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Original Research

Global Research Landscape and Intellectual Structure of Boron Neutron Capture Therapy Research: A Review Based on Scientometric Tools

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Abstract

Boron Neutron Capture Therapy (BNCT) is a non-invasive therapeutic technique for treating invasive malignant tumors. A tremendous amount of research is published in this area every year, and it needs to be analyzed and evaluated to measure the growth and trends of the research. This study aimed to visualize the global research landscape on BNCT based on the WoS database. This study applies co-citation and cluster analyses as a common scientometric approach to analyze the growth of research and trends in the field. Data was collected from the Web of Science database as indexed from 1980- 2021; 3639 records were retrieved. PreMap, UCINET, and NetDraw software packages were used for data visualization. As the most productive countries, the USA and Japan were in the top ranks, respectively. As the most influential researcher, BARTH, ROLF F, With the degree centrality SAKURAI, YOSHINORI, and in-betweenness centrality, MIYATAKE, SHIN-ICHI ranked first. The co-citation network of papers in the field depicted three main clusters: treatment, physics, and measurement. Social network analyses and the quality of links among papers in neutron therapy can be helpful in different aspects. Co-citation analysis depicts the internal structure of the field and helps in understanding the nature of relations among the scientometric entities. The study concludes by indicating the limitations of the present study and suggesting future research direction in the field. The results of this study may help policy-makers, researchers, practitioners, and other key stakeholders in the field.

Keywords: Scientometrics, Citation Analysis, Neutron Therapy, Boron Neutron Capture Therapy (BNCT), Research Policy, Intellectual Structure.

Introduction

The burden of oral cancer is increasing day by day. The mainstream treatment modalities for cancer are surgery, chemotherapy, and radiotherapy. Surgical annihilation is highly efficient in primary tumors but limited to surgically sizeable and approachable tumors. Therefore, cancer cells may not be completely evacuated. Chemotherapy is the use of chemical drugs to fight cancer. The systemically administrated drugs circulate in the body to kill cells that divide rapidly, especially cancer cells. It commonly has significant side effects due to drug toxicity to normal cells and is subject to the development of resistance by the cancer cells. Radiation utilizes high-energy ionization particles like X-rays, gamma rays, or electrons to damage cells at the molecular level. It is often used as an integral approach to exterminating remaining cancer cells after surgery. However, it can destroy the lively/healthy tissues neighboring the cancer cells or in the lane of a radiation beam (Nedunchezhian, Aswath, Thiruppathy & Thirugnanamurthy, 2016). Radiation therapy's role in cancer treatment is widely recognized, and radiation therapy is required in at least 50% of cancer patients (Kageji, Nagahiro, Mizobuchi, Matsuzaki, Nakagawa & Kumada, 2014). Although radiotherapy has long been considered a local treatment, it will likely lead to severe complications, especially in patients with recurrent cancer, making the symptoms more complex and challenging to cure. With the development of biological and physical technologies, researchers have developed several new approaches that may be used to solve these problems. One is Boron Neutron Capture Therapy (BNCT), a technology based on boron nuclear reactions (Wang, Zhang, Miao & Li, 2022).

BNCT is a technique that selectively aims to treat tumor cells sparring the normal cells using the Boron compound. Gordon Locher was the first to propose the principle of BNCT in 1936. He hypothesized that a higher radiation dose to the tumor relative to adjacent normal tissue would be produced if boron could be selectively concentrated in a tumor mass and the volume then exposed to thermal neutrons (Nedunchezhian et al., 2016). BNCT is a non-invasive therapeutic technique for treating invasive malignant tumors. It uses neutrons to generate energetic alpha particles to destroy cells within the tumor but not in the surrounding tissue. Recent breakthroughs in accelerator technologies enable broader use of this targeted technique. The unique outstanding feature of BNCT is its ability to deposit an immense dose gradient between the tumor and normal cells (Suzuki et al., 2014). This is the rationale for its clinical implementation in treating malignant cells, thus sparing normal healthy cells (Nedunchezhian et al., 2016). BNCT is a selective biological targeted nuclide technique for cancer therapy. It has the following attractive features: good targeting, high effectiveness, and it causes slight damage to surrounding healthy tissue compared with other traditional methods. It has been considered one of the promising methods for treating various cancers. Measuring 10B concentrations is vital for BNCT (Dai, Yang, Bao, Chen, Han & Wei, 2022). Another reason for the renewed interest in BNCT is a recent technological breakthrough in the compact accelerator-based production of neutrons, which allows the installation of accelerators in hospitals and cancer research centers. Just a decade ago, BNCT typically had to be performed in research reactors capable of offering the required intensity and quality of neutron beams for the irradiation of patients. Having to go to an irradiation facility, such as a research rector, negatively impacted public acceptance of this therapy. Thanks to recent developments in accelerator technology and accelerator-based neutron production options, patients can now undergo BNCT in a hospital environment, just like in more conventional therapies (Peeva, 2022). BNCT is a treatment method that combines nuclear physics, chemistry, biology, medicine, and other disciplines (He et al., 2021).

