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Original Research

A Comprehensive Bibliometric Analysis on Neuronavigation Researches

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ABSTRACT

Objective: Neuronavigation is a novel method that has made great advances in the field of neurosurgery. The aim of this study was to review the published literature on this topic and to investigate the current state of research and trending topics.

Methods: A bibliometric analysis of the neuronavigation on the Web of Science database was performed. The publications included in the study were analyzed with Bibliosiny, bibliometrix (version R 4.2.2), and the Literature Metrology Online Analysis Platform. Graphs from Web of Science were also utilized and some tables were created with the help of Excel.

Results: The current study included 3026 research articles on neuronavigation. 11040 authors, 2332 affiliations, and 93 countries contributed to the literature on neuronavigation. The earliest publications on neuronavigation were published in early 1990. The first article was published in Germany. The international co-authorship rate was 17.78%. Most of the international co-authorship was between the United States and Germany.

Conclusion: Neuronavigation research will remain a hot topic as technology advances. As a result, this study presented the trend and characteristics of neuronavigation studies, offering researchers a useful bibliometric analysis for future research.

Keywords: bibliometric analysis; neuronavigation; neurosurgery.

INTRODUCTION

Neuronavigation, or frameless stereotaxy, is a method that uses one of several localization procedures to locate an operating instrument in relation to the operating field without the use of a coordinate frame firmly fixed to the skulls of patients [1]. In other words, by this method, neurosurgeons can precisely locate various intracerebral disease processes with the aid of uses a variety of preoperative scans [computerized tomography (CT), magnetic resonance imaging (MRI), functional magnetic resonance imaging, positron emission tomography, single-photon emission computerized tomography, etc.] [2].

Modern neurosurgery places a significant emphasis on neuronavigation. It supports spatial orientation and enables intraoperative visualization of instruments and three-dimensional image data [3]. Only after a substantial technological advancement, particularly in the fields of informatics and imagistic, was computer-assisted surgery able to be developed [2].

Four decades after Spiegel and Wycis' successful clinical development of frame-based stereotactic neurosurgery, frameless stereotaxy was developed to allow for more complex image guidance during open neurosurgical procedures [1]. The visual pictures that are used by neuronavigation must be in three dimensions because the procedure itself is three-dimensional (3D). Since imaging technology was initially only capable of two-dimensional (2D) projection on traditional X-ray

scans, the use of neuronavigation was severely constrained. Stereotactic procedures gained enormously in popularity after the development of 3D imaging (helical CT, MRI) [2].

Roberts and Strohbehn, a surgeon and engineer group from Dartmouth (the United States), developed and first released a neuronavigation publication in 1986 [4]. It was reported that neuronavigation was first actively applied in real terms in four neurosurgical facilities in Romania in 2003 [3]. After that, as it is the simplicity, dependability, and efficiency of intraoperative stereotactic navigation in neurosurgery have all been enhanced. These developments have also made it possible for brand-new, minimally invasive neurosurgical methods to develop the properties of every neurosurgical navigation system vary [3,5]. This method enables the reduction of surgical risks and the acceleration of difficult surgical procedures. It is obvious how important it is to understand neuronavigation's accuracy and reliability given how widely available and utilized it has become. Unnoticed influences from various factors during surgery may affect the accuracy and deceive the surgeon. Every neurosurgeon must have a thorough understanding of the systems' weaknesses in addition to optimizing them as much as possible [2]. Stereotactic navigation will become more and more crucial as less invasive procedures for treating intracerebral hemorrhage such as passive catheter drainage and endoscopic evacuation gain support in the literature and become more widely used [3].

The scholarly impact of any scientific publication is frequently assessed using bibliometric analyses with different methods [6-16]. In recent years, bibliometric studies in the field of neurosurgery have started to be published at an increasing rate with the developing technological methods [17-22]. But no similar study focusing on neuronavigation research from the Web of Science database was published before. The aim of this study was to review the published literature on this topic and to investigate the current state of research and trending topics.

Main Points;

- Neuronavigation is a novel method that has made great advances in the field of neurosurgery.
- There is the first bibliometric analysis on neuronavigation research.
- Neuronavigation, frameless stereotaxy, image-guided surgery, Glioma, and Neurosurgery were among the top trend topics.
- The United States took first place with 784 articles. Germany ranked 2nd with 683 articles.

MATERIALS AND METHODS

Study Design

Ethical standards were adhered to in this study. Ethical approval was not required because the study used bibliometric data from the Web of Science database.

In this bibliometric study, a systematic search was conducted in the Web of Science Core Collection (all indexes). Firstly, the topics of articles were screened under the following terms: 'Neuronavigation* (Topic) OR Frameless stereotaxy* (Topic) were the search terms. To improve the quality of access we use the advanced search function and the search rules are defined as follows: Languages = 'All languages', Document types = 'Article', and Time range = '1990-31 December 2022'.

A total of 3026 documents from the Web of Science between 1990 and 31 December 2022 met the inclusion criteria. The dataset was downloaded as 7 separate "plain text" and "tab-delimited text files". Web of Science allows a maximum of 500 results to be downloaded at a time in "BibTeX" format and merged these 7 files.

The document types were other than research articles and the publications published before 1990 and after 31 December 2022 were excluded.

Bibliometric Analysis

The publications included in the study were uploaded to Bibliosiny, bibliometrix (version R 4.2.2) (an R tool / Biblioshiny R version 4.2.2 program [23] and the Literature Metrology Online Analysis Platform (at https://bibliometric.com/app). Graphs from Web of Science were also utilized and some tables were created with the help of Excel.

