	Q1
4	*Thyroid*	15	5.8	Q1
5	*Frontiers in Oncology*	10	3.5	Q2
6	*Journal of Clinical Endocrinology & Metabolism*	9	5	Q1
7	*Endocrine*	8	3	Q2
8	*Medicine*	7	1.3	Q2
9	*Endocrine-Related Cancer*	4	4.1	Q2
10	*Journal of Vascular and Interventional Radiology*	4	2.6	Q2

IF, impact factor; JCR, Journal Citation Reports; PTC, papillary thyroid cancer.

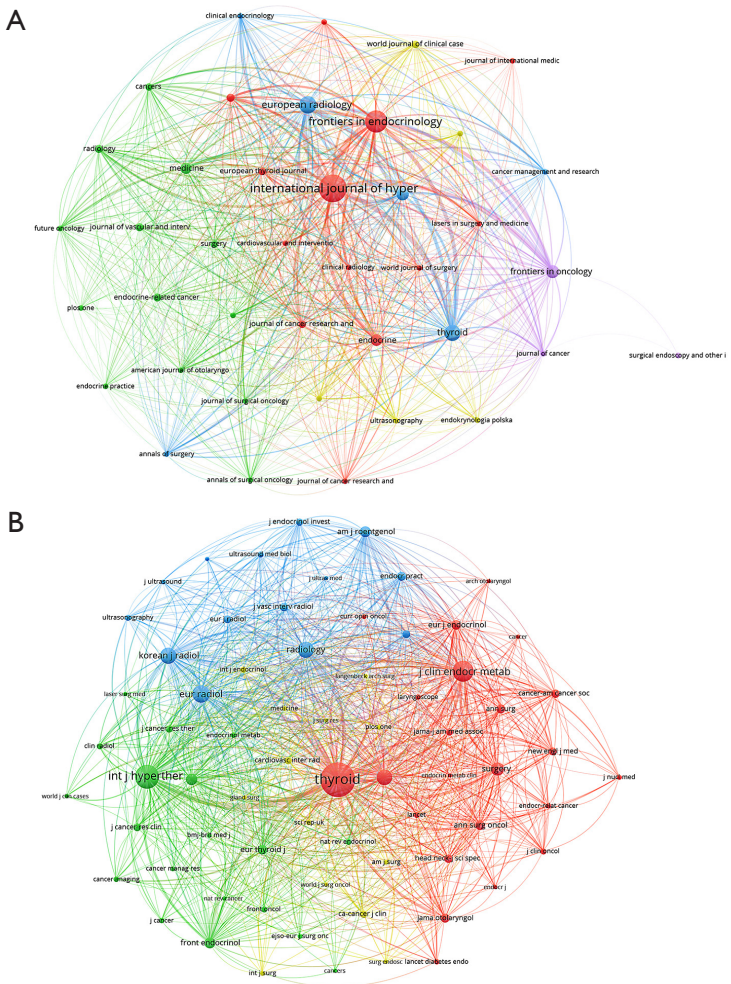

Figure 3 Collaborative network map of (A) the visualization of journal and (B) the visualization of co-cited journal.

Table 2 Top 10 authors with the most publications in the field of thermal ablation of PTC

Rank	Authors	Counts	TC	H-index
1	Luo YK	36	724	14
2	Zhang Y	28	705	13
3	Yan L	27	359	12
4	Zhang MB	25	586	13
5	Xiao J	21	247	8
6	Yu MA	19	210	9
7	Li Y	18	262	9
8	Baek JH	16	630	13
9	Wei Y	16	190	8
10	Peng LL	15	185	8

PTC, papillary thyroid cancer; TC, total citations.