Annually, most research output is published in many document types worldwide and indexed in major indexing and abstracting databases. This output should be analyzed and evaluated for budgeting, policy-making, and granting, as well as detecting possible strengths and weaknesses in research. Evaluative bibliometrics and consequent scientometrics continuously develop their theories, tools, and procedures for better depicting, comparing, and evaluating research and scientific output in different fields based on normalized and standardized indicators and considering possible differences among scientific fields and mapping the structure of scientific fields results in detecting their trends, newly-emerged and ever-superseded fields, and providing a road map for researchers and future research. Science maps can depict associated concepts as symbols for picturing nature, associations, and structures in the scientific world. In scientific visualization, researchers explore invisible and abstract scientific relations and represent them graphically and their multidimensionality as scientific maps (Assefa & Rorissa, 2013). They help detect research fields in a discipline and their relations to big data collection, as well as being helpful in scientific policy-making by determining factual scientific indicators (Van Eck & Waltman, (2007).

Researchers can use scientific maps to monitor, represent, and analyze science (Kay, Newman, Youtie, Porter & Rafols, 2014). They depict knowledge structure by representing the relative placement of scientific items (Small, 1999) by conducting, for example, author co-citation and word co-occurrence analyses. This study applies co-citation and cluster analyses as a common scientometric approach to representing the associations between authors, journals, keywords, etc. Co-citation and cluster analyses based on scientometrics provide objective and quantitative methods for identifying particular fields' core knowledge and academic communities. Author co-citation analysis helps understand a field's intellectual structure (Liu, Li, Shen, Yang & Luo, 2018). The citation represents a link between a source at hand and sources cited. By detecting co-cited works, co-cited authors can be identified. Paper co-citation analysis seeks conceptual relations between co-cited papers and related items (Wang, Chen, Rogers, Ellram & Grawe, 2017). This study was analyzed objectively to map the global research trends on BNCT and provide precise information regarding the research growth, performance measurement of authors and countries, and intellectual structure of the research publications.

Based on the authors' knowledge, the present study is the first research evaluation using the Scientometric tool in BNCT research. The result will benefit practitioners, policy planners, decision-makers, and other key stakeholders in the field.

Objectives

This study aimed to represent the scientific map of global research on neutron therapy indexed in the Web of Science (WoS) from 1980 to 2021 by measuring the growth trend of publications, identifying highly productive contributing countries and highly influential authors based on their total citations and co-citation counts, and clustering active researchers.

Materials and Methods

This study employed the standard Scientometric tools to evaluate the research growth, trends, and intellectual structure of the research publications on BNCT. The scientometric method and its tools are appropriate for measuring research growth and trends through performance measurement and scientific mapping techniques (Basumaary, Verma & Verma, 2023). The parameters of analysis in this study are based on the year-wise growth of publications, co-citation, contributing countries, and the most influential authors who contributed to the BNCT research. The research population included all papers in the neutron therapy field indexed in the Web of Science (WoS) from 1st January 1980 to 20th May 2021. WoS-based scientometric indicators are leading indicators in dedicating research grants and budgets for universities and research institutes worldwide. They are applied as criteria for ranking countries, universities, and research institutes worldwide (Khasseh, Soosaraei & Fakhar, 2016). A search query was defined without any language and document type limitations in the studied period and conducted in the topic field of WoS as follows: TS= (Neutron Capture Therapy *) OR TS= (Neutron Therapy*) OR TS= (Boron Neutron Capture Therapy*) OR TS= (BNCT*). 3,639 records were retrieved in total. All were downloaded as 500-packed items in the form of complete records and cited references in plain text tagged files and transformed into a PC after compounding as an integrated file. Then, the author names were integrated and modified in PreMap (version 1.0.0.0, 2017). In another step, UCINET (version 6.528.0.0, 2017) was applied to prepare raw matrices as readable ones for network analysis software packages, such as NetDraw (2017).

Co-citation couplings were analyzed to determine the shared research interests of researchers and collaborating countries. All references in papers were converted into PreMap format, and data related to the cited couplings were extracted from the software. For diagnosing highly influential authors, degree, closeness, and betweenness centralities were depicted in scientific maps by UCINET and its complement, NetDraw. Degree centrality manifests the number of links that enter or exit from a group in a network (Freeman, 1978). Moreover, it highlights an author's placement and influence on other authors (Parise, 2007). Closeness centrality refers to an entity's distance from others in a network. More closeness reflects more famousness and domination. Ones with high closeness have fewer mediators for information delivery (Frank, 2002). Betweenness centrality reflects nodes that are mediators for other nodes and are conceived as isolators and connectors in the network. It counts entities in a network that a particular entity connects indirectly (Landherr, Friedl & Heidemann, 2010; Dekker, 2008). Nodes with high betweenness centrality have a primary role in information circulation in the network (Landherr et al., 2010). For measuring the coefficient of publication growth, the following formula was used:

$$1 - 2^R = \frac{Log_e W_2 - Log_e W_1}{T_2 - T_1}$$

Where $1\text{-}2^R$ reflects the relative growth coefficient in a specific period, $Log_e W_1$ and $Log_e W_2$ show the logarithms of the initial and final numbers of papers in the studied period, respectively. $T_2\text{-}T_1$ shows the time difference between the two periods.

The hierarchical clustering was done in SPSS. The dendrogram depicting the hierarchical clustering of co-cited authors in the neutron therapy field in SPSS was depicted using a correlational matrix of the square matrix. Cut points for grouping indicators were prepared by halving the mean score of each variable. Clusters and dendrograms for co-cited papers were mapped by considering keywords with more than 25 occurrence frequencies and selecting six cut-point lines in SPSS. The keywords in each cluster were carefully considered for their inclusion in a particular cluster. The main subject of each cluster was identified by consulting with two specialists in the neutron therapy field. The subject of each cluster was determined by studying the papers published by the authors included in the cluster.

