The Application of Deep Brain Stimulation for Parkinson's Disease on the Motor Pathway: A Bibliometric Analysis across 10 Years

Song, Y., Liu, Y., Xiang, H. and Manyande, Anne ORCID: https://orcid.org/0000-0002-8257-0722 (2023) The Application of Deep Brain Stimulation for Parkinson's Disease on the Motor Pathway: A Bibliometric Analysis across 10 Years. Current Medical Science, 43. pp. 1247-1257.

http://dx.doi.org/10.1007/s11596-023-2811-9

The application of deep brain stimulation for Parkinson's disease on the motor pathway: A bibliometric analysis across 10 years

Yong-tang Song[1#], Yan-bo Liu [2], Hong-bing Xiang[2#], Anne Manyande[3], Zhi-gang He[2#],

[1] Department of Anesthesiology, Tongji Medical College, Tongji Hospital, Huazhong University of Science and Technology, Wuhan, China.
[2] School of Human and Social Sciences, University of West London, London, United Kingdom.
[3] Department of Neurosurgery, Tongji Medical College, Tongji Hospital, Huazhong University of Science and Technology, Wuhan, China

[#]These authors have contributed equally to this work
*Correspondence: Zhi-gang He, 1097685807@qq.com and Hongbing Xiang, xhbtj2004@163.com

Abstract

Parkinson's disease has been the focus of research and clinical development to date since James Parkinson reported it for the first time in 1817. The estimated prevalence of the disease is about 1% of adults over the age of 60 years. Deep brain stimulation as an alternative treatment in the end stage of the disease, has saved the lives of countless patients. The objective of this review is to examine and analyze the publications related to the influence of deep brain stimulation in the motor pathway in human Parkinson's disease in the past decade and visualize the outcomes using Citespace. Our results indicate that the United States of America (USA), United Kingdom (UK), Germany, and China are the primary contributors to this research field. University College London, Capital Medical University, and Maastricht University are the top 3 research institutions in this area. Tom Foltynie is the most published author, and the journal *Brain* and *Brain stimulation* publishes the most scholarly articles. The current research hotspots in this field that were identified by keyword burst are neuronal activity, nucleus, hyperdirect pathway, etc. In conclusion, this review has provided a new perspective through bibliometric analysis of the deep brain stimulation therapy for treating patients with Parkinson's disease, which can shed light on future research endeavors to advance our understanding of this study field.

Keywords: Deep brain stimulation, Parkinson's disease, motor pathway

Introduction

Parkinson's disease (PD, also known as paralysis agitans), is common in middle-aged and elderly people[1-3]. As one of the common movement disorders, PD is classically characterized by static tremor, rigidity, bradykinesia, dystonia, postural instability, and other non-motor symptoms, such as hyposmia, rapid eye movement sleep behavior disorder, restless leg syndrome[2-7]. The Global Burden of Disease (GBD) neurological disorders collaborator group has noted that 6.2 million new individuals were distressed from 1990-2015[8]. As of now, several beneficial treatment approaches including exercise training, medication regimens (e.g., levodopa, benzhexol, amantadine), physical therapy, and surgical treatments (e.g., lesioning therapies) for PD are available, but none represent a curative approach[9-17]. As a slowly progressive neurodegenerative disease, PD often has a poor prognosis[18-21]. Most patients are competent in their job in the early stage of PD, and as the disease progresses, severe symptoms finally lead to a gradual loss of working capacity[22-25]. Patients often die from complications (e.g., pneumonia) in the end-stage of PD[26-28].

The application of modern deep brain stimulation (DBS) on patients with PD was first introduced by Benabid in 1987[29,30]. After decades of development, DBS has become an important treatment for those patients with decreased medication efficacy after long-term non-surgical treatment or intolerance of medication adverse effects[31-33]. To implement DBS, one or more electrodes are implanted to specific targets in the brain. The implantable pulse generator (IPG) is connected to the other end of the electrodes[34]. The common electrodes implanted regions of DBS are the globus pallidus interna (GPi), and subthalamic nucleus (STN)[35-38]. When IPG is activated, several key brain regions related to PD in the basal ganglia are affected. Therefore, the excessive inhibition induced by the degenerated basal ganglia is regulated, leading to a more activated downstream motor pathway, which can alleviate motor symptoms[39-43]. However, DBS is effective only in cases of rigidity and tremor and not for postural instability[44,45].

In the past twenty years, DBS has become an alternative treatment for end-stage PD patients, which has gained substantial progress[46-48]. The potential mechanisms of such a method also became the focus of much research[49-51]. However, there are few bibliometric analysis studies in this field. This article is devoted to the DBS treatment and its influence on the motor pathway in human PD and a bibliometric analysis of publications based on Citespace to promote understanding in this area.

Materials and Methods

Data acquisition

As is described in previous studies[51-54], data were obtained from the Web of Science Core Collection via the library of Huazhong University of Science and Technology. The search strategy included the topics 'deep brain stimulation, 'Parkinson's disease', 'motor pathway', and 'human' from January 1, 2012, to December 1, 2022. The data was downloaded on October 24, 2022. The detailed search strategy was [TS = ['deep brain stimulation'] AND ['Parkinson's disease'] AND ['motor pathway'] AND [Articles] AND [Mesh Headings=Humans] AND [language=English].

The exclusion criteria were listed as follows: (1) Articles that were not related to the search topic, (2) Abstract, editorial material, letters, corrections, etc. The 255 validated records were then imported to Citespace 6.1 R3 for further visualization and analysis.

Data analysis

As described previously[55-58], Citespace has been applied to bibliometric analysis and visualization for decades since its debut in 2004[59]. After the data was imported, we conducted various analyses of the distribution of the publishments including institutions, authors, countries/ regions, and journals. The cooperation network was also constructed after the analyses. Furthermore, the analyses of keyword co-occurrence, keyword cluster, and citation burst were performed and visualized using Citespace. The Citespace parameters were set as follows: Time-slicing was chosen from 2012 to 2022, one year per slice. All the options in term slicing (including title, abstract, author keywords, and keywords plus) were selected. Pathfinder, pruning sliced networks and pruning the merged network were selected in Pruning. The node (tree ring) in the figure represents an observation (such as country, institution, author, etc.). The node size indicates the frequency of occurrence, and a larger node suggests a higher frequency of occurrence. The lines show the cooperation, co-occurring, or co-referential relationship between each observation.

Results

Analysis of the Annual Publication Outputs

From the annual trend depicted in Figure 1, it can be seen that the relative studies of motor pathway changes in DBS treatment in human PD have been an active research field with more than 10 papers published annually in the past ten years. Especially since 2016, the number of published research in this field increased significantly. We also noticed that the number of citations shows a steadily upward trend.