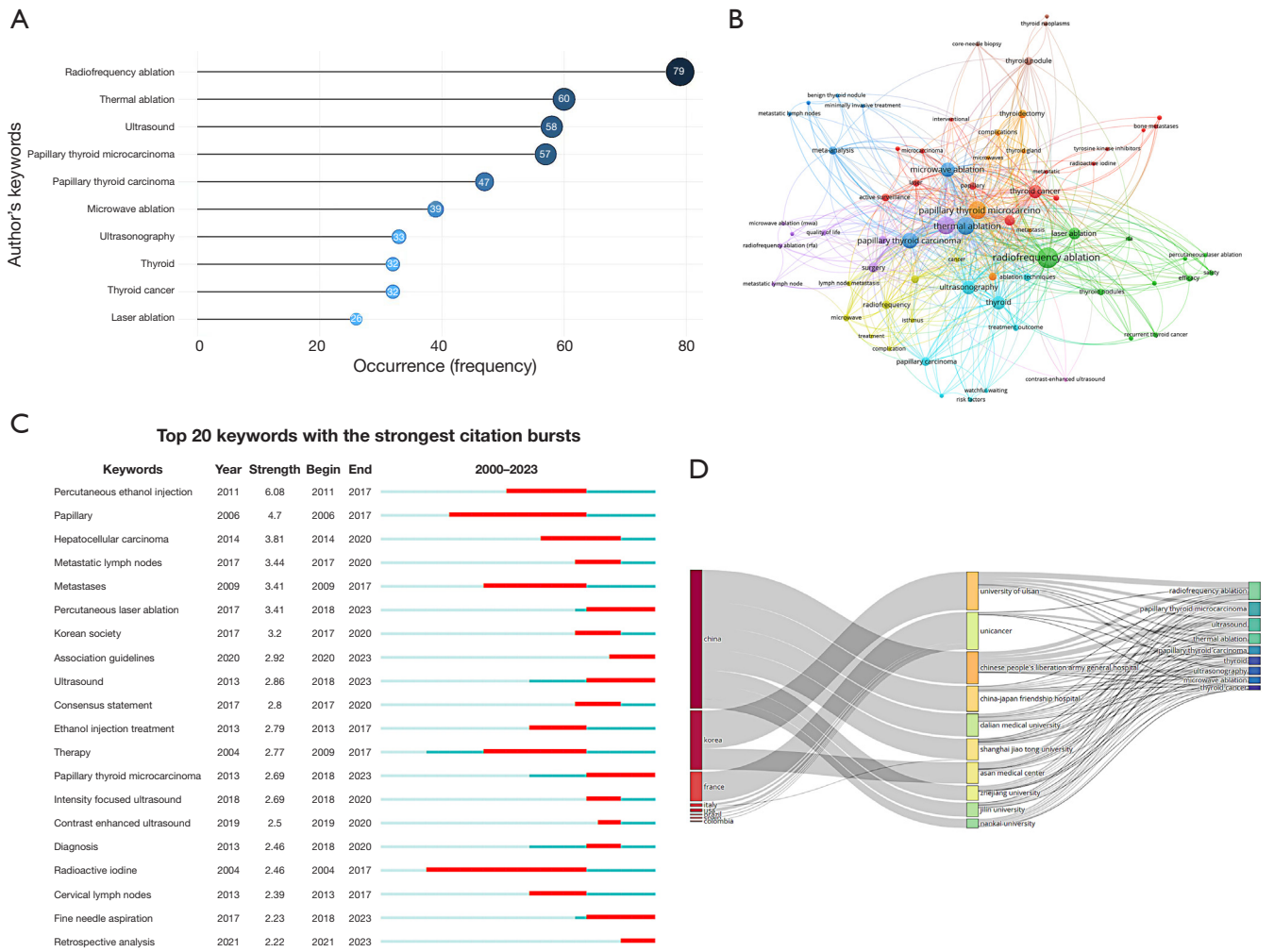

Figure 4 Keywords. (A) The top 10 keywords with the highest frequency. (B) Network visualization of the keywords. (C) The top 20 keywords with the strongest citation bursts. The green lines represent the occurrence and development of keywords, while the red lines represent the duration of the outbreak. (D) The three-field plot of thermal ablation and PTC. PTC, papillary thyroid cancer.

size of the nodes represents the frequency of keyword occurrence, while the distance between nodes represents their strength of association. *Figure 4C* displays the top 20 most frequently cited keywords, with the red line indicating the duration of the keyword outbreaks. As shown in the figure, in recent years, keywords such as "percutaneous laser ablation", "association guidelines", "ultrasound", "papillary thyroid microcarcinoma", "fine needle aspiration", and "retrospective analysis" have red lines extending to 2023, indicating that these keywords have received sustained attention in recent years. In addition, *Figure 4D* shows the associations between the top 10 countries, institutions, and authors' keywords.