Results

Publication growth trend

Figure 1 shows the annual growth rate of publications on neutron therapy during the studied period. The growth trend was increasing during 1980-2021 (r=.084). With a decreasing rate in 2010 (r=-.036) and 105 published papers, the trend increased in 2011 (r=.030) with 193 published papers. As seen in the figure, the publication was growing slowly in the initial phase, and from 1989, the growth was accelerated. Most publications were reported in 2011 (n=196).

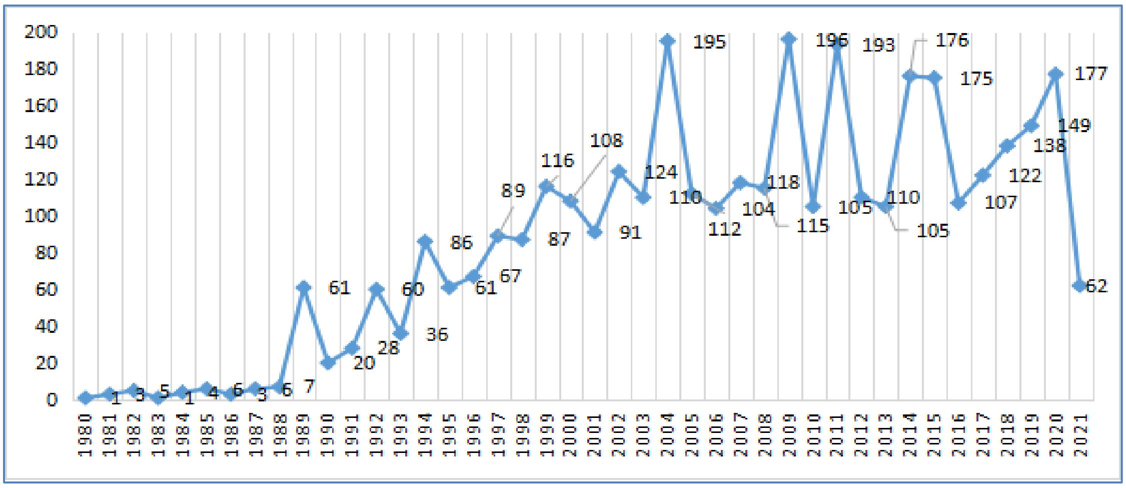

Figure 1: Annual growth rate of publications on neutron therapy during 1980-2021

Highly-productive countries

Table 1 shows the top 20 countries publishing ≥50 papers. The top three highly productive countries in neutron therapy during 1980-2021 were the USA (with 987 papers), Japan (with 815 papers), and Italy (with 284 papers), respectively.

Table 1
Top 20 countries publishing in neutron therapy during 1980-2021

Rank	Country	Number Of Papers	Rank	Country	Number Of Papers
1	USA	987	11	France	101
2	Japan	815	12	South Korea	97
3	Italy	284	13	Spain	95
4	Russia	246	14	Netherlands	92
5	Germany	232	15	Iran	90
6	China	209	16	Finland	83
7	Argentina	166	17	Poland	82
8	England	142	18	Australia	76
9	Sweden	130	19	Czech Republic	64
10	Taiwan	119	20	Canada	52

The following Figure 2 depicts the scientific map of countries contributing to the field during the studied period. The size of the blue circle nodes indicates the number of publications from the respective countries.

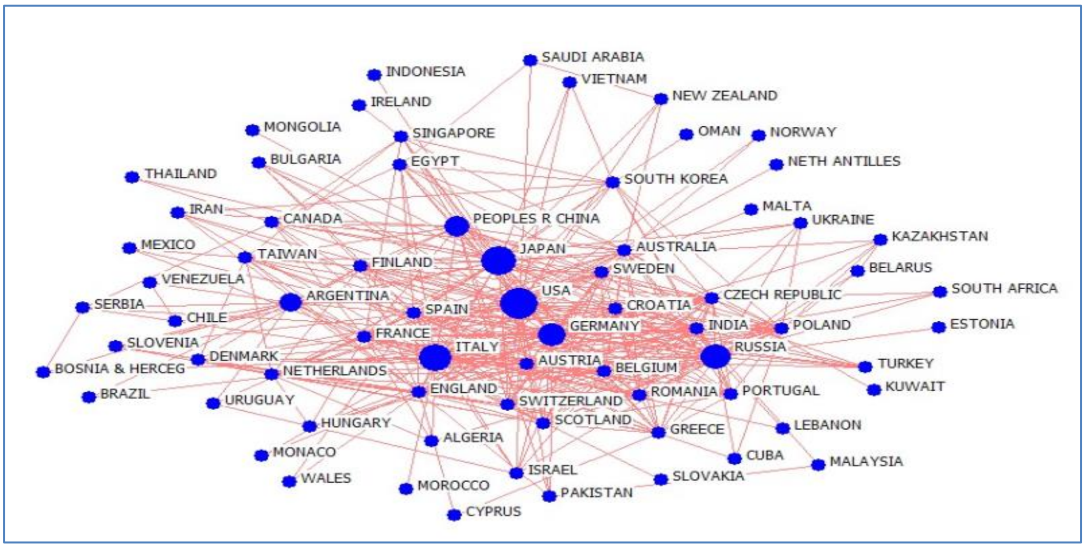

Figure 2: Scientific map of countries publishing papers in neutron therapy during 1980-2021

Table 2 shows the top 20 collaborating country couples active in neutron therapy from 1980 to 2021. The first to third ranks belonged to USA-Argentina (with 49 collaborated papers), USA-Japan (with 45 collaborated papers), and USA-Italy (with 29 collaborated papers), respectively.

