

Original Article

Technological Innovations and Trends in Neurosurgery Resident Education: A Bibliometric Analysis and Scientific Mapping

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KEYWORDS

Bibliometric analysis,
neurosurgery resident,
neurosurgery education,
scientific mapping.

The field of neurosurgery requires rigorous training and continuous education for residents, ensuring high standards of patient care and advancement through research. This bibliometric analysis reviews 1028 scholar publications related to neurosurgery resident education, collected from the Scopus database from 2014 to 2024. Our aim is to map educational advancements, identify key trends, influential works, and emerging themes in this critical area. Our analysis reveals a significant increase in global publications, particularly between 2019 and 2020, reflecting heightened interest and progress in neurosurgery resident education. Leading journals such as the Journal of World Neurosurgery, Journal of Neurosurgery, and Neurosurgery are identified as major contributors, underscoring their pivotal role in disseminating key research. Prominent authors, including M.N. Stienen, N. Agarwal, and N.R. Selden, have notably influenced the field with their substantial contributions. Technological advancements, including simulation-based training, virtual reality, and 3D printing, have revolutionized the training experience, making it more comprehensive and effective. However, challenges such as burnout, gender disparities, and unconscious biases remain prevalent, necessitating ongoing efforts to foster a supportive and inclusive environment for all residents. This bibliometric analysis not only underscores the evolution of neurosurgery resident education but also provides critical insights for educators, policymakers, and researchers. Addressing existing challenges and leveraging technological innovations are essential for enhancing training outcomes and advancing the educational framework for future neurosurgeons.

INTRODUCTION

The field of neurosurgery is both highly specialized and critically important, necessitating rigorous training and continuous education for residents (1). Neurosurgery resident education is pivotal in preparing future neurosurgeons to handle complex and delicate procedures, ensuring high standards of patient care and advancing the field through research and innovation. The educational journey for neurosurgery residents is multifaceted, encompassing clinical skills, medical knowledge, research acumen, and professional development (2).

In recent years, the landscape of neurosurgery resident education has evolved significantly, influenced by advancements in technology, changes in healthcare policies, and emerging educational methodologies. The integration of simulation-based training, virtual reality, and other digital tools has revolutionized how residents gain hands-on experience. Additionally, there is a growing emphasis on competencies such as professionalism, communication skills, and systems-based practice, which are crucial for holistic development (3,4).

A bibliometric analysis provides a quantitative approach to understanding the trends, impact, and progress in neurosurgery resident education. By examining the existing literature, citation patterns, and research outputs, we can identify key areas of focus, emerging themes, and potential gaps in the current educational framework. This analysis not only highlights the contributions of various studies but also sheds light on the evolution of educational practices over time (5).

The purpose of this bibliometric analysis is to systematically review and analyze the scholarly publications related to neurosurgery resident education. Through this comprehensive review, we aim to map the trajectory of educational advancements, identify influential works and authors, and provide insights into future directions for research and practice in neurosurgery resident education. This analysis serves as a valuable resource for educators, policymakers, and researchers dedicated to enhancing the training and education of neurosurgery residents.

MATERIAL AND METHODS

Data Resource strategy

The bibliometric data were collected from the Scopus database as of May 29, 2024. Scopus, one of the largest databases of curated abstracts and citations, was chosen for this bibliometric analysis (6). The research focused on the specific area of neurosurgery resident education, using search terms in the title, abstract, or keywords: 'Neurosurgery' AND 'Resident' AND 'Education'. A total of 1,028 documents ranging from 2014 to 2024 were found and subsequently integrated into the final data analysis procedure.

Data analysis

The search was conducted in the Scopus database, and the evaluation of the obtained documents was divided into three phases as seen in **Figure 1**. The first phase was conducted by defining search criteria to identify records in the Scopus database and refining the retrieved records (data collection phase), second phase was conducted by exporting documents to VOS viewer software for bibliometric analysis of publications, authors, countries, institutions, journals, and areas (data visualization phase), and the third phase was conducted by analyzing the data to identify the main themes addressed in research on neurosurgery resident education.

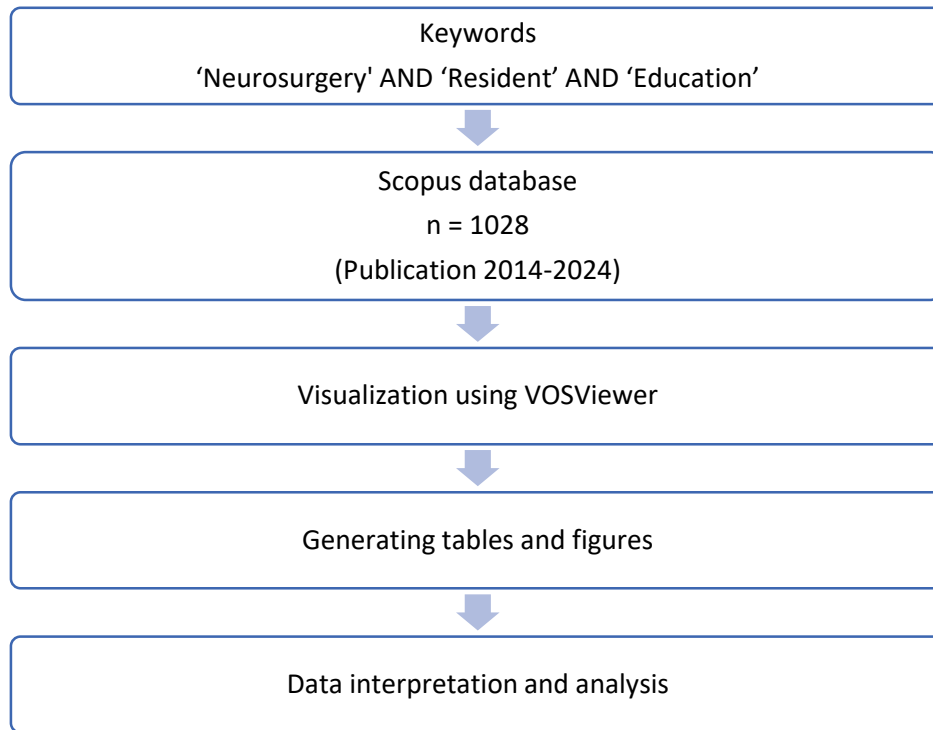


Figure 1. Flow diagram of method (search strategy and data processing).

