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A bibliometrics analysis based on the application of artificial intelligence in the field of radiotherapy from 2003 to 2023

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Abstract

Background Recent research has demonstrated that the use of artificial intelligence (AI) in radiotherapy (RT) has significantly streamlined the process for physicians to treat patients with tumors; however, bibliometric studies examining the correlation between AI and RT are not available. Providing a thorough overview of the knowledge structure and research hotspots between AI and RT was the main goal of the current study.

Method A search was conducted on the Web of Science Core Collection (WoSCC) database for publications pertaining to AI and RT between 2003 and 2023. VOSviewers, CiteSpace, and the R program "bibliometrix" were used to do the bibliometric analysis.

Results The analysis comprised 615 publications from 64 countries, with USA and China leading the pack. Since 2017, there have been more and more publications about RT and AI every year. The research center that made the biggest contribution to this topic was Maastricht University. The most articles published journal in this field was Frontiers in Oncology, while Medical Physics received the greatest number of citations. Dekker Andre is the author with the greatest number of published articles, while Philippe Lambin was the most often co-cited author. In the newly identified research hotspots, "autocontouring algorithm", "deep learning", and "machine learning" stand out as the main terms.

Conclusion In fact, our bibliometric analysis offers insightful information on current research directions and advancements pertaining to the use of AI in RT. For academics looking to understand the connection between AI and RT, this study is a great resource because it highlights current research frontiers and hot trends.

Keywords Artificial intelligence, Radiotherapy, Bibliometrics

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Introduction

Radiotherapy (RT) is an important cancer treatment modality that has drawn constant interest because to its application effects and technological advancements [1, 2]. Significant advances have occurred in the realm of medicine in recent years due to the rapid growth of artificial intelligence (AI), particularly in the application of radiation [3]. AI technology not only increases the precision of picture analysis, but it also streamlines the process of creating treatment plans and encourages the implementation of individualized care [3, 4]. Nevertheless, despite some promising outcomes from the use of AI in radiotherapy, there is still a lack of comprehensive examination of technological advancements in this area [5].

The goal of artificial intelligence (AI) is to replicate human intelligence in order to handle complicated and repetitive activities. Precision medicine has advanced significantly as a result of AI's impressive performance in the medical domain and the rapid growth of data volumes and technology advancements [6]. Machine learning, which allows programs to learn from training data for a certain task and have the ability to self-improve, is one of the key ways that AI is implemented. Deep learning is a branch of machine learning that simulates the human nervous system by building multi-layer neural networks between the input and output layers. It can be used with high-dimensional, unstructured data, which makes up the majority of big data produced in the field of medicine [7]. AI models can be trained far more quickly than human experts can over the course of a lifetime of employment. Recent decades have seen improvements in delivery methods and equipment for radiation (RT). But even with these advancements, complex activities like planning and quality control procedures still exist. The RT process requires cooperation between medical physicists, therapists, and physicians because it consists of multiple steps. CT/MR imaging is obtained for simulation after a clinical evaluation to ascertain appropriateness. Then, after outlining the contours of the organs and treatment targets, doctors prescribe dosages and fractions for the organs at risk (OARs). In order to create plans that maximize OAR protection while adhering to prescription standards, medical physicists collaborate with the treatment planning system (TPS). Quality assurance (QA) tests verify accuracy prior to treatment [8]. Image guidance corrects mistakes during the course of treatment. Clinical, biochemical, imaging, and machine data are among the many types of data that are gathered. Artificial intelligence can be used to correlate this data for accurate analysis and optimization.

Even while our understanding of how AI can be used in radiotherapy has advanced somewhat, there are still a lot of topics that require more research. A useful technique for examining the literature is bibliometrics, which offers both quantitative and qualitative information on the volume and standing of publications in a given field of study. This method offers comprehensive details about the writers, keywords, journals, nations, establishments, and references associated with the subject matter. Researchers frequently employ bibliometric tools like CiteSpace [9], VOSviewer [10], and the R software package "bibliometrix" to visually portray the results of their literature analysis. These instruments have been widely applied in many medical specialties. However, to date, no bibliometrics study has addressed artificial intelligence explicitly in the context of radiation. As a result, the goal of this study was to thoroughly review the literature on the subject of artificial intelligence and radiation therapy. It also makes an effort to assess the present level of this field's study and spot emerging patterns, thereby advancing knowledge and advancement in the field through such analysis.

This study used the bibliometrics analysis approach to carefully assess the research models and development trends of relevant literatures published in the last 20 years in order to gain a thorough understanding of the research trend and technical advancement of AI in the field of radiotherapy. Our goal is to identify the primary research avenues, technological advancements, and potential research hotspots for artificial intelligence in radiotherapy by examining author collaboration, citation networks, and keywords in the literature.

Methods and materials

Data sources and search strategies

Using the search formulas ((Topic=artificial intelligence) AND (Topic=radiotherapy) AND (Language=English), We searched the Web of Science Core Collection (WoSCC) database for the period from January 01, 2003 to December 31, 2023. The "Articles" and "Review" document types were selected (Fig. 1). Clarivate Analytics is the owner and operator of the multidisciplinary Web of Science (WOS) database. This database is regarded as one of the biggest and most reliable sources of scholarly information in the entire globe. The WOS platform, which covers almost 1.9 billion searchable cited references from over 171 million documents, is an effective tool for data analysis and document retrieval.

Data analysis

We used multiple techniques in our inquiry to perform a thorough bibliometric analysis. A well-known program for bibliometric research, VOSviewer (1.6.20), was used to examine networks of cooperation, co-citation, and co-occurrence of keywords. By depicting institutions, journals, and authors as nodes with different colors and sizes depending on their characteristics and connections, VOSviewer's visualizations aid in our understanding of the interactions between these entities. The degree of

