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Research article

Bibliometric analysis and research trends of artificial intelligence in lung cancer

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ABSTRACT

Background: Due to the rapid advancement of technology, artificial intelligence (AI) has become extensively used for the diagnosis and prognosis of various diseases, such as lung cancer. Research in the field of literature has demonstrated that artificial intelligence (AI) can be valuable in the timely detection of lung cancer and the formulation of an effective treatment plan. This study aims to conduct a bibliometric analysis to examine and illustrate the specific areas of focus, research frontiers, evolutionary processes, and trends in existing research on artificial intelligence in the context of lung cancer.
Methods: Publications on AI in lung cancer were selected from the SCIE and ESCI indexes on September 19, 2023. The examination of nations, academic publications, organizations, writers, citations, and terms in this domain was visually analyzed with InCites and VOSviewer.
Results: In this study, a total of 4275 publications were selected and analyzed. Artificial intelligence-related lung cancer publications have increased significantly in the last 5 years. China and the USA have contributed the most to the literature in this field (1418 publications with 13.92 citation impacts and 1117 publications with 37.34 citation impacts, respectively). The institution with the highest contribution was "Chinese Academy of Sciences," with 118 publications and 29.09 citation impacts. Among the research categories, "Radiology, Nuclear Medicine & Imaging", "Oncology", and "Engineering, Biomedical" were in first place.
Conclusion: The USA and China have always been leaders in this field and will continue to be for some time. Research in countries such as the Netherlands is increasing. However, research collaboration has to be strengthened in developing countries.

1. Introduction

One of the most common malignant tumors, lung cancer has a relatively high morbidity and mortality rate [1]. The 5-year survival rate for people diagnosed with lung cancer is merely 10–20 %, primarily due to the fact that a majority of these patients are already in the advanced stages of the disease and have few treatment options available [2,3]. Lung cancer is primarily categorized based on histology, resulting in the distinction between non-small cell lung cancer and small cell lung cancer, which necessitates different treatment approaches [4]. The International Association for the Study of Lung Cancer (IASLC) classifies lung cancer based on tumor size, the presence of cancer cells in nearby lymph nodes, and the spread of disease to distant parts of the body. Stage I-II lung cancer is classified as an early stage, whereas stage III-IV is classified as advanced stage lung cancer [5].

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Various diagnostic methods are used to detect and diagnose lung cancer. However, the primary method for diagnosing lung cancer is primarily dependent on computed tomography (CT) and tissue biopsy [6]. One commonly used method is positron emission tomography-computed tomography (PET-CT), which is effective for both the diagnosis and staging of lung cancer [7]. Another diagnostic method is touching imprint cytology. This method is particularly useful for obtaining a diagnosis from a small biopsy or cytological specimens [8]. Additionally, histopathological examination of guided lung biopsies is commonly used to differentiate between primary and metastatic lung cancers, as well as to classify the type of lung cancer for treatment purposes [9].

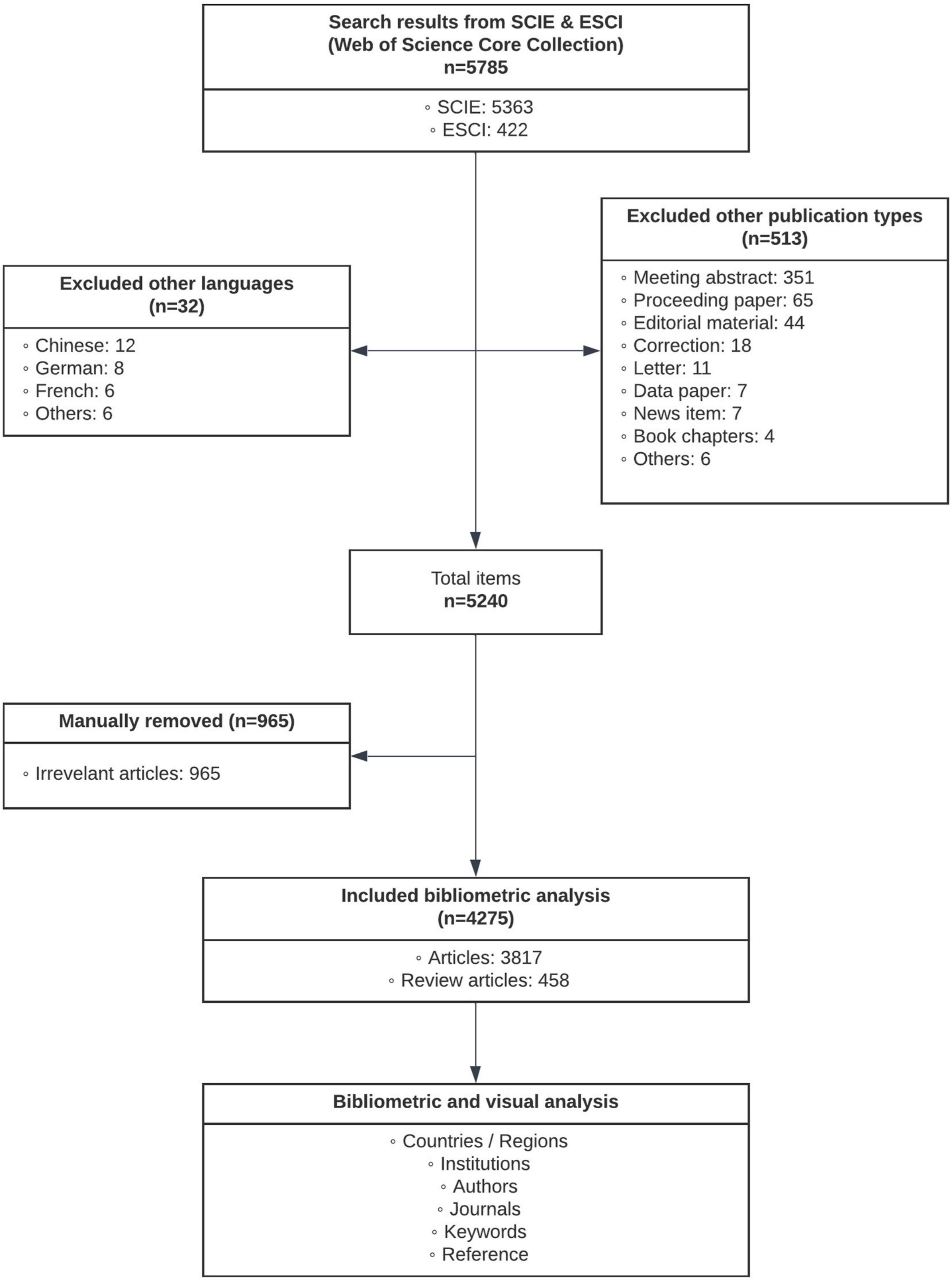

Fig. 1. Flowchart of the search strategy in the study.