The research focused on a specific area and included the application of the title, abstract, or keywords associated with the topic, namely ‘Neurosurgery’ AND ‘Resident’ AND ‘Education’. A total of 1,028 academic papers ranging from 2014 to 2024 were amassed and integrated into the final data analysis procedure.

All collected data were exported for co-authorship and co-occurrence analysis. Consequently, network maps of authors, countries, and keywords were generated. These maps were analyzed to produce citation networks and maps of scholarly journals.

RESULTS

Analysis of global publication trends

The growth of scientific publications on interprofessional collaboration in medical education experienced a worldwide increase from 2014 to 2024, as shown in **Figure 2**. In the last ten years, there have been 1,028 new journal articles. There was an upward trend in the number of publications annually, with the largest increase occurring in 2019–2020 (69.8%). This suggests a growing global interest in neurosurgery resident education.

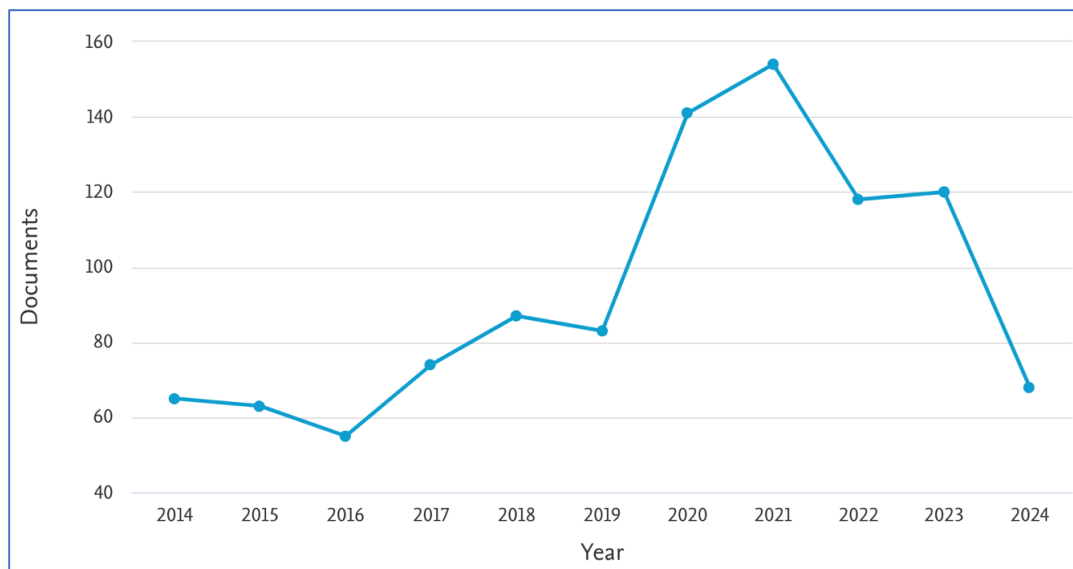


Figure 2. Research trends in the field of neurosurgery resident education.

Analysis of the core journal of Neurosurgery Resident Education

The top ten peer-reviewed journals that published the most articles in the field of neurosurgery resident education over the past 10 years are presented in **Figure 3**. The top three were the Journal of World Neurosurgery, the Journal of Neurosurgery, and Neurosurgery (H-index 88 and S.J.R 2023 1.04), BMC Medical Education (H-index 97 and S.J.R 2023 0.94), and Academic Medicine (H-index 188 and S.J.R 2023 1.56). This evidence supports the position of these journals as leading scientific publications worldwide.

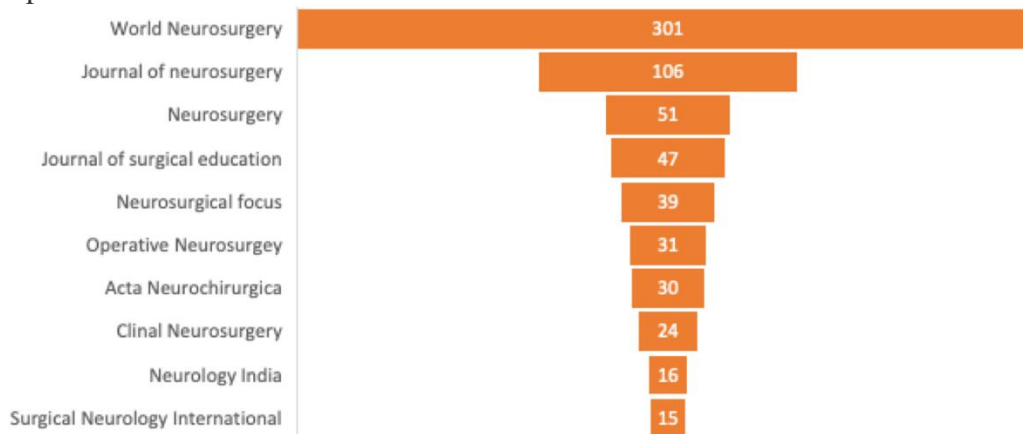


Figure 3. Top ten journals with the most publications in neurosurgery resident education.

