Mapping Global Neurosurgery Research Collaboratives: A Social Network Analysis of the 50 Most Cited Global Neurosurgery Articles

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Social network analysis of bibliometric data evaluates the relationships between the articles, authors, and themes of a research niche. The network can be visualized as maps composed of nodes and links. This study aimed to identify and evaluate the relationships between articles, authors, and keywords in global neurosurgery. The authors searched global neurosurgery articles on the Web of Science database from inception to June 18, 2020. The 50 most cited articles were selected and their metadata (document coupling, co-authorship, and co-occurrence) was exported. The metadata were analyzed and visualized with VOSViewer (Centre for Science and Technology Studies, Leiden University, The Netherlands). The articles were published between 1995 and 2020 and they had a median of 4.0 (interquartile range [IQR] = 5.0) citations. There were 5 clusters in the document coupling and 10 clusters in the co-authorship analysis. A total of 229 authors contributed to the articles and Kee B. Park contributed the most to articles (14 publications). Backward citation analysis was organized into 4 clusters and co-occurrence analysis into 7 clusters. The most common themes were pediatric neurosurgery, neurotrauma, and health system strengthening. The authors identified trends, contributors, and themes of highly cited global neurosurgery research. These findings can help establish collaborations and set the agenda in global neurosurgery research.

KEYWORDS: Bibliometrics, Global neurosurgery, Neurosurgery, Scientometrics, Social network analysis

The majority of patients in need of neurosurgical care live in resource-limited settings where they lack access to timely, safe, and affordable care.1,2 In these settings, patients often present late to definitive care facilities, face catastrophic neurosurgery-related expenditures, or are treated in hospitals that lack workforce, funding, and infrastructure.3,5 Global neurosurgery, a field at the intersection between neurosurgery and public health, researches, educates, and advocates universal access to neurosurgical care and improved health outcomes.6

Global neurosurgery has grown significantly over the past 5 years, gaining support from trainees, neurosurgeons, and neurosurgical societies.7 For example, the World Federation of Neurosurgical Societies (WFNS) has created an ad hoc committee to coordinate its member societies’ global neurosurgery efforts.8,9 This committee has defined 5 objectives for the global neurosurgery movement: i. Amplify access to neurosurgical care; ii. Align global neurosurgery efforts; iii. Advance global neurosurgery research (GNR); iv. Assimilate capacity building into surgical systems; and v. Advocate for universal health coverage. The advancement of GNR efforts has been the most successful.10

Research is an essential aspect of global neurosurgery. It provides data for advocacy, identifies barriers to universal

**ABBREVIATIONS:** GNR, global neurosurgery research; IQR, interquartile range; LMICs, low- and middle-income countries; WFNS, World Federation of Neurosurgical Societies
neurosurgical care, and informs policy making.⁷ For example, landmark global neurosurgery studies highlighted the workforce deficit, operative case volumes, and geographical distribution of equipment and infrastructure in low- and middle-income countries (LMICs).¹⁰,¹¹ The data from these studies have been used to advocate for and create global neurosurgery policies at high-level meetings.¹²,¹³

We aimed to describe the landscape of GNR based on the 50 most cited articles. The results will help identify trends, actors, and themes of GNR.

METHODS

Social network visualization illustrates the bibliometric relationships between articles, authors, co-authors, author affiliations, citations, or themes (collectively called items) within a field.

Definitions

A network or graph is an irregular and nonrandom pattern of pairwise interactions between nodes or vertices.¹⁴ The nodes in bibliometric social network analysis represent items (articles, authors, co-authors, author affiliations, citations, or keywords/co-occurrences), and their size is directly proportional to their connectivity (i.e., the number of connections the node possesses).¹⁵ Nodes are connected by links (edges) and the link’s length is inversely proportional to the connection between the nodes. A node “A” is considered central if the maximum distance between node “A” and the farthest node is equal to the smallest distance between any two nodes in the directed graph.¹⁴ Practically, these concepts permit the identification of influential and “well-connected” items (i.e., articles, researchers, and themes).

An ensemble of nodes forms a cluster (community). The more clusters a network has, the higher the probability that 2 nodes with another node in common will be linked.¹⁴,¹⁵ Practically, this allows for inferences on the possibility of collaborations between two authors who have never worked together, given that they have worked with a common author in the past.

