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REVIEW

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Mapping the landscape of Y90 radioembolisation research: a citation analysis of the top 100 papers

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Abstract

Background This study aims to identify trends, research gaps, leading journals, institutions, countries, and authors by examining the top 100 cited Yttrium-90 Radioembolization (Y90) research articles. The insights gained will assist funding and collaboration efforts in Y90 research. The team analyzed 981 articles from 36 peer-reviewed journals, gathering data on authors, publication year, journal, citations, affiliations, keywords, and references. Author affiliations were scrutinized to pinpoint institutions and countries. p values < 0.05 were deemed statistically significant.

Main body of abstract The most cited paper (703 citations) was authored by Salem et al. (2010), and the journal with the most publications (16) was Journal of Vascular and Interventional Radiology. There was no significant correlation between journal impact factor and citation metrics. A decreasing trend in the number of top 100 articles was observed since the peak period (2008–2013). Most papers were published in high-impact factor (IF > 3, n = 31/35) and SCImago Q1 journals (86/100), with Northwestern University, Clínica Universidad de Navarra, and Ludwig Maximilian University of Munich being the leading institutions. The most prolific authors were Salem, R., Lewandowski, R.J., and Mulcahy, M.F., with Salem, R. as the most influential. A statistically significant positive correlation between collaborative links and published articles was also discovered.

Short conclusion The top 100 cited articles were primarily published in high-impact journals, and Northwestern University and the USA showed greater productivity and collaboration. These findings have crucial implications for researchers, policymakers, and institutions, aiding in the improvement of Y90 application and understanding in clinical practice.

Keywords Y90 radioembolisation, Cancer, Radiation therapy, Citation analysis, Bibliometrics

Background

Yttrium-90 radioembolization (Y90) is a minimally invasive and targeted therapy that uses microspheres loaded with the beta-emitting radionuclide Yttrium-90 to selectively eradicate cancerous cells in the liver [1]. In recent years, Y90 radioembolization is a viable alternative to traditional therapies for primary liver tumors, including hepatocellular carcinoma (HCC) and intrahepatic cholangiocarcinoma (ICC) [2], and liver metastases from breast, neuroendocrine, and colorectal cancers [3]. This treatment modality is relatively well-tolerated with low morbidity and mortality rates, making it a suitable option for patients who are not eligible for

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surgery or systemic chemotherapy due to underlying medical conditions or advanced stages of their illness [4].

Understanding the scientific landscape of Y90 radioembolization is crucial due to the increasing prevalence of liver malignancies worldwide [5] and the growing demand for treatment. This study examines the top 100 most cited articles on Y90 radioembolization to offer valuable insights into the evolution, advancement, and influence of research in this field using bibliometric analysis.

Bibliometrics utilizes statistical and mathematical methods to analyze scientific publications, allowing for the identification of patterns, mapping of scientific research evolution, and assessment of research impact in a particular field [6]. In Y90 radioembolization, comprehending breakthroughs, emerging patterns, and potential future directions is vital for researchers, healthcare providers, and policymakers. Although bibliometric studies have previously been conducted in interventional radiology and oncology [7], none have focused exclusively on Y90 radioembolization.

By examining the top 100 most cited publications on Y90 radioembolization, the study aims to identify the most significant authors, institutions, countries, and journals contributing to the field. It also explores research themes and trends over time, providing insights into the development of this treatment modality and its impact on patient care. Understanding key drivers and contributors will stimulate further research and development, leading to improved patient outcomes and a higher quality of life for individuals affected by liver cancer.

Materials and methods

This retrospective bibliometric analysis did not require ethical approval as it did not involve human or animal subjects. The study aimed to examine the top 100 most cited peer-reviewed articles on Yttrium-90 Radioembolization (Y90) up until March 31st 2023, using the Web of Science database [8, 9]. Two authors conducted separate searches to reduce bias, and any disagreements were resolved by consulting a third author.

We employed various search terms using the "Topic" field in Web of Science [8], searching for terms in the title, abstract, author keywords, and Keywords Plus. The search terms were “Yttrium 90 radioembolization” OR “Yttrium-90 radioembolization” OR “Y90 radioembolization". The search was limited to "articles" and produced 981 articles with no language or keyword restrictions. The top 100 most cited articles were selected for analysis without any exclusions, using citation counts according to the Web of Science [8] CORE number.

To account for temporal bias and citation lag, we also analyzed the top 10 articles from the last five years (2019–2023) that were not already in the top 100. We used the same search criteria as before and manually excluded articles already in the top 100 most cited articles.

Bibliometric data collection involved extracting various information types, such as authors, publication year, journal, citations, affiliations, author keywords, and references. Authors’ affiliations were used to obtain information on institutions and countries, analyzed by VoxViewer [10, 11] and manually refined in Microsoft Excel [12]. Additionally, journal impact factors were obtained from the 2021 Clarivate "Journal Citation Reports" database [13] and the 2021 SCImago Journal Rank [14].

Data refinement and statistical analysis were conducted using a variety of software tools. Microsoft Excel [12] and Tableau [15] were used for data refinement, while Tableau [15], VOS Viewer [10, 11], and Web of Science [8] analysis tools were used for result visualization. R [16], specifically the Bibliometrix [17] package, was utilized for statistical analysis with the aid of Biblioshiny [18]. The Web of Science [8] dataset was uploaded to Biblioshiny [18] via R [16] for analysis.

Results

We analyzed 981 documents related to Yttrium-90 (Y90) radioembolization published from 1993 to 2023. Table 1 displays the top 20 studies along with information such as year of publication, average citations per year, journal title, JCR impact factor [13], and SCImago Journal quartile [14]. The full list of the top 100 can be found in Supplemental Table 1.

The most cited paper had 703 citations and reported long-term outcomes following Y90 radioembolization for patients with Hepatocellular carcinoma (HCC) [19]. The second and third most cited articles were [4] with 497 citations and [20] with 463 citations. The top 100 articles had a median of 108.5 citations, ranging from 69 to 703. The paper with the highest average citations per year (65.29) was published in "Lancet Oncology” [21]. The median average citations per year was 10.035, ranging from 4.18 to 65.29.