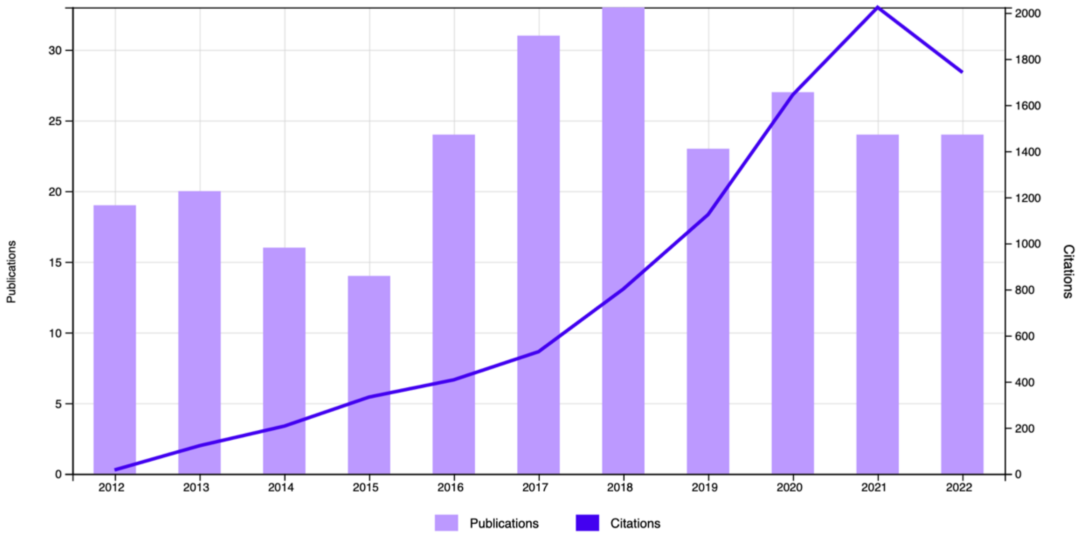

Figure 1. Annual publication and citation outputs

Analysis of articles attributed to Countries/ Regions

Citespace was used to visualize the distribution of the number of articles published in each country/ region[60]. As is shown in Figure 2, there were 40 nodes on the map, suggesting that 40 countries/ regions contributed to the publication of 255 articles over the past decade. From the results displayed in Table 1, it can be seen that the top three countries in terms of publications are the United States (98 publications), Germany (43 publications), and the United Kingdom (36 publications). However, the US and the UK are ranked top 2 in the centrality rankings with 0.45 and 0.46, indicating that they are the two influential countries in research in this field. However, it is obvious that academic communication between countries is urgently needed.

Table 1. Top 10 Countries/Regions

Rank	Country/Region	Year	Publications	Centrality
1	United States	2012	98	0.45
2	Germany	2012	43	0.15
3	England	2012	36	0.46
4	People R China	2014	29	0.06
5	France	2012	23	0.03
6	Canada	2012	18	0.10
7	Netherlands	2012	16	0.13
8	Italy	2012	15	0.06
9	Spain	2012	12	0.02
10	Brazil	2016	11	0.03

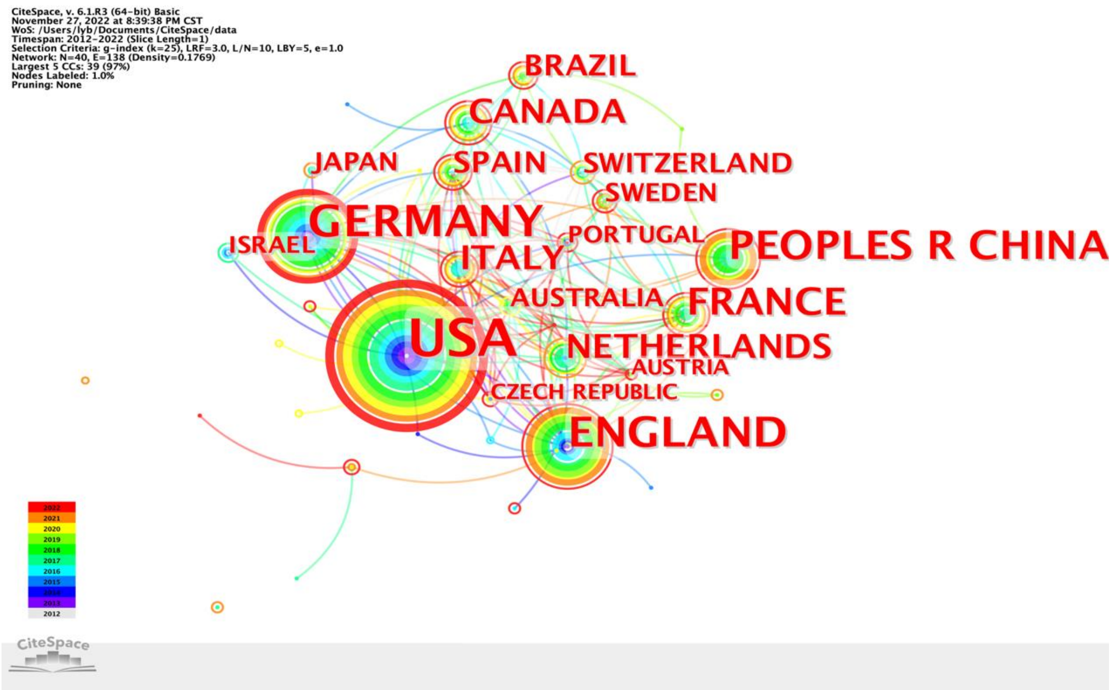

Figure1. Distribution map of different countries

Analysis of articles published by institutions

In order to probe deeper, the co-occurrence analysis of the institution was performed (Figure 2). The map consists of 260 nodes and 356 links, suggesting that 260 institutions all over the world have made contributions to this field. The top three institutions were University College London (UCL), Capital Medical University, and Maastricht University (Table 2). The centrality of UCL was the highest, while the others were no more than 0.2.

Table 2. Top10 leading Institutions related to DBS therapy in PD patients

Rank	Institution	Year	Publications	Centrality
1	University College London	2013	17	0.23
2	Capital Medical University	2016	9	0.03
3	Maastricht University	2012	7	0.14
4	University of Minnesota	2012	6	0.02

5	Beijing Institute for Brain Disorders	2017	5	0.00
6	Johns Hopkins University	2012	5	0.00
7	Charité – Universitätsmedizin Berlin	2018	5	0.01
8	Hannover Medical School	2013	5	0.04
9	Centre National de la Recherche Scientifique	2013	5	0.06
10	University of California, San Francisco	2018	4	0.01

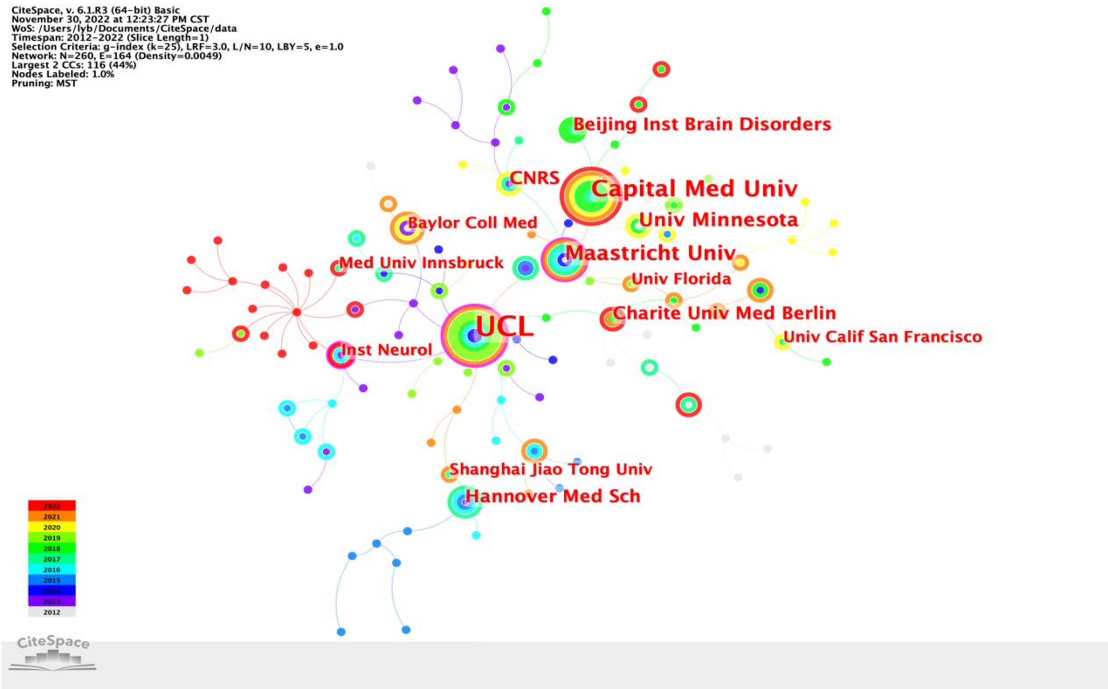

Figure 2. Network map of co-authorship from different institutions

Authors and co-cited authors

The distribution of the most active authors in this field are depicted in Figure 3. Tom Foltynie from University College London ranked first with 6 publications, followed by Harith Akram, Klaus Seppi, Patricia Limousin, and Mesbah Alam (Table 3). It is noteworthy that 6 authors of the current top 10 come from University College London. However, none of the centrality of the authors mentioned above is greater than 0.10.