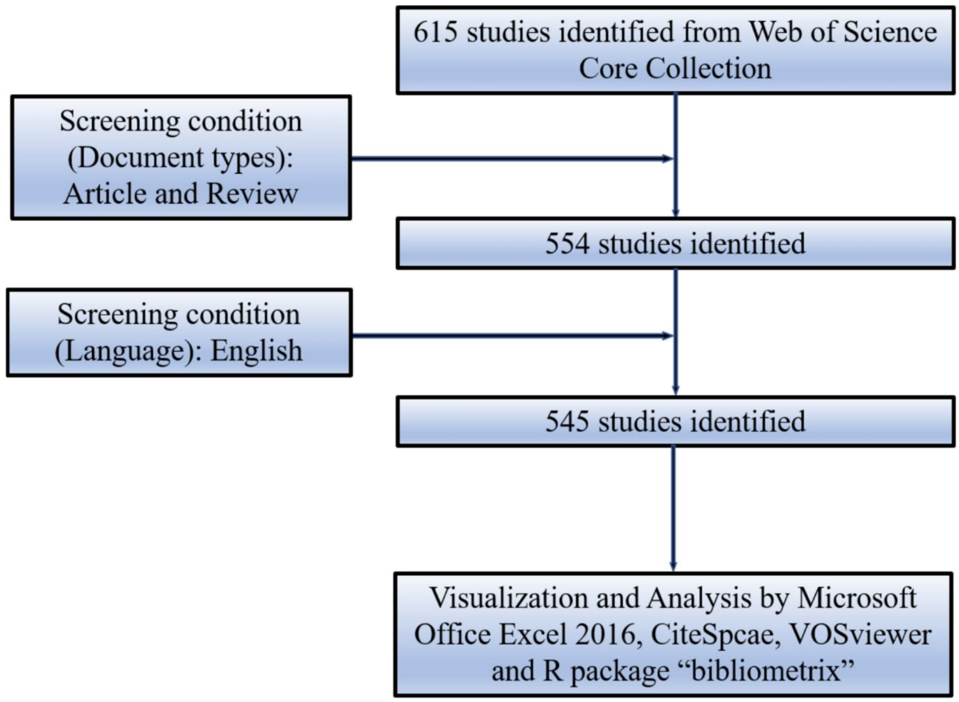

Fig. 1 Literature screening process

collaboration or co-citation is shown by the thickness of connecting lines, which has given researchers insight into relevant networks and research trends. In addition, we performed Citation Bursts analysis and created a journal dual-map overlay using CiteSpace (6.1.R1), which showed how influential journals and citation patterns changed over time. This additional perspective enhanced our understanding of how research topics and their prominence have shifted.

We used R package "bibliometrix" (version 3.2.1) for topic evolution analysis and to create a global distribution network of publications on AI in RT. With the use of this package, we were able to examine the evolution of research themes and map out their worldwide distribution, providing a more comprehensive understanding of the patterns and geographic dispersion of research endeavors.

Ultimately, quantitative analysis was conducted using Microsoft Office Excel 2016, which offered a stable framework for arranging and analyzing numerical data obtained from our bibliometric research. We were able to get a thorough picture of the study environment by combining various technologies, which made it easier to comprehend the dynamics in the field.

Results

Quantitative analysis of publication

We found 615 papers on artificial intelligence in radiotherapy over the previous 20 years, based on our search approach. There were 188 "reviews" and 366 "articles" total among them. We divided the whole time into three phases: the first phase (2003–2017), the second phase (2018–2020), and the third phase (2021–2023) based on the annual growth rate of publications. Figure 2 presented the trends in publications. There were just a few studies on artificial intelligence in radiotherapy undertaken during the first phase (2003–2017), which produced a maximum of two publications (Fig. 2). However, the number of published papers climbed steadily in the second phase (2018–2020), averaging about 32 per year, suggesting the beginning of this field's research. During the third phase (2021–2023), there was a noticeable increase in publications, with an average of about 144 papers produced annually. In particular, there were 73 relevant papers published in 2018, a 4.3-fold increase over the previous year. As research on artificial intelligence in radiation has continued to rise over the past ten years, the number of studies has increased steadily, reaching 166 in 2023. In comparison to the previous two phases, the third phase (2021–2023) showed a notable increase in the total number of published papers, suggesting the growing importance and interest of artificial intelligence in the field of radiation. Furthermore, in subsequent research, we speculate that the growth of publications may be closely related to the addition of new subdatasets and the expansion of scientific networks [11].

Country and institutional analysis

There were 1144 institutions and 64 countries represented in these articles. Table 1 listed the top 10

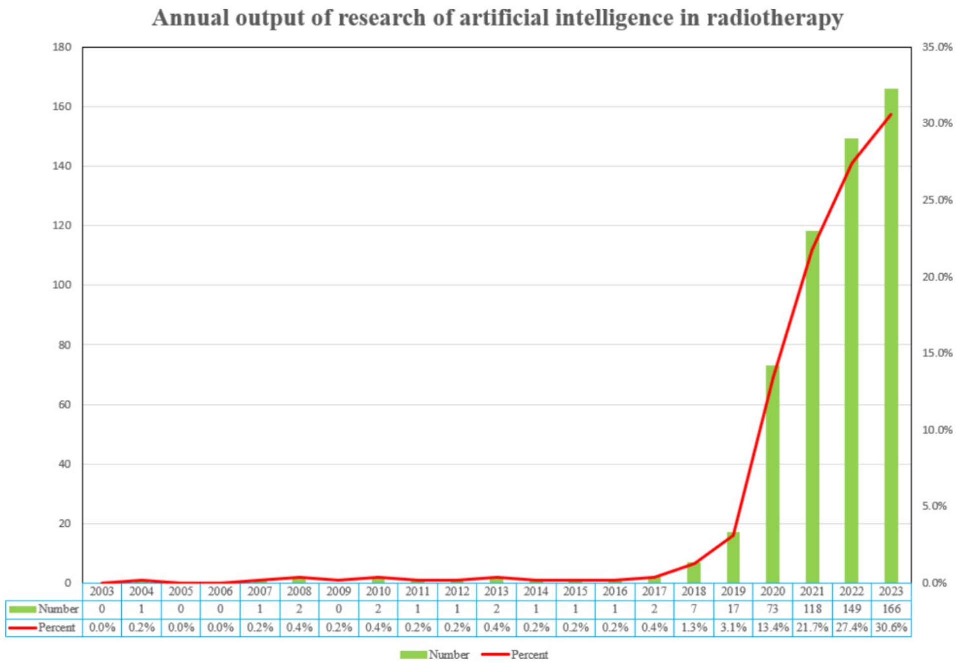

Fig. 2 The quantity of research publications on artificial intelligence in radiotherapy each year

Table 1 Top 10 countries and institutions on research of artificial intelligence in radiotherapy

Rank	Country	Documents	Citations	Total link strength	Organization	Documents	Citations	Total link strength
1	USA	167	2256	156	Maastricht University	27	679	49
2	China	90	936	44	Duke University	14	169	15
3	Italy	65	856	110	Harvard University	13	309	31
4	Netherlands	65	1245	120	University of Toronto	13	172	23
5	England	42	996	103	University Cattolica del SacroCuore	12	153	16
6	Germany	38	525	73	University Medical Center Utrecht	12	264	9
7	France	37	471	64	University of Texas MD Anderson Cancer Center	12	229	15
8	Canada	30	382	34	University of California San Francisco	11	379	21
9	Australia	26	325	30	University of Texas Southwestern Medical Center	10	54	8
10	Belgium	25	473	93	Emory University	9	34	20

countries, with a preponderance of Americans (2 out of 10) and Europeans (6 out of 10), including USA, China, Italy, Netherlands, England, Germany, France, Canada, Australia, and Belgium. USA ($n=167$, 30.6%) has the most papers among these countries, followed by China ($n=90$, 16.5%), Italy ($n=65$, 11.9%), and Netherlands ($n=65$, 11.9%). China and USA together account for almost half (47.1%) of all published papers. As an additional example, we created a collaborative network based on the amount of publications and inter-country linkages by screening and visualizing 64 nations based on publications with a number of one or more (Fig. 3). Interestingly, this data indicated a great deal of international cooperation. China, for example, maintained tight relations with USA, Italy, and France, while USA maintained active relations with Australia and Canada.