Out of the 36 journals examined, 9 had published four or more articles, accounting for 53 out of the top 100 most cited papers. Figure 1 illustrates the different journals along with citation metrics. The most prolific journal was "Journal of Vascular and Interventional Radiology" (JVIR), with 16 publications, a SCImago Quartile (Q) of Q1, and a JCR Impact Factor (IF) of 3.7. "Hepatology" had the highest number of citations, with 2201 in total, followed by JVIR with 1640. "Gastroenterology" had the highest average citations per paper, with an average of 496 citations for three papers published. Table 2 presents the detailed results. Most of the papers (86/100) were

Table 1 Top 20 most cited papers on Y90 radioembolization (ranked by descending citation count)

Rank	Article title	Publication year	Source title	JCR Impact Factor '21	SCImago Journal Quartile '21	Average citations per year	Times cited, WoS Core
1	Radioembolization for Hepatocellular Carcinoma Using Yttrium-90 Microspheres: A Comprehensive Report of Long-term Outcomes	2010	Gastroenterology	33.883	Q1	50	703
2	Recommendations for radioembolization of hepatic malignancies using yttrium-90 microsphere brachytherapy: A consensus panel report from the Radioembolization Brachytherapy Oncology Consortium	2007	International Journal Of Radiation Oncology Biology Physics	8.013	Q1	29	497
3	Survival After Yttrium-90 Resin Microsphere Radioembolization of Hepatocellular Carcinoma Across Barcelona Clinic Liver Cancer Stages: A European Evaluation	2011	Hepatology	17.298	Q1	35	463
4	Radioembolization Results in Longer Time-to-Progression and Reduced Toxicity Compared With Chemoembolization in Patients With Hepatocellular Carcinoma	2011	Gastroenterology	33.883	Q1	35	458
5	Efficacy and safety of selective internal radiotherapy with yttrium-90 resin microspheres compared with sorafenib in locally advanced and inoperable hepatocellular carcinoma (SARAH): an open-label randomised controlled phase 3 trial	2017	Lancet Oncology	54.433	Q1	65	457
6	Safety and efficacy of Y-90 radiotherapy for hepatocellular carcinoma with and without portal vein thrombosis	2008	Hepatology	17.298	Q1	27	441
7	A Comparative Analysis of Transarterial Downstaging for Hepatocellular Carcinoma: Chemoembolization Versus Radioembolization	2009	American Journal Of Transplantation	9.369	Q1	26	397
8	SIRveNIB: Selective Internal Radiation Therapy Versus Sorafenib in Asia–Pacific Patients With Hepatocellular Carcinoma	2018	Journal of Clinical Oncology	50.739	Q1	58	350
9	Yttrium-90 Radioembolization for Intermediate-Advanced Hepatocellular Carcinoma: A Phase 2 Study	2013	Hepatology	17.298	Q1	30	336
10	Y90 Radioembolization Significantly Prolongs Time to Progression Compared With Chemoembolization in Patients With Hepatocellular Carcinoma	2016	Gastroenterology	33.883	Q1	40	327
11	Radioembolization with Yttrium-90 Glass Microspheres in Hepatocellular Carcinoma: European Experience on Safety and Long-Term Survival	2010	Hepatology	17.298	Q1	22	319

Table 1 (continued)

Rank	Article title	Publication year	Source title	JCR Impact Factor '21	SCImago Journal Quartile '21	Average citations per year	Times cited, WoS Core
12	Radioembolization for unresectable neuroendocrine hepatic metastases using resin Y-90-microspheres: Early results in 148 patients	2008	American Journal of Clinical Oncology-Cancer Clinical Trials	2.787	Q2	18	296
13	Phase III Trial Comparing Protracted Intravenous Fluorouracil Infusion Alone or With Yttrium-90 Resin Microspheres Radioembolization for Liver-Limited Metastatic Colorectal Cancer Refractory to Standard Chemotherapy	2010	Journal of Clinical Oncology	50.739	Q1	18	261
14	Yttrium-90 microspheres (TheraSphere (R)) treatment of unresectable hepatocellular carcinoma: Downstaging to resection, RFA and bridge to transplantation	2006	Journal of Surgical Oncology	2.885	Q1	13	242
15	Radioembolization of liver metastases from colorectal cancer using yttrium-90 microspheres with concomitant systemic oxaliplatin, fluorouracil, and leucovorin chemotherapy	2007	Journal of Clinical Oncology	50.739	Q1	13	232
16	Liver disease induced by radioembolization of liver tumors—Description and possible risk factors	2008	Cancer	6.921	Q1	14	231
17	Partition model for estimating radiation doses from yttrium-90 microspheres in treating hepatic tumours	1996	European Journal of Nuclear medicine	3.464		8	225
18	Radioembolization with selective internal radiation microspheres for neuroendocrine liver metastases	2008	Cancer	6.921	Q1	12	201
19	Radiologic-Pathologic Correlation of Hepatocellular Carcinoma Treated with Internal Radiation Using Yttrium-90 Microspheres	2009	Hepatology	17.298	Q1	13	198
20	First-line selective internal radiotherapy plus chemotherapy versus chemotherapy alone in patients with liver metastases from colorectal cancer (FOXFIRE, SIRFLOX, and FOXFIRE-Global): a combined analysis of three multicentre, randomised, phase 3 trials	2017	Lancet Oncology	54.433	Q1	28	196