Among the 438 co-cited authors shown in Figure 5, eight authors were cited more than 40 times. Atsushi Nambu from the National Institute for Physiological Science, Japan, had the highest citation (65), followed by Mahlon Delong from Emory University School of Medicine, USA (55), Roger Albin from the University of Michigan, USA (52), Alim Louis Benabid from University Grenoble Alpes, France (48), Viviana Gradinaru from California Institute of Technology (45), suggesting that these authors have the greatest influence in the field. Among the top 10 co-cited authors, there were seven with a centrality higher than 0.10.

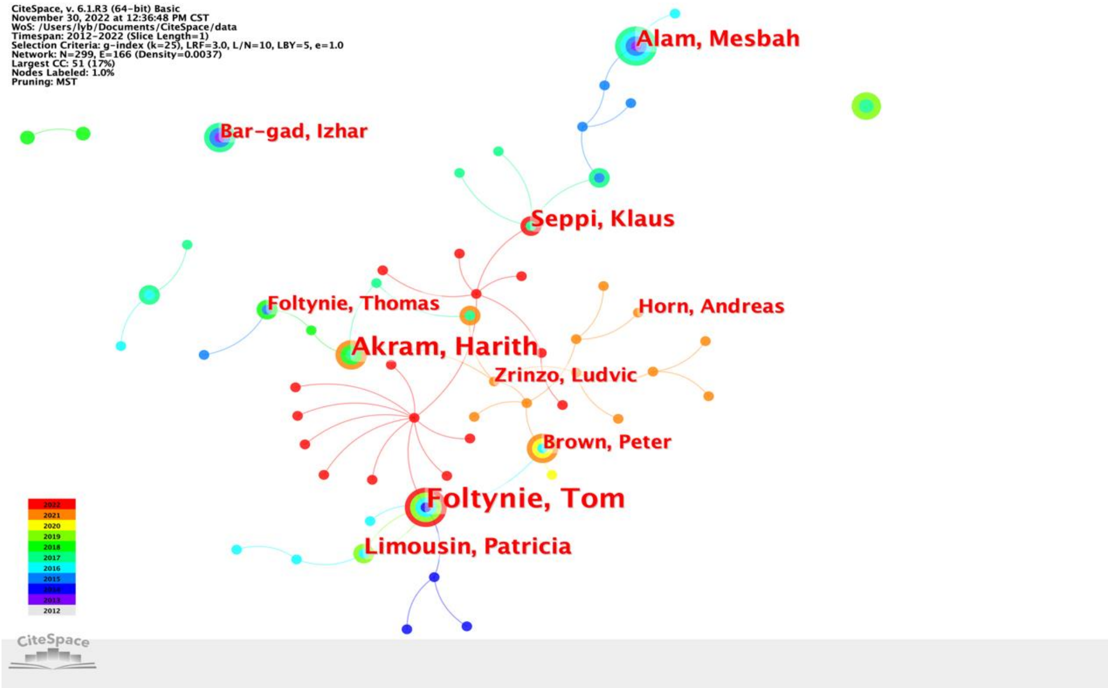

Figure 3. Map of authors related to DBS treatment in patients with PD

Table 3. Top 10 active authors related to DBS treatment in patients with PD

Rank	Author	Institution	Year	Count	Centrality
1	Tom Foltynie	University College London, UK	2014	6	0.03
2	Harith Akram	University College London, UK	2017	5	0.01
3	Klaus Seppi	Medical University of Innsbruck, Australia	2017	4	0.02
4	Patricia Limousin	University London College, UK	2016	4	0.00
5	Mesbah Alam	Hannover Medical School, Germany	2013	4	0.00
6	Thomas Foltynie	University London College, UK	2015	3	0.00
7	Izhar Bar-Gad	Bar Ilan University, Israel	2013	3	0.00
8	Andreas Horn	Charité – Universitätsmedizin Berlin, Germany	2021	3	0.00
9	Peter Brown	University of Oxford, UK	2016	3	0.03
10	Ludvic Zrinzo	University College London, UK	2021	3	0.02

Table 4. Top 10 co-cited authors

Rank	Co-cited Author	Institution	Year	Count	Centrality
1	NAMBU A (Atsushi Nambu)	National Institute for Physiological Science, Japan	2012	65	0.11
2	Mahlon R Delong (DELONG MR)	Emory University School of Medicine, USA	2012	55	0.10
3	Roger L Albin (ALBIN RL)	University of Michigan, USA	2012	52	0.13
4	Alim Louis Benabid (BENABID AL)	University Grenoble Alpes, France	2012	48	0.10

5	Viviana Gradinaru (GRADINARU V)	California Institute of Technology, USA	2012	45	0.12
6	Gene E Alexander (ALEXANDER GE)	Johns Hopkins University School of Medicine, USA	2012	43	0.04
7	BERGMAN H	The Hebrew University-Hadassah Medical School, Israel	2012	42	0.08
8	Andrea A Kühn (KUHN AA)	Charite-Universitatsmedizin Berlin, Germany	2012	41	0.10
9	Paul Krack (KRACK P)	Joseph Fourier University, France	2012	38	0.13
10	Günther Deuschl (DEUSCHL G)	Christian-Albrechts University, Germany	2012	34	0.05