Therefore, a social network quantifies and visualizes the roles and relations between nodes and clusters in a network.¹⁵

Data Analysis

In this scientometric analysis, the authors searched the science citation index on Web of Science from inception to June 18, 2020. The search included the terms “global neurosurgery” OR “global surgery” AND “neurosurgery.” The search results were sorted in descending order of citations and metadata were exported as text files into VOSViewer (Centre for Science and Technology Studies, Leiden University, The Netherlands), where document coupling, co-authorship, and co-occurrence visualizations were generated. Articles with fewer than 2 citations and no links with the other articles were excluded to reduce clutter on the visualizations.
| Article (year of publication) | Citations | Total link strength |
|------------------------------|-----------|---------------------|
| 1. Dewan et al (2018)        | 102       | 58                  |
| 2. Park et al (2016)         | 54        | 54                  |
| 3. Ellegala et al (2014)     | 24        | 26                  |
| 4. Abdelgadir et al (2017)   | 17        | 46                  |
| 5. Mukhopadhyay et al (2019) | 13        | 56                  |
| 6. Corley et al (2019)       | 12        | 60                  |
| 7. Kuo et al (2017)          | 12        | 18                  |
| 8. Dewan et al (2018)        | 10        | 80                  |
| 9. Warf et al (2015)         | 10        | 14                  |
| 10. Dewan et al (2018)       | 9         | 68                  |
| 11. Kinasha et al (2012)     | 8         | 0                   |
| 12. Barthélemy et al (2018)  | 7         | 77                  |
| 13. Eaton et al (2017)       | 7         | 6                   |
| 14. Karras et al (2017)      | 7         | 0                   |
| 15. Rosseau et al (2018)     | 6         | 85                  |
| 16. Venturini et al (2018)   | 6         | 63                  |
| 17. Leidinger et al (2018)   | 6         | 52                  |
| 18. Dempsey et al (2018)     | 6         | 45                  |
| 19. Nicolosi et al (2018)    | 6         | 40                  |
| 20. Santos et al (2018)      | 6         | 34                  |
| 21. Abdelgadir et al (2017)  | 5         | 60                  |
| 22. Vaca et al (2019)        | 5         | 26                  |
| 23. Almeida et al (2018)     | 4         | 86                  |
| 24. Vervoort et al (2019)    | 4         | 46                  |
| 25. Tropeano et al (2019)    | 4         | 22                  |
| 26. Xu et al (2018)          | 3         | 28                  |
| 27. West et al (2018)        | 3         | 9                   |
| 28. Leidinger et al (2019)   | 3         | 5                   |
| 29. Jean et al (2020)        | 3         | 0                   |
| 30. Krishna et al (2011)     | 3         | 0                   |
| 31. Magarik et al (2012)     | 3         | 0                   |
| 32. Parkinson et al (1995)   | 3         | 0                   |
| 33. Haglund et al (2019)     | 2         | 114                 |
| 34. Karekezi et al (2020)    | 2         | 75                  |
| 35. Park et al (2019)        | 2         | 47                  |
| 36. Bean et al (2017)        | 2         | 22                  |
| 37. Rosseau et al (2020)     | 1         | 64                  |
RESULTS

Document Coupling

We identified 50 articles published between 1995 and 2020. Most (88.0%, n = 44) articles were published in prominent specialty journals: World Neurosurgery (36.0%, n = 18), Neurosurgical Focus (22.0%, n = 11), Journal of Neurosurgery (20.0%, n = 10), Neurosurgery (6.0%, n = 3), and Acta Neurochirurgica (4.0%, n = 2). The Journal of Neurosurgery articles had 158 citations, while World Neurosurgery articles had 151, and Neurosurgical Focus articles had 49. The other specialty journals had fewer than 10 citations each.

The median number of citations per article was 4.0 (interquartile range [IQR] = 5.0). The most cited article had 102 citations, almost twice as many as the second most cited article (54 citations). There were 24 prominent articles organized into 5 clusters organized around Dewan et al (red), Park et al (purple), Ellegala et al (yellow), Abdelagdir et al (green), and Dewan et al (blue) (Figure 1). Four (8.0%) articles had no links with the other articles, while the 46 (92.0%) linked articles had 474 links and a total link strength of 932 (Table 1).