RESULTS

Main information of the articles and most productive authors/institutions and countries

The current study included 3026 research articles on neuronavigation. 11040 authors, 2332 affiliations, and 93 countries contributed to the literature on neuronavigation. English (95.737%), German (1.619%), French (1.058%), Spanish (0.463%), Japanese (0.297%), and Czech (0.264%) were mostly preferred languages by the authors. Portuguese, Polish, Chinese,

Hungarian, Italian, Russian, and Turkish also rarely publishing languages. 92.862% of the articles were published in journals indexed in the Science Citation Index Expanded index of the Web of Science core collection, also 5.188% of them Emerging Sources Citation Index.

Publications on neuronavigation were first published in early 1990. The first article was published by Roberts et al. [24] from Germany. There were 195 articles in 2021, which was the most productive year. After 2004, there was an acceleration in the number of publications (Figure 1).

A total of 58 of the publications were single-authored. The international co-authorship rate was 17.78%. Most of the international co-authorship was between the United States and Germany.

Christopher Nimsky, Professor of Neurosurgery at the University of Marburg in Germany, was the author of the largest number of publications (69 publications). In addition, Prof. Dr. Med. Oliver Ganslandt (Departments of Neurosurgery, Experimental Neuropsychiatry and Neurology, University of Erlangen-Nuremberg, Erlangen, Germany) and Prof. Rudolf Fahlbusch (Director of the Center for Endocrine Neurosurgery, International Institute for Neuroscience, Hannover, Germany) published most of the papers (51, 48 respectively).

Among the 93 publishing countries, the United States ranked first with 784 papers. American publications increased especially after 1999 (Figure 2). Most of these articles were published in 2019 (72 articles). Germany ranked 2nd with 683 articles (Table 2).

The University of Toronto (Canada) has published most of the papers on neuronavigation. The other top ten institutions publishing on neuronavigation were located in developed countries. Institutions from China, European countries (Germany, Austria, Norway), Canada, and the United States were among the top 10 list of top publishers of neuronavigation-related papers (Table 3). As can be seen in Figure 3, the blue color indicates the University of Erlangen-Nuremberg in Germany, where publications gained momentum towards the end of the 2000s. However, the University of Toronto in Canada, shown in pink, made a major breakthrough in 2017 (Figure 3).