The most productive authors in the publication of neurosurgery resident education

The top ten contributors of articles published in Scopus journals regarding neurosurgery resident education are presented in **Figure 4**. Stienen, M.N., has published approximately twenty-two publications, making them the most prolific on the list. Agarwal, N., and Selden, N.R., each published twenty publications, followed by Schaller, K., with nineteen publications, and Graffeo, C.S., and Winkler-Schwartz, A., with eighteen publications each. All of these authors have made

significant contributions to neurosurgery resident education. Moreover, the ten most valuable publications by citation weight are summarized in **Table 1**.

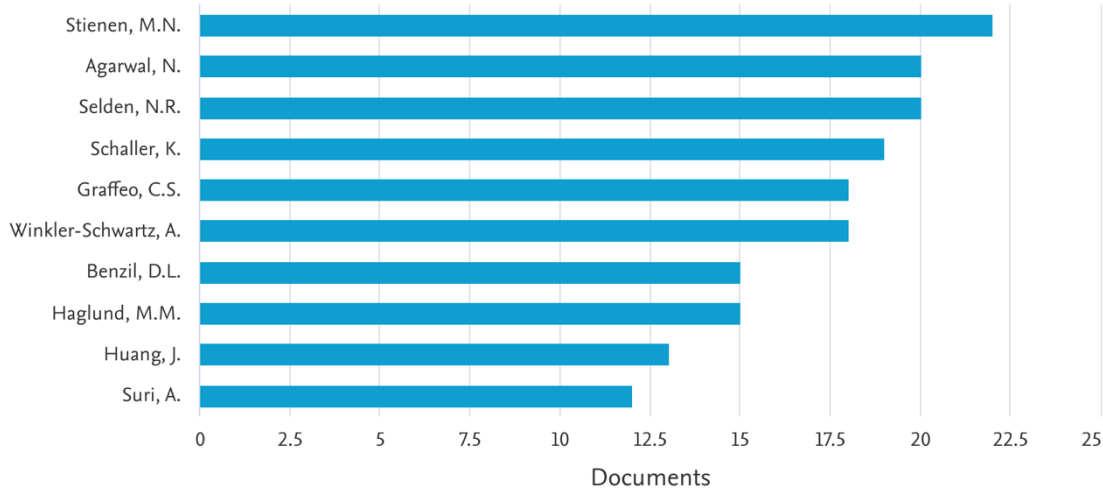


Figure 4. Top ten contributing authors in neurosurgery resident education.

Table 1. Top ten most valuable publications by citation weight.

Rank	Authors	Title	Year	Journal	Cited by	Reference
1	Pelargos, P. E., Nagasawa, D. T., Lagman, C., Tenn, S., Demos, J. V., Lee, S. J., ... & Yang, I.	Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery.	2017	Journal of clinical neuroscience	519	(7)
2	Chambers, C. C., Ihnow, S. B., Monroe, E. J., & Suleiman, L. I.	Women in orthopaedic surgery: population trends in trainees and practicing surgeons.	2018	Journal of Bone and Joint Surgery	363	(8)
3	Haider, A. H., Schneider, E. B., Sriram, N., Dossick, D. S., Scott, V. K., Swoboda, S. M., ... & Freischlag, J. A.	Unconscious race and social class bias among acute care surgical clinicians and clinical treatment decisions.	2015	JAMA surgery	201	(9)

4	Alaraj, A., Luciano, C. J., Bailey, D. P., Elsenousi, A., Roitberg, B. Z., Bernardo, A., ... & Charbel, F. T.	Virtual reality cerebral aneurysm clipping simulation with real-time haptic feedback.	2015	Operative Neurosurgery	109	(10)
5	Kirkman, M. A., Ahmed, M., Albert, A. F., Wilson, M. H., Nandi, D., & Sevdalis, N.	The use of simulation in neurosurgical education and training: A systematic review.	2014	Journal of neurosurgery	95	(11)
6	Jagsi, R., Griffith, K. A., DeCastro, R. A., & Ubel, P.	Sex, role models, and specialty choices among graduates of US medical schools in 2006–2008.	2014	Journal of the American College of Surgeons	94	(12)
7	Mota, P., Carvalho, N., Carvalho-Dias, E., Costa, M. J., Correia-Pinto, J., & Lima, E.	Video-based surgical learning: improving trainee education and preparation for surgery.	2018	Journal of surgical education	91	(13)
8	Langridge, B., Momin, S., Coumbe, B., Woin, E., Griffin, M., & Butler, P.	Systematic review of the use of 3-dimensional printing in surgical teaching and assessment.	2018	Journal of surgical education	70	(14)
9	Renfrow, J. J., Rodriguez, A., Liu, A., Pilitsis, J. G., Samadani, U., Ganju, A., ... & Wolfe, S. Q.	Positive trends in neurosurgery enrollment and attrition: analysis of the 2000–2009 female neurosurgery resident cohort.	2016	Journal of neurosurgery	69	(15)
10	Attenello, F. J., Buchanan, I. A., Wen, T., Donoho, D. A., McCartney, S.,	Factors associated with burnout among US neurosurgery residents: a nationwide survey	2018	Journal of neurosurgery	69	(16)

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Source: Authors

Top ten countries of authors based on publication number in the field of neurosurgery resident education

The top ten countries based on publication number are presented in **Figure 5**. United States published the most articles concerning Neurosurgery Resident Education, with 692 publications (67,31%), followed by Canada with 82 (7,9%), United Kingdom with 51 (4,9%), and Indonesia in the 42 positions with 4 publications (0,38%).