Co-Authorship Analysis

A total of 229 authors contributed to the 50 articles, and of these, 82 (35.8%) authors had contributed to a single manuscript and had no links with other authors. The remaining 147 (64.2%) authors were organized into 10 clusters connected by 994 links and a total link strength of 1185 (Figure 2).

Notable research collaboratives included the Duke Global Neurosurgery and Neurology-Mulago National Referral Hospital dyad (brown cluster), the WFNS Global Neurosurgery and WFNS-World Health Organization team (green cluster),
| Author           | Number of publications | Citations | Citations per publication | Total link strength |
|------------------|------------------------|-----------|---------------------------|---------------------|
| 1. Park, Kee B.  | 14                     | 222       | 15.86                     | 68                  |
| 2. Haglund, Michael M. | 9                 | 55        | 6.11                      | 80                  |
| 3. Servadei, Franco | 7                  | 122       | 17.43                     | 62                  |
| 4. Dewan, Michael C. | 5                 | 135       | 27.00                     | 43                  |
| 5. Johnson, Walter D. | 5                 | 172       | 34.40                     | 32                  |
| 6. Kiryabwire, Joel | 5                 | 26        | 5.20                      | 54                  |
| 7. Mukasa, John  | 5                     | 26        | 5.20                      | 54                  |
| 8. Ssenyonjo, Hussein | 5                | 26        | 5.20                      | 54                  |
| 9. Muhumuza, Michael | 4                 | 21        | 5.25                      | 45                  |
| 10. Rattani, Abbas | 4                 | 125       | 31.25                     | 38                  |
| 11. Vaca, Silvia D. | 4                 | 21        | 5.25                      | 45                  |
| 12. Vissoci, Joao Ricardo | 4               | 19        | 4.75                      | 41                  |
| 13. Warf, Benjamin C. | 4                | 131       | 32.75                     | 23                  |
| 14. Abdelgadir, Jihad | 3                | 23        | 7.67                      | 25                  |
| 15. Barthelemy, Ernest J. | 3               | 9         | 3.00                      | 16                  |
| 16. Corley, Jacquelyn | 3               | 14        | 4.67                      | 19                  |
| 17. Dempsey, Robert J. | 3                | 69        | 23.00                     | 12                  |
| 18. Eligala, Dilantha B. | 3               | 35        | 11.67                     | 18                  |
| 19. Hartl, Roger  | 3                     | 10        | 3.33                      | 24                  |
| 20. Leidinger, Andreas | 3               | 10        | 3.33                      | 21                  |
| 21. Muhindo, Alex  | 3                     | 23        | 7.67                      | 25                  |
| 22. Muhumuza, Christine | 3               | 16        | 5.33                      | 34                  |
| 23. Punchak, Maria | 3                     | 31        | 10.33                     | 28                  |
| 24. Shabani, Hamisi K. | 3                | 10        | 3.33                      | 24                  |
| 25. Staton, Catherine A. | 3               | 18        | 6.00                      | 33                  |
| 26. Xu, Linda W.  | 3                     | 9         | 3.00                      | 32                  |
| 27. Bernstein, Mark | 2                 | 5         | 2.50                      | 14                  |
| 28. Charles, Anthony | 2                 | 8         | 4.00                      | 9                   |
| 29. Eaton, Jessica | 2                     | 8         | 4.00                      | 9                   |
| 30. Elahi, Cyrus   | 2                     | 2         | 1.00                      | 17                  |
| 31. Faruque, Serena | 2                 | 22        | 11.00                     | 19                  |
| 32. Grant, Gerald A. | 2                 | 17        | 8.50                      | 24                  |
| 33. Hutchinson, Peter J. | 2               | 5         | 2.50                      | 13                  |
| 34. Karekezi, Claire | 2                 | 6         | 3.00                      | 30                  |
| 35. Karekezi, Claire | 2                 | 11        | 5.50                      | 8                   |
### Table 2. Continued