Lung cancers are treated with combinations of surgery, radiation, and systemic therapy, depending on the stage of the disease, lung function, and the patient's performance status. Predictors of success include disease stage, location, histology, age, gender, and treatment received [10].

The adventure of artificial intelligence, which started in the 1950s, continues to develop not only in computing, mathematics, and computers but also in many other disciplines. Artificial intelligence is extensively studied in the medical sector, particularly in areas such as biology, genetics, radiology, and pathology. It is particularly focused on improving the diagnosis, treatment, and prognosis of diseases like cancer. Advancements in technology have also led to the development of artificial intelligence (AI) systems for lung cancer diagnosis. AI-assisted diagnostic systems, specifically designed for CT imaging, have shown promising results in terms of diagnostic accuracy for lung cancer [11].

With the increasing interest in AI applications for lung cancer research, numerous articles have been published. However, researchers have challenges in keeping up with the latest discoveries and identifying the current research trends in this field. The discipline of AI is seeing tremendous development, with ongoing opportunities for advancements in the domain of lung cancer. It is crucial to identify and emphasize the current global research trends and hotspots in order to guide future research.

Bibliometric analysis is an information visualization technique that has been widely used in many fields to understand the knowledge structure and pinpoint research frontiers or hotspots in a given field [12–14]. This is achieved by consolidating a comprehensive overview of all the literature in the specific topic and conducting a quantitative analysis of the data extracted from that literature, together with meteorological characteristics, employing statistical and mathematical methodologies. In the meantime, by employing this technique, we can assess international scientific articles and the most recent advancements in frontier research, gain a deeper understanding of scientific publications, and visualize their trends by comparing the research status of different nations, institutions, authors, or journals from the database [15,16].

Several bibliometric studies in the literature related to artificial intelligence in different diseases. Bibliometric studies in areas such as esophageal [17], colorectal [18,19], liver [20], and prostate cancer [21] are extremely important in revealing the development of artificial intelligence, which is a new subject. The aim of this study was to utilize bibliometric analytical techniques to examine the progress of artificial intelligence (AI) applications in the domain of lung cancer till September 2023. Our purpose was to present an overview of the current research progress, identify key areas of interest, and highlight developing trends. This analysis aims to assist new researchers in gaining a better understanding of potential possibilities for future research.

2. Material and methods

2.1. Data sources

Clarivate Analytics' Web of Science (WoS) Core Collection is a comprehensive, multidisciplinary, authoritative core journal citation database containing more than 21,000 peer-reviewed, high-impact journals, 300,000 conferences, and 134,000 books in 254 subject categories across the sciences. SCIE (Science Citation Index Expanded), as a journal citation index of the WoS Core Collection, is a multidisciplinary, comprehensive database covering the field of natural science, with over 9500 global authoritative journals and 61 million publications in 182 subject categories. ESCI (Emerging Sources Citation Index) is another index of the WoS Core Collection, with over 8000 high-quality journals and 4 million publications in 254 subject categories. This study utilized the SCIE and ESCI indexes from the WoS Core Collection database as the primary data sources.

2.2. Search strategy

In order to ensure no data updates, we retrieved the data within a day, on September 19, 2023.

The search query string was defined as follows: (TS=("AI") OR TS=("artificial intelligence") OR TS=("neural network") OR TS=("transfer learning") OR TS=("machine learning") OR TS=("deep learning")) AND (TS=("lung cancer") OR TS=("lung neoplasm") OR TS=("lung tumor") OR TS=("lung carcinoma"))

The query resulted in 5785 records. Only SCIE and ESCI indexes were included. To maintain the precision and impartiality of the analysis, only articles and review articles written in English were included, while other forms of publications such as meeting abstracts, proceeding papers, and editorial materials were excluded. After the preliminary search, the remaining 5240 results were transferred to a private list on the Web of Science. The records in the list were manually screened for relevance by reading the title and (if necessary) abstracts. To obtain the most accurate analysis, 965 irrelevant publications were removed from the list. Finally, 4275 papers (3817 articles and 458 review articles) were included in our study to perform bibliometrics and visual analysis. Fig. 1 shows the workflow of the search process in the study.

2.3. Data analysis and visualization

First, basic analyses such as the number of publications, citations, and global trends were made through the Web of Science's search and citation analysis. After that, the data was transferred to Clarivate Analytics InCites. However, since 179 of the 4275 records could not be transferred to the InCites for various reasons (records may not be available if they were published before 1980 or were recently added to the Web of Science™ Core Collection), some bibliometric analysis was performed on 4091 records.

In addition, the data was exported in "plain text format" as "full record and cited references" for subsequent analysis using VOSviewer. VOSviewer is a software application designed for the purpose of generating and visualizing bibliometric networks. These networks can consist of many entities, such as academic journals, researchers, or individual publications, and they can be formed using several types of relationships, such as citation, bibliographic coupling, co-citation, or co-authorship. VOSviewer additionally provides text mining capabilities that enable the creation and visualization of co-occurrence networks of significant keywords retrieved from a body of scholarly literature.

2.4. Terms used in the study

Times cited refers to the total number of citations that papers in the Web of Science Core Collection have received from other documents within the same collection.

The citation index (CI) represents the arithmetic mean of the number of citations received each work.

The Journal Normalized Citation Index (JNCI) is a measure of citation impact that takes into account the number of citations per paper, while also normalizing for factors such as the journal, year, and document type.

Category Normalized Citation Impact (CNCI) refers to the citation impact of a paper, measured by the number of citations it receives, which is adjusted or normalized based on the subject, year, and document type.

The term “documents in the top 10 %" refers to publications that rank within the highest 10 % based on their citations, categorized by year, document type, and subject.

International collaboration pertains to research publications that involve the participation of one or more co-authors from different countries.

The h-index, commonly known as the Hirsch index, was introduced by J. Hirsch in 2005. Its definition is as follows: An h-index is achieved by a researcher when they have published at least h papers that have earned at least h citations.

Highly Cited articles are articles that rank in the top 1 % in terms of the amount of citations they get, relative to other papers published in the same field and year.

2.5. Ethical approval

The data sources utilized in our analysis were obtained from a publicly accessible repository. It is important to note that our research did not involve any experiments involving human or animal participants. Approval from the ethics committee is unnecessary.

3. Results

3.1. Global trend of publications and citations

Referring to the strategic flowchart depicted in Fig. 1; our search resulted in 4275 publications in SCI-Expanded and ESCI indexes over the last 29 years (from 1994 to September 19, 2023), including 3817 original research and 458 review articles.

The earliest research on the application of artificial intelligence technology in the field of lung cancer was a study entitled “Artificial Neural Networks for Early Detection and Diagnosis of Cancer” authored by Rogers et al., and published in the journal “Cancer Letters” in the year 1994 [22]. This publication received 17 citations in total.