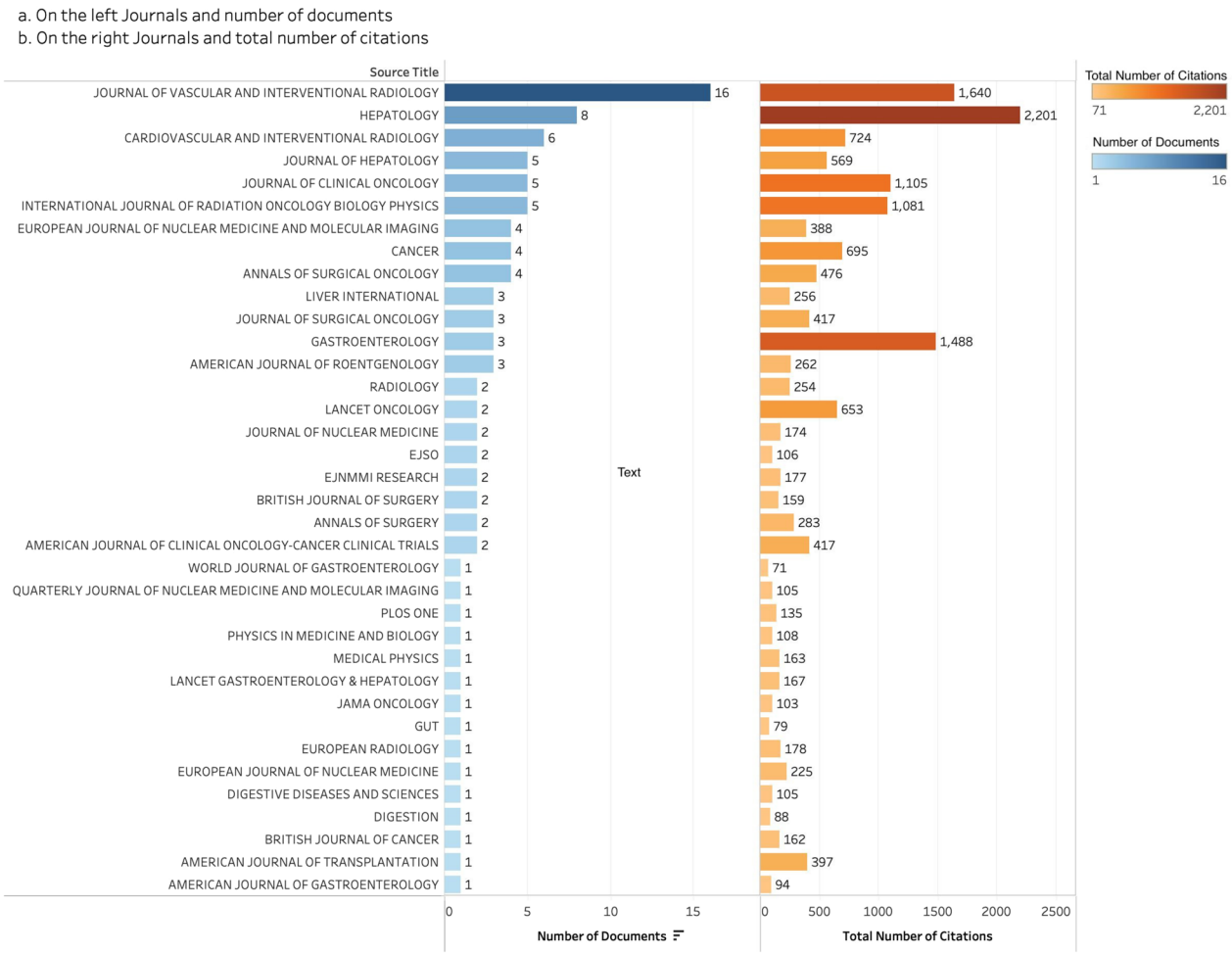

Fig. 1 Journals ranked by number of documents. **a** On the left: journal's and number of documents, **b** On the right: journals and total number of citations

published in Q1 journals, with a minority being published in Q2 (12/100) and only one in Q3.

The H-index [22] of each journal was equal to the number of articles published, since the lowest total citations (69) surpassed the highest number of articles (16) published by a single journal.

Three of the top 100 most cited articles were published in 2021 [23–25]. Figure 2 shows the distribution of articles published per year, with the most productive years being from 2008 to 2013, during which over eight articles per year achieved top 100 citation status. In the last five years (2019–2023), eight articles made it to the top 100, but none from 2022 or 2023 have achieved this status. Temporal bias and citation lag likely affect these results.

To account for temporal bias and citation lag, we analyzed the top 10 articles from the last five years (2019–2023) not already in the top 100. The results can be found in Supplemental Table 2.

All of these articles had an average citation rate per year of 5.8 or more [26, 27]. The "European Journal of Nuclear and Molecular Imaging" published three of the top 10 articles [26, 28, 29], highlighting its recent productive contribution to the field. While this suggests that these articles may enter the top 100 list, it's important to remember that citation rates can fluctuate over time [4].

For the top 100 most cited articles, the journal with the highest impact factor was "Lancet Oncology," with an IF of 54.433 and an average of 326 citations per paper[13] (see Table 2).

We found no significant correlation between impact factor and average citations per article ($r^2 = 0.14$, $p = 0.02$), total citations ($r^2 = 0.05$, $p = 0.18$), and number of articles published ($r^2 = 0.0005$, $p = 0.89$), using a p-value of < 0.05 as the threshold for statistical significance (Fig. 3) [30–32].

Table 2 Journals ranked by JCR impact factor

Rank	JCR Impact Factor '21	Source Title	SCImago Journal Quartile '21	Average Citations per Paper	Number of Documents	Total Number of Citations
1	54.433	Lancet Oncology	Q1	326	2	653
2	50.739	Journal Of Clinical Oncology	Q1	221	5	1105
3	45.042	Lancet Gastroenterology & Hepatology	Q1	167	1	167
4	33.883	Gastroenterology	Q1	496	3	1488
5	33.012	Jama Oncology	Q1	103	1	103
6	31.795	Gut	Q1	79	1	79
7	30.083	Journal of Hepatology	Q1	113	5	569
8	29.146	Radiology	Q1	127	2	254
9	17.298	Hepatology	Q1	275	8	2201
10	13.787	Annals of Surgery	Q1	141	2	283
11	12.045	American Journal of Gastroenterology	Q1	94	1	94
12	11.782	British Journal of Surgery	Q1	79	2	159
13	11.082	Journal of Nuclear Medicine	Q1	87	2	174
14	10.057	European Journal of Nuclear Medicine and Molecular Imaging	Q1	97	4	388
15	9.369	American Journal of Transplantation	Q1	397	1	397
16	9.082	British Journal of Cancer	Q1	162	1	162
17	8.754	Liver International	Q1	85	3	256
18	8.013	International Journal of Radiation oncology Biology Physics	Q1	216	5	1081
19	7.034	European Radiology	Q1	178	1	178
20	6.921	Cancer	Q1	173	4	695
21	6.582	American Journal of Roentgenology	Q1	87	3	262
22	5.374	World Journal of Gastroenterology	Q1	71	1	71
23	4.506	Medical Physics	Q1	163	1	163
24	4.339	Annals of Surgical Oncology	Q1	119	4	476
25	4.174	Physics in Medicine and Biology	Q1	108	1	108
26	4.037	EJSO	Q1	53	2	106
27	3.752	Plos ONE	Q1	135	1	135
28	3.682	Journal of Vascular and Interventional Radiology	Q1	102	16	1640
29	3.672	Digestion	Q2	88	1	88
30	3.487	Digestive Diseases and Sciences	Q2	105	1	105
31	3.464	European Journal OF Nuclear Medicine		225	1	225
32	3.434	EJNMMI research	Q2	88	2	177
33	2.885	Journal of Surgical Oncology	Q1	139	3	417
34	2.797	Cardiovascular and Interventional Radiology	Q2	120	6	724
35	2.787	American Journal of Clinical oncology-cancer Clinical Trials	Q2	208	2	417
36	1.56	Quarterly Journal of Nuclear Medicine and Molecular Imaging	Q3	105	1	105

We categorized journals into five groups: Radiology, Gastroenterology & Hepatology, Oncology, Surgery, and Other. Radiology journals published the most papers (40) across 12 journals, resulting in 4398 citations. Gastroenterology & Hepatology journals had the highest total citations at 5118, with 25 articles across eight journals. Oncology journals were the third most significant in terms of total articles and citations, with 20 articles across seven journals and 4216 citations. When considering average citations per article, Gastroenterology & Hepatology journals ranked highest with an average of 639.79, followed by Oncology (602.28), Radiology (366.5), and Surgery (306).