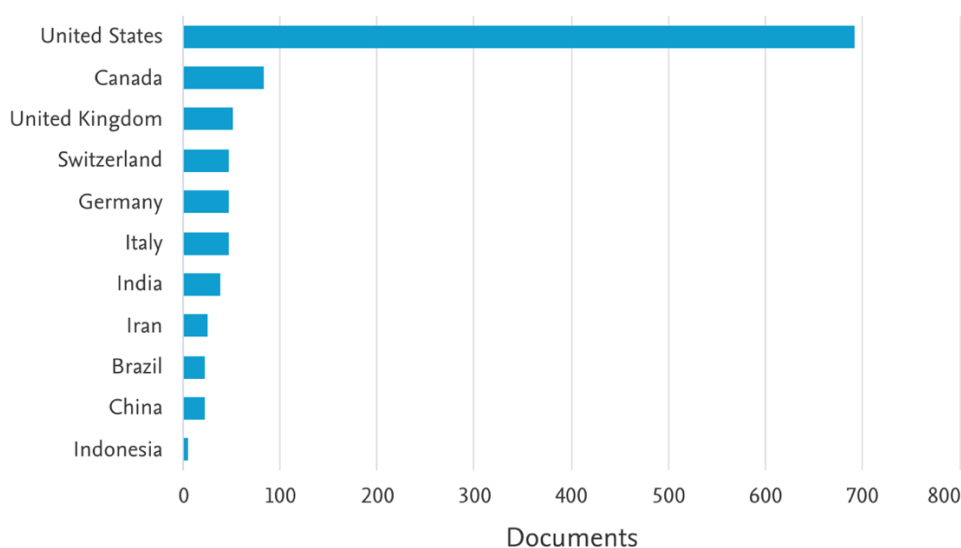


Figure 5. Top ten countries in the field of neurosurgery resident education

Type of publication in the field of neurosurgery resident education

Based on the type of publication, majority of publications were journal articles, accounting for 774 documents (75,3%), while 31 (8,6%) were reviews as seen in **Figure 6**. Other forms of publication conference papers, editorials, short survey, note, and letter are shown in **Figure 6**.

Documents by type

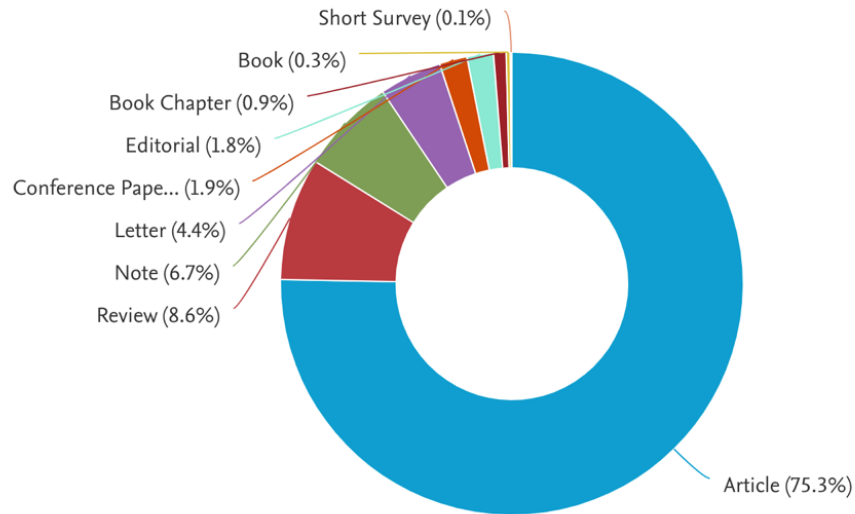


Figure 6. Type of documents that published in neurosurgery resident education

Network visualization of co-occurrence

The VOSviewer tool was utilized to visualize the keywords associated with neurosurgery resident education themes. In the default visualization, keywords were represented as circles as seen in **Figure 7**. The size of each circle corresponded to the frequency and significance of a keyword. "Neurosurgery" (264 occurrences) and "Education" (130 occurrences) emerged as the top research topics due to their high frequency. To improve clarity, colours were assigned to each circle based on their respective clusters.

The results were obtained by analyzing the frequency of keywords using bibliographic data with VOS viewer. A minimum keyword occurrence of five was set for inclusion. The search yielded a total of 1,870 keywords, but only 124 met the inclusion criteria. After analyzing the data, seven groupings were formed to represent research trends in interprofessional collaboration and medical education, each denoted by a different colour. The terms "Neurosurgery," "Resident," and "Education" were the most emphasized not only in cluster 1 but throughout the entire network.