| Author                  | Number of publications | Citations | Citations per publication | Total link strength |
|-------------------------|------------------------|-----------|---------------------------|--------------------|
| 36. Kim, Eliana E.      | 2                      | 9         | 4.50                      | 13                 |
| 37. Kitya, David        | 2                      | 18        | 9.00                      | 16                 |
| 38. Kolas, Angelos G.   | 2                      | 10        | 5.00                      | 11                 |
| 39. Kuo, Benjamin J.   | 2                      | 17        | 8.50                      | 24                 |
| 40. Lerman, Benjamin J. | 2                      | 4         | 2.00                      | 21                 |
| 41. Magarik, Jordan     | 2                      | 11        | 5.50                      | 8                  |
| 42. Naik, Juliet        | 2                      | 4         | 2.00                      | 21                 |
| 43. Onen, Justin        | 2                      | 12        | 6.00                      | 29                 |
| 44. Rice, Henry E.      | 2                      | 17        | 8.50                      | 24                 |
| 45. Rosseaux, Gail      | 2                      | 7         | 3.50                      | 12                 |
| 46. Rutabasibwa, Nicephorus | 2                  | 4         | 2.00                      | 16                 |
| 47. Rutka, James T.     | 2                      | 5         | 2.50                      | 6                  |
| 48. Spaggiari, Riccardo | 2                      | 5         | 2.50                      | 13                 |
| 49. Ssenyonga, Peter    | 2                      | 11        | 5.50                      | 16                 |
| 50. Venturini, Sara     | 2                      | 7         | 3.50                      | 6                  |
| 51. Warf, Benjamin      | 2                      | 2         | 1.00                      | 18                 |

University of Toronto team (purple cluster), and the WFNS Rabat Training Center (dark blue cluster) (Figure 2). The WFNS Rabat Training Center had the strongest links. Other research groups included Vanderbilt University, Icahn School of Medicine, Meharry Medical College, University of Wisconsin, Stanford University, University of Cambridge, Medical University of South Carolina, Muhimbili Orthopedic Institute, and Makerere University.

Kee B. Park (14 articles), Michael Haglund (9 articles), Franco Servadei (7 articles), Hussein Ssenyonga (5 articles), Joel Kiryabwire (5 articles), Michael Dewan (5 articles), and Walter Johnson (5 articles) published the highest number of articles. The following authors cumulated the highest number of citations: Kee B. Park (222 citations), Walter Johnson (172 citations), Michael Dewan (135 citations), Benjamin Warf (131 citations), Abbas Ratani (125 citations), and Franco Servadei (122 citations). Also, Walt Johnson (34.40), Benjamin Warf (32.8), Abbas Rattani (31.3), Michael Dewan (27.0), and Robert Dempsey (23.0) had the highest number of citations per publication (Table 2).

#### Backward Citation Analysis

The GNR articles regularly cited 35 articles organized into 4 clusters.6,10,58-69 Among these referenced articles, Park et al6 (20 references) and Meara et al64 (18 references) were the most cited (Figure 3).

#### Keyword Analysis

There were 65 common keywords (co-occurrences) organized into 7 clusters. “Global Neurosurgery” appeared in 35 (70.0%) papers, while the combination of “Global Surgery” and “Neurosurgery” appeared in the remaining 15 (30.0%). “Traumatic brain injury” appeared in 12 (24.0%) documents, and “epidemiology” appeared in 8 (16.0%). Between 2017 and 2018, keywords referred to the treatment of hydrocephalus (dark blue cluster). More recent articles were focused on neurotrauma, neurosurgical workforce density, and myelomeningocoele (yellow cluster) (Figure 4).

#### DISCUSSION

##### Influential Articles, Authors, and Institutions

This study is the first to describe influential GNR authors, institutions, and themes. Our analysis showed that the most cited GNR is published primarily by HIC academic institutions and researchers. Also, most LMIC research groups published in collaboration with HIC institutions.

Dewan et al2 defined the number of patients in need of essential neurosurgical intervention, and calculated the global specialist workforce deficit. They highlighted 2 regions that needed immediate attention: Sub-Saharan Africa and Southeast Asia.2 The results were then used to design an executive
summary for the Global Neurosurgery Initiative at the Program in Global Surgery and Social Change, Harvard Medical School. The publication had a diverse authorship—representatives from every region, continental society, and major global neurosurgery academic centers contributed to the paper. The diverse experience and perspectives may explain why the article is central to GNR. In a similar study, researchers quantified the pediatric neurosurgery workforce density, access to equipment, and expressed local pediatric neurosurgeons’ training needs.\textsuperscript{70} This revealed that the pediatric population faced greater disparities than adults.