We used box and whisker plots (Fig. 4) to visualize the distribution of published articles and citations received by journal category.

Radiology had the highest average number of articles per journal, with an Interquartile Range (IQR) ranging from 1 to 3.5 articles. JVIR was an outlier, having published 16 articles. In Gastroenterology & Hepatology,

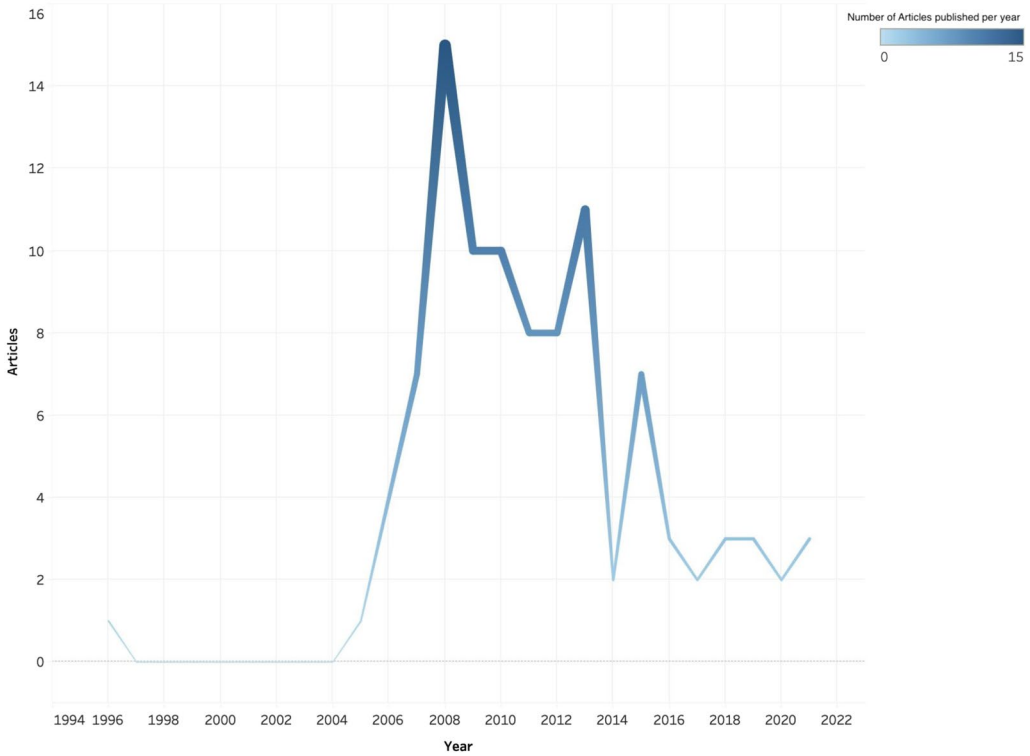

Fig. 2 Number of articles publisher per year

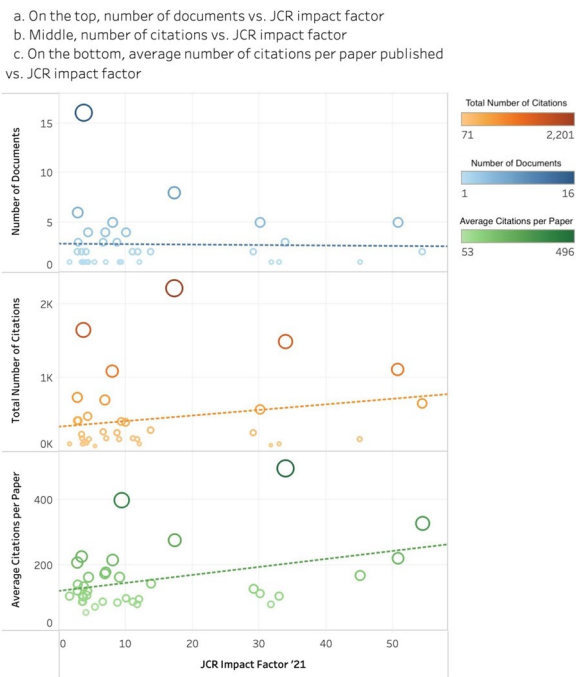

Fig. 3 Scatter plots. **a** On the top, number of documents versus JCR impact factor, **b** Middle, number of citations versus JCR impact factor, **c** On the bottom, average number of citations per paper published versus JCR impact factor

IQR ranged from 1 to 3 articles per journal with "Hepatology" as an outlier having published 8 articles. Oncology had an IQR spanning 1.5–4.5 articles with no outliers.

Oncology journals had the highest average citations per paper at 201. Gastroenterology and Hepatology journals averaged 157 citations per paper, with an IQR of 88 to 569. Two outliers in this category were "Gastroenterology" (1488 citations) and "Hepatology" (2201 citations). Surgery journals had an average of 155 citations per paper. Radiology journals had the lowest average citations per article (124) and an IQR of 168.5 to 325, with two significant outliers: "Cardiovascular and Interventional Radiology" (724 citations) and "Radiology" (1640 citations).