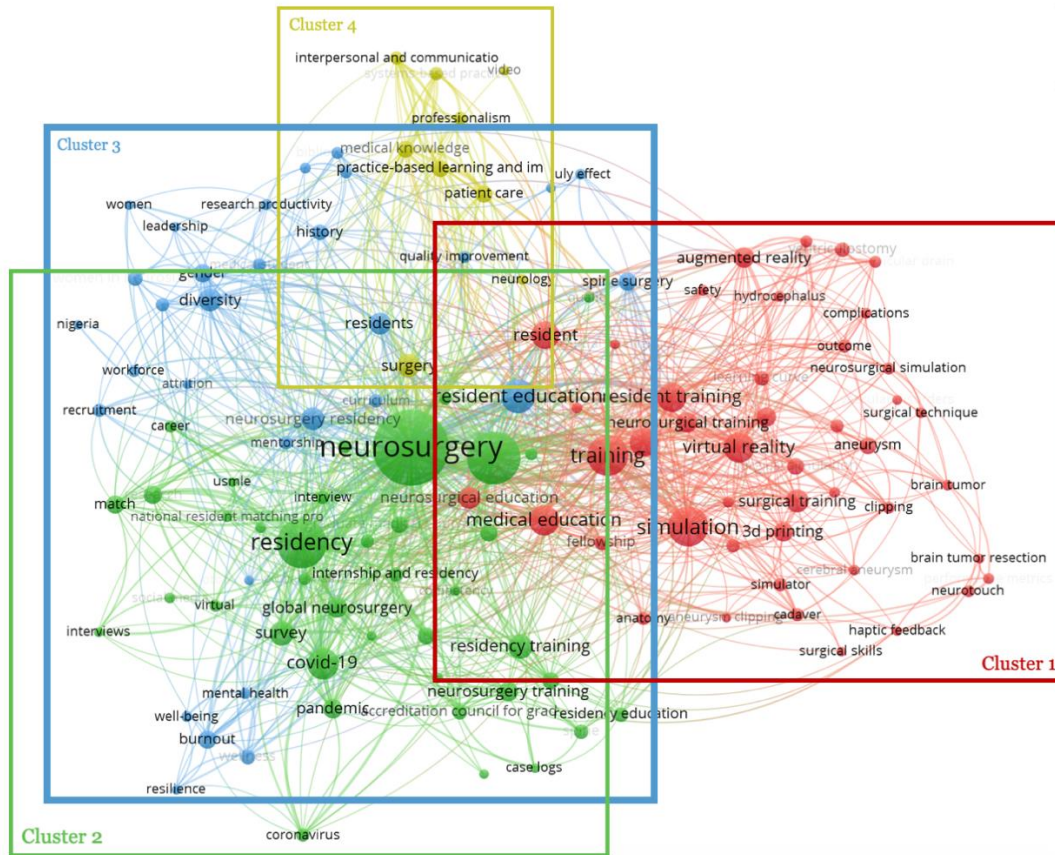


Figure 7. Network visualization of Interprofessional collaboration and medical education co-occurrence map using VOSviewer.

The network visualization describes four clusters and their linkages among examined areas is presented in **Figure 7**. Each cluster consisted of numerous keywords with a high agreement in the map structure. There were specific high-frequency occurrences of keywords signifying the research topic pursued in the past for each cluster. Detailed information regarding the result of cluster analysis is documented in **Table 2**.

Table 2. Result of cluster analysis

Cluster	Most frequent keywords	Keywords
Red-39 items	Training (77), Simulation (74), Virtual reality (42)	Medical education (41), surgical education (39), resident training (38), resident (37), surgical training (26), neurosurgical education (23), neurosurgical training (20), augmented reality (19), microsurgery (18), 3d printing (17), surgical simulation (14), aneurysm (13), learning curve (11), fellowship (10), ventriculostomy (10), cadaver (9), simulator (9), vascular neurosurgery (9), anatomy (8), outcome (8), skull base (8), clipping (7), external ventricular drain (7), mixed reality (7), neurosurgical simulation (7), neurotouch

		(7), brain tumor (6), cerebral aneurysm (6), cerebrovascular (6), complications (6), hydrocephalus (6), neuroanatomy (6), neurosurgical residency (6), performance metrics (6), safety (6), surgical technique (6), aneurysm clipping (5), artificial intelligence (5), brain tumor resection (5), haptic feedback (5), surgical skills (5), vascular disorders (5)
Green – 39 items	Neurosurgery (264), Education (130), Residency (114)	Covid-19 (46), residency training (27), survey (27), global neurosurgery (20), pandemic (18), neurosurgery training (17), match (15), research (15), acgme (14), graduate medical education (14), neurosurgery education (14), neurological surgery (13), accreditation council for graduate medical education (10), internship and residency (10), residency education (10), spine (10), coronavirus (9), global surgery (9), interview (9), africa (8), assessment (7), career (7), communication (7), global health (7), virtual (7), competency (6), national resident matching program (6), pediatric neurosurgery (6), quality (6), residency program (6), social media (6), case logs (5), interviews (5), low- and middle-income countries (5), stereotactic radiosurgery (5), usmle (5)
Blue - 31 items	Resident Education (54), Neurosurgery Residency (25), Diversity (24)	residents (23), burnout (16), gender (16), spine surgery (16), history (12), women in neurosurgery (11), wellness (10), curriculum (9), medical student (9), mentorship (9), recruitment (9), medical students (8), academic neurosurgery (7), bibliometrics (7), quality improvement (7), workforce (7), h-index (6), july effect (6), mental health (6), research productivity (6), well-being (6), attrition (5), leadership (5), nigeria (5), otolaryngology (5), outcomes (5), resilience (5), women (5)
Olive - 9 items	Surgery (26), Patient Care (14), Practice-Based Learning And Improvement (14)	medical knowledge (13), interpersonal and communication skills (8), professionalism (8), systems-based practice (8), neurology (6), video (5)

Source: Authors

DISCUSSION

Advancements in Technology

Neurosurgery resident education has undergone significant transformations, primarily driven by technological innovations. The incorporation of virtual and augmented reality (VR/AR) into training programs stands out as one of the most impactful advancements (17,18). These

technologies create immersive and interactive environments that replicate real-life surgical scenarios, enhancing the training experience without the associated risks of live surgery. For instance, VR-based simulations for cerebral aneurysm clipping with real-time haptic feedback allow residents to develop surgical skills and confidence in a controlled, risk-free setting. This hands-on approach not only improves technical proficiency but also prepares residents for high-stress surgical environments, ultimately leading to better patient outcomes (19). As demonstrated in Hey et al., AR has emerged as a transformative tool in neurosurgery, providing increased surgical planning and refined neuro navigation, hence boosting surgical precision and efficiency. Furthermore, incorporating augmented reality into training programs has been demonstrated to reduce patient risk while providing neurosurgeons with important learning opportunities in a variety of surgical specialities, including neuro-oncology, spine, and paediatric neurosurgery. However, as the study reveals, the current phase of AR research is still limited by small sample sizes and preliminary implementations, emphasising the need for additional developments to optimise its use in both educational and therapeutic settings (17).