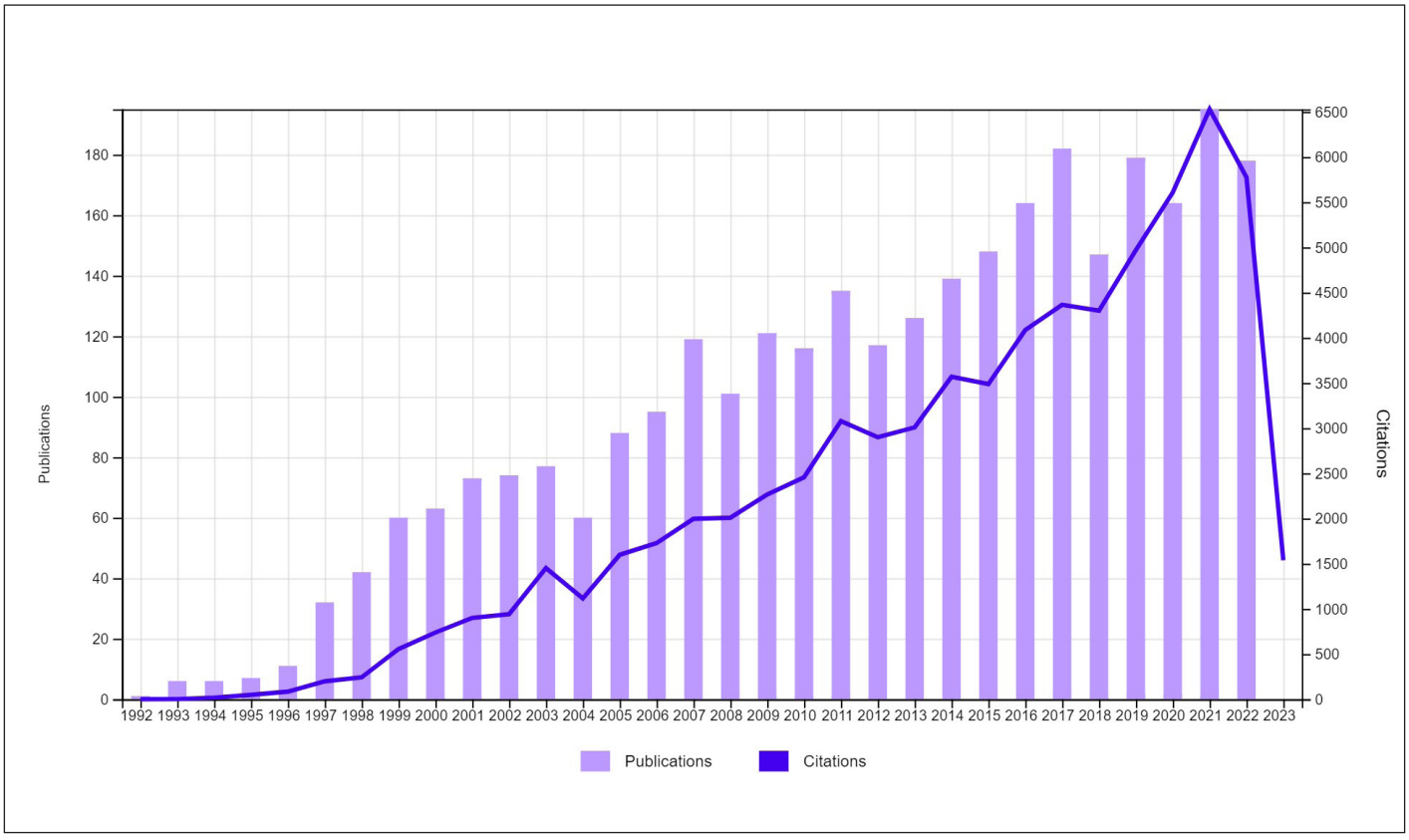


Figure 1. Publications and Citatons Over Time

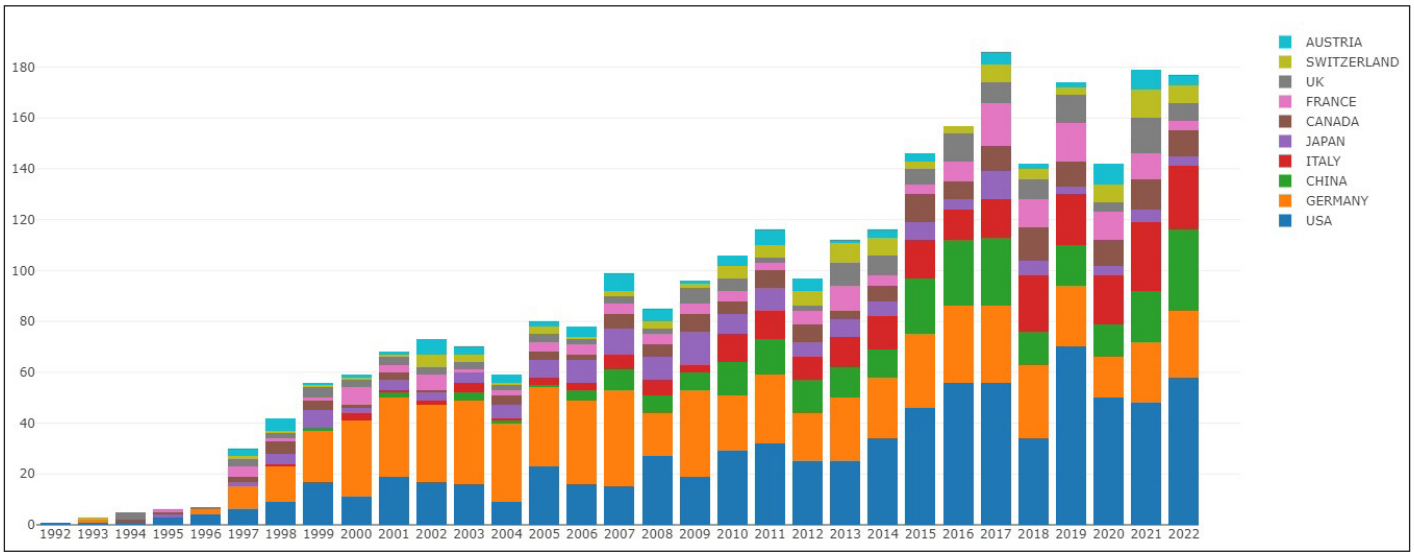
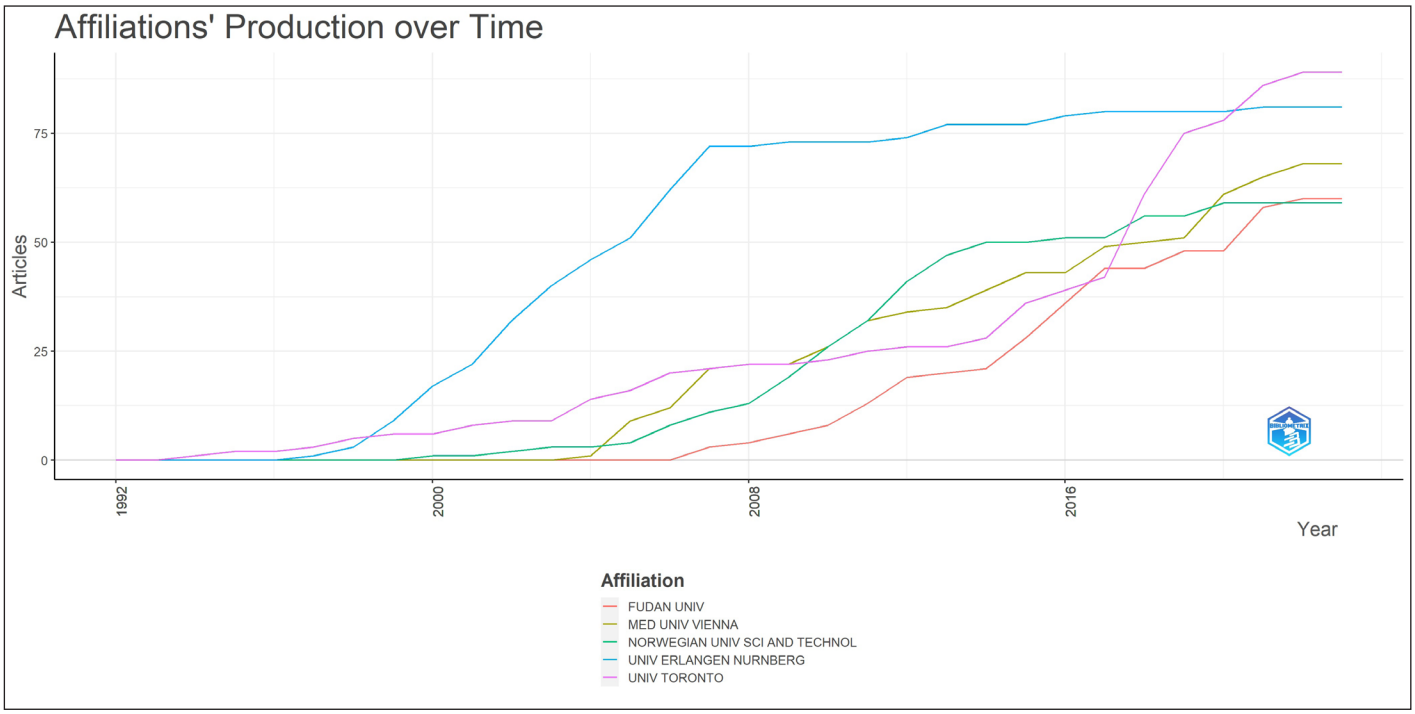