Table 2
Top 20 collaborating country couples co-authoring in neutron therapy during 1980-2021

Rank	Country	Number of Collaborated Papers	Rank	Country	Number of Collaborated Papers
1	USA- Argentina	49	11	Japan- South Korea	17
2	USA- Japan	45	12	Italy- Germany	16
3	USA- Italy	29	13	Czech Republic- Italy	14
4	USA- China	25	14	Sweden- Italy	13
5	Germany- Netherlands	24	15	USA- Australia	12
6	USA- England	23	16	Spain- France	12
7	Japan- China	23	17	USA- France	12
8	Argentina- Italy	22	18	Japan- Russia	12
9	USA- Sweden	21	19	USA- Finland	11
10	Austria- Germany	17	20	Czech Republic- Finland	10

Highly-cited and highly-co-cited researchers and their centralities

Table 3 shows the top 10 highly-cited authors cited in the papers on neutron therapy during 1980-2021. By publishing 106 papers, BARTH, ROLF F from Ohio State University ranked first receiving 4,776 WoS-extracted citations and 4,978 total citations.

Table 3
Top 10 highly-cited authors cited in the papers on neutron therapy during 1980-2021

Rank	Author Name	Citation number in WoS	Total citation number	Paper number
1	Barth, Rolf F.	4776	4978	106
2	Coderre, Jeffrey A.	2891	2980	78
3	Tjarks, Werner	2686	2794	65
4	Sakurai, Yoshinori	2499	2663	157
5	Bregadze, Vladimir I.	2330	2364	75
6	Ono, Koji	2091	2229	103
7	Soloway, Ah	2171	2225	46
8	Hawthorne, M. Frederick	1975	2014	46
9	Suzuki, Minoru	1801	1924	131
10	Ono, Katsuhiko	1761	1895	74

For identifying authors with shared research interests, Table 4 shows the top 20 co-cited author couplings, which means the authors who cited each other the most. As the table shows, the first, second and third ranks belonged to SUZUKI, MINORU -SAKURAI, YOSHINORI (with 89 co-citations), SUZUKI, MINORU -ONO, KOJI (with 73 co-citations) and SAKURAI, YOSHINORI- MASUNAGA, SHINICHIRO (with 66 co-citations), respectively.

Table 4
Top 20 highly-co-cited author couples cited in the papers on neutron therapy during 1980-2021

Rank	Cited Couples	Co-Citation Number	Rank	Cited Couples	Co-citation number
1	SUZUKI, MINORU - SAKURAI, YOSHINORI	89	11	SUZUKI, MINORU- TANAKA, HIROKI	51
2	SUZUKI, MINORU - MASUNAGA, SHINICHIRO	73	12	SUZUKI, MINORU- KINASHI, YUKO	49
3	SUZUKI, MINORU - ONO, KOJI	66	13	MIYATAKE, SHIN ICHI- KAWABATA, SHINJI	45
4	SAKURAI, YOSHINORI- MASUNAGA, SHINICHIRO	65	14	SAKURAI, YOSHINORI- KINASHI, YUKO	44
5	SAKURAI, YOSHINORI- TANAKA, HIROKI	59	15	MASUNAGA, SHINICHIRO- ONO, KOJI	44
6	MASUNAGA, SHINICHIRO- KINASHI, YUKO	56	16	SAKURAI, YOSHINORI- ONO, KATSUHIKO	44
7	SAKURAI, YOSHINORI- ONO, KOJI	55	17	SUZUKI, MINORU- MARUHASHI, AKIRA	41
8	BREGADZE, VLADIMIR I.- SIVAEV, IGOR B.	52	18	SCHWINT, AMANDA E.- TRIVILLIN, VERONICA A.	41
9	ALTIERI, SAVERIO-	51	19	MASUNAGA,	39

Rank	Cited Couples	Co-Citation Number	Rank	Cited Couples	Co-citation number
	BORTOLUSSI, SILVA			SHINICHIRO- ONO, KATSUHIKO	
10	SAKURAI, YOSHINORI-MARUHASHI, AKIRA	51	20	TJARKS, WERNER-BARTH, ROLF F.	38

Figure 3 depicts the degree of centrality network of highly cited authors. The bigger the nodes are, the more influential the corresponding author is in the network.