Beyond VR/AR, simulation-based training methods such as video-based learning and 3D printing have also revolutionized neurosurgery education. Video-based learning enables trainees to observe expert surgeons and gain insights into complex procedures, which enhances their preparedness for actual surgeries. Meanwhile, 3D printing technology provides tangible models of anatomical structures, allowing for tactile and visual learning crucial for mastering intricate surgical techniques. These tools collectively contribute to the practical and cognitive development of neurosurgery residents, ensuring a well-rounded educational experience (20). According to Mishra et al., VR and AR technologies not only help with neurosurgery planning, but they also have a wide range of applications in training, rehabilitation, and procedural practice. Furthermore, VR/AR can be integrated into these simulation-based approaches to improve both the visual and tactile learning components, providing residents with an immersive environment in which to practise in a safe, controlled setting. The combination of these innovative technologies has the potential to develop a comprehensive instructional platform that enhances neurosurgery residents' skills while assuring patient safety and reducing the dangers associated with live surgeries (20).

Despite these technological advancements, challenges remain. Burnout among neurosurgery residents is a significant concern, often stemming from high workloads, stress, and insufficient work-life balance. Addressing these issues is vital to maintaining the well-being of residents, enabling them to fully engage with advanced training tools. Furthermore, gender disparities within surgical education pose additional challenges. Although there are positive trends in enrollment and reduced attrition rates among female residents, disparities persist, particularly in specialties like orthopaedic surgery. Female role models and mentors play a crucial role in influencing the specialty choices of medical graduates, underscoring the importance of fostering a supportive and inclusive environment (12).

Unconscious biases related to race and social class further complicate the educational and clinical landscape. Such biases can impact clinical treatment decisions and interactions within surgical teams, highlighting the need for cultural competency and bias training in residency programs. Promoting equitable care and creating an inclusive environment for all trainees is essential for advancing the field and ensuring the best outcomes for patients (9).

Core Journals and Publications

The analysis of core journals in neurosurgery resident education underscores the importance of leading scientific publications in disseminating research and knowledge. Journals such as the Journal of World Neurosurgery, the Journal of Neurosurgery, and Neurosurgery have emerged as key platforms for sharing advancements and best practices in the field. These journals not only highlight the latest research but also influence educational methodologies and standards, playing a pivotal role in shaping the future of neurosurgery resident education.

The analysis of core journals in neurosurgery resident education underscores the importance of leading scientific publications in disseminating research and knowledge. These core journals serve as the bedrock for both academic and practical advancements within the field. By regularly publishing cutting-edge research, these journals ensure that neurosurgery residents have access to the most current information, techniques, and technological developments. This continuous flow of up-to-date knowledge is essential for residents to stay informed about the evolving landscape of neurosurgery, thereby enhancing their training and clinical decision-making capabilities.

Journals such as the Journal of World Neurosurgery, the Journal of Neurosurgery, and Neurosurgery have emerged as key platforms for sharing advancements and best practices in the field. Each of these publications is renowned for its rigorous peer-review process, ensuring that only high-quality, impactful research is disseminated to the medical community. These journals cover a broad spectrum of topics, from novel surgical techniques and patient management strategies to groundbreaking discoveries in neuroanatomy and pathology. By featuring comprehensive reviews, case studies, and original research articles, they provide a rich repository of knowledge that is invaluable for both educators and learners in neurosurgery (17-19).

These journals not only highlight the latest research but also influence educational methodologies and standards, playing a pivotal role in shaping the future of neurosurgery resident education. As noted in the study by Hey et al., AR and VR technologies are increasingly recognized for their potential to enhance neurosurgical training (17). These technologies not only refine surgical planning and neuro navigation but also present innovative training opportunities, improving both technical proficiency and decision-making in real-world scenarios. By promoting evidence-based practices and showcasing successful training models, such as the integration of AR/VR in training protocols, these publications help set benchmarks for neurosurgical education worldwide, ensuring that residency programs are equipped with the latest advancements in both technology and pedagogy (17,20). Consequently, the continuous interaction between journal content and residency curricula ensures that neurosurgery training programs are aligned with the highest standards of clinical practice and academic excellence, fostering the development of skilled and knowledgeable neurosurgeons.

Type of Publications

The predominance of journal articles in neurosurgery resident education highlights the field's reliance on scholarly research and evidence-based practices. However, the presence of other publication types, such as reviews, conference papers, and editorials, indicates a diverse range of content contributing to the literature. This diversity enriches the field by providing various perspectives and insights, which are crucial for a comprehensive understanding of educational practices and their implications. Discussing the significance of different publication types can offer

a nuanced view of how knowledge is advanced and disseminated in neurosurgery resident education.

The predominance of journal articles in neurosurgery resident education underscores the field's deep reliance on scholarly research and evidence-based practices. Journal articles are the cornerstone of academic discourse, offering detailed reports on experimental studies, clinical trials, and innovative techniques. These articles are typically subjected to rigorous peer review, ensuring the integrity and validity of the research presented. For neurosurgery residents, engaging with these articles is crucial for developing a strong foundation in current medical knowledge and for fostering critical thinking skills necessary for clinical practice and research.

However, the presence of other publication types, such as reviews, conference papers, and editorials, indicates a diverse range of content that enriches the field of neurosurgery. Reviews, for example, synthesize existing research on a particular topic, providing residents with comprehensive overviews that can help them understand complex subjects more thoroughly. Conference papers often present cutting-edge research and emerging trends that have not yet made it into peer-reviewed journals, offering residents a glimpse into the latest developments and fostering a dynamic learning environment. Editorials, on the other hand, provide expert opinions and commentary on current issues, encouraging residents to engage with ongoing debates and to consider broader implications of their work.