Three-fifths of the top 10 colleges were situated in the United States and the top 10 colleges represent five different countries. Interestingly, Maastricht University ($n=27$, 5.0%), Duke University ($n=14$, 2.6%), Harvard University ($n=13$, 2.4%), and University of Toronto ($n=13$, 2.4%), were the top four universities in terms of published papers. To further explain, we built a collaborative network based on publication volume and institutional ties, and we picked 139 institutions for visualization, guaranteeing a minimum publication count of three (Fig. 4).

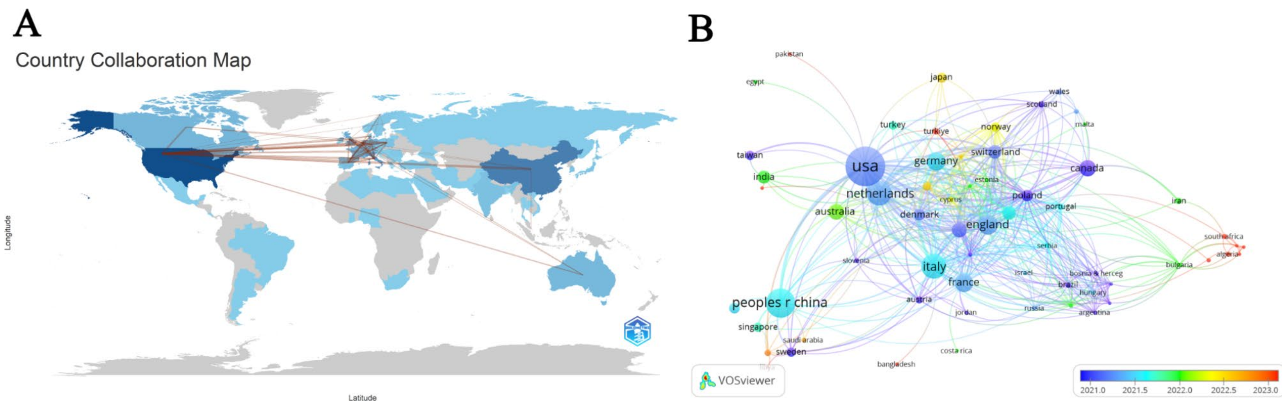

Fig. 3 The geographical dispersion and visual representation of nations about AI in radiotherapy

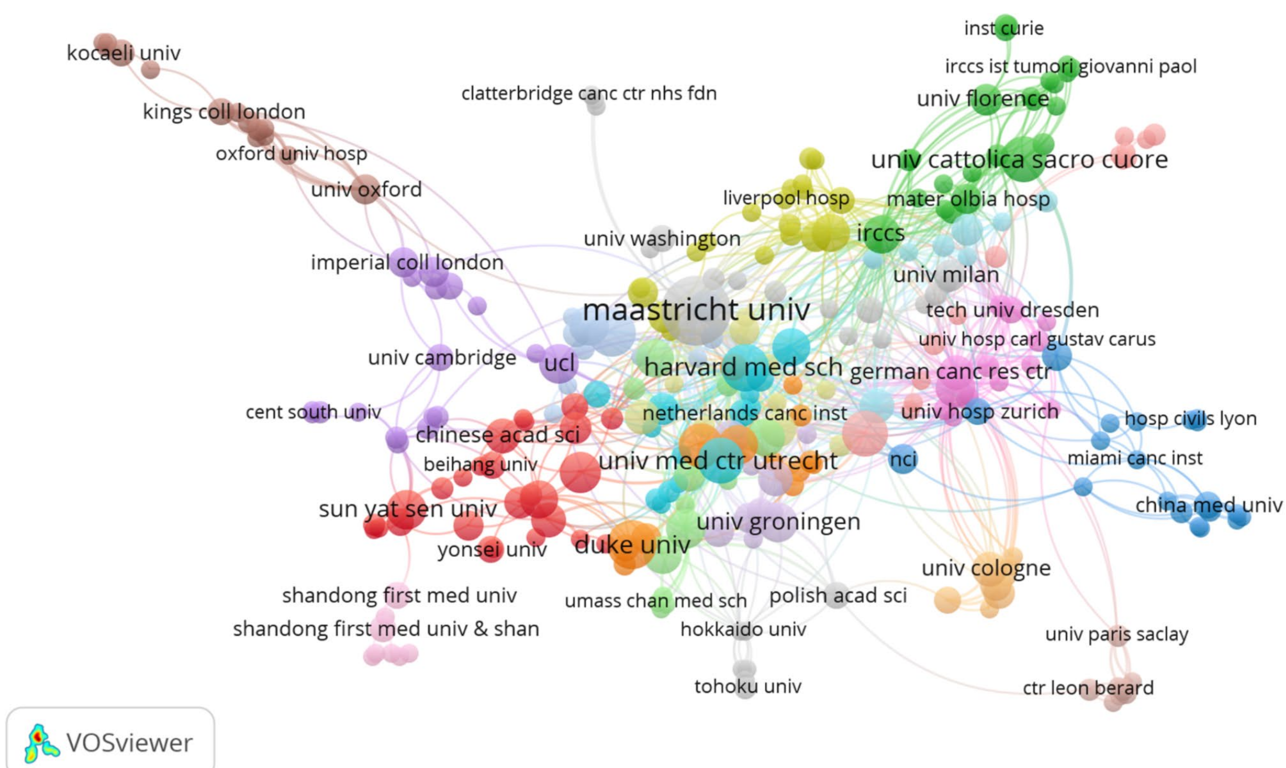

Fig. 4 An illustration of research institutes focused on AI in radiotherapy

Journals and co-cited journals analysis

213 journals contained publications about artificial intelligence in radiation therapy. Notably, Table 2 demonstrated that, with 45 publications published, Frontiers in Oncology is first (n=45, 8.2%), followed by Radiotherapy and oncology (n=32, 5.9%), Medical Physics (n=26, 4.8%), and Cancers (n=25, 4.6%). Medical Physics was the most cited journal among the top 10 (Citations=2275), closely followed by International Journal of Radiation Oncology (Citations=1921). After doing this analysis, we were able to display the journal network map (Fig. 5A) and identify 67 journals that had at least two relevant publications. The relationship between cancer, Radiotherapy and oncology, and medical physics was shown in the diagram as one of active citation. Furthermore, our analysis showed that, in 2020, Radiotherapy and oncology was the most often cited journal concerning artificial intelligence in radiotherapy, and it was projected that citations related to cancer will rise until 2023.