Figure 2. The number of publications of the mostly publishing countries over years



Figer 3. Affiliations' Production over Time

Table 2. Mostly publishing countries and citation analysis of these countries

Country	Total number of articles	Total citations	Average citations	H index
The United States	784	21287	27.15	73
Germany	683	21351	31.26	71
Italy	245	4748	19.38	34
China	240	2801	11.67	26
Japan	163	2870	22.92	34

Table 3. Most Relevant Affiliations

Ranking	Affiliation/Country	Number of articles
1	The University of Toronto, Canada	89
2	University of Erlangen-Nuremberg, Germany	81
3	The Medical University of Vienna, Austria	68
4	Fudan University, China	60
5	Norwegian University of Science and Technology, Norway	59
6	Hravard UNiversity, the United States	53
7	McGill University, Canada	53
8	The University of California, San Francisco, the United States	48
9	The University of Freiburg, Germany	48
10	Barrow Neurological Institute, the United States	46

Publishing Journals

Publications on neuronavigation were published in 575 different journals and Neurosurgery (214 articles), World Neurosurgery (200 articles), Journal of Neurosurgery (177 articles), Acta Neurochirurgica (156 articles) ranked first in the ranking of journals that published the most publications. The summary of the journals that published the most publications on neuronavigation is given in Table 4.

Citations over time and highly cited articles

The first article [23] was cited 26 times. The total number of citations was 71548 (57950 excluding self-citations), the average number of citations per article was 23.64 and the h-index was 108. In 2021, the most productive year, there were 195 articles and 6528 citations. After 2004, there was an acceleration in the number of publications and citations (Figure 1).

The most cited paper was published in 2003 by Herwig et al [25] and cited 661 times. Black et al [26] also published the second most cited paper on neuronavigation. This paper was published in 1997 and received 607 citations. The 20 most cited papers on neuronavigation are given in Table 1.

The United States published most of the articles, but Germany had higher citation counts (21287 vs. 21351 respectively) and also average citation counts per article (27.15 vs. 31.26). However, American publications had the highest H-index. A summary of the citation parameters of the top publishing countries is given in Table 2.

Keyword Analysis and Trend Topics

A total of 4541 keywords and 3602 keywords plus were used in these publications. Statistical results of keyword analysis were analyzed and summarized by the Literature Metrology Online Analysis Platform (Figure 4a and Figure 4b) and Bibliosiny [22] (Figure 4c). Also statistical results of trend topic analysis were analyzed and summarized by Bibliosiny [22] (Figure 5 and Table 5). Frequently used keywords can test whether a research area is hot in a given period and can highlight emerging topics. Figure 4a and Figure 4b illustrate the distribution of keywords and plus keywords by year. According to (Figure. 4c), neuronavigation—the same as the research topic—is the word with the highest frequency. Based on (Figure 4c), the second biggest word is surgery, also neuronavigation is a surgical method in neurosurgery. MRI, CT, and USG are diagnostic methods used in neuronavigation; brain tumors and sup-topic glioblastoma multiforme are among the main keywords.

Neuronavigation (747 occurrences), frameless stereotaxy (214 occurrences), image-guided surgery (119 occurrences), Glioma (115 occurrences), and Neurosurgery (86 occurrences), were among the top trend topics (Table 5).

Table 1.