The GNR co-authorship network is highly connected. The high connectivity in GNR can be attributed in part to the central role of some institutions and authors. For example, Michael Dewan and Kee B. Park, the authors with the most combined citations in global neurosurgery, were both affiliated with the Global Neurosurgery Initiative at the Program in Global Surgery...
and Social Change. Kee B. Park leads this program and co-chairs the WFNS Global Neurosurgery Committee. As such, he has served as a bridge between organized and academic global neurosurgery.

The WFNS has contributed equally and substantially to GNR. Franco Servadei (WFNS President), Gail Rosseau (WFNS-World Health Organization Liaison Committee), and Angelos Kolias (WFNS Young Neurosurgeons Forum Chair) figure among the most prominent GNR contributors of the most cited articles. This attests to the WFNS Global Neurosurgery Committee’s commitment to map GNR output, establish grants, advocate for global neurosurgery publication in specialty journals, foster research capacity building, and networking in the field.

Other institutions and collaborators play an important role in GNR: (1) the Duke Global Neurosurgery and Neurology group (represented in Figure 2 by Michael Haglund, Anthony Fuller) and their partners at Mulago Hospital/Makerere University College of Health Sciences in Kampala, Uganda; this group has published extensively on the barriers and solutions to neurosurgery education, research, and practice in Uganda; and (2) the University of Toronto group [represented by Mark Bernstein and Claire Karekezi (Figure 2, purple)] and the WFNS Rabat Training Center (Figure 2, dark blue): these 2 groups have contributed significantly to the training of LMIC residents and neurosurgeons.

While LMIC researchers are key actors of GNR, they are under-represented among the most cited articles’ co-authors. They generate, collect, and curate GNR data; however, the most cited publications do not reflect their contributions. This is a cause of concern for the GNR community. The GNR community should promote collaborations, especially between LMIC institution/co-author clusters that are far apart. For example, the North and East African co-author clusters could spearhead an African GNR collaborative. In addition, few LMIC journals had articles among the most cited GNR publications. The GNR community should support LMIC research through publication in local journals and citation of local manuscripts, especially those published in local journals. While most of these journals are not on major databases they can be found in the World Health Organization Library Database, in regional registries (eg, African Journals Online database), and on Google Scholar. Furthermore, neurosurgery professional societies should promote GNR capacity building by encouraging the submission of LMIC abstracts to their scientific events. This should help increase exposure of LMIC research.

Citation metrics give an insight into the level of interest garnered by an article. By curating a list of the most cited global neurosurgery articles, we have curated a list of must read GNR:

- “Global Neurosurgery: The Unmet Need” defines global neurosurgery and identifies the barriers to universal neurosurgical care.
- “Global Neurosurgery: The Current Capacity and Deficit in the Provision of Essential Neurosurgical Care. Executive Summary of the Global Neurosurgery Initiative at the Program in Global Neurosurgery and Social Change” estimates the global burden of neurosurgical diseases and the workforce deficit.
- “Operative and Consultative Proportions of Neurosurgical Disease Worldwide: Estimation From the Surgeon Perspective” discusses surgeons’ perspective of the workload (proportion of diseases needing surgical intervention and proportion of diseases needing the consultation with a neurosurgeon). This paper makes the case for workforce innovations like task-sharing/task-shifting.
- “Global Neurosurgery: Current and Potential Impact of Neurosurgeons at the World Health Organization and the World Health Assembly. Executive Summary of the World Federation of Neurosurgical Societies-World Health Organization Liaison Committee at the 71st World Health Assembly” highlights the role of global neurosurgeons in high-level public health meetings. This article is the epitome of advocacy in global neurosurgery.
- “Global Neurosurgery: Innovators, Strategies, and the Way Forward: JNSPG 75th Anniversary Invited Review Article” identifies successful global neurosurgery innovations.