Table 2 showed the top 10 journals overall in terms of citations, with four journals having more than 1300 citations each. With a total citation count of 2275, medical physics was the most referenced field. It was followed by the International Journal of Radiation Oncology (total citation=1921), Radiotherapy and Oncology (total citation=1617), and Physics in Medicine and Biology (total

Table 2 Top 10 journals and co-cited journals for artificial intelligence in radiotherapy

Rank	Journal	Documents	Citations	Total link strength	Co-journal	Citations	Total link strength
1	Frontiers in oncology	45	559	5124	Medical physics	2275	152,979
2	Radiotherapy and oncology	32	815	4519	International Journal of Radiation Oncology	1921	113,646
3	Medical physics	26	441	4057	Radiotherapy and oncology	1617	96,582
4	Cancers	25	164	1880	physics in medicine and biology	1394	101,953
5	Physica medica-european Journal of medical physics	15	221	2829	Frontiers in oncology	608	43,054
6	physics in medicine and biology	15	326	2757	Radiotherapy and oncology	553	40,701
7	Radiation oncology	13	124	1273	Scientific Reports	549	36,379
8	Physics & imaging in radiation oncology	12	187	1272	Journal of Clinical Oncology	465	22,085
9	Journal of applied clinical medical physics	10	126	1079	Radiology	389	29,416
10	Cancer radiotherapie	9	46	1392	Journal of Applied Clinical Medical Physics	388	28,165

citation = 1394). A co-citation network map was created after we conducted additional analysis on 158 journals with more than 30 co-citations (Fig. 5B). The graphic showed that the International Journal of Radiation Oncology had a favorable co-citation connection with eminent publications like Frontiers in Oncology and Medical Physics. This implied that International Journal of Radiation Oncology had close ties to other publications within the area, which highlighted the importance of the journal in research.

With the cluster of citing journals on the left and the cluster of cited journals on the right, the double-graph superposition of journals illustrated the citation link between journals and co-cited journals (Fig. 6). The orange and green paths in this visualization stood for the various primary cited paths, respectively. This indicated that the majority of literature references in the fields of molecular biology/immunology and medicine/medical/clinical originated from these journals when it referred to molecular biology/genetics research or health/nursing/medicine. This highlighted the interdisciplinary nature of study in this topic and showed a strong connection and influence between various fields.

Authors and co-cited authors analysis

In all, 3556 writers took part in the research on AI in radiation treatment. Three writers published more than nine publications between them among the top ten: Dekker Andre published ten, Valentini Vincenzo and Boldrini Luca each published nine (Table 3). After that, we chose authors who had one or more articles published, and we created a collaborative network around those authors (Fig. 7A).

Two writers out of the 18,401 co-cited authors received more than 80 citations (Table 3). Philippe Lambin ($n=85$) was the most often referenced author, followed by Dan Nguyen ($n=83$), Issam Elnaqa ($n=79$), and Gilmer Valdes ($n=79$). After identifying writers who had at least 16 co-citations, we produced a co-citation network diagram (Fig. 7B). The figure showed the active cooperation of Issam Elnaqa, Philippe Lambin, and Gilmer Valdes, among other co-cited writers. This suggested a high degree of collaboration and interaction between researchers in the field, which will further develop our understanding of artificial intelligence in radiotherapy and its application.

Co-cited references analysis

A total of 25,181 papers about artificial intelligence in radiotherapy have been cited within the last 20 years. All ten of the most frequently cited works (Table 4 and 5) had at least 28 citations, and two of them had as least 40 citations. To create a co-citation network diagram (Fig. 8), we chose literatures with a total citation quantity of at least 12 and included 158 co-cited references. This graphic facilitated further research and analysis of important themes and trends by offering a thorough perspective of the connections and influences between numerous research papers in the subject.

Reference with citation bursts analysis

Works with explosive citation were those that academics in a particular discipline had quoted a lot over a given length of time. CiteSpace found four papers in our analysis with significant bursts of citations (Fig. 9). Strong citation epidemics were represented by the red bar in Fig. 9. The eruption of references in citations started in 2015 and continued until 2016. Suzani, Amin, et al.'s paper, "Fast Automatic Vertebrae Detection and Localization in Pathological CT Scans - A Deep Learning Approach", was published in the 18th International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI), and it contained the strongest literature cited for the outburst (intensity = 6.64). "Evaluation of a