First author	Title	Source Title	Publication Year	DOI	Total Citations
Herwig, et al	Using the International 10-20 EEG System for Positioning of Transcranial Magnetic Stimulation	BRAIN TOPOGRAPHY	2003	10.1023/B:BRAT.0000006333.93597.9d	661
Black, et al	Development and implementation of intraoperative magnetic resonance imaging and its neurosurgical applications	NEUROSURGERY	1997	10.1097/00006123-199710000-00013	607
Paus, et al	Transcranial magnetic stimulation during positron emission tomography: a new method for studying connectivity of the human cerebral cortex	JOURNAL OF NEUROSCIENCE	1997	10.1523/JNEUROSCI.17-09-03178.1997	568
Nimsky, et al	Quantification of, visualization of, and compensation for brain shift using intraoperative magnetic resonance imaging	NEUROSURGERY	2000	10.1097/00006123-200011000-00008	408
Jakola, et al	Comparison of a strategy favoring early surgical resection vs a strategy favoring watchful waiting in low-grade gliomas	JAMA-JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION	2012	10.1001/jama.2012.12807	407
Hopf, et al	Endoscopic third ventriculostomy: outcome analysis of 100 consecutive procedures	NEUROSURGERY	1999	10.1097/00006123-199904000-00062	381
Nabavi, et al	Serial intraoperative magnetic resonance imaging of brain shift	NEUROSURGERY	2001	10.1097/00006123-200104000-00019	360
Cardinale, et al	Stereoelectroencephalography: surgical methodology, safety, and stereotactic application accuracy in 500 procedures	NEUROSURGERY	2013	10.1227/NEU.0b013e31827d1161	356
Burgel, et al	White matter fiber tracts of the human brain: three-dimensional mapping at microscopic resolution, topography and intersubject variability	NEUROIMAGE	2006	10.1016/j.neuroimage.2005.08.040	319
Nimsky, et al	Preoperative and intraoperative diffusion tensor imaging-based fiber tracking in glioma surgery	NEUROSURGERY	2005	10.1227/01.NEU.0000144842.18771.30	305
GOLFINOS, et al	Clinical use of a frameless stereotactic arm: results of 325 cases	JOURNAL OF NEUROSURGERY	1995	10.3171/jns.1995.83.2.0197	301
Hu, et al	Relative cerebral blood volume values to differentiate high-grade glioma recurrence from posttreatment radiation effect: direct correlation between image-guided tissue histopathology and localized dynamic susceptibility-weighted contrast-enhanced perfusion MR imaging measurements	AMERICAN JOURNAL OF NEURORADIOLOGY	2009	10.3174/ajnr.A1377	280
Steinmeier,et al	Intraoperative magnetic resonance imaging with the magnetom open scanner: concepts, neurosurgical indications, and procedures: a preliminary report	NEUROSURGERY	1998	10.1097/00006123-199810000-00005	270
Herwig, et al	Transcranial magnetic stimulation in therapy studies: examination of the reliability of “standard” coil positioning by neuronavigation	BIOLOGICAL PSYCHIATRY	2001	10.1016/S0006-3223(01)01153-2	266
Sack, et al	Optimizing functional accuracy of TMS in cognitive studies: a comparison of methods	JOURNAL OF COGNITIVE NEUROSCIENCE	2009	10.1162/jocn.2009.21126	261
Dorward, et al	Postimaging brain distortion: magnitude, correlates, and impact on neuronavigation	JOURNAL OF NEUROSURGERY	1998	10.3171/jns.1998.88.4.0656	255
Dickman, et al	Posterior C1-C2 transarticular screw fixation for atlantoaxial arthrodesis	NEUROSURGERY	1998	10.1097/00006123-199808000-00056	243
Tronnier, et al	Intraoperative diagnostic and interventional magnetic resonance imaging in neurosurgery	NEUROSURGERY	1997	10.1097/00006123-199705000-00001	239
Schroeder, et al	Complications of endoscopic third ventriculostomy	JOURNAL OF NEUROSURGERY	2002	10.3171/jns.2002.96.6.1032	232
Wu, et al	Clinical evaluation and follow-up outcome of diffusion tensor imaging-based functional neuronavigation: a prospective, controlled study in patients with gliomas involving pyramidal tracts	NEUROSURGERY	2007	10.1227/01.neu.0000303189.80049.ab	231