We found that 130 institutions contributed to the authorship of the top 100 most cited papers on Y90 radioembolization. Among these, 36 institutions contributed to three or more papers (Supplemental Fig. 1). Northwestern University had the highest number of documents (39) and total citations (7188), followed by Clínica Universidad de Navarra (CUN) with 13 documents and 2392 citations. The University of Illinois had the highest average citations per paper (251.5) for their four articles. Northwestern University had a relatively

a. Top: Subject of journal vs. number of documents published
b. Bottom: Subject of journal vs. total number of citations

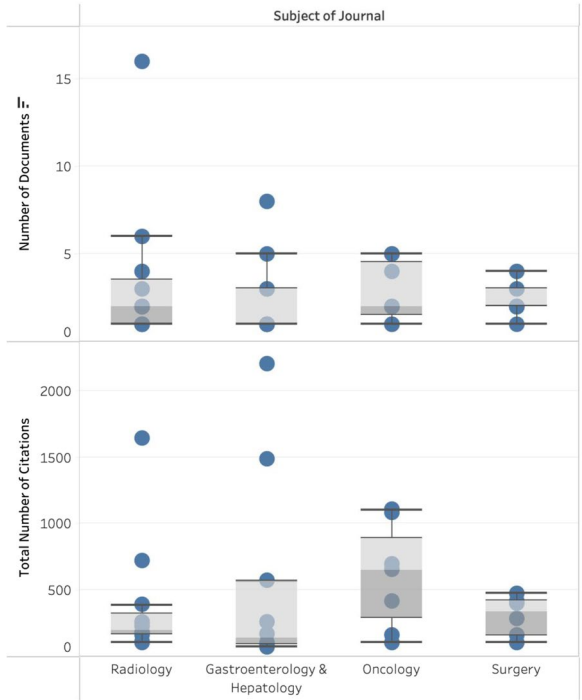

Fig. 4 Box and Whisker plots. **a** Top: subject of journal versus number of documents published. **b** Bottom: subject of journal versus total number of citations

high average citations per paper of 184.3 for their 39 articles.

In this study, we used Links and Link Strength to assess collaboration. Links represent connections based on co-occurrence, while Link Strength indicates the connection's weight determined by co-occurrence frequency. These metrics help identify important patterns and connections within the data.

Northwestern University had the highest number of links (n = 64) with a link strength of 103. Clínica Universidad de Navarra (CUN) had the second-highest number of links (n = 61) with a link strength of 92. Figure 5 provides a visual representation of the collaboration network.

Our study categorized institutions into distinct clusters to investigate patterns of collaboration in Y90 research. Geographical location played a significant role in collaboration. East Asian and Oceanian universities dominated Cluster 1, while Cluster 2 was mainly composed of German universities. French universities were grouped in Cluster 3, while British universities formed Cluster 4. Italian universities were primarily included in Cluster 6. Clusters 5, 8, and 11 were predominantly composed of American institutions, while Cluster 7 exhibited a mix of European universities from various countries, such as Spain, Germany, Italy, and The Netherlands. Cluster 9 and 10 included a combination of European and American institutions, with "University of Hong Kong" also included in the mix. (See Table 3 for details).

Sixteen countries authored at least two documents among the top 100 most cited on Y90 (Table 4). The United States was the most prolific contributor with 55 articles, followed by Germany (22), Australia (15), Spain (15), France (13), and Italy (12). These countries also had the highest total citation counts, with the United States having the highest at 9356, followed by Germany (3290) and Spain (2709) (Fig. 6).

Taiwan had the highest average citations per paper at 254, based on two papers. The United States had an average of 170 citations per paper, Germany 150, and Spain 181. The United States ranked fifth in terms of total links (20) despite contributing the most articles (55). Australia was the most collaborative country (26 links), followed

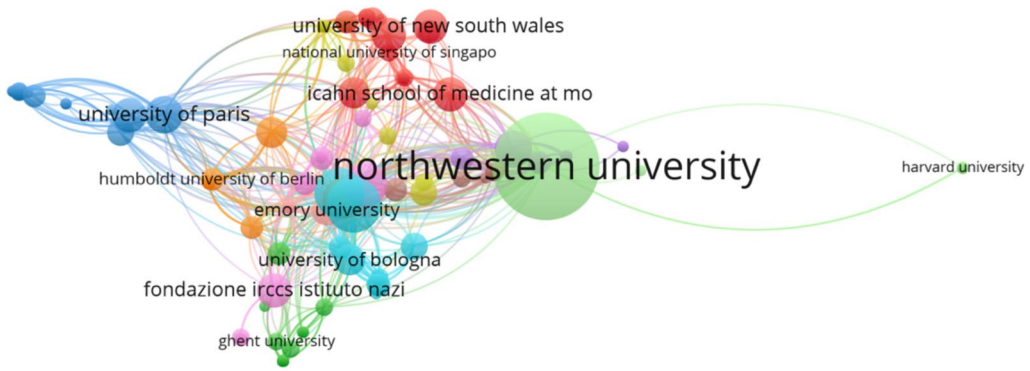

Fig. 5 Collaboration network of institutions

Table 3 Institutions divided into collaboration clusters with relative links and link strength

Cluster	Institution	Link strength	Links
1	Duke-NUS medical school	40	32
1	University of Sydney	34	30
1	Icahn school of medicine at Mount Sinai	35	27
1	University of Western Australia	22	18
1	National University of Singapore (NUS)	16	15
1	Chinese University of Hong Kong (CUHK)	11	11
1	Korea University	11	11
1	National Yang-Ming University	11	11
1	North Carolina State University	11	11
1	University of Melbourne	13	9
1	Sirtex Medical Limited	7	6
1	ASTAR (agency for science, technology and research)	9	5
1	Leiden University	9	5
1	University of Adelaide	4	4
1	University of Leicester	4	4
1	University of New South Wales (UNSW)	5	4
2	Universite Libre de Bruxelles (ULB)	23	22
2	The Institute of Cancer Research, London	17	17
2	University of Basel	15	15
2	Ghent University	12	12
2	Claude Bernard University Lyon 1	9	9
2	Erasmus University	9	9
2	European Institute of Oncology (IEO)	9	9
2	Lund University	9	9
2	Maastricht University	9	9
2	University of ULM	9	9
2	Medical Eniversity of Vienna	6	6
2	Technical University of Dresden (TU Dresden)	6	6
2	University of Heidelberg	6	6
2	Institut Jules Bordet	3	3
3	University of Paris	66	50
3	Institut National de la Sante et de la Recherche medicale (INSERM)	35	30
3	Universite de Rennes 1	23	19
3	University Paris-EST Cržteil Val-de-Marne (UPEC)	19	12
3	University of Lorraine	14	10
3	University of Montpellier	14	10
3	University of Poitiers	14	10
3	Aix-Marseille University	8	8
3	Paoli-Calmettes Institute	8	8
3	University of Angers	8	8
3	University of Nantes	6	6
3	Institute of Nutrition, Metabolism, and Cancer	5	5
3	Montpellier University	5	5
3	French National Cancer Institute (INCA)	1	1
4	University of Oxford	17	16
4	University of Cambridge	15	15
4	Imperial College London	13	13
4	Pennsylvania state university	13	13
4	University College London (UCL)	13	13

Table 3 (continued)