This diversity in publication types is crucial for a comprehensive understanding of educational practices and their implications in neurosurgery resident education. By engaging with a variety of publication formats, residents gain access to a wide array of perspectives and insights. This multifaceted approach to learning helps them to appreciate the complexity of medical knowledge and the various ways in which it can be applied to improve patient care. Moreover, it encourages a culture of lifelong learning and adaptability, as residents are exposed not only to established practices but also to new ideas and innovations that challenge the status quo. Ultimately, this rich tapestry of scholarly content ensures that neurosurgery residents are well-equipped to contribute to the advancement of their field.

Global Publication Trends

The global publication trends reveal a growing interest in neurosurgery resident education worldwide. The increasing number of publications over the years signifies a heightened focus on enhancing the training and education of neurosurgery residents. This trend reflects the global commitment to improving surgical education and outcomes. Discussing the implications of this trend can provide valuable insights for educators, policymakers, and researchers, emphasizing the need for continuous improvement and adaptation to new challenges and technologies (16).

The increasing number of publications over the years highlights an intensified focus on refining the training methodologies and educational frameworks that shape future neurosurgeons. This surge in scholarly output not only underscores the importance placed on high-quality education but also mirrors the dynamic nature of the medical field, where continuous innovation and evidence-based practices are paramount. According to Kirkman et al., simulation technologies have emerged as a critical tool in neurosurgery training, providing high-quality, time-efficient techniques for trainees to learn fundamental skills in a safe setting (11). This has proven notably useful in neurosurgery, where technical errors can have catastrophic implications, emphasizing the importance of thorough training solutions. Similarly, Langridge et al., found that 3D printing has

quickly acquired traction in surgical education, particularly in neurosurgery, where it aids both anatomical education and preoperative planning, resulting in better patient outcomes than traditional techniques (14). The global interest in neurosurgery education signifies a collective effort to enhance surgical proficiency and patient outcomes across diverse healthcare systems (11-14).

The implications of these global publication trends are far-reaching for educators, policymakers, and researchers alike. For educators, the burgeoning body of literature provides a wealth of resources and insights that can be integrated into residency programs to foster more effective and up-to-date training approaches. This comprehensive knowledge base enables educators to draw from a variety of international perspectives and best practices, thereby enriching the learning experiences of residents. Policymakers can leverage this trend to advocate for and implement policies that support sustained investment in neurosurgery education, ensuring that training programs are well-equipped to meet the evolving demands of the field. Researchers, on the other hand, can identify emerging areas of interest and gaps in the literature, guiding future studies and innovations in neurosurgery education.

Furthermore, the emphasis on continuous improvement and adaptation to new challenges and technologies is critical in the context of these global publication trends. The rapid advancements in medical technology and surgical techniques necessitate a corresponding evolution in educational strategies. By staying abreast of global research developments, neurosurgery residency programs can incorporate cutting-edge technologies and methodologies into their curricula, preparing residents to adeptly navigate the complexities of modern surgical practice. This forward-looking approach ensures that neurosurgeons are not only proficient in current standards but are also equipped to lead future advancements in the field. The global commitment to enhancing neurosurgery education, as reflected in these publication trends, ultimately aims to improve patient care and surgical outcomes on a worldwide scale.

Future Directions

The bibliometric analysis concludes by suggesting future directions for research and practice in neurosurgery resident education. These directions include exploring new technological innovations, addressing existing challenges such as burnout and gender disparities, and promoting cultural competency. By focusing on these areas, stakeholders can stimulate further research, innovate educational strategies, and enhance collaboration. Reflecting on the identified gaps and potential areas for development will be crucial for advancing the field and ensuring that neurosurgery residents receive the best possible training and support.

CONCLUSION

In conclusion, the bibliometric analysis of neurosurgery resident education highlights the significant impact of technological advancements such as VR/AR, video-based learning, and 3D printing. These tools enhance the training experience, making it more comprehensive and effective. While these technologies offer promising benefits, the study acknowledges the need for better integration into traditional curricula and further exploration of their long-term effectiveness in real-world settings. However, addressing challenges such as burnout, gender disparities, and unconscious biases is crucial for maximizing the benefits of these advanced training tools and creating a supportive and inclusive environment for all neurosurgery residents. Additionally,

efforts should be made to develop strategies for mitigating these challenges, ensuring that all residents can thrive in their education and career. Future research and educational strategies should continue to focus on these areas to further advance the field and improve training outcomes. Further research into the best blend of technical tools and conventional educational approaches could aid in the development of more efficient, balanced training programs.

Ethics approval

Ethics approval not required.

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Conflict of interest

I undersign, certificate that I do not have any financial or personal relationships that might bias the content of this work.