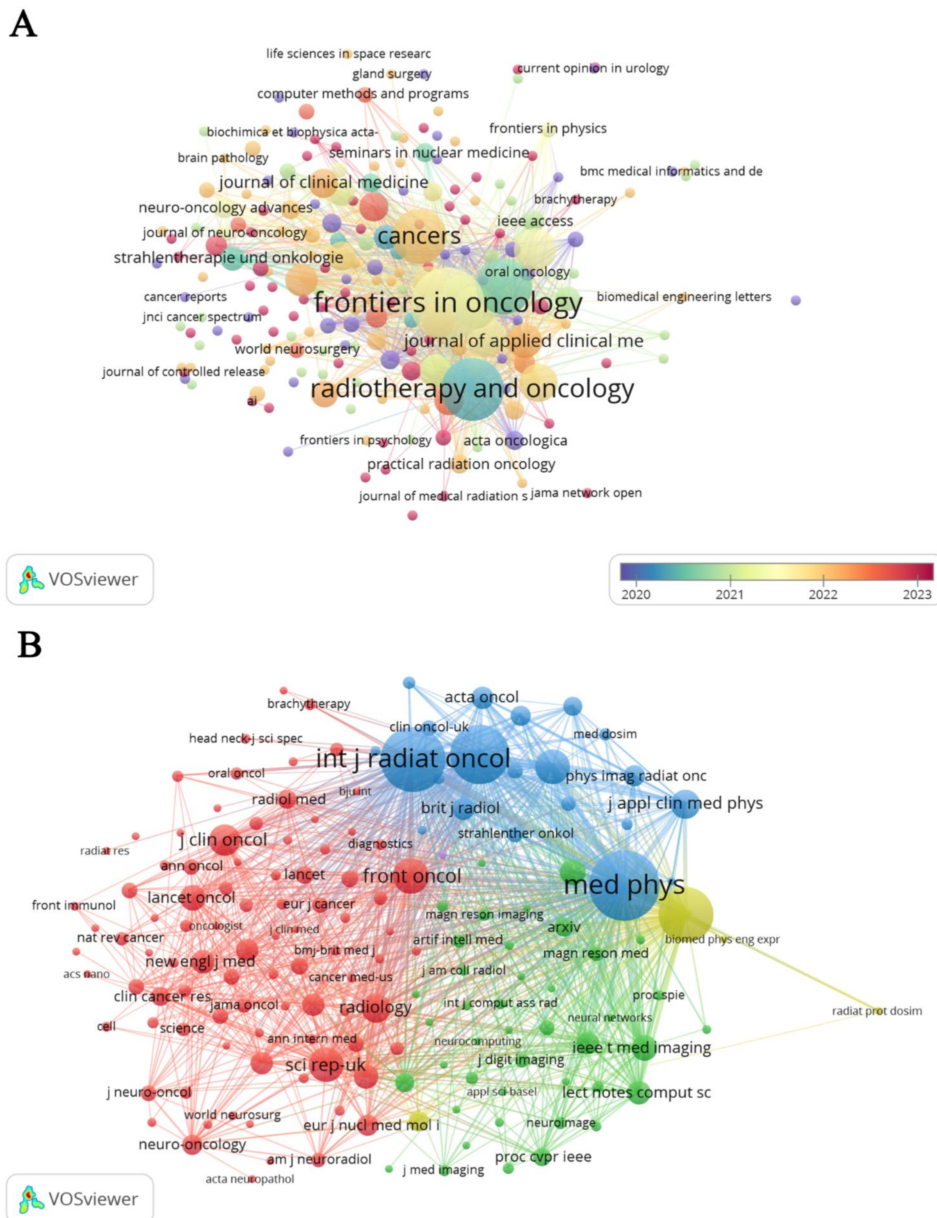

Fig. 5 The display of artificial intelligence in radiotherapy research publications (**A**) and co-cited journals (**B**)

knowledge-based planning solution for head and neck cancer" was the title of the reference with the second strongest citation burst (strength = 3.52).

Hotspots and frontiers analysis

With the use of keyword co-occurrence analysis, we may quickly pinpoint areas of study interest within a given topic. The top 20 keywords pertaining to artificial intelligence in radiotherapy were displayed in Table 6. Of them, "Deep learning" and "Machine learning" came up more than a hundred times, suggesting that they were important areas for future study on artificial intelligence in radiotherapy. This report offered insightful information about the hot subjects and areas of interest in the nexus of radiation and artificial intelligence.

Using VOSviewer, we did cluster analysis and filtered terms that appeared three times or more (Fig. 10A). The intensity of the relationship between keywords was indicated by the thickness of the lines connecting nodes. We found four two clusters, each corresponding to different study directions, as shown in Fig. 10A. The keywords that were included in the pink cluster include radiotherapy and artificial intelligence. Data science, big data, and bioinformatics were the keywords found in the purple clusters. The most prolonged period of artificial intelligence research in radiotherapy had been focused on normal

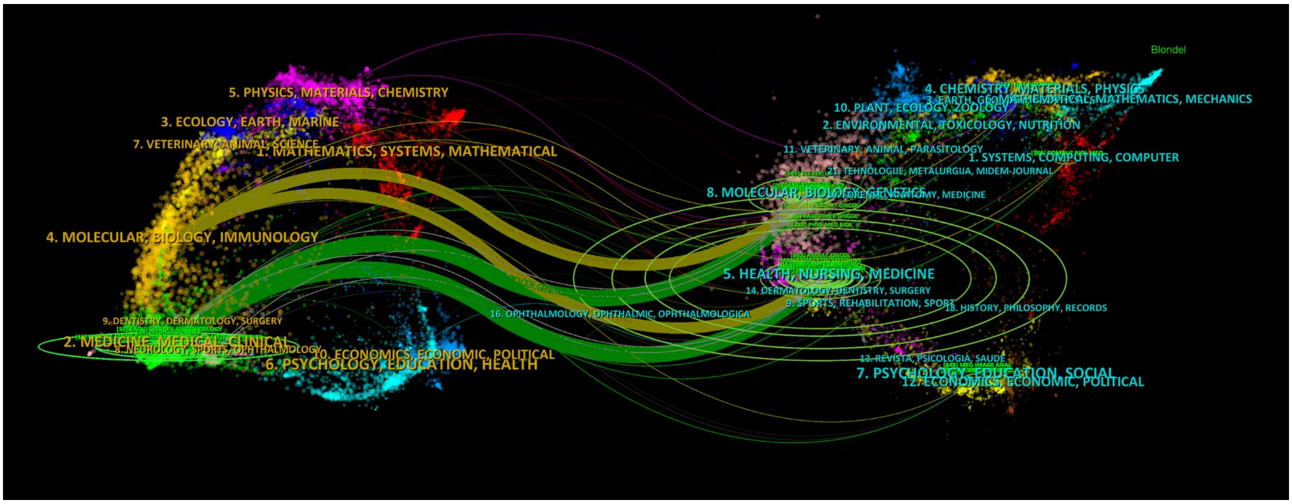

Fig. 6 The journals' dual-map overlay on artificial intelligence research in radiotherapy

Table 3 Top 10 authors and co-cited authors on research of artificial intelligence in radiotherapy

Rank	Author	Documents	Citations	Total link strength	Rank	Co-author	Citations	Total link strength
1	Dekker, Andre	10	43	29	1	Philippe Lambin	85	1195
2	Valentini, Vincenzo	9	149	60	2	Dan Nguyen	83	1790
3	Boldrini, Luca	9	144	55	3	Issam Elnaqa	79	1266
4	Jiang, Steve	8	227	16	4	Gilmer Valdes	79	1486
5	Nguyen, San	8	146	18	5	Kuo Men	76	1313
6	Cusumano, Davide	8	119	62	6	Carlos E Cardenas	69	1229
7	Elnaqa, Issam	8	91	17	7	Bulat Ibragimov	65	1423
8	Jia, Xun	7	318	11	8	Olaf Ronneberger	63	1001
9	Maspero, Matteo	7	220	11	9	Matteo Maspero	55	1172
10	Placidi, Lorenzo	7	109	51	10	Charlotte L Brouwer	51	756

tissue, according to a trending topic analysis of keywords (Fig. 10B). By 2023, autocontouring algorithms would be the primary area of study.