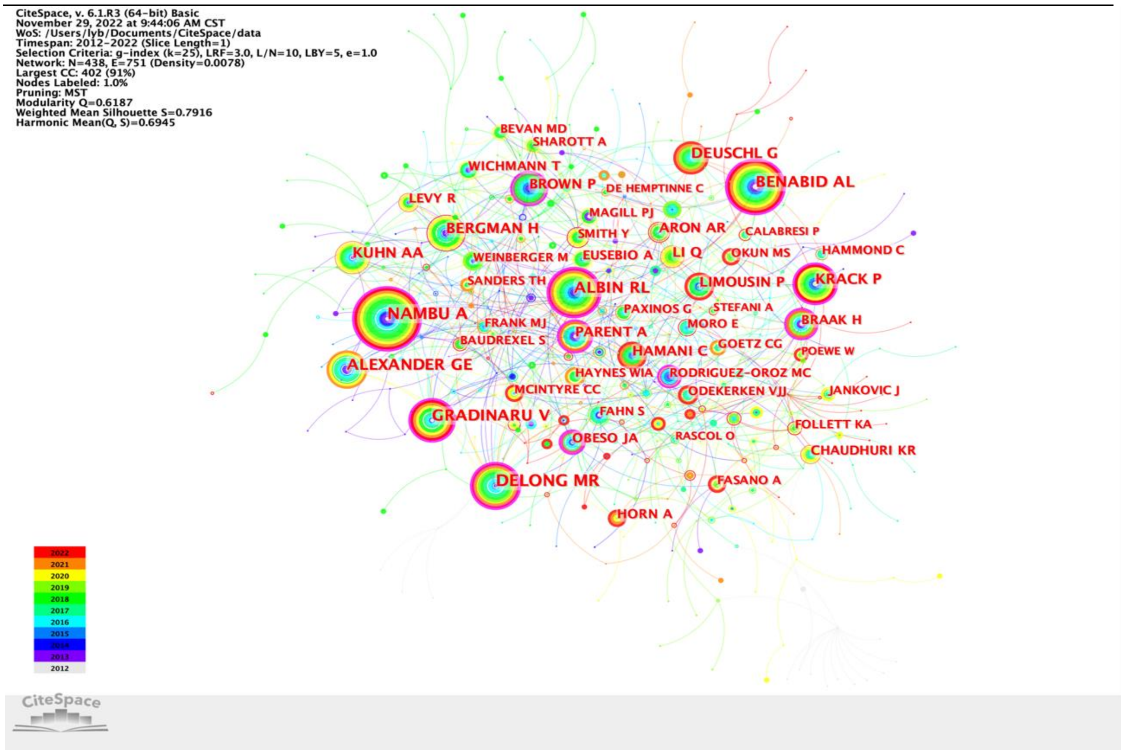

Figure 4. Network map of the co-cited authors

Journals and Co-cited Journals

We further analyzed the source of published articles. Two hundred and fifty-five articles related to DBS therapy in human PD were published in 141 academic journals. The journal of *Brain* (10, 3.92%) published 10 publications which was the most productive journal, followed by *Brain stimulation* (7, 2.75%), *Journal of neurophysiology* (7, 2.75%), *Movement disorders* (7, 2.75%) and *Parkinson related disorders* (7, 2.75%). The top 10 journals are presented in Table 5. The impact factor score of the *Brain* is the highest (IF: 13.501), followed by *Brain stimulation* (IF: 8.955), *Journal of neurophysiology* (IF: 2.714), *Movement disorders* (IF: 10.338), *Parkinson related disorders* (IF: 4.891). Of the top 15 journals, 40% were classified as JCR Q1, the remaining were Q2 (47%), and Q3 (13%). Table 5 also illustrates the top 15 popular co-cited journals, *Brain* (216) was the most frequently cited journal, followed by *Movement disorders* (213), *Journal of neuroscience* (196), *Neurology* (164), and *Journal of neurology and psychiatry* (160). Among the top 15 co-cited journals, 67% were classified as JCR Q1, the remaining were Q2 (20%), and Q3

(13%).

Table 5. Top 15 Journals and Co-cited Journals

Rank	Journal	Count (%)	IF (2021)	JCR (2021)	Co-cited journal	Citation	IF (2021)	JCR (2021)
1	Brain	10 (3.922%)	13.501	Q1	Brain	216	13.501	Q1
2	Brain stimulation	7 (2.745%)	8.955	Q1	Movement disorders	213	10.338	Q1
3	Journal of neurophysiology	7 (2.745%)	2.714	Q2	Journal of neuroscience	196	6.167	Q1
4	Movement disorders	7 (2.745%)	10.338	Q1	Neurology	164	9.91	Q1
5	Parkinsonism related disorders	7 (2.745%)	4.891	Q2	Journal of neurology and psychiatry	160	10.154	Q1
6	Journal of neurosurgery	6 (2.353%)	5.115	Q1	Annals of Neurology	156	10.422	Q1
7	Neuroimage clinical	6 (2.353%)	4.881	Q2	Journal of neurophysiology	146	2.714	Q2
8	Neuroscience	6 (2.353%)	3.59	Q3	Parkinsonism related disorders	139	4.891	Q2
9	Journal of neuroscience	5 (1.961%)	6.167	Q1	European Journal of neuroscience	128	3.386	Q3
10	Behavioural brain research	4 (1.596%)	3.332	Q2	Neuron	2012	17.173	Q1
11	Brain research	4 (1.596%)	3.252	Q3	Experimental neurology	2012	125	Q2
12	Experimental neurology	4 (1.596%)	5.33	Q2	neuroimage	2012	125	Q1
13	Frontiers in neurology	4 (1.596%)	4.003	Q2	Neuroscience	2012	124	Q3
14	Journal of neural engineering	4 (1.596%)	5.379	Q2	Proceedings of the national academy of sciences of the United States of	2012	122	Q1

15	Neurobiology of disease	4 (1.596%)	5.996	Q1	America Science	120	47.728	Q1

Co-cited References

A total of 470 co-cited references are presented in Figure 5. We listed the top 15 most frequently co-cited references related to DBS treatment in human PD and these are listed in table 6. As shown, the most frequently cited publication was written by Ketaki Bhalsing, and published in the *Journal of neurological scienc*e in 2013, followed by the article published in *Neurobiology of disease* in 2016, and 'Therapeutic deep brain stimulation reduces cortical phase-amplitude coupling in Parkinson's disease' written by Coralie de Hemptinne et al[61] published in Nature neuroscience. Among the top 15 articles, 'Subthalamic nucleus stimulation reverses mediofrontal influence over decision threshold' written by James F Cavanagh et al. has the highest centrality of 0.18[62].

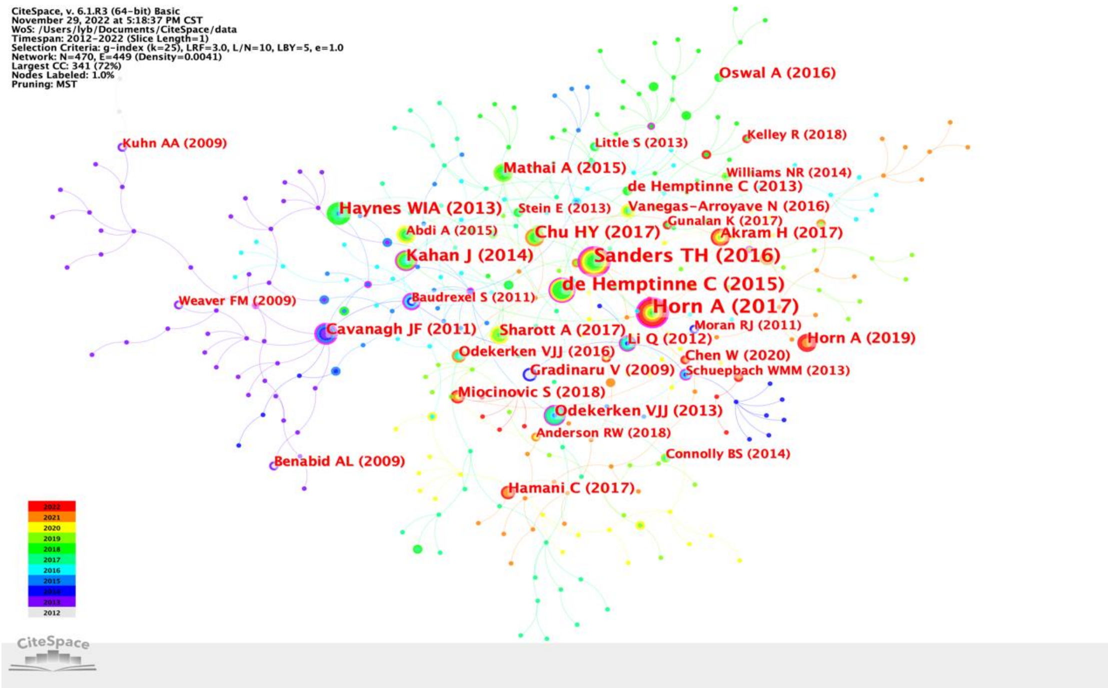

Figure 5. Map of Co-cited References

Table 6. Top 15 Co-cited References

Rank	Reference	Citation	Year	Centrality
1	Bhalsing KS, 2013, J NEUROL SCI, V335, P9, DOI 10.1016/j.jns.2013.09.003	17	2017	0.12
2	Sanders TH, 2016, NEUROBIOL DIS, V95, P225, DOI 10.1016/j.nbd.2016.07.021	16	2016	0.11
3	de Hemptinne C, 2015, NAT NEUROSCI, V18, P779, DOI 10.1038/nn.3997	14	2015	0.11
4	Kahan J, 2014, BRAIN, V137,	10	2014	0.08