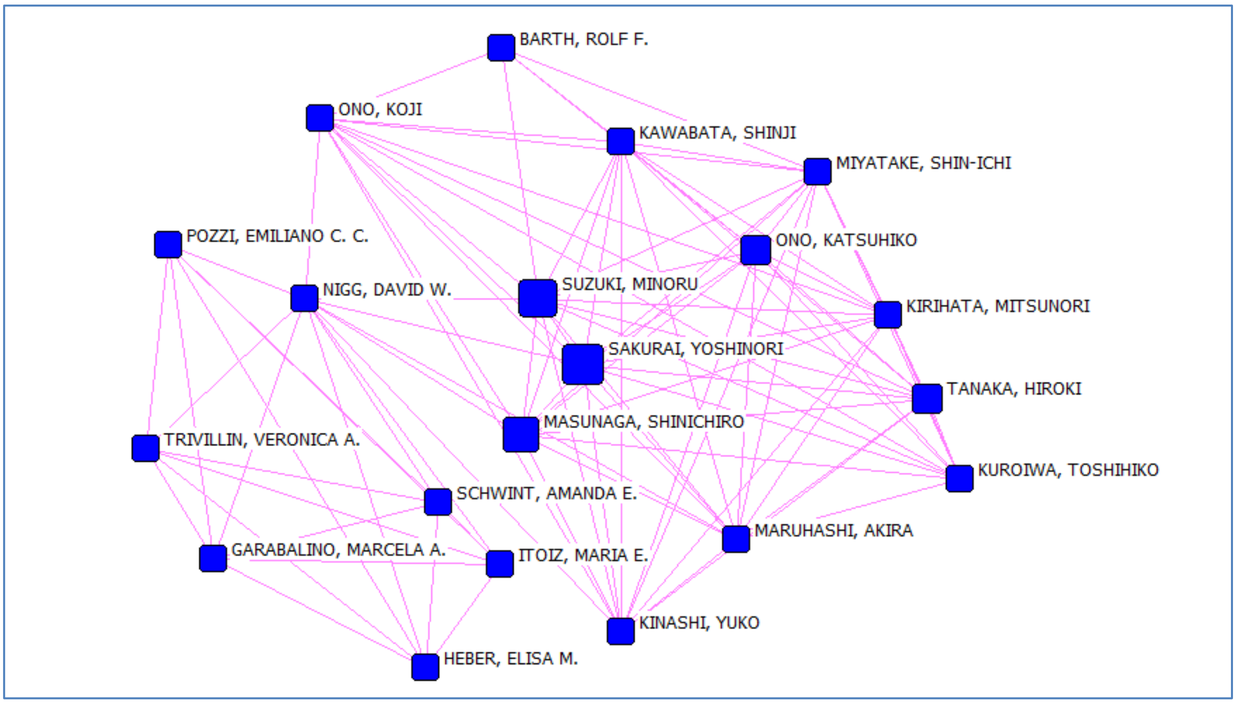

Figure 3: Authors' degree centrality network in neutron therapy during 1980-2021

Table 5 shows the top 10 authors with high degree centralities. SAKURAI, YOSHINORI (with 615), SUZUKI, MINORU (with 558), and MASUNAGA, SHINICHIRO (with 450), all from Kyoto University, Japan, were first—to third-ranked in degree centrality, respectively.

Table 5
Top 10 authors with high degree centralities in neutron therapy during 1980-2021

Rank	Author name	Degree centrality
1	SAKURAI, YOSHINORI	615
2	SUZUKI, MINORU	558
3	MASUNAGA, SHINICHIRO	450
4	ONO, KOJI	414
5	TANAKA, HIROKI	320
6	KINASHI, YUKO	300
7	MARUHASHI, AKIRA	295
8	ONO, KATSUHIKO	292
9	SCHWINT, AMANDA E.	242
10	KAWABATA, SHINJI	241

Figure 4 depicts the betweenness centrality network of highly cited authors. The bigger and closer the node to others, the more influential the mediator the corresponding author is in the network.

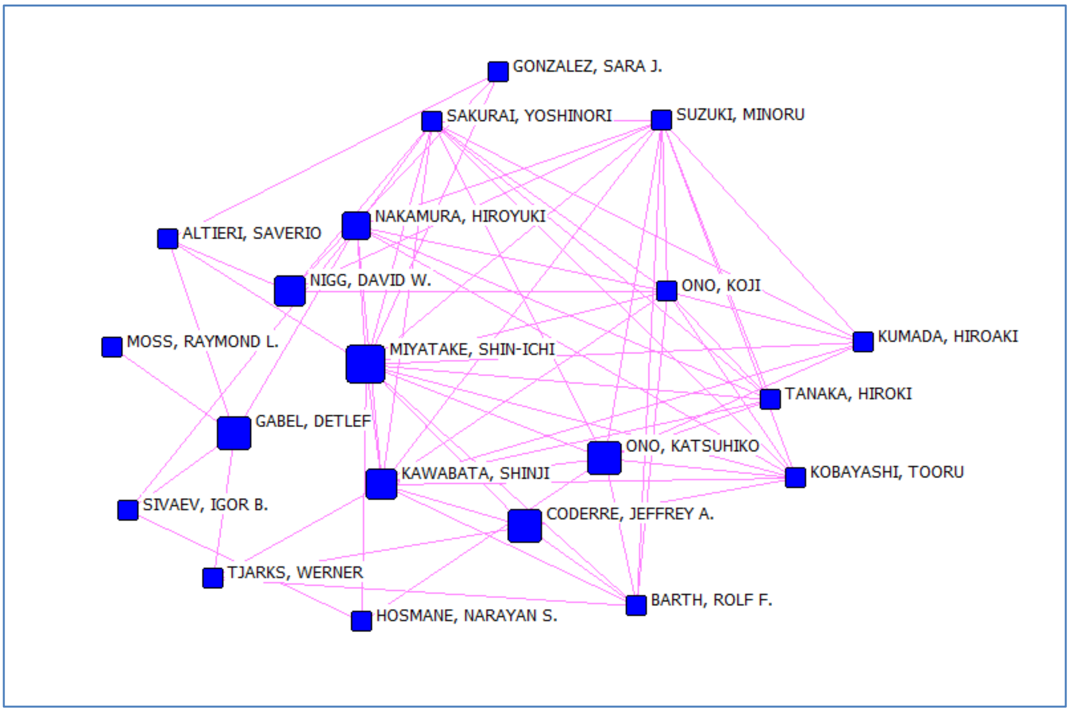

Figure 4: Authors' betweenness centrality network in neutron therapy during 1980-2021

Table 6 shows the top 10 authors with high betweenness centralities. MIYATAKE, SHIN-ICHI from Osaka Medical College, Japan (with 370.03), CODERRE, JEFFREY A. from Massachusetts Institute of Technology, USA (with 367.40), and GABEL, DETLEF from University of Bremen, Germany (with 294.35) were first to third-ranked in degree centrality, respectively.