After this date, there were not many publications until 2003 (<10 publications per year). Between 2003 and 2017, there was a partial increase (<100 publications per year). In 2018, the number of annual publications exceeded 200, and the number of publications has increased rapidly in the last 5 years with the developments in technology. In 2022, the annual number of publications exceeded 1000, and in 2023, 763 studies have been published so far, and new studies continue to be published every day (Fig. 2). The number of citations has also been increasing over the years in proportion to the number of publications. Among the publications, 100

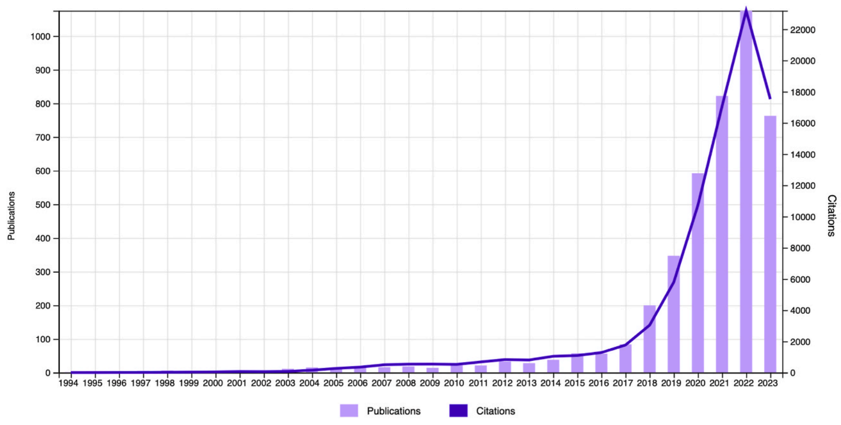

Fig. 2. Global trend of publications and citations.

were identified as highly cited papers by Clarivate Analytics.

As of the search date (September 19, 2023), all publications were cited a total of 87,988 times (71,464 without self-citations), and the average citation per item was 20.58 and the H-index was 123.

3.2. Analysis of countries or regions

We used the Clarivate Incites system to analyze countries and regions. As seen in Table 1, China Mainland and the USA were the countries with more than 1000 publications in total (1418 and 1118, respectively). Although China ranked first in the list of countries with the most publications, the USA ranked first with 41711 citations. Countries with 10000 or more citations were USA, China Mainland, and Netherlands (41711, 19734, and 10963, respectively) (Table 1).

The countries with more than 10 "highly cited papers" were the USA with 51, Mainland China with 25, the Netherlands with 15, the United Kingdom with 14, and England with 14 articles (4.57 %, 1.76 %, 8.57 %, 5.86 %, and 6.36 %, respectively).

In terms of the number of publications in the top 10 % of journals, the USA is again in first place. According to the number of publications in the top 10 % of journals, the USA has 330 publications, the China Mainland has 270 publications, the United Kingdom has 66 publications, the Netherlands has 63 publications, and England has 63 publications (29.54 %, 19.04 %, 27.62 %, 36 %, and 28.64 %, respectively) (Fig. 3A).

Fig. 3B shows the degree of cooperation between countries or regions when the minimum number of publications was at least 5. The lines between nodes indicate co-authorships between countries, where a thicker line indicates stronger cooperation (total link strength, TLS). The USA, China, England, the Netherlands, and Germany are the top 5 countries and regions with the most TLS (TLS: 872, 549, 396, 309, and 279, respectively) (Fig. 3B).

3.3. Analysis of institutions

According to InCites, more than 2600 institutions have published articles on artificial intelligence in lung cancer. Table 2 lists the top 10 institutions that have contributed the most to this topic. The top institutions were the Chinese Academy of Sciences, Harvard University, the University of Texas System, and Shanghai Jiao Tong University, which have a total of 118, 116, 110, and 103 articles, respectively. As shown in Table 2, five of the top 10 institutions were from the USA, four were from China, and one was from the Netherlands (Table 2). The most cited institutions were Harvard University (USA), Harvard Medical School (USA), Dana-Farber Cancer Institute (USA), Maastricht University (Netherlands), Brigham & Women's Hospital (USA), and Stanford University (11 %, 10.2 %, 8.1 %, 7.8 %, 7.7 %, and 5.5 %) (Fig. 4A).

Fig. 4B shows the relationship between a total of 73 institutions that have published at least 20 articles. The lines represent cooperation between institutions, and the more cooperation, the thicker the lines. The top three institutions with the highest TLS were the Chinese Academy of Sciences, Harvard University, and Shanghai Jiao Tong University (133, 131, and 97, respectively) (Fig. 4B).

3.4. Analysis of authors

Based on the WOS Author Record, a total of 22,208 authors made contributions to a combined total of 4086 publications. Regarding the quantity of published works, Li Weimin (China Mainland) had the largest number of publications, followed by Gillies Robin (USA), Lambin Philippe (Netherlands), Schabath Matthew B. (USA), and Qi Shouliang (China Mainland) (22, 20, 19, 17, and 17 publications, respectively) (Table 3).

The individual with the greatest cumulative number of citations was "Aerts, Hanna" affiliated with Harvard Medical School (USA) with 4472 times cited, followed by "Parmar, Chintan", "Hosny, Ahmed", "Beets-Tan, Regina", "Narayan, Vivek", and "Fedorov, Andrey" (4300, 3781, 2703, 2467, and 2446 times cited, respectively). The most productive authors (Fig. 5A) and the most cited authors (Fig. 5B) are shown in Fig. 5.

In the co-authorship authors and co-citation cited authors analysis we conducted on VOSviewer, the authors with the highest TLS in terms of co-authorship are "Li, Weimen", "wang, Chengdi", "Jixiang, Guo", "Xu, Xiuyuan", and "Yi, Zhang" (TLS = 58, 50, 44, 44, and

Table 1
Top 10 productive countries/regions related to artificial intelligence in lung cancer.

Country/Region	Documents	Times cited	Highly cited papers	Documents in Top 10 %	CI (CNCI)	TLS
China Mainland	1418	19,734 (75.53 %)	25 (1.76 %)	270 (19.04 %)	13.92 (1.46)	549
USA	1117	41,711 (87.11 %)	51 (4.57 %)	330 (29.54 %)	37.34 (2.45)	872
India	405	4189 (67.41 %)	5 (1.23 %)	51 (12.59 %)	10.34 (1.16)	215
United Kingdom	239	6260 (87.87 %)	14 (5.86 %)	66 (27.62 %)	26.19 (2.39)	
South Korea	224	3225 (76.79 %)	8 (3.57 %)	47 (20.98 %)	14.4 (1.63)	149
England	220	6043 (88.18 %)	14 (6.36 %)	63 (28.64 %)	27.47 (2.51)	396
Japan	215	4583 (86.05 %)	3 (1.4 %)	42 (19.53 %)	21.32 (1.42)	138
Germany	176	5284 (82.95 %)	5 (2.84 %)	51 (28.98 %)	30.02 (2.29)	279
Netherlands	175	10,963 (89.14 %)	15 (8.57 %)	63 (36.0 %)	62.65 (3.84)	309
Italy	168	4966 (86.31 %)	9 (5.36 %)	45 (26.79 %)	29.56 (1.95)	213

CI: Citation Impact. CNCI: Category Normalized Citation Impact. TLS: Total Link Strength.