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REFERENCES

1. Murakami, M., Morikawa, K., Matsuno, A., Kaneda, K., & Nagashima, T. (2000). Spontaneous intracranial hypotension associated with bilateral chronic subdural hematomas—Case report. *Neurologia Medico-Chirurgica (Tokyo)*, 40(9), 484–488. <https://doi.org/10.2176/nmc.40.484>
2. Keler, T., Graziano, R. F., Mandal, A., Wallace, P. K., Fisher, J., Guyre, P. M., & et al. (1997). Bispecific antibody-dependent cellular cytotoxicity of HER2/neu-overexpressing tumor cells by Fc gamma receptor type I-expressing effector cells. *Cancer Research*, 57(18), 4008–4014. <https://doi.org/10.1158/0008-5472.CAN-97-1641>
3. Konakondla, S., Fong, R., & Schirmer, C. M. (2017). Simulation training in neurosurgery: Advances in education and practice. *Advances in Medical Education and Practice*, 8, 465–473. <https://doi.org/10.2147/AMEP.S113565>
4. Kilbourn, K. J., Leclair, N. K., Martin, J. E., Bookland, M. J., Kureshi, I. U., Bulsara, K. R., & et al. (2023). Incorporating simulation into the neurosurgical residency curriculum: A program director survey. *Journal of Neurosurgery*, 139(1), 286–291. <https://doi.org/10.3171/2023.1.JNS222589>
5. Kanmounye, U. S., Robertson, F. C., Sebopelo, L. A., Senyuy, W. P., Sichimba, D., Keke, C., & et al. (2021). Bibliometric analysis of the 200 most cited articles in *World Neurosurgery*, 149, 226–231.e3. <https://doi.org/10.1016/j.wneu.2020.12.035>
6. Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quantitative Science Studies*, 1(1), 377–386. https://doi.org/10.1162/qss_a_00010

7. Pelargos, P. E., Nagasawa, D. T., Lagman, C., Tenn, S., Demos, J. V., Lee, S. J., & et al. (2017). Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery. *Journal of Clinical Neuroscience*, 35, 1–4. <https://doi.org/10.1016/j.jocn.2016.09.002>
8. Chambers, C. C., Ihnow, S. B., Monroe, E. J., & Suleiman, L. I. (2018). Women in orthopaedic surgery: Population trends in trainees and practicing surgeons. *Journal of Bone and Joint Surgery, American Volume*, 100(17), e116. <https://doi.org/10.2106/JBJS.17.01291>
9. Haider, A. H., Schneider, E. B., Sriram, N., Dossick, D. S., Scott, V. K., Swoboda, S. M., & et al. (2015). Unconscious race and social class bias among acute care surgical clinicians and clinical treatment decisions. *JAMA Surgery*, 150(5), 457–464. <https://doi.org/10.1001/jamasurg.2014.4038>
10. Alaraj, A., Luciano, C. J., Bailey, D. P., Elsenousi, A., Roitberg, B. Z., Bernardo, A., & et al. (2015). Virtual reality cerebral aneurysm clipping simulation with real-time haptic feedback. *Neurosurgery*, 11(Suppl 2), 52–58. <https://doi.org/10.1227/NEU.0000000000000583>
11. Kirkman, M. A., Ahmed, M., Albert, A. F., Wilson, M. H., Nandi, D., Sevdalis, N. (2014). The use of simulation in neurosurgical education and training: A systematic review. *Journal of Neurosurgery*, 121(2), 228–246. <https://doi.org/10.3171/2014.5.JNS131766>
12. Jagsi, R., Griffith, K. A., DeCastro, R. A., & Ubel, P. (2014). Sex, role models, and specialty choices among graduates of US medical schools in 2006-2008. *Journal of the American College of Surgeons*, 218(3), 345–352. <https://doi.org/10.1016/j.jamcollsurg.2013.11.012>
13. Mota, P., Carvalho, N., Carvalho-Dias, E., Costa, M. J., Correia-Pinto, J., & Lima, E. (2018). Video-based surgical learning: Improving trainee education and preparation for surgery. *Journal of Surgical Education*, 75(3), 828–835. <https://doi.org/10.1016/j.jsurg.2017.09.027>
14. Langridge, B., Momin, S., Coumbe, B., Woin, E., Griffin, M., & Butler, P. (2018). Systematic review of the use of 3-dimensional printing in surgical teaching and assessment. *Journal of Surgical Education*, 75(1), 209–221. <https://doi.org/10.1016/j.jsurg.2017.06.033>
15. Renfrow, J. J., Rodriguez, A., Liu, A., Pilitsis, J. G., Samadani, U., Ganju, A., & et al. (2016). Positive trends in neurosurgery enrollment and attrition: Analysis of the 2000-2009 female neurosurgery resident cohort. *Journal of Neurosurgery*, 124(3), 834–839. <https://doi.org/10.3171/2015.3.JNS142313>
16. Attenello, F. J., Buchanan, I. A., Wen, T., Donoho, D. A., McCartney, S., Cen, S. Y., & et al. (2018). Factors associated with burnout among US neurosurgery residents: A nationwide survey. *Journal of Neurosurgery*, 129(5), 1349–1363. <https://doi.org/10.3171/2017.9.JNS17996>
17. Hey, G., Guyot, M., Carter, A., & Lucke-Wold, B. (2023). Augmented reality in neurosurgery: A new paradigm for training. *Medicina (Buenos Aires)*, 59(10), 1721. <https://doi.org/10.3390/medicina59101721>
18. Hyer, L., Boyd, S., Scurfield, R., Smith, D., & Burke, J. (1996). Effects of outward bound experience as an adjunct to inpatient PTSD treatment of war veterans. *Journal of Clinical*

- Psychology*, 52(3), 263–278. [https://doi.org/10.1002/\(SICI\)1097-4679\(199605\)52:3<263::AID-JCLP3>3.0.CO;2-T](https://doi.org/10.1002/(SICI)1097-4679(199605)52:3<263::AID-JCLP3>3.0.CO;2-T)
19. Haq, M. Z., Willett, A., & Holland, J. (2023). Augmented reality as a tool for enhancing neurosurgery: An exploration of mixed reality surgical technologies. *Journal of Scientific Innovation in Medicine*, 6(1). <https://doi.org/10.29024/jsim.179>
 20. Mishra, R., Narayanan, M. D. K., Umana, G. E., Montemurro, N., Chaurasia, B., & Deora, H. (2022). Virtual reality in neurosurgery: Beyond neurosurgical planning. *International Journal of Environmental Research and Public Health*, 19(3), 1719. <https://doi.org/10.3390/ijerph19031719>