Table 6

Top 10 authors with high betweenness centralities in neutron therapy during 1980-2021

Rank	Author name	Betweenness centrality
1	MIYATAKE, SHIN-ICHI	370/03
2	CODERRE, JEFFREY A.	367/40
3	GABEL, DETLEF	294/35
4	ONO, KATSUHIKO	285/73
5	NIGG, DAVID W.	282/27
6	KAWABATA, SHINJI	214/85
7	NAKAMURA, HIROYUKI	206/79
8	BARTH, ROLF F.	199/91
9	ONO, KOJI	177/53
10	MOSS, RAYMOND L.	154/50

Figure 5 illustrates the closeness centrality network of highly cited authors. The bigger and closer the node is to others, the more influential the co-citer and the corresponding author is in the network.

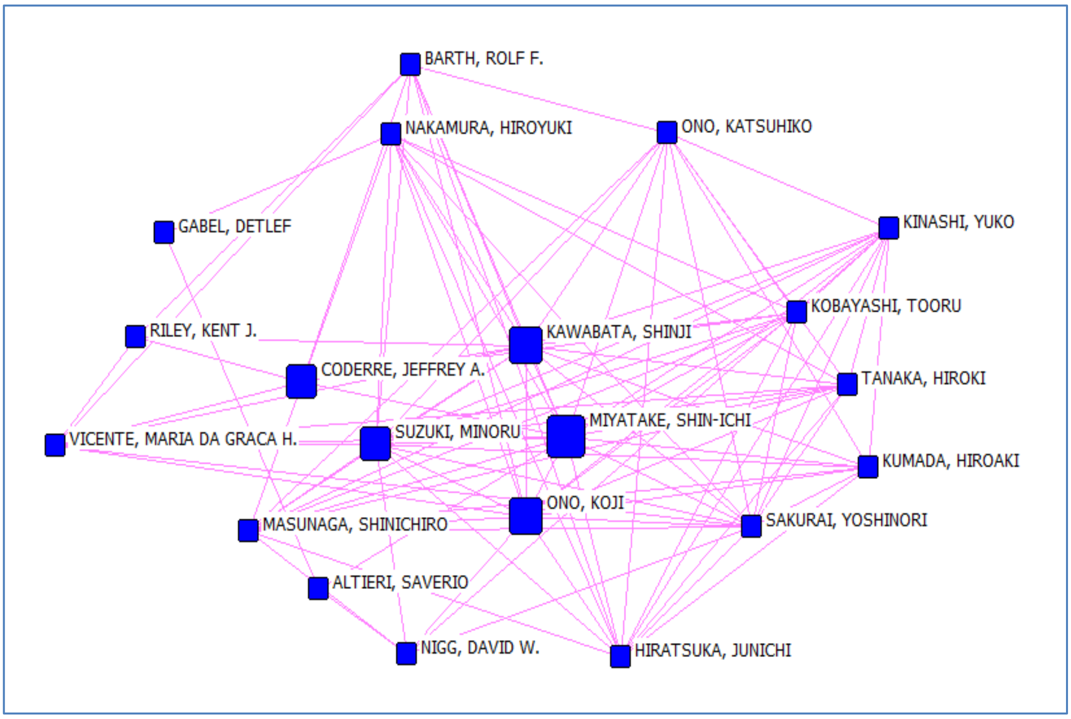

Figure 5: Authors' closeness centrality network in neutron therapy during 1980-2021

Table 7 shows the top 10 authors with high closeness centralities. With a closeness centrality of 37.23, MIYATAKE, SHIN-ICHI from Osaka Medical College, Japan, ranked first, followed by ONO, KOJI from Osaka Medical College, Japan (35.74) and SUZUKI, MINORU from Kyoto University, Japan (35.60), respectively.

Table 7

Top 10 authors with high closeness centralities in neutron therapy during 1980-2021

Rank	Author name	Closeness centrality
1	MIYATAKE, SHIN-ICHI	37/23
2	ONO, KOJI	35/74
3	KAWABATA, SHINJI	35/74
4	SUZUKI, MINORU	35/60
5	CODERRE, JEFFREY A.	35/60
6	ONO, KATSUHIKO	35/31
7	SAKURAI, YOSHINORI	34/90
8	BARTH, ROLF F.	34/90
9	KOBAYASHI, TOORU	34/36
10	MASUNAGA, SHINICHIRO	34/23

In total, centrality indicators of researchers in the neutron therapy field during the studied period showed that MIYATAKE, SHIN-ICHI ranked first in both betweenness and closeness centralities, and SUZUKI, MINORU ranked first in degree centrality and third in closeness centrality. These two researchers are more influential in the field.

Hierarchical clustering of co-cited authors

Figure 6 illustrates the dendrogram of 3 clusters of co-cited authors in the field. Table 8 provides detailed information on the clusters.