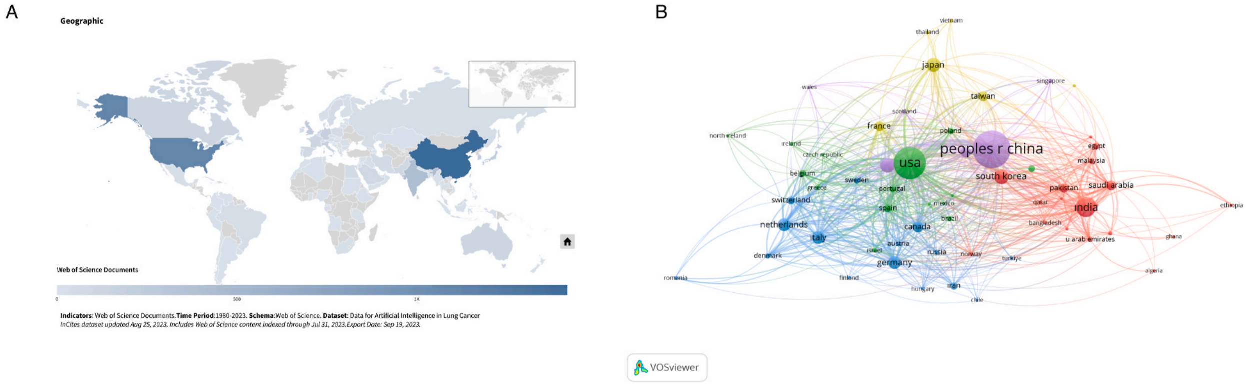

Fig. 3. Top countries or regions. (A) Geographic distribution of publications. (B) Network visualization map of countries or regions.

Table 2
Top 10 productive institutions related to artificial intelligence in lung cancer.

Institution	Documents	Times cited	CI (JNCI-CNCI)	H-index	International Collaborations	TLS
Chinese Academy of Sciences (China Mainland)	118	3433 (83.05 %)	29.09 (1.41–2.41)	26–26	40 (33.9 %)	133
Harvard University (USA)	116	9110 (94.83 %)	78.53 (2.03–4.85)	37–36	77 (66.38 %)	
University of Texas System (USA)	110	3315 (85.45 %)	30.14 (1.59–2.37)	31–30	60 (36.89 %)	37
Shanghai Jiao Tong University (China Mainland)	103	1481 (83.5 %)	14.38 (1.63–1.57)	21–21	38 (36.89 %)	97
Harvard Medical School (USA)	88	8375 (93.18 %)	95.17 (2.25–5.53)	32–30	66 (75 %)	131
Fudan University (China Mainland)	85	1040 (78.82 %)	12.24 (1.25–1.3)	19–17	18 (21.28 %)	82
University of California System (USA)	79	4190 (89.87 %)	53.04 (1.83–3.16)	25–24	38 (48.1 %)	33
Stanford University (USA)	69	4523 (86.96 %)	65.55 (1.68–4.49)	27–26	45 (65.22 %)	56
Peking Union Medical Collage (China Mainland)	66	612 (77.27 %)	9.27 (0.97–1.09)	14–14	12 (18.18 %)	41
Maastricht University (Netherlands)	63	6422 (90.48 %)	101.94 (3.27–5.29)	27–26	50 (79.37 %)	46

CI: Citation Impact. JNCI: Journal Normalized Citation Impact. CNCI: Category Normalized Citation Impact. TLS: Total Link Strength.

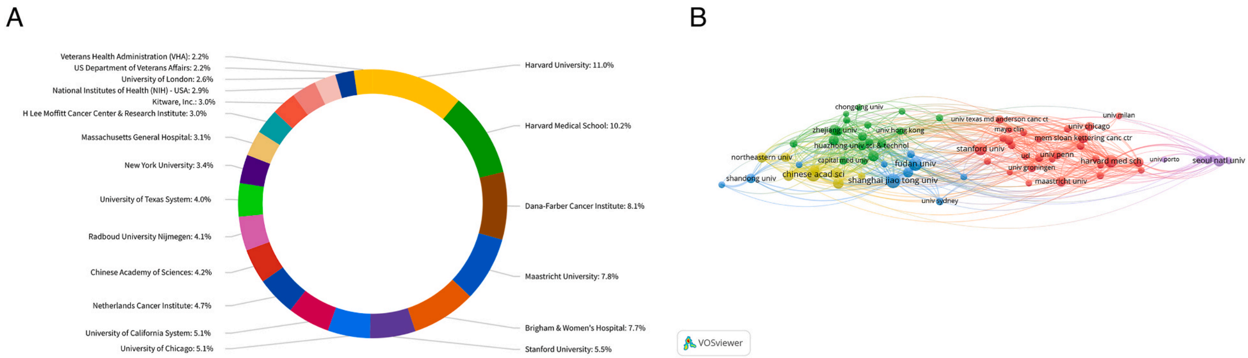

Fig. 4. Cooperation and citations between Institutions. (A) Most cited Institutions. (B) Network visualization map of Institutions.

42, respectively) (Fig. 6A), while the authors with the highest TLS in terms of co-citation are "Armato, Sg", "Setio, Aaa", "Lambin, P", "Aerts, HJWL", and "Aberle, Dr" (TLS = 7695, 5483, 4520, 4019, and 3997, respectively). Fig. 6 shows the authors' cooperation network maps. The visualization network map of the most productive authors is shown in Fig. 6A, and the most cited authors are shown in Fig. 6B.

3.5. Analysis of journals

A total of 4096 publications on the use of artificial intelligence in lung cancer were published in 942 journals. The journals that contributed the most to the literature with 100 or more publications are "frontiers in oncology" in oncology, "medical physics" in radiology, nuclear medicine & medical imaging, "scientific reports" in multidisciplinary sciences, and "cancers" in oncology (times cited 1673, 3652, 2385, and 771, respectively) (Table 4).

The most cited journals were "Medical Physics", "IEEE Transactions on Medical Imaging", "Cancer Research", "Nature Medicine", and "Scientific Reports" (127, 27, 8, 5, and 115 publications, respectively). Fig. 7 shows the most productive journals; the node size

Table 3
Top 10 productive authors related to artificial intelligence in lung cancer.