Cluster	Institution	Link strength	Links
4	University of Antwerp	13	13
4	University of Auckland	13	13
4	University of Cardiff	13	13
4	University of Nottingham	13	13
4	University of Alberta	10	10
4	University of Washington	11	10
4	University of Illinois (UIUC)	12	9
4	St. George's university (SGU)	2	2
5	University of North Carolina	56	39
5	Oakland University William Beaumont School of Medicine	26	22
5	University of Maryland	25	22
5	UCLA	22	20
5	Kaiser Permanente	10	10
5	Loyola University Chicago	10	10
5	National Institute of Standards and Technology (NIST)	10	10
5	Uniformed Services University of the Health Sciences (USUHS)	10	10
5	University of Wisconsin	10	10
5	Vanderbilt University	10	10
5	Oregon Health & Science University (OHSU)	3	3
5	St Vincents Med Ctr	3	3
6	Clinica Universidad de Navarra	92	61
6	Ludwig Maximilian University of Munich (LMU)	67	49
6	University of Bologna	40	28
6	Ospedale Santa Maria Goretti	37	27
6	University of Bonn	25	18
6	ifo regina elena national cancer institute	20	11
6	University of Udine	20	11
6	Catholic University of the Sacred Heart	17	10
6	National Cancer Institute "Pascale Foundation"	9	9
6	National Cancer Institute "Giovanni Paolo II"	8	8
6	Fondazione Irccs Istituto Nazionale Tumori Regina Elena	3	3
7	Centro de Investigacion Biomedica en Red (CIBER)	76	56
7	Otto Von Guericke University Magdeburg	47	39
7	Katholieke Universiteit Leuven	35	30
7	Free University of Berlin	12	12
7	Humboldt University of Berlin	14	12
7	Medical University of Graz	12	12
7	Universita Cattolica del Sacro Cuore	12	12
7	University of Amsterdam	12	12
7	University of Ljubljana	12	12
7	University of Pisa	12	12
8	Yale University	37	33
8	Ohio State University	23	20
8	Banner Good Samaritan Medical Center	23	18
8	University of California, San Diego (UCSD)	23	18
8	University of Colorado	23	18
8	duke University	15	15
8	Goshen Medical Center	15	15
8	University of Texas at Dallas	15	15

Table 3 (continued)

Cluster	Institution	Link strength	Links
8	Texas State University	8	8
9	MD Anderson Cancer Center	50	39
9	Fondazione IRCCS Istituto Nazionale dei Tumori (national cancer institute)	41	37
9	Stanford University	29	26
9	University of Hong Kong	20	19
9	The Christie	9	9
9	University of Miami	9	9
9	University of Utrecht	9	9
9	La Sapienza UNIVERSITY Of Rome	2	2
9	university of Milan	3	2
10	Emory University	21	21
10	Netherlands Cancer Institute (NKI)	20	20
10	Sarah Cannon Research Institute (SCRI)	20	20
10	Technical University of Munich (tum)	20	20
10	University of British Columbia	20	20
10	University of Lausanne	20	20
10	Thomas Jefferson University	2	2
11	Northwestern University	103	64
11	Harvard University	4	4
11	Johns hopkins University	4	4
11	Memorial Sloan Kettering Cancer Center	4	4
11	University of Pittsburgh	4	4
11	Evanston Hospital	1	1

by South Korea, Germany, France, Spain, Singapore, and Belgium. Germany had the highest link strength (63), followed by the United States, Spain, and France. Egypt and Grenada had one and two collaborative links, respectively (Table 4).

Table 4 Countries ranked by number of Citations (included those with > / + 2 articles)

Rank	Country	Articles	Citations	Average citations per paper	Link strength	Links
1	USA	55	9356	170.1091	59	20
2	Germany	22	3290	149.5455	63	22
3	Spain	15	2709	180.6	48	26
4	Australia	15	2254	150.2667	54	21
5	France	13	1923	147.9231	54	22
6	Italy	12	1906	158.8333	45	19
7	England	7	1410	201.4286	49	21
8	Belgium	8	1257	157.125	32	15
9	Netherlands	8	940	117.5	37	19
10	Canada	4	836	209	30	21
11	Singapore	6	835	139.1667	26	16
12	New Zealand	3	703	234.3333	29	23
13	South Korea	3	667	222.3333	25	19
14	Taiwan	2	507	253.5	18	11
15	Switzerland	3	320	106.6667	17	14
16	China	2	232	116	11	10

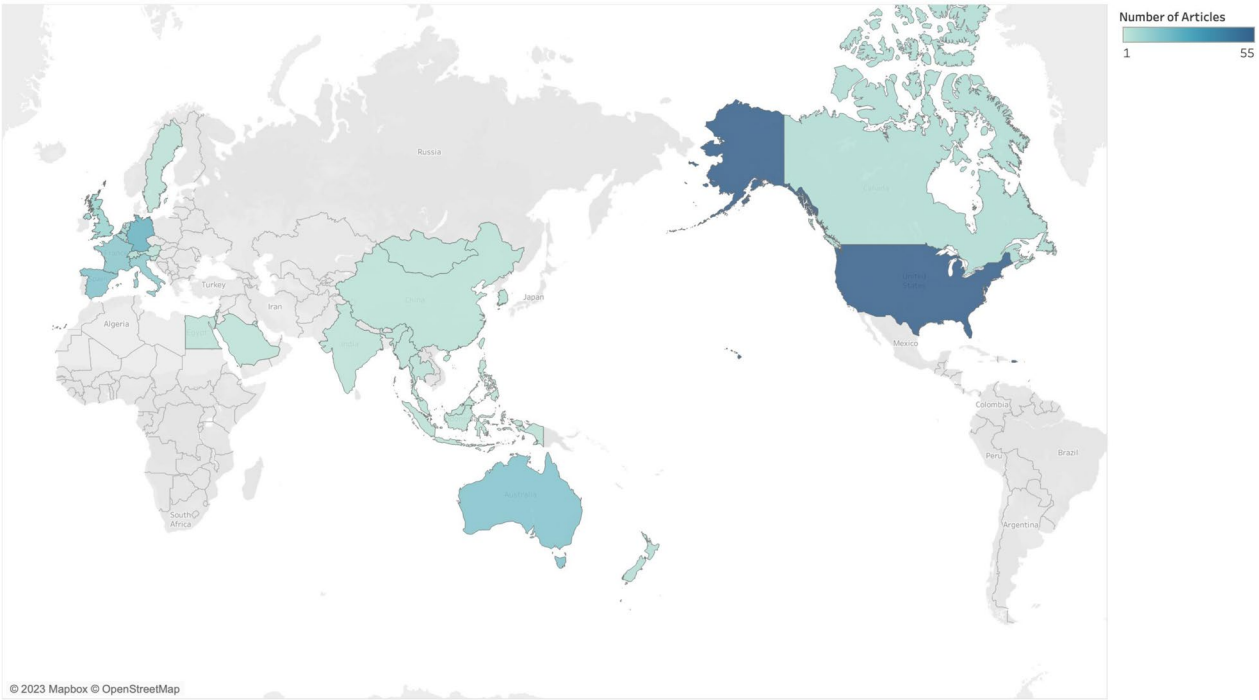

Fig. 6 World map with colour gradient indicating number of articles published

a. Authors vs. number of articles published
b. Authors vs. total number of citations
c. Authors vs. average citations per paper