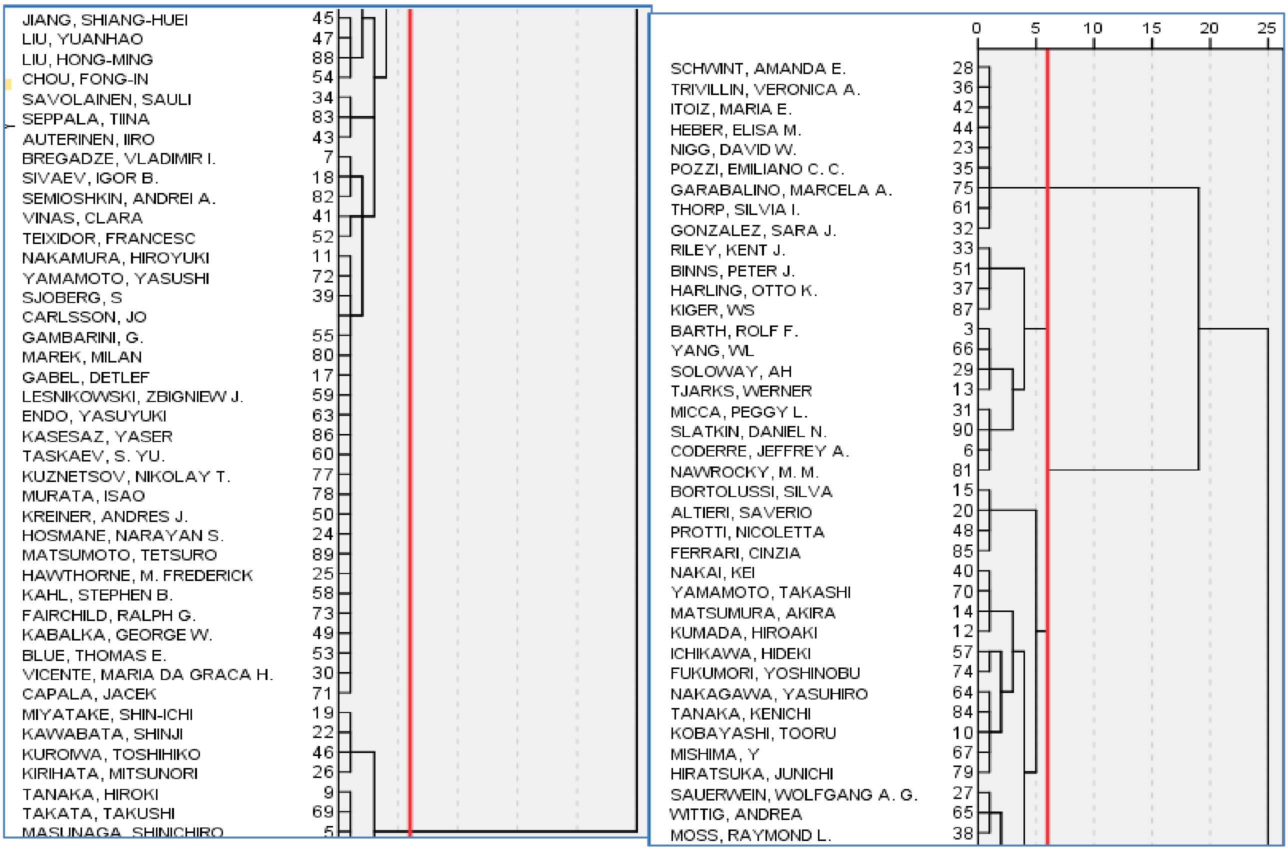

Figure 6: Dendrogram for depicting the hierarchical clustering of co-cited authors in the neutron therapy field

Table 8

Subject clusters of authors in neutron therapy

Cluster number	Number of authors	Subject	Author names
1	16	Treatment	SAKURAI, YOSHINORI; SUZUKI, MINORU; ONO, KOJI; MASUNAGA, SHINICHIRO; ONO, KATSUHIKO; TANAKA, HIROKI; KINASHI, YUKO; MIYATAKE, SHIN-ICHI; MARUHASHI, AKIRA; KAWABATA, SHINJI; KIRIHATA, MITSUNORI; KUROIWA, TOSHIHIKO; YANAGIE, HIRONOBU; TAKAGAKI, MASAO; TAKATA, TAKUSHI; IMAHORI, YOSHIO
2	65	Physics	BARTH, ROLF F; CODERRE, JEFFREY A; BREGADZE, VLADIMIR I; KOBAYASHI, TOORU; NAKAMURA, HIROYUKI; KUMADA, HIROAKI; TJARKS, WERNER; MATSUMURA, AKIRA; BORTOLUSSI, SILVA; GABEL, DETLEF; SIVAEV, IGOR B; ALTIERI, SAVERIO; HOSMANE, NARAYAN S; HAWTHORNE, M. FREDERICK; SAUERWEIN, WOLFGANG A. G;

Cluster number	Number of authors	Subject	Author names
			SOLOWAY, AH; VICENTE, MARIA DA GRACA H; MICCA, PEGGY L; RILEY, KENT J; SAVOLAINEN, SAULI; HARLING, OTTO K; MOSS, RAYMOND L; SJOBERG, S; NAKAI, KEI; VINAS, CLARA; AUTERINEN, IIRO; JIANG, SHIANG-HUEI; LIU, YUANHAO; PROTTI, NICOLETTA; KABALKA, GEORGE W; KREINER, ANDRES J; BINNS, PETER J; TEIXIDOR, FRANCESC; BLUE, THOMAS E; CHOU, FONG-IN; GAMBARINI, G; CARLSSON, JO; ICHIKAWA, HIDEKI; KAHL, STEPHEN B; LESNIKOWSKI, ZBIGNIEW J; TASKAEV, S. YU; ENDO, YASUYUKI; NAKAGAWA, YASUHIRO; WITTIG, ANDREA; YANG, WL; MISHIMA, Y; YAMAMOTO, TAKASHI; CAPALA, JACEK; YAMAMOTO, YASUSHI; FAIRCHILD, RALPH G; FUKUMORI, YOSHINOBU; KUZNETSOV, NIKOLAY T; MURATA, ISAO; HIRATSUKA, JUNICHI; MAREK, MILAN; NAWROCKY, M. M; SEMIOSHKIN, ANDREI A; SEPPALA, TIINA; TANAKA, KENICHI; FERRARI, CINZIA; KASESAZ, YASER; KIGER, WS; LIU, HONG-MING; MATSUMOTO, TETSURO; SLATKIN, DANIEL N
3	9	Measurement	NIGG, DAVID W; SCHWINT, AMANDA E; GONZALEZ, SARA J; POZZI, EMILIANO C. C; TRIVILLIN, VERONICA A; ITOIZ, MARIA E; HEBER, ELISA M; THORP, SILVIA I; GARABALINO, MARCELA A