Discussion

Medicine is one of the many sectors that artificial intelligence (AI) is now being introduced into. Machine learning models in radiation oncology can automate and optimize workflows, increasing productivity [25, 26]. The normal clinical workflow has been greatly improved with the introduction of adaptive radiotherapy (ART). Machine learning (ML) and deep learning (DL) are two subdomains of artificial intelligence (AI), which is defined as a group of algorithms that mimic human cognition or intelligence [27]. Review publications on the use of AI, ML, and DL in radiotherapy have increased exponentially in recent years [28]. Furthermore, an analysis of the clinical application of AI in radiation indicated that the most widely used AI-supported applications were automated segmentation and treatment planning, with synthetic CT generation coming in second [29]. This survey also underscores the need for guidance on implementing AI in clinical practice. The purpose of this study is to examine the use of artificial intelligence in radiotherapy and to identify areas of frontier research in this field using bibliometrics.

Every publication that was a part of our analysis comes from 1144 institutions across 64 nations. USA (n=167, 30.6%) had the most papers among the top 10 countries, followed by China (n=90, 16.5%), Italy (n=65, 11.9%), and Netherlands (n=65, 11.9%), with a preponderance in North America (2 out of 10) and Europe (6 out of 10). Additionally, China and USA together accounted for almost half (47.1%) of all published publications, suggesting that the two nations' primary contributions had been to the study of artificial intelligence in radiotherapy. The author keyword cluster analysis indicated that deep learning was a research hotspot in 2023, in line with our bibliometrics data. Scholars from China and USA should collaborate more in the field of deep learning in the future to advance the use of AI in radiotherapy. Many studies on AI in radiation conducted in the past (2008–2018) concentrated on normal tissues [30]. As science and technology had advanced, radiotherapy had transitioned from the two-dimensional to the three-dimensional era and finally to the current intensity-modified

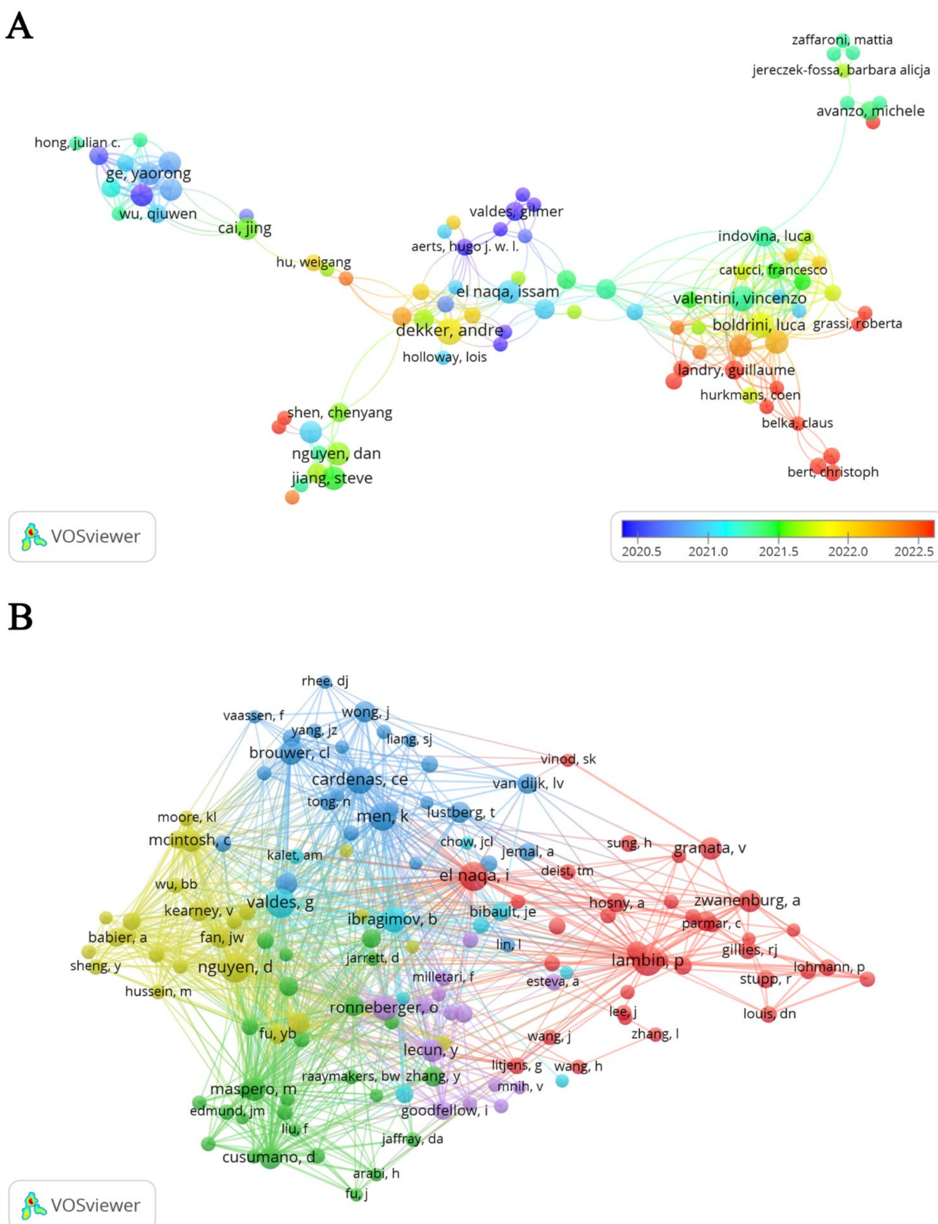

Fig. 7 The illustration of the research on artificial intelligence in radiotherapy by authors (**A**) and co-cited authors (**B**)

radiotherapy. Because of this, we have improved our ability to shield important organs or healthy tissues from radiation [31, 32]. It is feasible to minimize the radiation exposure to normal tissue by optimizing the tumor's therapeutic effect. The most widespread and developed use of AI in head and neck tumor radiotherapy was due to the fact that there were a lot more risk organs that must be protected during treatment than there are in other areas of the tumor [5]. According to the results of our bibliometric analysis, the article published by Wilko F.A.R. Verbakel entitled "Evaluation of a Knowledge-Based Planning Solution for Head and Neck Cancer" is the most important explosive citation [22]. Deep learning therefore still has a lot of potential applications in the field of protecting threatened organs, and it is crucial to reinvent the old, merge the new and old hotspots, and work toward using AI to radiation on a deeper level. The research hotspots identified by our findings further highlight the significance of applying AI to safeguard normal tissue. Automatic mapping algorithms have become a hot topic for research during the last two years and are a field that merits more investigation.Its leadership position in this field was indicated by the popularity of journals like Radiotherapy and Oncology and Frontiers in Oncology, which publish research on the interaction between AI and radiotherapy. Furthermore, the majority of the