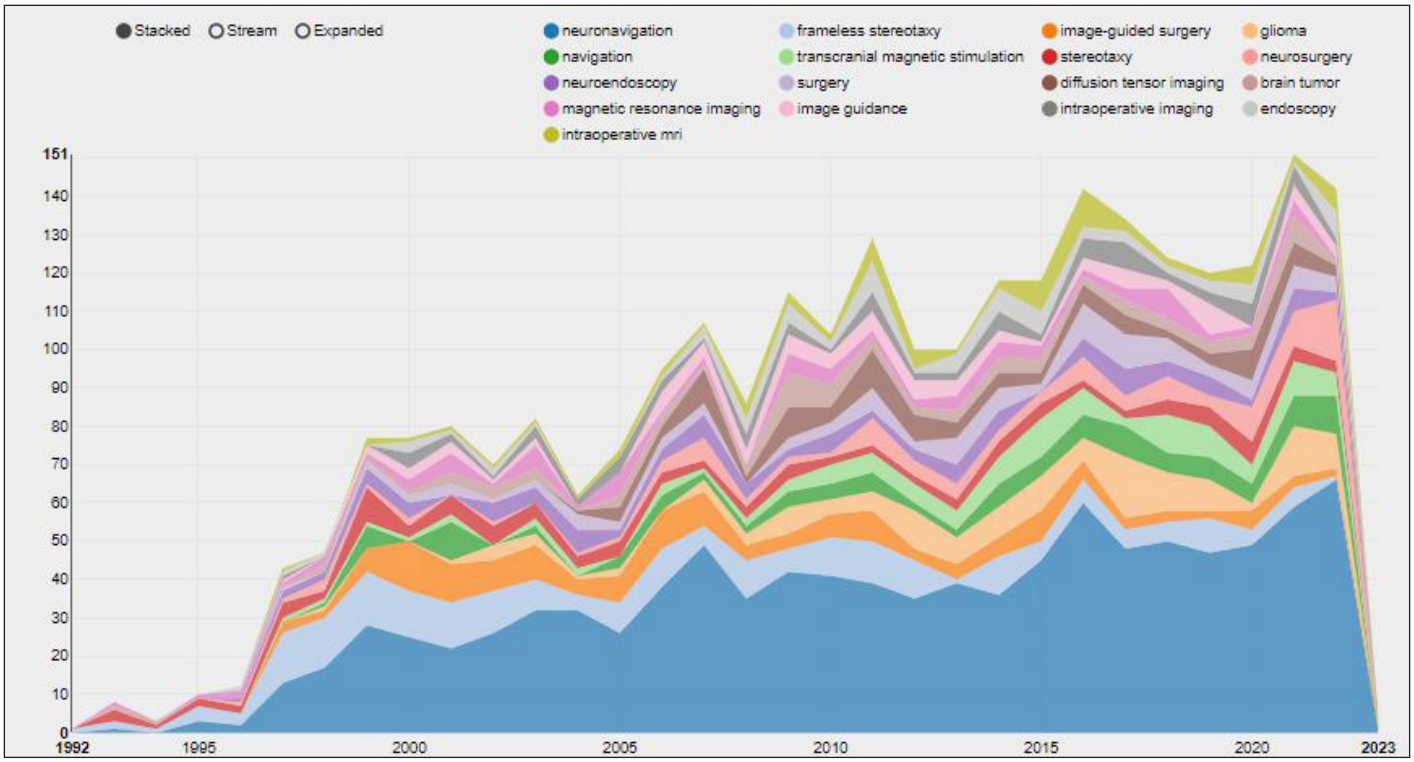


Figure 4a. Keywords by years

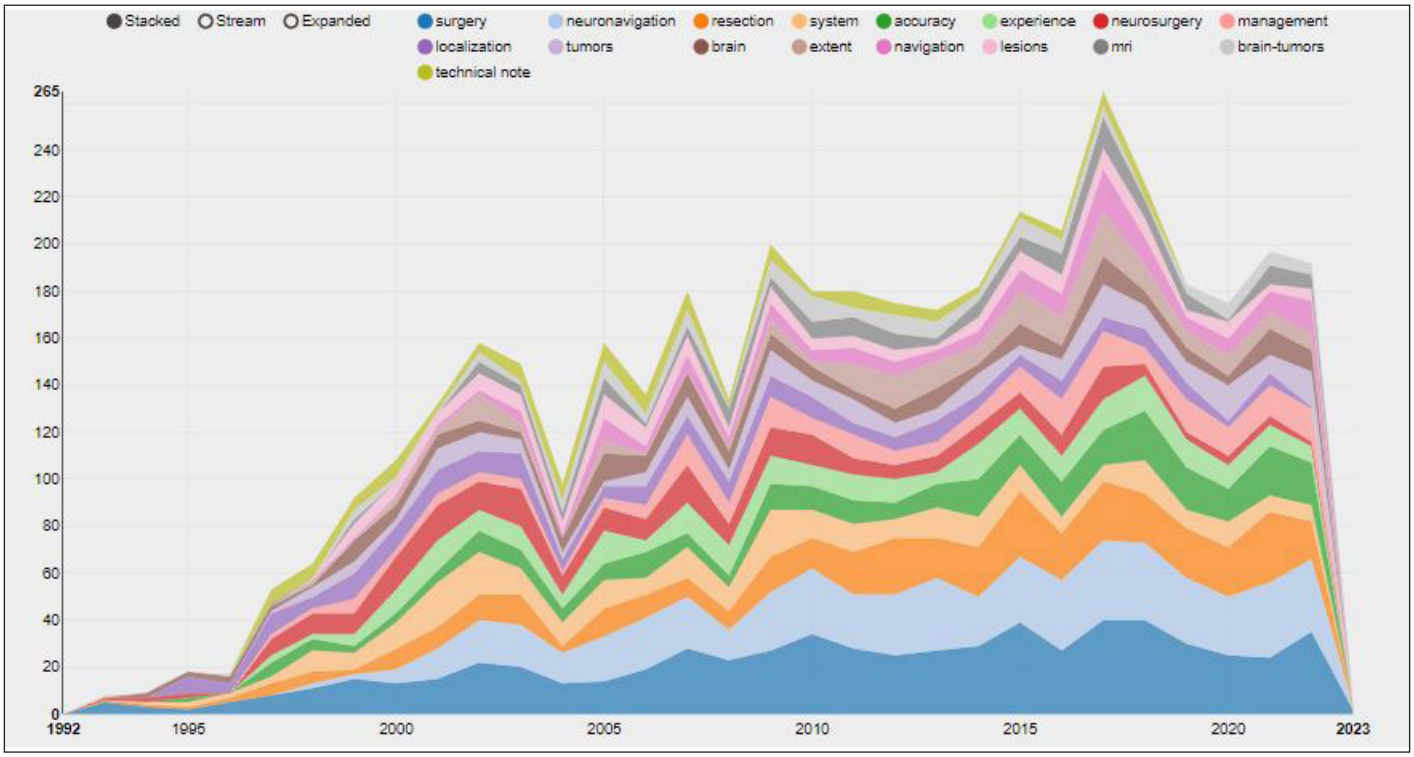


Figure 4b. Expand keywords by years

Figure 4c. Wordcloud

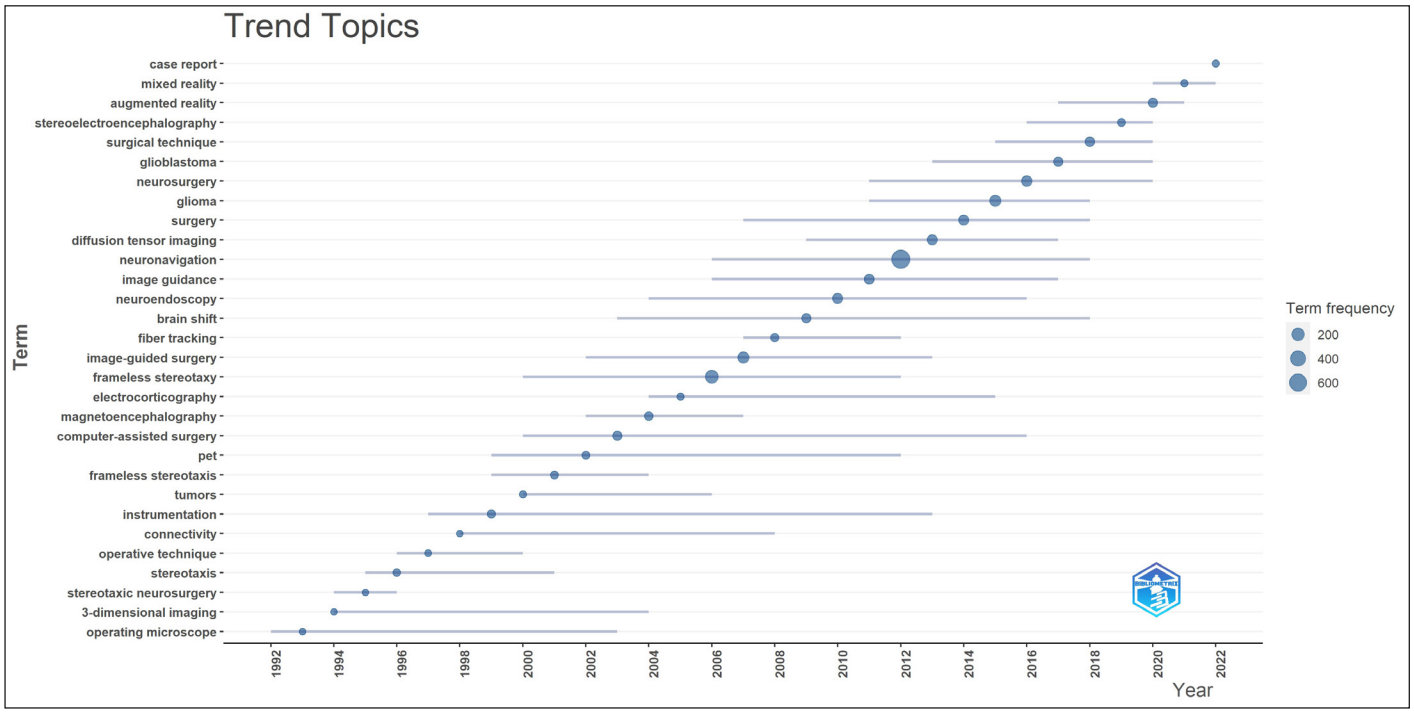


Figure 5. Trend topics

Table 4. Top publishing journals

Publication Titles	Article Count	%
Neurosurgery	214	7.072
World Neurosurgery	200	6.609
Journal Of Neurosurgery	177	5.849
Acta Neurochırurgıca	156	5.155
Mınımally Invasıve Neurosurgery	104	3.437
Operatıve Neurosurgery	84	2.776
Stereotactıc And Functıonal Neurosurgery	76	2.512
Chılds Nervous System	68	2.247
Clınıcal Neurology And Neurosurgery	57	1.884
Journal Of Clınıcal Neuroscıence	52	1.718
Neurosurgıcal Revıew	52	1.718
Neurosurgıcal Focus	48	1.586
Brıtısh Journal Of Neurosurgery	41	1.355

Journal Of Neurosurgery Pedıatrıcs	39	1.289
Internatıonal Journal Of Computer Assısted Radıology And Surgery	35	1.157
Neurologıa Medıco Chırurgıca	31	1.024
Neuroımage	30	0.991
Journal Of Neurologıcal Surgery Part A Central European Neurosurgery	29	0.958
Neurochırurgıe	29	0.958
Surgıcal Neurology	28	0.925
Turkısh Neurosurgery	25	0.826
Neurologıcal Research	24	0.793
Braın Stımulatıon	21	0.694
Neurosurgery Clınıcs Of North Amerıca	21	0.694