Author	Documents	Times cited	H-index	CI (JNCI - CNCI)	TLS
Li, Weimin @ Beijing University of Agriculture, China Mainland	22	275	9–8	12.5 (1.69–2.29)	398
Gillies, Robyn @ H Lee Moffitt Cancer Center & Research Institute, USA	20	2188	17–17	109.4 (2.57–7.06)	456
Lambin, Philippe @ Maastricht University Medical Centre (MUMC), Netherlands	19	1817	17–16	95.63 (4.06–4.98)	291
Schabath, Matthew B. @ H LEE MOF FITT CANC CTR & RES INST, USA	17	1414	13–13	83.18 (2.16–5.1)	423
Qi, Shouliang @ Dalian Maritime University, China Mainland	17	339	10–9	19.94 (2.33–1.82)	213
Suzuki, Kenji @ SPACE COMMUN SYST LAB, Japan	16	1164	14–13	72.75 (1.73–1.81)	144
Madabhushi, Anant @ Atlanta VA Health Care System, USA	15	885	11–10	59 (1.69–4.27)	430
Velcheti, Vamsidhar @ NEW YORK UNIV NYU LANGONE HLTH, USA	14	833	10–10	59.5 (1.96–4.1)	414
Wang, Chengdi @ Sichuan University, China Mainland	14	169	8–6	12.07 (1.82–1.78)	252
Qiang, Yan @ Lanzhou University of Technology, China Mainland	13	40	3–3	3.08 (0.56–0.39)	137

CI: Citation Impact. JNCI: Journal Normalized Citation Impact. CNCI: Category Normalized Citation Impact. TLS: Total Link Strength.

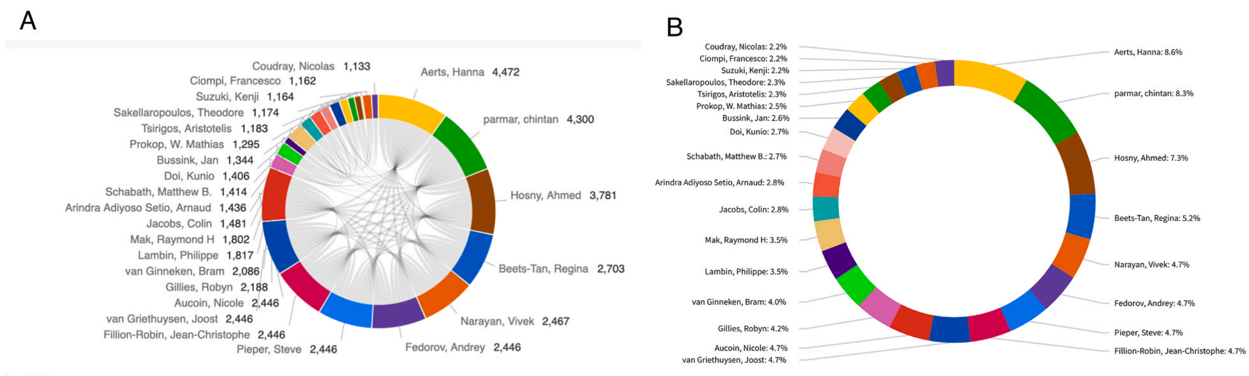

Fig. 5. Authors collaboration. (A) Top productive authors. (B) Most cited authors.

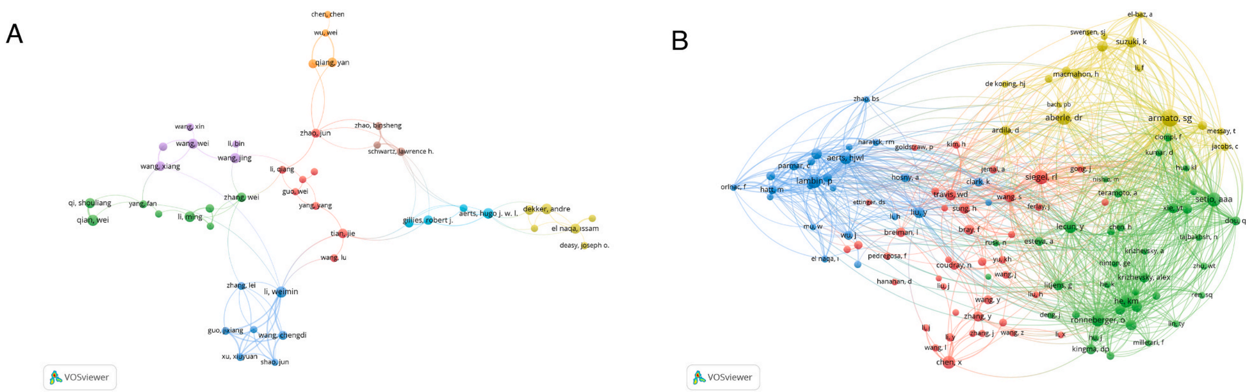

Fig. 6. Cooperation between authors. (A) Visualization map of authors. (B) Visualization map of most cited authors.

Table 4
Top 10 productive journals related to artificial intelligence in lung cancer.

Journal	Documents	Times cited	Eigenfactor	JIF - 5y JIF	CI (JNCI - CNCI)	JCI - JIF Quartile
Frontiers in Oncology Frontiers Media SA @ Switzerland	155	1673	0.09710	4.7–5.2	10.79 (1.49–0.92)	Q2 - Q2
Medical Physics Wiley @ USA	127	3652	0.02230	3.8–4.0	28.76 (1.88–1.99)	Q1 - Q2
Scientific Reports Nature Portfolio @ England	115	2385	1.05870	4.6–4.9	20.74 (1.55–1.56)	Q1 - Q2
Cancers MDPI @ Switzerland	101	771	0.12240	5.2–5.6	7.63 (1.25–0.94)	Q2 - Q2
IEEE Access IEEE Inc @ USA	93	1134	0.32870	3.9–4.1	12.19 (1.38–1.2)	Q2 - Q2
Physics in Medicine and Biology IOP Publishing Ltd @ England	77	1822	0.01940	3.5–3.4	23.66 (1.71–1.52)	Q2 - Q2
Computers in Biology and Medicine Pergamon-Elsevier Science Ltd @ USA	64	1401	0.02110	7.7–6.9	21.89 (1.53–2.35)	Q1 - Q1
Diagnostics MDPI @ Switzerland	56	253	0.02190	3.6–3.7	4.52 (1.48–1.3)	Q1 - Q2
Computer Methods and Programs in Biomedicine Elsevier Ireland Ltd @ USA	49	1356	0.01660	6.1–6.1	27.67 (1.53–1.96)	Q1 - Q1
European Radiology Springer @ Germany	47	728	0.04490	5.9–5.5	15.49 (1.17–1.91)	Q1 - Q1

JIF: Journal Impact Factor. JCI: Journal Citation Indicator. CI: Citation Impact. JNCI: Journal Normalized Citation Impact. CNCI: Category Normalized Citation Impact.