The articles above give an overview of neurosurgical care in LMICs; however, LMICs are not a homogenous group. Each country has a unique set of difficulties and resources. Hence, every global neurosurgery initiative should be adapted to the unique context of the target country. The following articles describe tailor-made situational analyses and solutions:

- “The Challenges and Opportunities of Global Neurosurgery in East Africa: The Neurosurgery and Education Development Model” identifies successful global neurosurgery innovations.
- “Neurosurgical Capacity Building in the Developing World Through Focused Training” presents a model for neurosurgical capacity building in low-resource settings.
- “Subspecialty Pediatric Neurosurgery Training: A Skill-Based Training Model for Neurosurgeons in Low-Resourced Health Systems” describes a skill-based training model for neurosurgeons in low-resource settings.

Together, these articles cover research, advocacy, education, and health system strengthening in global neurosurgery both globally and locally.

We noted a co-citation and co-occurrence transition from the more general global surgery to more specific global neurosurgery themes. This transition points towards the emancipation of global neurosurgery as a distinct field and the acceptance of global neurosurgery by the neurosurgical community.

**Neurosurgical Subspecialties Within Global Neurosurgery**

Traumatic brain and spine injuries are responsible for significant mortality and disability worldwide, and LMICs bear the bulk of the disease burden. Although there have been numerous studies on neurotrauma in LMICs, most of them have focused on individual countries or regions. More recently, however,
Limitations

We recognize a few limitations to our work. First, the top 50 most cited global neurosurgery articles are not a representative sample of all GNR. By selecting articles based on their citation metrics, we excluded most articles from LMICs, which represent global neurosurgery at the grassroots level.

Next, our search strategy only included articles that self-identified as global neurosurgery or global surgery with a neurosurgery focus. Stricto sensu, GNR encompasses any research that focuses on the determinants of or solutions to neurosurgery-related health disparities irrespective of language, geography, or what the researchers label their study.

Despite the limitations mentioned above, we portrayed a comprehensive image of the landscape of GNR. We mapped out interactions between GNR articles, researchers, and themes. We equally identified the influential articles, researchers, and academic institutions in global neurosurgery.

CONCLUSION

Global neurosurgery articles are published in reputable specialty journals by teams from all over the world. GNR academic institutions collaborate with one another, but they could benefit from more collaborations, especially with and between LMICs. The most cited GNR has focused on neurotrauma, neuropsychiatry, and neurological workforce to the detriment of other subspecialties and surgical system components. Future GNR collaboratives should focus on building new partnerships and exploring neglected research areas.

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1. Dewan MC, Rattani A, Bariculon RE, et al. Operative and consultative neurosurgical care (Figure 4, bottom left-hand side). The WFNS-World Health Organization liaison committee, headed by Gail Rosseau, has represented the interests of the WFNS at the World Health Assembly, the G4 Alliance, and has shared its experience on engaging policy makers in high-level meetings with the rest of the community.12,13

Advocacy

The global neurosurgery community understands the importance of advocacy and collaboration in expanding access to neurological care (Figure 4, bottom left-hand side). The WFNS-World Health Organization liaison committee, headed by Gail Rosseau, has represented the interests of the WFNS at the World Health Assembly, the G4 Alliance, and has shared its experience on engaging policy makers in high-level meetings with the rest of the community.12,13
Global Neurosurgery is a fairly recent and essential academic focus, and collaborative research on the epidemiology of neurosurgical disease, workforce challenges, and health systems solutions are paramount to driving value-based interventions to improve neurosurgical care worldwide. The authors present a social network analysis of bibliometric data to identify Global Neurosurgery research stakeholders, influential articles, and gaps in literature. Through citations, nodes, links, and connections, this article illustrates that landscape for the 50 most cited articles. These publications focus primarily on neurotrauma, neuropsychiatrics and neurosurgical workforce, which remain the greatest demands in low resource settings. As health system strengthening continues, the enhancement of and publication on other subtopics within Global Neurosurgery will likely follow. Importantly, the results included a diverse group of 229 authors; however, the most frequent authors and academic institutions involved were from High Income Countries (HICs). As the authors astutely point out, researchers from Low- and Middle-Income Countries (LMICs) are key actors and stakeholders in this research. Individuals from LMICs are often the ones generating and collecting the data, and as the ones living within the systems most affected, their voices must be present in the literature. Thus, there should be continued emphasis on empowering such individuals to develop research skills, recognizing them as authors, and sponsoring their investigatory efforts. Through these continued and new partnerships, we can strengthen neurosurgical, and more broadly, health systems to provide, safe and timely access to care. 

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