Journal Of Neuro Oncology	20	0.661

*Showing 25 out of 575 journals

Table 5. Trend topics

Item	Freq	year_q1	year_med	year_q3
Neuronavigation	747	2006	2012	2018
Frameless Stereotaxy	214	2000	2006	2012
Image-Guided Surgery	119	2002	2007	2013
Glioma	115	2011	2015	2018
Neurosurgery	86	2011	2016	2020
Diffusion Tensor İmaging	81	2009	2013	2017
Surgery	78	2007	2014	2018
Neuroendoscopy	74	2004	2010	2016
Image Guidance	65	2006	2011	2017
Surgical Technique	50	2015	2018	2020
Brain Shift	47	2003	2009	2018
Glioblastoma	46	2013	2017	2020
Computer-Assisted Surgery	45	2000	2003	2016
Augmented Reality	42	2017	2020	2021
Magnetoencephalography	25	2002	2004	2007
Fiber Tracking	20	2007	2008	2012
Instrumentation	17	1997	1999	2013
Frameless Stereotaxis	16	1999	2001	2004
Pet	14	1999	2002	2012
Stereoelectroencephalography	13	2016	2019	2020
Stereotaxis	9	1995	1996	2001
Tumors	7	2000	2000	2006
Electrocorticography	6	2004	2005	2015
Mixed Reality	6	2020	2021	2022
Case Report	6	2022	2022	2022
Operative Technique	4	1996	1997	2000
Operating Microscope	3	1992	1993	2003
3-Dimensional İmaging	3	1994	1994	2004
Stereotaxic Neurosurgery	3	1994	1995	1996
Connectivity	3	1998	1998	2008