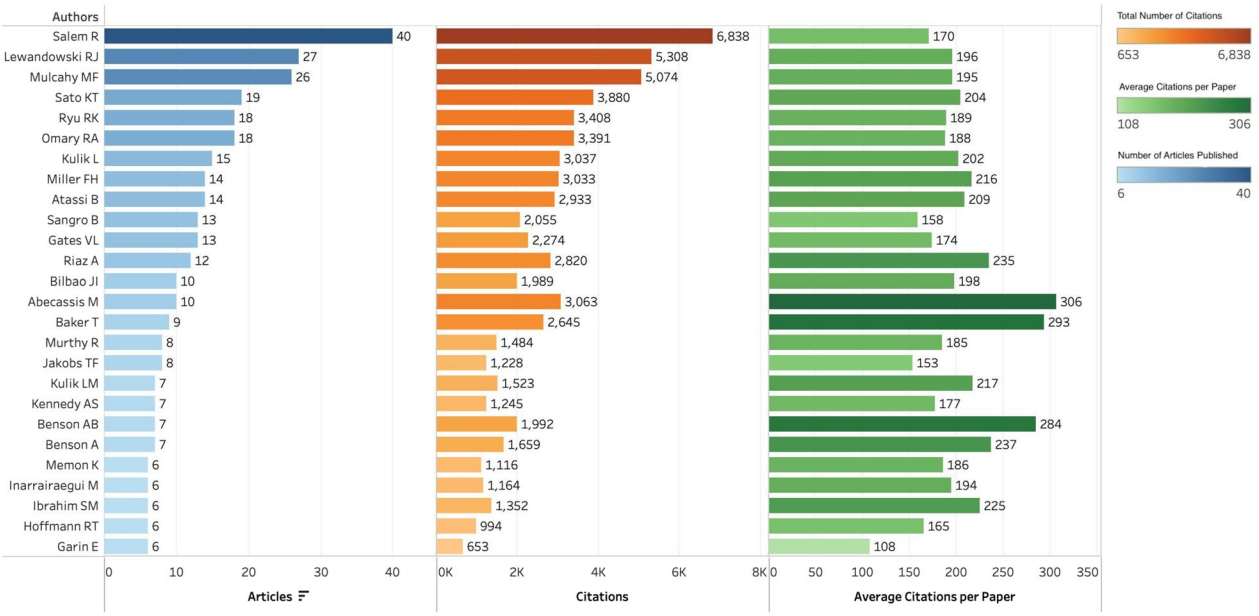

Fig. 7 Bar chart ranked by number of articles published by each author (including authors with >/=6 articles). **a** Authors versus number of published, **b** authors versus total number of citations, **c** Authors versus average citations per paper

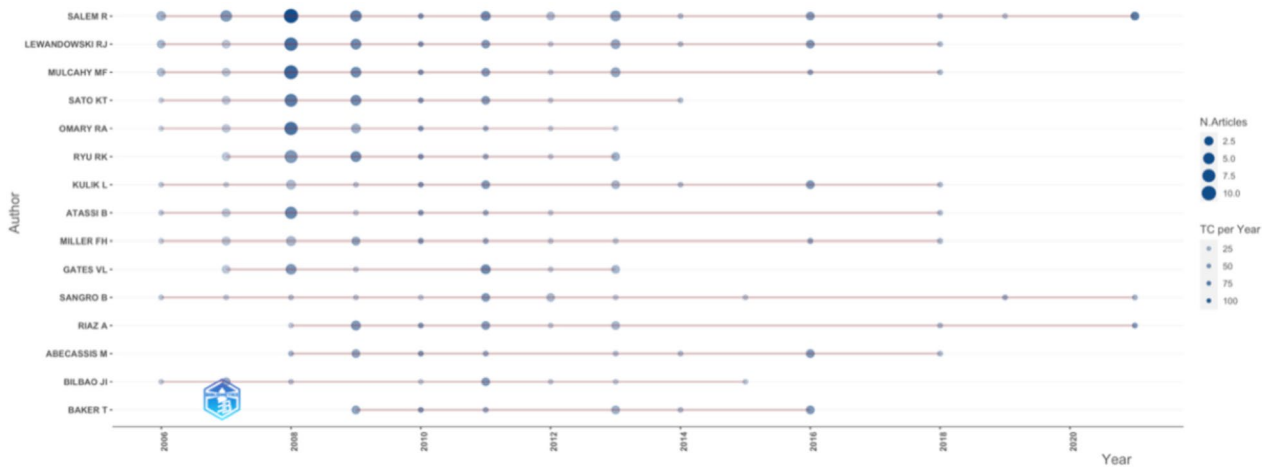

Fig. 8 Author production over time (top 15)

Salem, R. emerged as the most prolific author with 40 articles, 6838 citations, and an average of 170 citations per paper. Lewandowski, R.J. and Mulachy, M.F. were also notable contributors. Abecassis, M. had the highest average citations per paper (306) among ten documents. Figure 7 shows data for the 26 authors who published six or more articles, including the number of articles, citations, and average citations per paper.

Fractional authorship was used to assess the authors' relative importance based on their contributions. Salem, R. had the highest fractionalized authorship score of 3.1/100, with Mulcahy, M.F. and Lewandowski, R.J. also exhibiting significant contributions.

Seven of the top 10 most productive authors, including the top four, were affiliated with Northwestern University. The remaining three were associated with USC, University of Zurich, and CUN.

We analyzed the citation data of the top 100 publications to determine the frequency with which authors were referenced by other publications in the top 100. Salem, R. was the most commonly referenced author with 252 citations. Lewandowski, R.J. and Mulcahy, M.F. followed with 186 and 163 citations, respectively.

The analysis of author productivity over time in the field of Y90 radioembolization reveals a decline in high-citation research output since 2013 (Fig. 2). This is likely influenced by citation lag but may also signify waning interest, challenges in innovation, or shifting research priorities. Salem, R. has maintained a consistent pattern of publication, with recent articles [23, 25] entering the top 100 most cited publications in the field (Fig. 8).