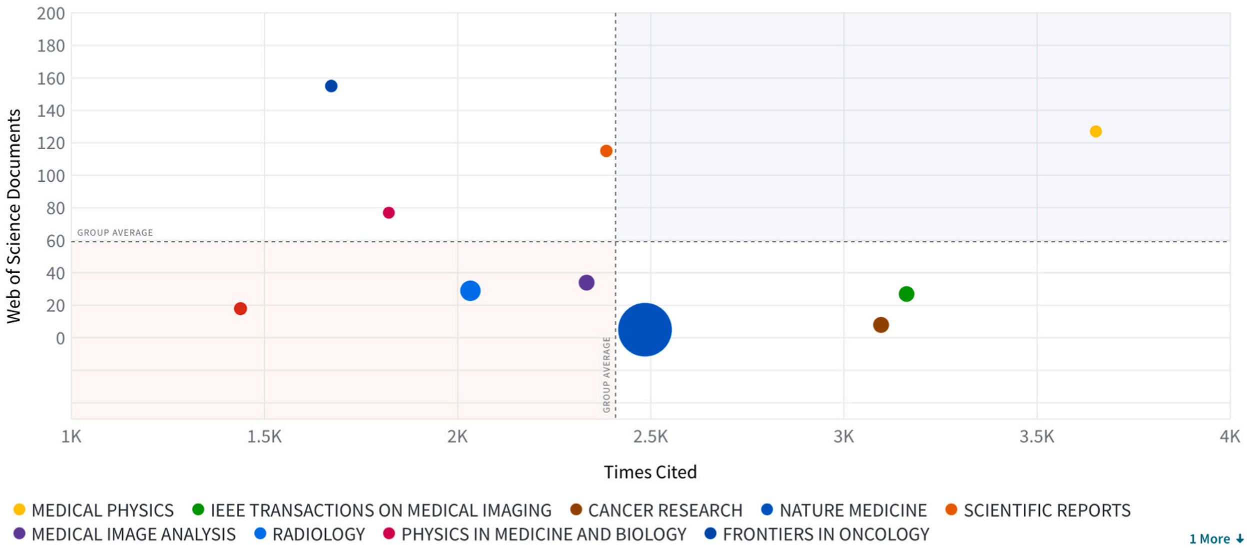

Fig. 7. The most productive journals.

represents the JIF (journal impact factor) of the associated journal.

3.6. *Analysis of research areas*

Publications related to the use of artificial intelligence in lung cancer have been published in 119 categories. The research areas with the most publications were "Radiology, Nuclear Medicine & Imaging", "Oncology", and "Engineering, Biomedical" (1005, 948, and 437 documents, respectively) (Table 5). The most co-cited research areas were "Radiology, Nuclear Medicine & Imaging", "Oncology", "Engineering, Biomedical", "Computer Science, Interdisciplinary Applications", and "Computer Science, Artificial Intelligence" (CI = 27.37, 21.3, 33.08, 32.73, and 24.56, respectively) (Fig. 8).

3.7. *Analysis of highly cited papers*

The most cited research on artificial intelligence and lung cancer is displayed in Table 6. The article "Computational Radiomics

Table 5
Top 10 research areas related to artificial intelligence in lung cancer.

Research Area	Documents	Times cited	CI (JNCI - CNCI)	Highly Cited Papers	Documents in Top 10 %
Radiology, Nuclear Medicine & Imaging	1005	27,507	27.37 (1.8–2.32)	25 (2.49 %)	275 (27.36 %)
Oncology	948	20,193	21.3 (1.41–1.48)	28 (2.95 %)	186 (19.62 %)
Engineering, Biomedical	437	14,454	33.08 (1.64–2.09)	14 (3.2 %)	96 (21.97 %)
Engineering, Electrical & Electronic	355	8556	24.1 (1.5–1.9)	7 (1.97 %)	73 (20.56 %)
Computer Science, Artificial Intelligence	354	8695	24.56 (1.55–1.59)	11 (3.11 %)	70 (19.77 %)
Computer Science, Interdisciplinary Applications	339	11,097	32.73 (1.59–2.22)	12 (3.54 %)	91 (26.84 %)
Computer Science, Information Systems	250	3423	13.69 (1.48–1.43)	1 (0.4 %)	50 (20 %)
Mathematical & Computational Biology	245	4454	18.18 (1.58–1.97)	10 (4.08 %)	51 (20.82 %)
Medical Informatics	200	4783	23.92 (1.64–2.06)	5 (2.5 %)	50 (25 %)
Respiratory System	166	3012	18.14 (1.29–1.54)	3 (1.81 %)	34 (20.48 %)

CI: Citation Impact. JNCI: Journal Normalized Citation Impact. CNCI: Category Normalized Citation Impact.

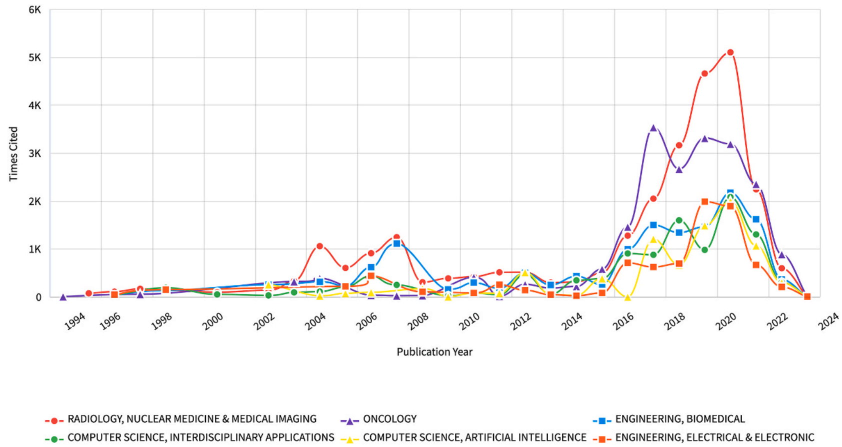

Fig. 8. Web of Science research categories.

Table 6
Top 10 highly cited papers related to artificial intelligence in lung cancer.

Author	Journal	Year	DOI	Citations
Van Griethuysen et al.	Cancer Research	2017	10.1158/0008–5472.CAN-17-0339	2572
Coudray, N et al.	Nature Medicine	2018	10.1038/s41591-018-0177-5	1178
Ardila, D et al.	Nature Medicine	2019	10.1038/s41591-019-0447-x	783
Zhou, ZW et al.	IEEE Transactions on Medical Imaging	2020	10.1109/TMI.2019.2959609	739
Setio, AAA et al.	IEEE Transactions on Medical Imaging	2016	10.1109/TMI.2016.2536809	731
Bi, WL et al.	CA-A Cancer Journal for Clinicians	2019	10.3322/caac.21552	651
Parmar, C et al.	Scientific Reports	2015	10.1038/srep13087	605
Yu, KH et al.	Nature Communications	2016	10.1038/ncomms12474	523
Rajpurkar, P et al.	Plos Medicine	2018	10.1371/journal.pmed.1002686	521
Formenti, SC et al.	Nature Medicine	2018	10.1038/s41591-018-0232-2	506

DOI: Digital object identifier.