Cluster 1, named "treatment," included 16 authors, mainly active in treatment and trials. Of them, SAKURAI, Yoshinori, SUZUKI, and MINORU were among the top ten authors in citation counts and degree and closeness centrality rates. ONO, KOJI, and KATSUHIKO were among the top ten authors in citation counts and author centralities. MASUNAGA, SHINICHIRO was among the top 10 authors in degree and closeness centralities. TANAKA, HIROKI KINASHI, YUKO and MARUHASHI, AKIRA were among top 10 ones in degree centrality. MIYATAKE, SHIN-ICHI was among the top ten authors on in-betweenness and closeness centrality indicators. KAWABATA, SHINJI was among the top ten authors regarding degree, betweenness, and closeness centralities. Therefore, the papers published by these authors are highly influential in the field.

Cluster 2, named "physics," included most authors. BARTH, ROLF F, and CODERRE, JEFFREY A were among the top ten authors in citation counts and betweenness and closeness indicators. BREGADZE, VLADIMIR I, TJARKS, WERNER, HAWTHORNE, M. FREDERICK, and SOLOWAY, AH were among the top 10 authors. In closeness centrality, KOBAYASHI and TOORU were among the top 10 authors. NAKAMURA, HIROYUKI, GABEL, DETLEF, and MOSS, RAYMOND was included among the top ten highly-ranked authors in betweenness centrality.

Cluster 3, named "measurement," included 9 authors. NIGG, DAVID W, and SCHWINT, AMANDA E, were among the top 10 highly ranked authors in betweenness and degree centrality indicators.

Discussion

Scientometrics deals with the quantitative aspects of the scientific research trend as a communicative system. It focuses mainly on the analysis of citations in the academic literature. It has played a primary role in measuring research effectiveness in recent years (Mingers & Leydesdorff, 2015). In the past decades, the study of scientific maps as central aspects of scientific measures directed knowledge retrieval and flow. It facilitated knowledge visualizations and understanding of big scientific data. Scientific maps help form scientific structures and explore research communication in different fields (Börner, 2010).

The scientific growth in the field of neutron therapy has been ascending with fluctuating, with the growth rate coefficient amounting to .084 during 1980-2021, but in 2010. This shows that the field found its way as a scientific research area. As the most productive countries with strong interactions with other countries, the USA and Japan were in the top ranks, respectively. As the most influential researcher in the field, BARTH, ROLF F affiliated with Ohio State University, ranked first, receiving 4,978 citations and 106 published papers.

The centrality indicator reflects the ability and efficacy of an individual researcher in a field. It quantifies the role-playing power of a researcher. It shows a researcher's internal and external links with others on a scientific map. With a degree centrality of 615, SAKURAI, YOSHINORI from Kyoto University ranked first. Degree centrality reflects a researcher's famousness and interactive ability in the field. In betweenness centrality, MIYATAKE, SHIN-ICHI from Osaka Medical College of Japan ranked first, scoring 370.03. This indicator reflects the mediating status of an individual researcher in making connections with other researchers. MIYATAKE, SHIN-ICHI from Osaka Medical College of Japan achieved the first rank in the closeness centrality indicator, which amounted to 37.23. The indicator shows the chance of an individual researcher being co-cited with other researchers. The co-citation network of papers in the field depicted three main clusters: treatment, physics, and measurement.

Conclusion

Nowadays, top-ranked scientific entities are determined by applying scientometric techniques. The scientometric indicators consider the reach and influence of the entities (such as citation counts and altmetrics, the quality of publishing journals, rand the esearcher's placement in scientific networks) rather than their mere production. The knowledge flow, scientific development, and research frontiers can be detected by depicting scientific maps for better policy-making. Therefore, social network analyses and the quality of links among papers in neutron therapy can be helpful in different aspects. Co-citation analysis depicts the internal structure of the field and helps in understanding the nature of relations among the scientometric entities (Basumaary et al., 2023). As a result, papers have a primary role in neutron therapy in depicting the topical structure of the field. Policy-makers in this field can make macro-level policies and identify potential gaps by monitoring scientometric data. The results can be helpful for innovators in converting the ideas embedded in papers into products with collaboration with researchers and engineers in the field. However, this study was limited to the WoS database only. Future research may be conducted by acquiring comprehensive data from databases like Scopus, PubMed, Dimensions, Google Scholar, etc., applying different search terms and parameters. Moreover, further study can be conducted at the micro-level and in particular geographical areas to evaluate the research publications that may provide different results.

Competing Interest Statement

The authors declare no potential conflict of interest in this research.

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