The most productive year was 2008, with 15 articles being published on Y90 radioembolization that are in the top 100 most cited. Many authors published over five articles that year, primarily due to collaboration on seminal articles that have become heavily cited over time [33–37].

Five authors had 25 links: Salem, R., Lewandowski, R.J., Mulcahy, M.F., Sato, K., and Gates, V.L., all affiliated with Northwestern University. Salem, R. had the highest link strength (240), followed by Mulcahy, M.F. (206) and Lewandowski, R.J. (201).

Furthermore, our analysis found a positive correlation between the number of links and the number of articles published by individual authors ($r^2 = 0.4$, $p = 0.0008$), suggesting that collaboration is likely to be associated with increased publication output. This finding is intuitive, as collaboration can increase overall output by expanding capacity to do work.

Discussion

Our bibliometric analysis of publication records and citation metrics provides valuable insights into the field of Yttrium-90 radioembolization. By identifying research hubs and leading voices, our analysis can aid in directing funding and collaboration efforts.

The most cited study [19] significantly contributed to understanding Yttrium-90 radioembolization's long term efficacy in treating hepatocellular carcinoma (HCC). Its high citation rate indicates that it serves as a valuable reference for researchers and practitioners.

Nine journals accounting for 53 of the top 100 most cited articles, with JVIR, "Hepatology," and "Gastroenterology" making substantial contributions. Radiology journals had the highest number of published papers, while Gastroenterology & Hepatology journals had the highest total citations. This information can help researchers and institutions prioritize their reading and submission efforts to the most influential information sources in Yttrium-90 microsphere research.

As we demonstrated journal impact factors and no direct correlation with citation metrics and each has different relevance based on the circumstance [38, 39]. Thus a journal's impact factor alone is not a reliable indicator of scientific impact or exposure of articles, necessitating additional metrics and tools for a comprehensive evaluation of research quality and impact [38].

As shown by the high average yearly citation rates of recently published articles (2019–2023), Y90 research quality strong, requiring more time to overcome citation lag and be more widely recognised. These insights into temporal bias and trends enable stakeholders to allocate resources more effectively and support the continued advancement of this vital cancer treatment area.

Northwestern University, Clínica Universidad de Navarra, and Ludwig Maximilian University of Munich are highly productive in Y90 radioembolization research, indicating strong research environments, robust funding, and access to cutting-edge resources. Identifying such institutions helps researchers, funders, and policymakers understand key players and their contributions. For Y90 radioembolization researchers, these findings can guide institution selection for employment, collaboration, or training opportunities [40].

Geographical location plays a significant role in determining collaboration patterns among institutions, with the majority of collaborative clusters in Y90 radioembolization research being regionally focused [41, 42]. In the future, researchers in one cluster could collaborate with those in another cluster to share resources, expertise, and data, leading to new research projects and knowledge advancement [43].

We also found that language is a vital consideration in collaborations. This could pose a challenge to collaboration, as language barriers may impede communication and limit the flow of information. Future research could investigate the impact of language on collaborations and identify strategies to overcome language barriers to facilitate collaborations across borders [40].

The United States is the most prolific contributor to Y90 radioembolization research, with a high number of authored articles and overall citation count. The strong academic focus of the USA can be attributed to the country's well-funded institutions and renowned universities [44].

Collaboration among authors, particularly those affiliated with Northwestern University, highlights the importance of establishing strong professional connections and working together on research projects in the field of Y90 radioembolization. The united dedication of Salem, R., Lewandowski, R.J., Mulcahy, M.F., Sato, K.T., and Kulik, L. resulted in remarkable research output, with 16 co-authored articles [19, 33, 45], receiving a total of 2030 citations (excluding self-citations). The authors' strong collaboration ties and high link strength emphasize the significance of promoting intra-institutional collaboration to facilitate high-impact research.

Encouraging collaboration among researchers, both within and across institutions, could lead to groundbreaking findings, driving innovation and advancements in the field of Y90 radioembolization. The significant positive correlation between the number of links and published articles highlights the critical role of collaboration in increasing research output, making this finding valuable for researchers seeking to maximize their impact and contribute effectively to their field.

Conclusions

In conclusion, this comprehensive bibliometric analysis of the top 100 cited articles in Yttrium-90 Radioembolization (Y90) research provides critical insights into the evolution, advancement, and influence of research within this domain. Key findings indicate that most impactful studies have been published in high-impact journals, with significant contributions from leading institutions like Northwestern University. Despite no significant correlation between journal impact factors and citation metrics, the clustering of citations in specific journals highlights the need for strategic targeting when disseminating research outputs. Additionally, the correlation between collaborative links and publication productivity underscores the importance of collaboration in driving impactful research. These insights are not only vital for researchers and institutions in aligning their efforts towards impactful studies but also for policymakers and funders in prioritizing support for areas yielding high collaboration and citation impacts. Thus, the study aids in refining strategies for future research directions, funding allocations, and institutional collaborations, ultimately enhancing the application and understanding of Y90 treatments in clinical settings.

Limitations

Bibliometric analyses face accuracy and reliability limitations due to factors such as temporal bias, citation lag, self-citation, preferential citation practices, and citation cartels, which can influence article rankings. The study's focus on the Web of Science database, which prioritizes English publications, may introduce biases. Finally, although the study acknowledges language's role in collaboration patterns, the study does not explore strategies for facilitating cross-border collaborations or address inherent limitations, which could be a focus for future research.

Abbreviations

Y90	Yttrium-90 radioembolisation
TARE	Trans-arterial radioembolization
HCC	Hepatocellular carcinoma
ICC	Intrahepatic cholangiocarcinoma
JVIR	Journal of vascular and interventional radiology
IQR	Interquartile range

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

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The authors declare that they had full access to all of the data in this study and the authors take complete responsibility for the integrity of the data and the accuracy of the data analysis.

Author contributions
Hassan Mahmood: Conceptualisation, Methodology, Software, Formal analysis, Investigation, Writing—Original Draft, Visualisation, Supervision. Avinash Deshwal: Validation, Investigation, Writing—Review & Editing. Aleena Khalid: Software, Formal analysis, Visualisation. Ethel Mc Manus: Validation, Investigation, Writing—Review & Editing.

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The dataset(s) supporting the conclusions of this article is(are) is available in data repositories.

Declarations

Ethics approval and consent to participate
No ethics approval was required as this was a bibliometric study based on previously published literature. No subjects were involved in the study this no consent was required.

Consent for publication
Not applicable.

Competing of interest
The authors declare that they have no competing interests to this work.

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