* freq: number of occurrance, Year q1: first occurance year, year_q3: last year of occurance, year_med: most frequently occured year

DISCUSSION

Although this topic is of great interest in the field of neurosurgery, no published bibliometric study has been published on how the scientific literature has evolved. There was one similar study using machine learning methods for topic analysis on neuronavigation research [30]. In this study [30] PubMed database was used to obtain data. In the current study, the Web of Science database was used to retrieve the study's data. The Web of Science database is a bibliometric analysis database frequently used in similar studies [9,11,1531-34]. In this study, general information about the bibliometric parameters such as the most prolific authors/organizations/countries, most published journals, number of citations, H-indexes, etc. were analyzed. And also keywords and trending topics were also analyzed and visualized using detailed visualization programs.

There were 3896 articles, according to Watanabe's study [27]. The quantity of neuronavigation publications increased by 80% between 1999–2009 and 2010–2020. There was a 0.3% decrease between 2009-2014 and 2015-2020. According to the current study, there was an acceleration in the number of publications and citations after 2004. This difference may be due to the fact that Pubmed and Web of Science databases index different journals.

The first scientific data on neuronavigation technologies were first published in the United States [4], and in the following years, great progress was made in Japan [28], the United States [29] and Germany [30]. Although neuronavigation was first actively implemented in four neurosurgical facilities in Romania in 2003 [3], according to the results of the present study, Romania was not included in the ranking of both the countries with the most publications or the countries with the most publications. Among 93 publishing countries, the United States took first place with 784 articles. American publications increased especially after 1999. Germany ranked 2nd with 683 articles. Institutions from China, European countries (Germany, Austria, Norway), Canada, and the United States were among the top 10 lists of top publishers of these articles. Watanabe's study [27] does not address the issue of broadcasting institutions or countries. Also in the current study, the top cited 20 articles were summarized.

Since analyzing in which journals the most publications on a topic are published can guide researchers on that topic, the journals that publish the most publications were also examined in this study. Neurosurgery (214 articles), World Neurosurgery (200 articles), Journal of Neurosurgery (177 articles), and Acta Neurochirurgica (156 articles) ranked first in the ranking of journals that published the most publications. These journals are also among the most prestigious journals in the field of neurosurgery.

In bibliometric research, a researcher must choose a number of keywords to serve as a representation of the primary study themes in the area if they hope to learn more about the specifics of the major research issues of a field and their micro-level relationships. Prior research had a tendency to choose keywords based on network-based measurements or frequency, both of which have been shown to be substantially connected with keyword frequency [35]. Studies that use keyword frequency analysis for hotspot detection and trend analysis are relevant [36]. Also, the bibliometrics idea states that keywords reveal hotspots and trends in a research area. As keywords indicate the subject matter of an article or an author, they also offered a typical overview of research trends that applied to the publication [37]. A common strategy for revealing the knowledge structure of study areas is to use publication keywords. The choice of which keywords should be preserved as analysis objects once a large number of keywords are acquired from domain publications is a significant but under-addressed subject [36]. Therefore, trend topic and keyword analysis were given priority in this study. According to Watanabe's study [27], publications within the top 10 topics were further analyzed by obtaining citation counts, main MeSH terms, and MeSH subheadings. Google Scholar was used to calculate the number of citations. The number of publications and citations in the current study were calculated using data and graphs from the Web of Science database. According to Watanabe's research [27], the most commonly assigned themes were "brain", "brain neoplasms", "MRI", and "3D imaging" and neuronavigation research is increasingly focusing on clinical evaluation of existing neuronavigation tools rather than the development of new systems. Neuronavigation research on standards, education, adverse effects, and economics is limited. This study [27] identified distinct themes in neuronavigation research and quantified their representation and growth in the academic literature. In the current study, neuronavigation—the same as the research topic—is the word with the highest frequency. The second biggest word is surgery, also neuronavigation is a surgical method in neurosurgery. MRI, CT, and USG are diagnostic methods used in neuronavigation; brain tumors and sup-topic glioblastoma multiforme are among the main keywords. Neuronavigation (747 occurrences),

frameless stereotaxy (214 occurrences), image-guided surgery (119 occurrences), Glioma (115 occurrences), and Neurosurgery (86 occurrences) were among the top trend topics.

Limitations

This study included a single database data. The time range was limited to 1990-31 December 2022. The year 2023 was excluded as the year was not yet complete and database updates were still ongoing. For these reasons, it may not reflect all the literature.

CONCLUSION

The results of this study show that neuronavigation research in neurosurgery will continue to be a topic open to development with today's advancing technology. As a result, this study can reveal the trends and characteristics of neuronavigation studies and provide researchers with ideas for future research. According to both the number of citations and publications the leading countries were the United States and Germany. Apart from the United States and Germany, neuronavigation publications are increasing and are likely to continue to increase in countries such as China, European countries (Germany, Austria, Norway), and Canada.

Informed Consent: None.

Conflict of Interest: The authors declare that they have no conflict of interest.

Financial Disclosure: The authors declared that they did not receive financial support for this study.

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