	P1130, DOI 10.1093/brain/awu027			
5	Chu HY, 2017, NEURON, V95, P1306, DOI 10.1016/j.neuron.2017.08.038	10	2017	0.04
6	Haynes WIA, 2013, J NEUROSCI, V33, P4804, DOI 10.1523/JNEUROSCI.4674-12.2013	10	2013	0.03
7	Cavanagh JF, 2011, NAT NEUROSCI, V14, P1462, DOI 10.1038/nn.2925	8	2011	0.18
8	Akram H, 2017, NEUROIMAGE, V158, P332, DOI 810.1016/j.neuroimage.2017.07.012	8	2017	0.13
9	Odekerken VJJ, 2013, LANCET NEUROL, V12, P37, DOI 10.1016/S1474-4422(12)70264-8	8	2013	0.11
10	Sharott A, 2017, J NEUROSCI, V37, P9977, DOI 10.1523/JNEUROSCI.0658-17.2017	8	2017	0.06
11	Mathai A, 2015, BRAIN, V138, P946, DOI 10.1093/brain/awv018	8	2015	0.01
12	Horn A, 2019, NEUROIMAGE, V184, P293, DOI 10.1016/j.neuroimage.2018.08.068	8	2019	0.00
13	Li Q, 2012, NEURON, V76, P1030, DOI 10.1016/j.neuron.2012.09.032	7	2012	0.09
14	Miocinovic S, 2018, J NEUROSCI, V38, P9129, DOI 10.1523/JNEUROSCI.1327-18.2018	7	2018	0.04
15	Miocinovic S, 2018, J NEUROSCI, V38, P9129, DOI 10.1523/JNEUROSCI.1327-18.2018	7	2013	0.02

Keyword co-occurrences and Clusters

Keyword co-occurrences and clusters reflect the research spotlight and hotspot of the research area[63-65]. The analysis of the most popular keywords is shown in Table 7. The most frequently mentioned keywords in publications of this field are basal ganglia (110), subthalamic nucleus (96), the motor cortex (31), subthalamic nucleus stimulation (27), substantia nigra (27), globus pallidus (25), high frequency stimulation (22), activation (20), transcranial magnetic stimulation (18), beta oscillation (17). However, the keyword 'motor cortex' has the highest centrality (0.41), followed by ‘subthalamic nucleus stimulation’ (0.35), and ‘substantia nigra’ (0.29).

We further performed a cluster analysis, which detected 15 clusters (Figure 6). We noticed that ‘reactive inhibition’ (cluster 0), ‘external globus pallidus’ (cluster 1), ‘hyperdirect pathway’ (cluster 2), ‘beta-band oscillations’ (cluster 3), ‘essential tremor’ (cluster 4), ‘locus coeruleus’ (cluster 5), ‘computational modeling’ (cluster 6), ‘pain’ (cluster 7), ‘pedunculopontine tegmental nucleus’ (cluster 8), ‘tremor’ (cluster 9), ‘guideline’ (cluster 10), ‘animal models’ (cluster 11), ‘midbrain’ (cluster 12), ‘motor function’ (cluster 13), ‘telerehabilitation’ (cluster 14), ‘subthalamic nucleus’ (cluster 15) were the spotlights in this field over the past ten years. The timeline view of the keywords is depicted in Figure 7, which presents the evolution of the keywords. The most frequently mentioned keywords from 2012 to 2022 are shown on the timeline view. The larger ring represents the frequency of occurrence.

Furthermore, citation bursts were analyzed through Citespace[66-68]. The top ten keywords with the strongest citation bursts are illustrated in Figure 8. Keywords that burst up to the end of 2022 are transcranial magnetic stimulation, rat model, motor, nonmotor symptom, and oscillatory activity, which indicate the frontiers of research in this area (Figure 9).

Table 7. Top 20 high-frequency keywords

Rank	Keywords	Count	Centrality	Rank	Keywords	Count	Centrality
1	basal ganglia	110	0.09	11	hyperdirect pathway	17	0.03
2	subthalamic nucleus	96	0.17	12	disease	17	0.13
3	motor cortex	31	0.41	13	cerebral cortex	14	0.01
4	subthalamic nucleus stimulation	27	0.35	14	movement	14	0.03
5	substantia nigra	27	0.29	15	model	14	0.01
6	globus pallidus	25	0.05	16	movement disorder	14	0.41
7	high frequency stimulation	22	0.02	17	functional connectivity	12	0.41
8	activation	20	0.35	18	primary motor cortex	12	0.67
9	transcranial magnetic stimulation	18	0.07	19	connectivity	12	0.55
10	beta oscillation	17	1.17	20	motor	11	0.00