Most-cited references

Table S3 presents the top 10 most cited articles in the field of thermal ablation for PTC. These articles were published between 2006 and 2021, with 90% published in the last decade and 60% were articles. The most cited article was published in the *Annals of Surgery* in 2006 entitled "Radiofrequency ablation and percutaneous ethanol injection treatment for recurrent local and distant well-differentiated thyroid carcinoma", which has been cited 163 times.

Figure S4 displays the top 20 co-cited references with the strongest citation bursts, ranging in burst strength from

2.7 to 19.7. Red line segments denote periods of frequent citations. The most cited reference was a 2016 article published in the journal *Thyroid* titled "2015 American Thyroid Association Management Guidelines for Adult Patients with Thyroid Nodules and Differentiated Thyroid Cancer: The American Thyroid Association Guidelines Task Force on Thyroid Nodules and Differentiated Thyroid Cancer".

Detail of the types of articles

Most of the literature on thermal ablation treatment for PTC focuses on primary thyroid cancer. There are a total of 38 studies related to the treatment of metastatic papillary carcinoma, which we have listed and included in Table S4. Regarding tumor size, the majority of thermal ablation treatments for PTC involve microcarcinomas, defined as those with a maximum diameter of less than 1 cm. We carefully reviewed the included literature and identified 12 studies that involved part or all of T1b stage PTC, which we have listed in Table S5.

In the included literature, there were a total of 130 publications on radiofrequency ablation, 67 on microwave ablation, 41 on laser ablation, and the remaining publications were comprehensive summaries, including reviews or meta-analyses on thermal ablation in the field of PTC, without detailed classification. Therefore, we can see that radiofrequency ablation was the most widely used method in PTC.

Discussion

This study performed a bibliometric analysis spanning from 2000 to 2023 to evaluate the scholarly output concerning thermal ablation therapy for PTC. It delineates emerging research patterns, global distribution, and thematic emphases within this domain. The findings underscore a marked surge in research pertaining to thermal ablation therapy for PTC in recent years, notably originating from countries such as China, the United States, and South Korea. The ensuing discourse expands upon these observations, their clinical implications, and prospective avenues for further investigation.

The evolution of academic publications serves as a pivotal barometer of developmental trajectories within a field (22). As evidenced by the results of curve fitting, the volume of literature pertaining to PTC thermal ablation therapy exhibited a significant rise from 2000 to 2023. Initially, from 2000 to 2012, scholarly output remained minimal and erratic, with fewer than 10 publications annually; however, a pronounced upward trend has been observed since 2013. This progression mirrors the gradual acceptance and validation of thermal ablation technology in the treatment of PTC. Early investigations primarily focused on establishing the feasibility and safety of this modality (23-25), while recent studies have increasingly explored its clinical applications and efficacy assessments (12,16,26). This shift underscores the transition of thermal ablation technology from laboratory experimentation to clinical implementation, offering a viable therapeutic avenue for PTC patients. As technology continues to advance and clinical evidence accumulates, thermal ablation is anticipated to emerge as a cornerstone of PTC treatment. Future research endeavors are likely to focus on optimizing treatment protocols, enhancing therapeutic outcomes, and integrating this technology more seamlessly into clinical practice. Concurrently, ongoing vigilance among researchers and healthcare providers will be crucial to staying abreast of the latest advancements, thereby enhancing treatment efficacy and patient care standards.

Regionally, China, the United States, South Korea, and Italy have emerged as key players in the realm of PTC thermal ablation therapy research. This distribution mirrors findings in ultrasound-guided thermal ablation for thyroid nodules, where China, Italy, and South Korea similarly take precedence (27). Notably, China stands out prominently with 167 publications, constituting 59% of the total corpus. This dominance underscores China's rapid strides in medical research and technological innovation in recent years (28). Furthermore, the United States and South Korea have also made notable contributions, each contributing 32 publications. At the institutional level, a total of 290 organizations have engaged in research on PTC thermal ablation therapy. Chinese institutions not only lead in quantity but also in impact, with the Chinese People's Liberation Army General Hospital leading the pack in terms of publication output. This underscores China's substantial advantage and influence in advancing the field of PTC thermal ablation therapy research.