System to Decode the Radiographic Phenotype" by Van Griethuysen et al., published in Cancer Research in 2017, has received 2572 citations up to the time of the study [23]. In second place is the article titled "Classification and mutation prediction from non-small cell lung cancer histopathology images using deep learning" by Coudray, N. et al., published in Nature Medicine in 2018 [24]. In third place is the article titled "End-to-end lung cancer screening with three-dimensional deep learning on low-dose chest computed tomography" by Ardila, D. et al., published in Nature Medicine in 2019 [25] (Table 6).

3.8. *Analysis of funding*

"National Natural Science Foundation of China (NSFC), China Mainland", "United States Department of Health & Human Services, USA", "National Institutes of Health (NIH), USA", "NIH National Cancer Institute (NCI), USA", "National Research Foundation of Korea, South Korea", "Fundamental Research Funds for the Central Universities, China Mainland", "Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan", "Japan Society for the Promotion of Science, Japan", "National Science Foundation

(NSF), USA", and "Grants-in-Aid for Scientific Research (KAKENHI), Japan" provided the most support for the use of AI in lung cancer (589, 309, 304, 127, 71, 65, 61, 51, 47 and 44 publications, respectively).

3.9. *Analysis of keywords*

The dataset includes 7635 author keywords, and there were 99 author keywords with at least 20 co-occurrences. The most frequent keywords are "lung cancer", "deep learning", "machine learning", "artificial intelligence", "radiomics", "computed tomography", "cancer", "convolution neural network", "non-small cell lung cancer", and "lung adenocarcinoma" (867, 814, 772, 347, 324, 228, 200, 183, 144, and 135 occurrences, respectively) (Fig. 9A). The overlay visualization map of keywords illustrates evolution of keywords over time (Fig. 9B). The size of a node in Fig. 9 indicates the frequency of a keyword, and the line connecting nodes signifies the simultaneous appearance of two keywords in the same document. The cluster of keywords is represented by the node color in Fig. 9A, and the average year of keyword occurrence is represented by the node color in Fig. 9B. The yellow nodes represented emerging keywords, suggesting their potential to become focal points of current research. The keywords "artificial intelligence", "machine learning", "deep learning", and "radiomics" frequently appeared over the course of the past three years (Fig. 9B).

4. Discussion

Artificial intelligence (AI) technology, which has made a name for itself in recent years, has developed quite rapidly since the 2000s and has become available in many disciplines. This development is inevitable in the fields of medicine and health. Clinical decision support systems, the determination of treatment protocols, drug research, and image processing are the most widely used and researched parts of artificial intelligence in medicine. Lung cancer, like many other cancers, is one of the leading areas where artificial intelligence is being investigated due to its high mortality rate and the importance of imaging in its diagnosis. There are many articles in the literature discussing the application of artificial intelligence in the field of lung cancer. Unlike systematic reviews, bibliometric analysis studies comprehensively analyze the current literature using diverse visualization methods to gain an intuitive understanding of the research's development pattern and indicate upcoming research areas of interest. This study utilizes bibliometric indicators to provide a comprehensive overview of publications pertaining to the application of artificial intelligence in the domain of lung cancer. The objective is to analyze the development trajectory, identify emerging research areas, and predict future research trends. In bibliometric research, VOSviewer is a commonly used bibliometric analysis and visualization application [26]. Another bibliometric tool, InCites, is a comprehensive bibliographic analysis tool developed by Clarivate that serves as a benchmarking and analysis tool that utilizes publishing data to evaluate the productivity, impact, and collaborations seen in the literature indexed in the Web of Science databases. In this study, we used the InCites application together with VOSviewer.

4.1. *General information*

Upon analyzing the literature on the application of artificial intelligence in lung cancer, it becomes apparent that the published papers and citations align with the progress of artificial intelligence. The first study on these subjects dates back to 1994. Although the study titled "Artificial Neural Networks for Early Detection and Diagnosis of Cancer" by Rogers et al. is not specific to lung cancer, it is the first study to use an artificial neural network in the field of cancer [22]. Between this period and 2003, there was a shortage of literature papers regarding the utilization of artificial intelligence in the context of lung cancer. Although there has been a relative increase in the following years, the largest increase has been recorded in the last five years, especially after 2018. Although the foundations of artificial intelligence technology are based on the ideas put forward by Alan Turing in 1950, the realization of these ideas has only been possible with the development of technology [27]. In 2017, artificial intelligence gained global recognition for the first time [28]. By using deep learning to innovate and better itself, Alpha Go Zero defeated Alpha Go [29]. In addition, Watson, an artificial intelligence developed by IBM, was able to analyze and interpret massive medical data and literature through machine learning and then create treatment plans that largely overlapped with doctors' treatment recommendations [30]. In parallel with these developments, there has been a notable rise in papers focusing on artificial intelligence in the domain of lung cancer in recent years.

China and the USA are the leading contributors to the literature on the application of artificial intelligence in lung cancer, based on the number of publications. Although China has contributed to the literature with a higher number of publications, it is seen that the publications published in the USA are more noteworthy and cited. Although the number of publications is relatively low, countries and regions such as the United Kingdom and the Netherlands are among the leading countries in this field with high citation rates.

Similarly, the institutions that have contributed most to the literature are based in China and the USA. Popular universities in China and the USA have published a lot of research on AI in lung cancer and are leading the field with high H-index values. Another prominent institution is Maastricht University in the Netherlands. The 63 articles published by Maastricht University received a total of 6422 citations (H-index 27, CI: 101.94), making the Netherlands one of the top contributing countries. When the network structure in Fig. 6 is examined, it is seen that the institutions are mostly in cooperation with institutions in the same country or region. The use of medical data in artificial intelligence studies is extremely important. Difficulties and countries' legal policies on data sharing may be one of the limitations to working together.

4.2. *Knowledge base*

From the authors' perspective, there are some minor differences in the statistics obtained from InCites and VOSviewer. One of the

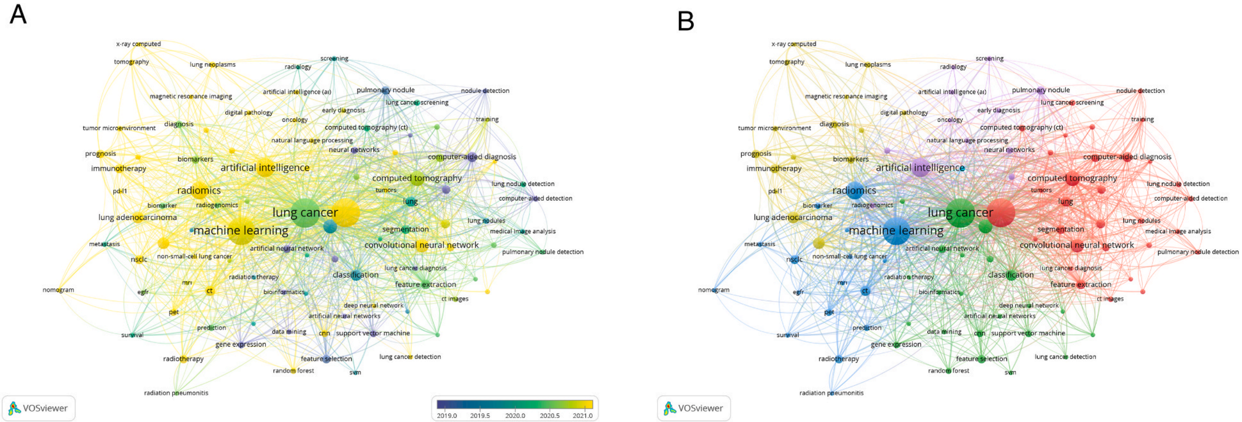

Fig. 9. Co-occurrence analysis of keywords. (A) The network visualization map of keywords. (B) Overlay visualization map of keywords.