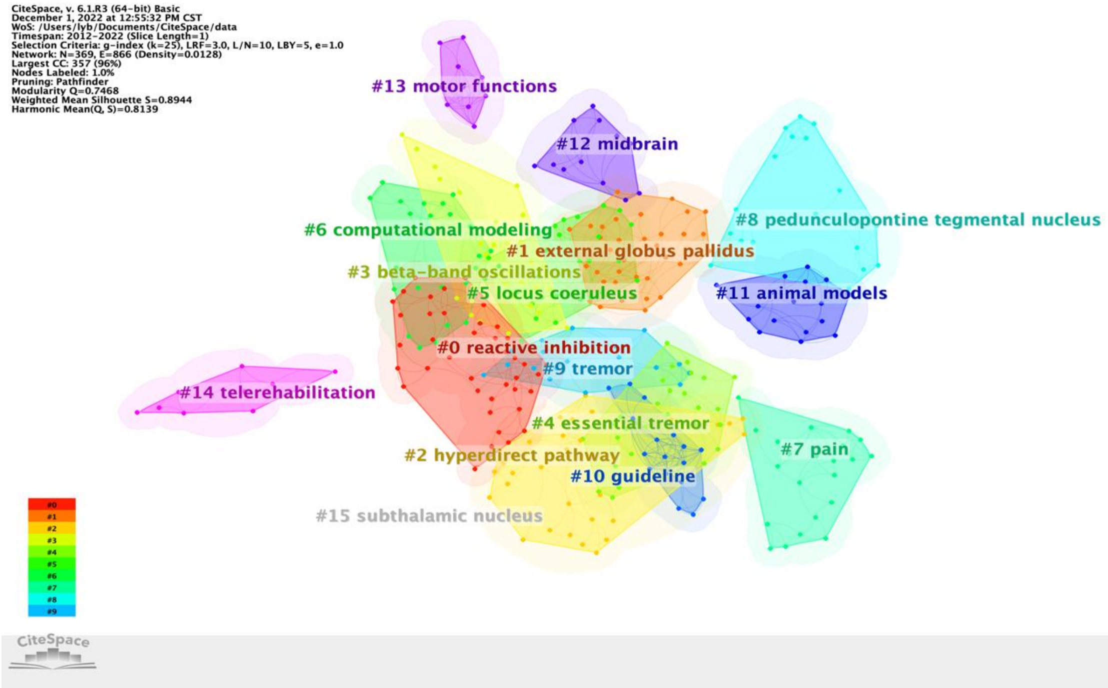

Figure 6. The map of Keyword Clustering

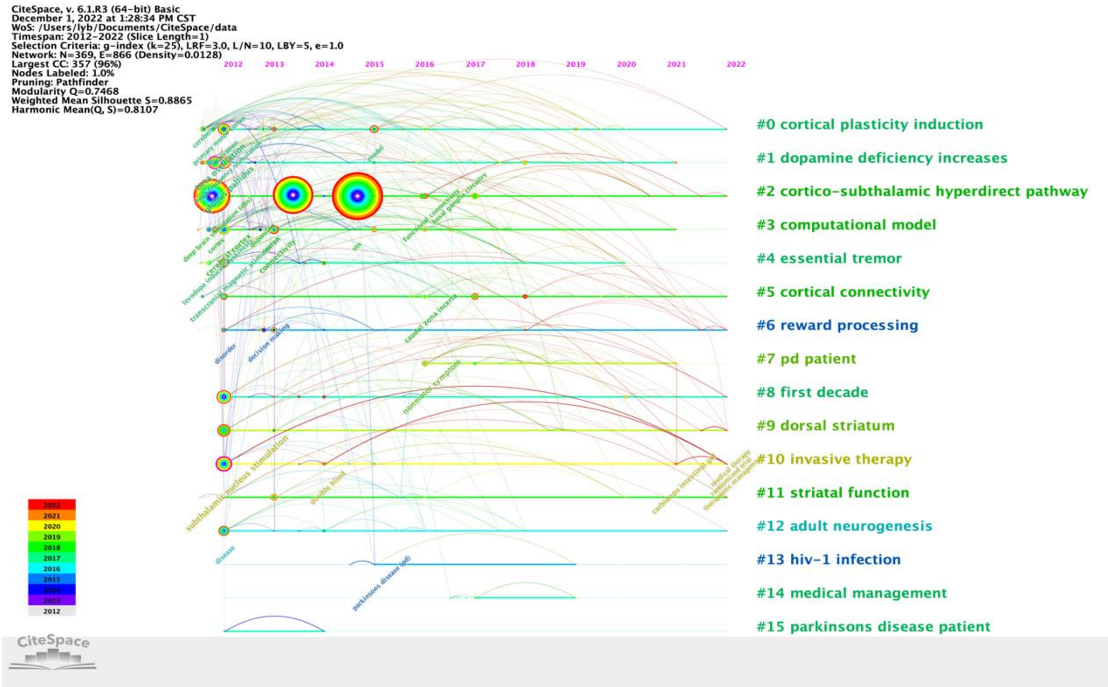

Figure 7. Timeline view of the keywords

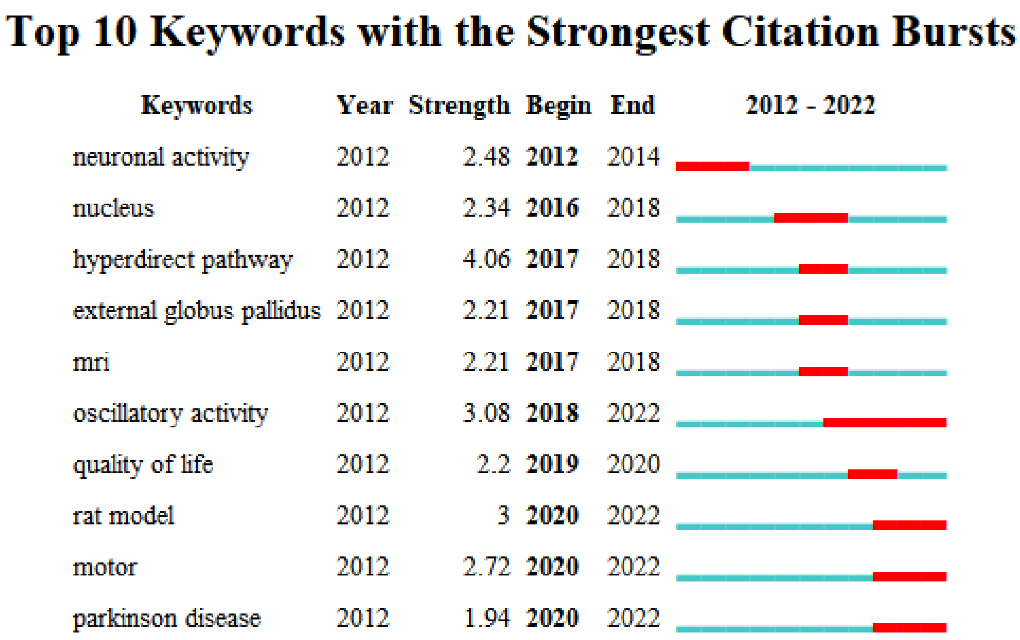

Figure 8. The top 10 keywords with the strongest citation bursts

Figure 9. Keywords that burst up to the end of 2022

Discussion

In this bibliometric analysis, we aimed to investigate the influence of DBS treatment in the motor pathway of PD patients based on Citespace to promote understanding in this field. The results show that developed countries including the US, UK, Japan, and Germany are the main force of related studies because most of the influential institutions and authors, such as Tom Foltynie from the UCL, Andreas Horn from Charité–Universitätsmedizin Berlin, and the University of Minnesota come from these countries/regions. However, it is noteworthy that institutions and scientists in developing countries are also contributing to the study of DBS in PD patients. Capital Medical University and Beijing Institute for Brain Disorders from China ranked 2 and 5, respectively, in the top 10 co-occurrence analysis of the institution. The journal *Brain* published the most related studies compared with other journals, and it also has the highest centrality, suggesting that *Brain* tends to be influential in this area. The most frequently co-cited article, 'Subthalamic nucleus stimulation reverses mediofrontal influence over decision threshold', was written by Cavanagh et al. in 2011, and included two separate studies that elaborated the communication network between the medial prefrontal cortex and the subthalamic nucleus which is closely associated with cognitive side effects of DBS[62].

Citespace was used to identify the frontiers and spotlights through keywords with the strongest citation bursts[69-71]. Through this analysis, we can acknowledge the development of different hotspots. The keyword 'hyperdirect pathway' (4.06) had the highest burst intensity. Through the recently ended keywords with citation bursts, we observed the following two study hotspots, in which transcranial magnetic stimulation and oscillatory activity were the most popular research spotlight for DBS therapy in PD patients. Transcranial magnetic stimulation is a noninvasive brain stimulation therapy that modulates neuronal excitability in brain regions through an electromagnetic field generated by coil[72-75]. As we described above, DBS is only effective for reducing rigidity and tremor. However, DBS has little effect on nonmotor symptoms, freezing of gait, and PD-related cognitive dysfunctions. Repetitive transcranial magnetic stimulation on the motor cortex was found to be effective in PD patients with non-motor symptoms and walking speed[76-78]. Transcranial magnetic stimulation to the right dorsolateral prefrontal cortex (DLPFC) in PD patients also improves cognitive function[79]. The therapeutic effect of combining DBS and transcranial magnetic stimulation has been confirmed in previous studies[80].

In summary, this is an important study that elaborates on the progress made on DBS treatment for PD patients. However, a major limitation is that the studies related to this field are too few compared with other bibliometric analyses. In addition, some influential publications are not well known as yet which contributed to a relatively low number of citations (obliteration by incorporation)[81].

Author contributions

All authors listed made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Funding

This work was funded by the National Natural Science Foundation of China (81873467 and 81670240).

References

1. Samii A, Nutt JG, Ransom BR. Parkinson's disease. *Lancet*. 2004;363:1783-1793. doi: 10.1016/s0140-6736(04)16305-8
2. Ascherio A, Schwarzschild MA. The epidemiology of Parkinson's disease: risk factors and prevention. *Lancet Neurol*. 2016;15:1257-1272. doi: 10.1016/s1474-4422(16)30230-7
3. Schneider RB, Iourinets J, Richard IH. Parkinson's disease psychosis: presentation, diagnosis and management. *Neurodegener Dis Manag*. 2017;7:365-376. doi:

10.2217/nmt-2017-0028
4. Reich SG, Savitt JM. Parkinson's Disease. *Med Clin North Am*. 2019;103:337-350. doi: 10.1016/j.mcna.2018.10.014
5. Tolosa E, Wenning G, Poewe W. The diagnosis of Parkinson's disease. *Lancet Neurol*. 2006;5:75-86. doi: 10.1016/s1474-4422(05)70285-4
6. Schapira AHV, Chaudhuri KR, Jenner P. Non-motor features of Parkinson disease. *Nat Rev Neurosci*. 2017;18:435-450. doi: 10.1038/nrn.2017.62
7. Jankovic J, Sherer T. The future of research in Parkinson disease. *JAMA Neurol*. 2014;71:1351-1352. doi: 10.1001/jamaneurol.2014.1717
8. Global, regional, and national burden of neurological disorders during 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet Neurol*. 2017;16:877-897. doi: 10.1016/s1474-4422(17)30299-5
9. Sharma VD, Patel M, Miocinovic S. Surgical Treatment of Parkinson's Disease: Devices and Lesion Approaches. *Neurotherapeutics*. 2020;17:1525-1538. doi: 10.1007/s13311-020-00939-x
10. Hayes MT. Parkinson's Disease and Parkinsonism. *Am J Med*. 2019;132:802-807. doi: 10.1016/j.amjmed.2019.03.001
11. Vijiaratnam N, Simuni T, Bandmann O, Morris HR, Foltynie T. Progress towards therapies for disease modification in Parkinson's disease. *Lancet Neurol*. 2021;20:559-572. doi: 10.1016/s1474-4422(21)00061-2
12. Lees AJ, Hardy J, Revesz T. Parkinson's disease. *Lancet*. 2009;373:2055-2066. doi: 10.1016/s0140-6736(09)60492-x
13. Armstrong MJ, Okun MS. Diagnosis and Treatment of Parkinson Disease: A Review. *Jama*. 2020;323:548-560. doi: 10.1001/jama.2019.22360
14. Alves Da Rocha P, McClelland J, Morris ME. Complementary physical therapies for movement disorders in Parkinson's disease: a systematic review. *Eur J Phys Rehabil Med*. 2015;51:693-704.
15. Mak MK, Wong-Yu IS, Shen X, Chung CL. Long-term effects of exercise and physical therapy in people with Parkinson disease. *Nat Rev Neurol*. 2017;13:689-703. doi: 10.1038/nrneurol.2017.128
16. Day JO, Mullin S. The Genetics of Parkinson's Disease and Implications for Clinical Practice. *Genes (Basel)*. 2021;12. doi: 10.3390/genes12071006
17. Saranza G, Lang AE. Levodopa challenge test: indications, protocol, and guide. *J Neurol*. 2021;268:3135-3143. doi: 10.1007/s00415-020-09810-7
18. Schuepbach WMM, Tonder L, Schnitzler A, Krack P, Rau J, Hartmann A, Hälbig TD, Pineau F, Falk A, Paschen L, et al. Quality of life predicts outcome of deep brain stimulation in early Parkinson disease. *Neurology*. 2019;92:e1109-e1120. doi: 10.1212/wnl.0000000000007037
19. Fereshtehnejad SM, Postuma RB. Subtypes of Parkinson's Disease: What Do They Tell Us About Disease Progression? *Curr Neurol Neurosci Rep*. 2017;17:34. doi: 10.1007/s11910-017-0738-x
20. Chung SJ, Yoo HS, Shin NY, Park YW, Lee HS, Hong JM, Kim YJ, Lee SK, Lee PH, Sohn YH. Perivascular Spaces in the Basal Ganglia and Long-term Motor Prognosis in Newly Diagnosed Parkinson Disease. *Neurology*. 2021;96:e2121-e2131. doi:

10.1212/wnl.0000000000011797

21. Pajares M, A IR, Manda G, Boscá L, Cuadrado A. Inflammation in Parkinson's Disease: Mechanisms and Therapeutic Implications. *Cells*. 2020;9. doi: 10.3390/cells9071687
22. Khan AU, Akram M, Daniyal M, Zainab R. Awareness and current knowledge of Parkinson's disease: a neurodegenerative disorder. *Int J Neurosci*. 2019;129:55-93. doi: 10.1080/00207454.2018.1486837
23. Armstrong MJ, Okun MS. Choosing a Parkinson Disease Treatment. *Jama*. 2020;323:1420. doi: 10.1001/jama.2020.1224
24. Grayson M. Parkinson's disease. *Nature*. 2010;466:S1. doi: 10.1038/466S2a
25. Espay AJ, Brundin P, Lang AE. Precision medicine for disease modification in Parkinson disease. *Nat Rev Neurol*. 2017;13:119-126. doi: 10.1038/nrneurol.2016.196
26. Chen Z, Li G, Liu J. Autonomic dysfunction in Parkinson's disease: Implications for pathophysiology, diagnosis, and treatment. *Neurobiol Dis*. 2020;134:104700. doi: 10.1016/j.nbd.2019.104700
27. Feng YS, Yang SD, Tan ZX, Wang MM, Xing Y, Dong F, Zhang F. The benefits and mechanisms of exercise training for Parkinson's disease. *Life Sci*. 2020;245:117345. doi: 10.1016/j.lfs.2020.117345
28. Claus I, Muhle P, Czechowski J, Ahring S, Labeit B, Suntrup-Krueger S, Wiendl H, Dziewas R, Warnecke T. Expiratory Muscle Strength Training for Therapy of Pharyngeal Dysphagia in Parkinson's Disease. *Mov Disord*. 2021;36:1815-1824. doi: 10.1002/mds.28552
29. Hariz M. Twenty-five years of deep brain stimulation: celebrations and apprehensions. *Mov Disord*. 2012;27:930-933. doi: 10.1002/mds.25007
30. Benabid AL, Pollak P, Louveau A, Henry S, de Rougemont J. Combined (thalamotomy and stimulation) stereotactic surgery of the VIM thalamic nucleus for bilateral Parkinson disease. *Appl Neurophysiol*. 1987;50:344-346. doi: 10.1159/000100803
31. Bronstein JM, Tagliati M, Alterman RL, Lozano AM, Volkmann J, Stefani A, Horak FB, Okun MS, Foote KD, Krack P, et al. Deep brain stimulation for Parkinson disease: an expert consensus and review of key issues. *Arch Neurol*. 2011;68:165. doi: 10.1001/archneurol.2010.260
32. Habets JGV, Heijmans M, Kuijf ML, Janssen MLF, Temel Y, Kubben PL. An update on adaptive deep brain stimulation in Parkinson's disease. *Mov Disord*. 2018;33:1834-1843. doi: 10.1002/mds.115
33. Jankovic J, Tan EK. Parkinson's disease: etiopathogenesis and treatment. *J Neurol Neurosurg Psychiatry*. 2020;91:795-808. doi: 10.1136/jnnp-2019-322338
34. Hariz M, Blomstedt P. Deep brain stimulation for Parkinson's disease. *J Intern Med*. 2022;292:764-778. doi: 10.1111/joim.13541
35. Ramirez-Zamora A, Ostrem JL. Globus Pallidus Interna or Subthalamic Nucleus Deep Brain Stimulation for Parkinson Disease: A Review. *JAMA Neurol*. 2018;75:367-372. doi: 10.1001/jamaneurol.2017.4321
36. Okun MS. Deep-brain stimulation for Parkinson's disease. *N Engl J Med*. 2012;367:1529-1538. doi: 10.1056/NEJMct1208070
37. Limousin P, Foltynie T. Long-term outcomes of deep brain stimulation in Parkinson disease. *Nat Rev Neurol*. 2019;15:234-242. doi: 10.1038/s41582-019-0145-9
38. Kosutzka Z, Rivaud-Pechoux S, Pouget P, Bonnet C, Tisch S, Roze E, Grabli D, Gaymard B,

Yelnik J, Habert MO, et al. Pathophysiology of gait disorders induced by bilateral globus pallidus interna stimulation in dystonia. *Brain*. 2020;143:e3. doi: 10.1093/brain/awz356