Table 4 Top 10 co-cited references on research of artificial intelligence in radiotherapy

Rank	Cited reference	Citations	Total link strength
1	Ronneberger o, 2015, lect notes comput sc, v9351, p234, doi https://doi.org/10.1007/978-3-319-24574-4_28[12]	52	439
2	Vandewinckele l, 2020, radiother oncol, v153, p55, doi https://doi.org/10.1016/j.radonc.2020.09.008[8]	41	339
3	Lustberg t, 2018, radiother oncol, v126, p312, doi https://doi.org/10.1016/j.radonc.2017.11.012[13]	37	382
4	Ibragimov b, 2017, med phys, v44, p547, doi https://doi.org/10.1002/mp.12045[14]	36	465
5	Cardenas ce, 2019, semin radiat oncol, v29, p185, doi https://doi.org/10.1016/j.semradonc.2019.02.001[15]	34	392
6	Fan jw, 2019, med phys, v46, p370, doi https://doi.org/10.1002/mp.13271[16]	34	399
7	Sahiner b, 2019, med phys, v46, pe1, doi https://doi.org/10.1002/mp.13264[17]	32	373
8	Gillies rj, 2016, radiology, v278, p563, doi https://doi.org/10.1148/radiol.2015151169[18]	30	150
9	Lambin p, 2017, nat rev clin oncol, v14, p749, doi https://doi.org/10.1038/nrclinonc.2017.141[19]	29	151
10	Nguyen d, 2019, phys med biol, v64, doi https://doi.org/10.1088/1361-6560/ab039b[20]	29	332

Table 5 The main research content of 4 highly cited literatures

Rank	Strength	IF	Main research content
1	6.64	-	Fast Automatic Vertebrae Detection and Localization in Pathological CT Scans - A Deep Learning Approach[21]
2	3.52	6.4	Evaluation of a knowledge-based planning solution for head and neck cancer[22]
3	3.46	3.2	Knowledge-based prediction of three-dimensional dose distributions for external beam radiotherapy[23]
4	3.23	50.5	Deep learning[24]

co-cited journals are high-impact Q1 publications, such as International Journal of Radiation Oncology, demonstrating their significance in promoting this field of study. Specifically, when it came to the literature analysis, we did not rule out ARXIV and original studies or reviews from conferences. However, there were some confounding factors, particularly in the journal analysis, as some studies were not published in official journals. Despite this, our conclusions remained unaffected because there were so few of these studies. Three authors—Dekker Andre with ten publications, Valentini Vincenzo with nine, and Boldrini Luca with nine—had published more than nine papers between them among the top ten authors. Two writers out of the 18,401 co-cited authors received more than 80 citations (Table 3). Philippe Lambin (n=85) was the most often referenced author, followed by Dan Nguyen (n=83), Issam Elnaqa (n=79), and Gilmer Valdes (n=79). Co-cited references, which stand for significant works that were generally acknowledged and mentioned by academics, form the cornerstone of study in an area. Understanding the main studies, trends, significant contributors, and knowledge network within the research community was made easier by analyzing co-cited literature, which also helps to clarify the linkages and evolution of the topic [33]. By choosing the four most often cited articles, we conducted a bibliometric analysis to look at the research base for artificial intelligence in radiotherapy. For example, the study by Satomi Shiraishi et al. (2016) emerged as one of the explosive citations, providing a comprehensive analysis of Knowledge-based prediction of three-dimensional dose distributions for external beam radiotherapy. Citation bursts in references identified newly developing issues within a particular field since they had been mentioned a lot recently, indicating an increasing trend or area of interest. Finding references with bursts of citations might provide important information about hot issues and possible avenues for further research.

This study had a number of special benefits. First of all, it was the first thorough bibliometric examination of studies concerning the connection between radiotherapy and artificial intelligence. For academics interested in this field of study, our analysis offered insightful recommendations. Second, we simultaneously employed three of the most popular bibliometric tools for our analysis: CiteSpace and VOSviewer, both of which are well-established and often used in the bibliometrics community [34]. By using this method, we can increase the impartiality and dependability of our data analysis process and make sure that the research landscape on AI in radiotherapy was appropriately reflected in our findings. Finally, in comparison to traditional reviews, bibliometric analysis offered a more thorough understanding of the frontiers and hotspots. It was important to take into account the limitations of this study, though. First off, this study's data were taken exclusively from the WoSCC database and excluded other databases, such as the Scopus database, which meant that pertinent research from other databases might have been missed. Second, the study's inclusion criteria were centered on English-language publications, which may have underestimated the significance of non-English papers. It was also important to note that articles from 2024 were left out of the analysis because there was not enough data available for it.

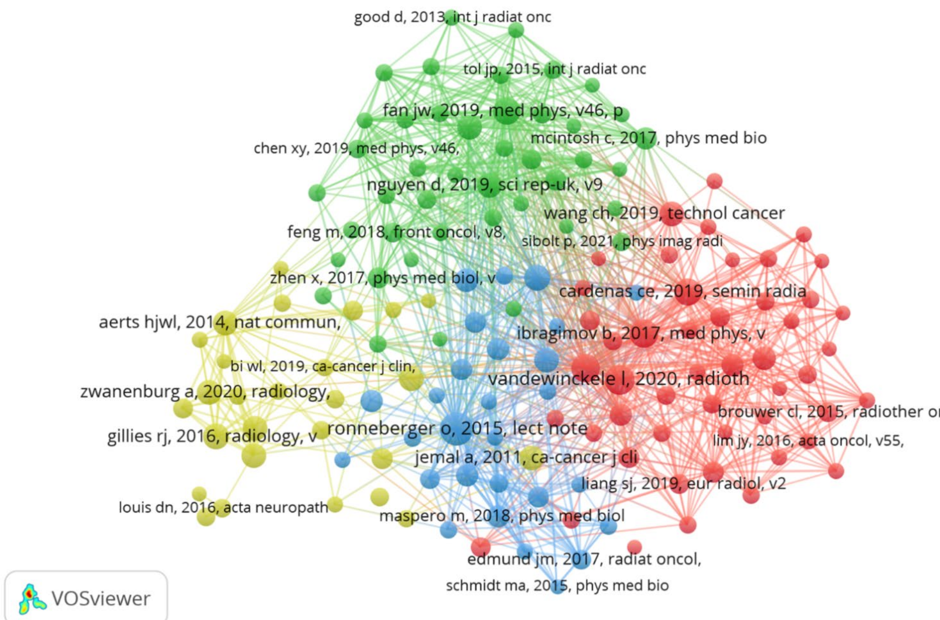

Fig. 8 The display of co-cited references of artificial intelligence research in radiotherapy