reasons for this situation is some data loss we experienced during the analysis, as we explained in the limitations section. However, another reason is due to letter errors or misspellings in the authors' names. We think that the InCites application will give more accurate results because InCites, offered by Web of Science, matches authors with Researcher ID and ORCID, regardless of their names.

The first artificial intelligence publication of Weimin Li, the author with the most publications by number of publications, and the first publication of this author in the field of lung cancer is titled "DeepLNAnno: a Web-Based Lung Nodules Annotating System for CT Images" in 2019 [31]. This publication, which received 10 citations in total, was published in the "Journal of Medical Systems". Another "author, Aerts, Hanna", with the highest number of citations, publishes articles on radiomics. The author has published 22 papers on the application of artificial intelligence in the field of lung cancer. However, when we examine the InCites system in detail, the real name of "Aerts, Hanna", which is reported as the most cited author, is "Aerts, Hugo J. W. L." It has been determined that there are inconsistencies in author statistics, probably due to the abbreviations used. Therefore, as mentioned in the limitations section, it should be taken into consideration that the analysis of authors in bibliographic studies may be inaccurate due to typographical and abbreviation errors in author names.

Among the journals where studies on artificial intelligence in lung cancer are published, "Frontiers in Oncology" ranks first. Frontiers in Oncology, which is in the Q2 quarter, is one of the important journals with a high impact factor in this field. Frontiers in Oncology has published 155 research articles in this field. Since artificial intelligence is a subject that basically involves multidisciplinary fields of study, journals publishing in fields other than medicine also include publications on the use of artificial intelligence in lung cancer.

Similarly, according to research fields, the research fields that produce the most publications and receive the most citations are "Radiology, Nuclear Medicine & Imaging", "Oncology" and "Biomedical Engineering". When evaluated according to the Web of Science category, it is seen that the fields of artificial intelligence, oncology, radiology, biomedical science, and computer science stand out. The respiratory system research field ranks 10th with 166 publications and 3012 citations.

As a result of our research, the study titled "Computational Radiomics System to Decode the Radiographic Phenotype" on radiomics published in the journal "Cancer Research" by Van Griethuysen et al., in 2017 is the most cited study in the field of artificial intelligence in lung cancer [23]. Coudray's "Classification and mutation prediction from non-small cell lung cancer histopathology images using deep learning" study, published in Nature Medicine in 2018, ranks second [24]. The most often referenced publications on the application of artificial intelligence in lung cancer are radiomics, which entails the examination of histological and radiographic images using deep learning techniques and convolutional neural networks, as well as genetic investigations.

Artificial intelligence studies have been widely supported financially in recent years. According to the InCites analysis, 383 funding agencies supported the 1962 studies. Among the institutions that provide the most support, the USA and China are followed by the European Union, the Netherlands, the United Kingdom, and Japan. Approximately half of the supported publications were supported by the United States Department of Health & Human Services, the National Institutes of Health (NIH), the National Cancer Institute (NCI), and the National Science Foundation (NSF), all located in the USA. It is obvious that financial support for publications is related to the economic situation of countries.

Through the authors' selection of keywords, bibliometric studies can identify hot spots and trends in the field of research. Keywords such as "convolutional neural network", "deep learning", "machine learning", and "artificial neural network", which are sub-topics of artificial intelligence, are used a lot. Additionally, general keywords describing the subject, such as "cancer", "lung cancer", "lung adenocarcinoma", "non-small cell lung cancer", and so on, were also frequently used. "Radiomics" and "computed tomography" were other keywords that describe the study method and are frequently used in artificial intelligence research on lung cancer. In our study, we found that authors often prefer keywords with general usage when choosing keywords.

Based on the data provided, our bibliometric study conducted a comprehensive examination of the current state, prominent areas of research, and future directions in the field of artificial intelligence applied to lung cancer, with a particular focus on visualization. Hence, the outcomes of our bibliometric analysis might furnish a full manual for physicians and academics engaged in this domain.

Given the crucial significance of AI technology in lung cancer and its notable benefits in radiologic diagnosis, treatment, and prognosis prediction, it is unquestionable that the use of AI in this area is currently a prominent focus of research and will provide guidance to scientists in the future.

4.3. Limitations

Although bibliometric studies provide us with very important data, this bibliometric study has some limitations. First of all, we used only the SCIE and ESCI indexes of the Web of Science Core Collection in our study. Although the Web of Science Core Collection database is the most comprehensive, reliable, systematic, and administrative database in the field of medicine, it does not cover the entire literature. It is possible that more comprehensive studies that include other databases, such as Scopus, will provide more accurate results. Another issue is that the publications we included in the study are only in English. Although the majority of the publications we found as a result of the search were written in English, the exclusion of publications in local languages other than English from the study inevitably affects the results.

A more important limitation of the study is the method of examining the data obtained. The algorithms used by the applications for bibliometric analysis and the losses experienced in data export lead to contradictions in the study results. As experienced in this study, some data loss occurs when transferring data from the Web of Science searching system to InCites. Editorial and typographical errors, especially in old publications, cause confusion. It is possible to encounter different statistical results, especially in author names, due to reasons such as abbreviating author names in different ways, surname or name changes, institutional changes, and typography errors. This issue causes problems for both VOSviewer and InCites. The use of author identifiers such as ORCID in many publications in recent years will overcome this problem.

5. Conclusion

In conclusion, AI is widely used in lung cancer research, especially in the fields of radiomics, medical imaging, and diagnosis. The US and China have always been leaders in this field and will continue to be for some time to come. Studies in countries such as the Netherlands are on the rise. However, there is a need to increase the intensity of research collaboration, particularly for emerging nations, and these nations should actively continue to work closely with advanced nations like the United States and China. In order to improve the generalizability of AI deep learning, additional participants' contributions and the availability of more data sources will be crucial to the field's future progress.

Ethical approval

The data sources utilized in our analysis were obtained from a publicly accessible repository. It is important to note that our research did not involve any experiments involving human or animal participants. Approval from the ethics committee is unnecessary.

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Data availability statement

The data that support the findings of this study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

CRediT authorship contribution statement

Adem Gencer: Writing - review & editing, Writing - original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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