In terms of scholarly journals, the *International Journal of Hyperthermia* emerges as the foremost contributor, having published 42 articles on PTC thermal ablation therapy. It is closely followed by *Frontiers in Endocrinology* and *European Radiology*, which have published 27 and 17 articles, respectively. The robust impact and citation metrics of these journals underscore their pivotal role in shaping

research within the realm of PTC thermal ablation therapy. Regarding prolific authors, Luo YK leads the field with 36 publications, illustrating substantial leadership in this area of study. Other notable contributors include Zhang Y, Yan L, and Zhang MB, whose extensive research efforts have significantly advanced the understanding and application of thermal ablation in treating PTC.

Recent developments in thermal ablation for PTC are reflected in a surge of new keywords, signaling emerging frontiers in this field. Keyword co-occurrence analysis identifies "radiofrequency ablation" as the most prevalent term, underscoring its pivotal role in PTC thermal ablation therapy. Additionally, "thermal ablation" and "ultrasound" are also prominent keywords, highlighting their widespread utilization and ongoing research emphasis in the treatment of PTC. Further scrutiny into keyword bursts reveals evolving research focuses on "percutaneous laser ablation", "association guidelines", "papillary thyroid microcarcinoma", and "fine needle aspiration". These emerging hotspots denote dynamic shifts within the research landscape and suggest potential future directions. Notably, there is a growing emphasis on technical innovation and standardized treatment protocols, alongside heightened attention to early disease detection and assessment. These insights into future research directions are pivotal for guiding clinical practice and advancing therapeutic approaches in PTC thermal ablation.

Currently, guidelines and consensus statements on the appropriateness of thermal ablation for PTC exhibit slight variations across different professional associations. The 2015 American Thyroid Association Management Guidelines and the 2017 South Korean Thyroid Radiofrequency Ablation Guidelines advocate that thermal ablation should be reserved for high-risk surgical candidates and patients unwilling to undergo additional surgery (29,30). In contrast, the 2018 Austrian Practice Guidelines do not endorse thermal ablation as a therapeutic option for malignant thyroid nodules (31). In 2020, Chinese experts published a consensus aiming to standardize the application of thermal ablation in treating thyroid tumors (32). The 2021 European Thyroid Association and Cardiovascular and Interventional Radiological Society of Europe recommend considering thermal ablation for PTC in patients categorized as: (I) high surgical risk; (II) with limited life expectancy; (III) having significant comorbidities; (IV) ineligible for surgery; or (V) opting against active surveillance (33). However, with the expanding clinical adoption of thermal ablation for PTC and the accumulation of research evidence, the Chinese expert consensus on PTC thermal ablation has progressively broadened its indications. This includes recommending thermal ablation as a primary treatment for T1aN0M0 PTC, proposing it as an alternative for T1bN0M0 PTC, considering its use following thorough evaluation in cases of PTC with capsule invasion limited to the capsule, isthmic PTC, or multifocal PTC (up to three nodules), and advocating for its application in managing new or recurrent lesions within residual thyroid tissue post-partial thyroidectomy, particularly in patients prioritizing thyroid function preservation or unable to undergo repeat surgery (34). Despite the increasing application of thermal ablation in PTC, its long-term safety and efficacy necessitate further investigation to provide robust support for clinical decision-making and treatment guidelines.

The bibliometric analysis provides new and objective perspectives on the emerging research focal points and trends in ultrasound-guided thermal ablation therapy for PTC across various dimensions. Nonetheless, this study is not without limitations. Firstly, while the WOSCC database is widely recognized as a reliable source for bibliometric analyses, it may not encompass all relevant articles. Secondly, there could be a selection bias attributable to the predominance of articles published in English. Thirdly, our study shows that Chinese scholars have published significantly more papers in this field than other countries, reflecting China's investment in medical technology, equipment, and research funding, as well as the country's active involvement and emphasis on this area of research. However, these studies may carry potential biases. Many are conducted by a limited number of institutions with small sample sizes, and are concentrated in specific regions, which may affect the generalizability of the results. To improve the reliability of the research, multi-center, large-sample, prospective studies should be strengthened, and international collaboration and academic exchange should be encouraged.

Conclusions

In conclusion, thermal ablation therapy for PTC represents a promising minimally invasive treatment with substantial clinical implications. Continued research and technological advancements are anticipated to further establish thermal ablation as a safe and efficacious option for a broader spectrum of PTC patients in the foreseeable future.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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