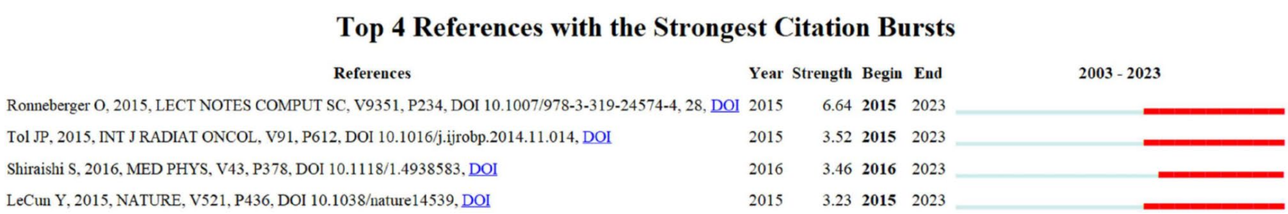

Fig. 9 The top 4 sources with powerful, eye-catching citations. High citations for the year are indicated by red bars

Table 6 Top 20 keywords on research of artificial intelligence in radiotherapy

Rank	Keyword	Occurrences	Total link strength	Rank	Keyword	Occurrences	Total link strength
1	Artificial intelligence	292	783	11	Quality assurance	19	56
2	Deep learning	124	366	12	Breast cancer	17	40
3	Radiotherapy	110	337	13	Lung cancer	17	43
4	Machine learning	106	337	14	MRI	16	54
5	Radiomics	50	157	15	Adaptive radiotherapy	15	48
6	Radiation therapy	31	98	16	Cancer	15	40
7	Radiation oncology	23	60	17	Auto-segmentation	14	42
8	Head and neck cancer	22	79	18	Magnetic resonance imaging	14	43
9	Treatment planning	21	72	19	Convolutional neural network	12	42
10	Prostate cancer	19	44	20	Glioma	12	36

Conclusion

A bibliometric analysis indicates that the field of research on the interaction between AI and radiation therapy has bright futures and is developing quickly. The United States of America holds the record for both publication volume and breakthrough achievement. Frontiers in Oncology, Radiotherapy and oncology, and Medical Physics are the three publications that have published the majority of the most recent studies and developments in this field. Notably, studies have shown that the autocontouring algorithm, deep learning, machine learning, and normal tissue are the primary areas in which artificial intelligence is applied in radiation. These results may offer future research direction for enhancing treatment outcomes and aid in the identification of cutting-edge research hotspots for the use of AI in radiotherapy.

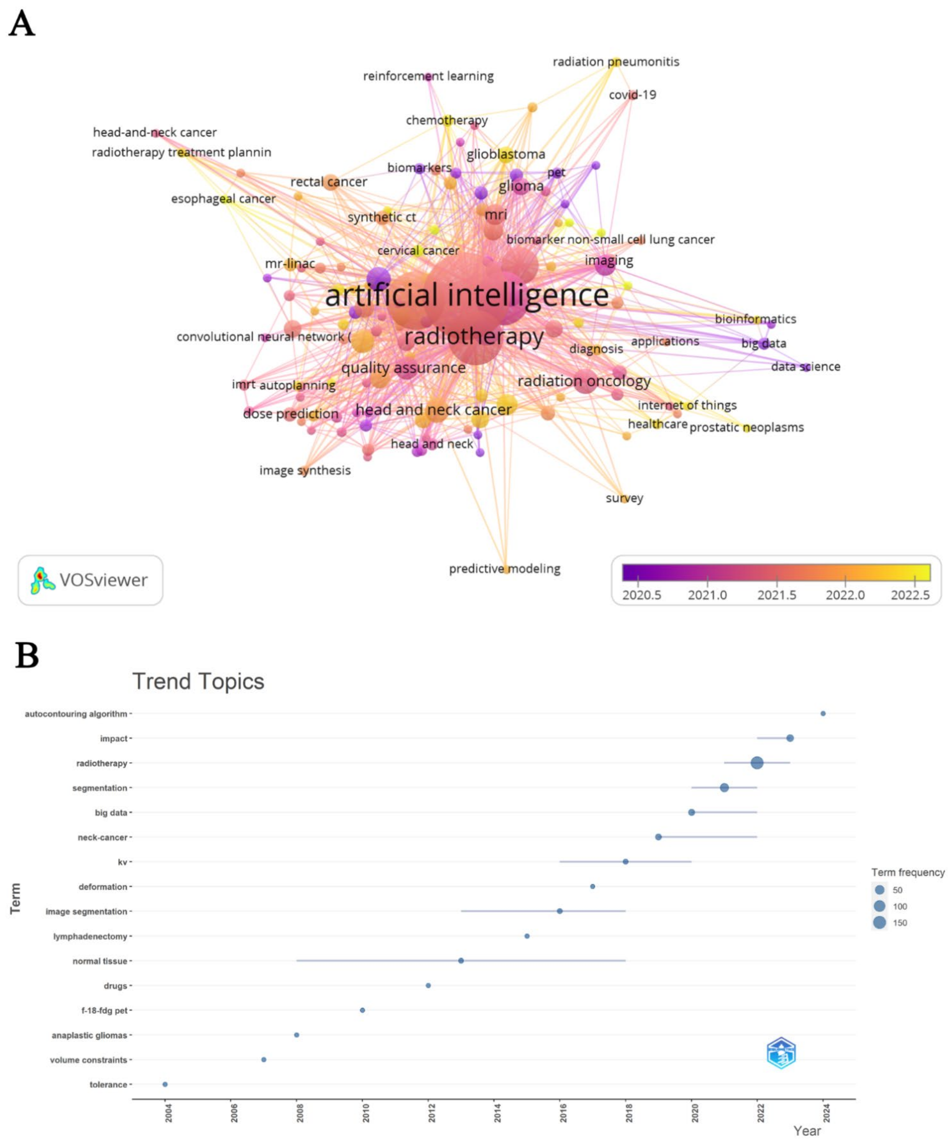

Fig. 10 The visualization of cluster analysis of keywords (**A**) and trend topic analysis (**B**)

Abbreviations

AI	artificial intelligence
RT	radiotherapy
TPS	treatment planning system
QA	quality assurance
WoSCC	Web of Science Core Collection

Supplementary Information

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Supplementary Material 1

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All the authors declare their consent to the publication of the article.

Competing interests
The authors declare no competing interests.

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