39. McGregor MM, Nelson AB. Circuit Mechanisms of Parkinson's Disease. *Neuron*. 2019;101:1042-1056. doi: 10.1016/j.neuron.2019.03.004
40. Walter BL, Vitek JL. Surgical treatment for Parkinson's disease. *Lancet Neurol*. 2004;3:719-728. doi: 10.1016/s1474-4422(04)00934-2
41. Fox SH, Katzenschlager R, Lim SY, Barton B, de Bie RMA, Seppi K, Coelho M, Sampaio C. International Parkinson and movement disorder society evidence-based medicine review: Update on treatments for the motor symptoms of Parkinson's disease. *Mov Disord*. 2018;33:1248-1266. doi: 10.1002/mds.27372
42. Kogan M, McGuire M, Riley J. Deep Brain Stimulation for Parkinson Disease. *Neurosurg Clin N Am*. 2019;30:137-146. doi: 10.1016/j.nec.2019.01.001
43. Pringsheim T, Day GS, Smith DB, Rae-Grant A, Licking N, Armstrong MJ, de Bie RMA, Roze E, Miyasaki JM, Hauser RA, et al. Dopaminergic Therapy for Motor Symptoms in Early Parkinson Disease Practice Guideline Summary: A Report of the AAN Guideline Subcommittee. *Neurology*. 2021;97:942-957. doi: 10.1212/wnl.0000000000012868
44. Dong J, Cui Y, Li S, Le W. Current Pharmaceutical Treatments and Alternative Therapies of Parkinson's Disease. *Curr Neuropharmacol*. 2016;14:339-355. doi: 10.2174/1570159x14666151120123025
45. de Almeida Marcelino AL, Horn A, Krause P, Kühn AA, Neumann WJ. Subthalamic neuromodulation improves short-term motor learning in Parkinson's disease. *Brain*. 2019;142:2198-2206. doi: 10.1093/brain/awz152
46. Mansouri A, Taslimi S, Badhiwala JH, Witiw CD, Nassiri F, Odekerken VJJ, De Bie RMA, Kalia SK, Hodaie M, Munhoz RP, et al. Deep brain stimulation for Parkinson's disease: meta-analysis of results of randomized trials at varying lengths of follow-up. *J Neurosurg*. 2018;128:1199-1213. doi: 10.3171/2016.11.Jns16715
47. Kalia SK, Sankar T, Lozano AM. Deep brain stimulation for Parkinson's disease and other movement disorders. *Curr Opin Neurol*. 2013;26:374-380. doi: 10.1097/WCO.0b013e3283632d08
48. Jakobs M, Lee DJ, Lozano AM. Modifying the progression of Alzheimer's and Parkinson's disease with deep brain stimulation. *Neuropharmacology*. 2020;171:107860. doi: 10.1016/j.neuropharm.2019.107860
49. Holewijn RA, Verbaan D, van den Munckhof PM, Bot M, Geurtsen GJ, Dijk JM, Odekerken VJ, Beudel M, de Bie RMA, Schuurman PR. General Anesthesia vs Local Anesthesia in Microelectrode Recording-Guided Deep-Brain Stimulation for Parkinson Disease: The GALAXY Randomized Clinical Trial. *JAMA Neurol*. 2021;78:1212-1219. doi: 10.1001/jamaneurol.2021.2979
50. Mostofi A, Morgante F, Edwards MJ, Brown P, Pereira EAC. Pain in Parkinson's disease and the role of the subthalamic nucleus. *Brain*. 2021;144:1342-1350. doi: 10.1093/brain/awab001
51. Lee LN, Huang CS, Chuang HH, Lai HJ, Yang CK, Yang YC, Kuo CC. An electrophysiological perspective on Parkinson's disease: symptomatic pathogenesis and therapeutic approaches. *J Biomed Sci*. 2021;28:85. doi: 10.1186/s12929-021-00781-z
52. Zhao J, Zhu J, Huang C, Zhu X, Zhu Z, Wu Q, Yuan R. Uncovering the information

immunology journals transmitted for COVID-19: A bibliometric and visualization analysis. *Front Immunol*. 2022;13:1035151. doi: 10.3389/fimmu.2022.1035151

53. Xia D, Yao R, Wang S, Chen G, Wang Y. Mapping Trends and Hotspots Regarding Clinical Research on COVID-19: A Bibliometric Analysis of Global Research. *Front Public Health*. 2021;9:713487. doi: 10.3389/fpubh.2021.713487
54. Xi M, Gao X. Bibliometric Analysis of Research Relating to IgA Nephropathy from 2010 to 2021. *Med Sci Monit*. 2022;28:e937976. doi: 10.12659/msm.937976
55. Yuan G, Shi J, Jia Q, Shi S, Zhu X, Zhou Y, Shi S, Hu Y. Cardiac Rehabilitation: A Bibliometric Review From 2001 to 2020. *Front Cardiovasc Med*. 2021;8:672913. doi: 10.3389/fcvm.2021.672913
56. Ahmad T, Ornos EDB, Ahmad S, Al-Wassia RK, Mushtaque I, Shah SM, Al-Omari B, Baig M, Tang K. Global Research Mapping of Psycho-Oncology Between 1980 and 2021: A Bibliometric Analysis. *Front Psychol*. 2022;13:947669. doi: 10.3389/fpsyg.2022.947669
57. Zhang X, Cai J, Chen L, Yang Q, Tian H, Wu J, Ji Z, Zheng D, Li Z, Chen Y. Mapping global trends in research of stem cell therapy for COVID-19: A bibliometric analysis. *Front Public Health*. 2022;10:1016237. doi: 10.3389/fpubh.2022.1016237
58. Li R, Sun J, Hu H, Zhang Q, Sun R, Zhou S, Zhang H, Fang J. Research Trends of Acupuncture Therapy on Knee Osteoarthritis from 2010 to 2019: A Bibliometric Analysis. *J Pain Res*. 2020;13:1901-1913. doi: 10.2147/jpr.S258739
59. Chen C. Searching for intellectual turning points: progressive knowledge domain visualization. *Proc Natl Acad Sci U S A*. 2004;101 Suppl 1:5303-5310. doi: 10.1073/pnas.0307513100
60. Zhou Q, Kong HB, He BM, Zhou SY. Bibliometric Analysis of Bronchopulmonary Dysplasia in Extremely Premature Infants in the Web of Science Database Using CiteSpace Software. *Front Pediatr*. 2021;9:705033. doi: 10.3389/fped.2021.705033
61. de Hemptinne C, Swann NC, Ostrem JL, Ryapolova-Webb ES, San Luciano M, Galifianakis NB, Starr PA. Therapeutic deep brain stimulation reduces cortical phase-amplitude coupling in Parkinson's disease. *Nat Neurosci*. 2015;18:779-786. doi: 10.1038/nn.3997
62. Cavanagh JF, Wiecki TV, Cohen MX, Figueroa CM, Samanta J, Sherman SJ, Frank MJ. Subthalamic nucleus stimulation reverses mediofrontal influence over decision threshold. *Nat Neurosci*. 2011;14:1462-1467. doi: 10.1038/nn.2925
63. Xu D, Wang YL, Wang KT, Wang Y, Dong XR, Tang J, Cui YL. A Scientometrics Analysis and Visualization of Depressive Disorder. *Curr Neuropharmacol*. 2021;19:766-786. doi: 10.2174/1570159x18666200905151333
64. Luo H, Cai Z, Huang Y, Song J, Ma Q, Yang X, Song Y. Study on Pain Catastrophizing From 2010 to 2020: A Bibliometric Analysis via CiteSpace. *Front Psychol*. 2021;12:759347. doi: 10.3389/fpsyg.2021.759347
65. Miao L, Zhang J, Zhang Z, Wang S, Tang F, Teng M, Li Y. A Bibliometric and Knowledge-Map Analysis of CAR-T Cells From 2009 to 2021. *Front Immunol*. 2022;13:840956. doi: 10.3389/fimmu.2022.840956
66. Huang X, Fan X, Ying J, Chen S. Emerging trends and research foci in gastrointestinal microbiome. *J Transl Med*. 2019;17:67. doi: 10.1186/s12967-019-1810-x
67. Ding H, Wu C, Liao N, Zhan Q, Sun W, Huang Y, Jiang Z, Li Y. Radiomics in Oncology: A 10-Year Bibliometric Analysis. *Front Oncol*. 2021;11:689802. doi:

10.3389/fonc.2021.689802
68. Sun HL, Bai W, Li XH, Huang H, Cui XL, Cheung T, Su ZH, Yuan Z, Ng CH, Xiang YT. Schizophrenia and Inflammation Research: A Bibliometric Analysis. *Front Immunol*. 2022;13:907851. doi: 10.3389/fimmu.2022.907851
69. Liu S, Sun YP, Gao XL, Sui Y. Knowledge domain and emerging trends in Alzheimer's disease: a scientometric review based on CiteSpace analysis. *Neural Regen Res*. 2019;14:1643-1650. doi: 10.4103/1673-5374.255995
70. Zhong D, Li Y, Huang Y, Hong X, Li J, Jin R. Molecular Mechanisms of Exercise on Cancer: A Bibliometrics Study and Visualization Analysis via CiteSpace. *Front Mol Biosci*. 2021;8:797902. doi: 10.3389/fmolb.2021.797902
71. Dang Q, Luo Z, Ouyang C, Wang L. First Systematic Review on Health Communication Using the CiteSpace Software in China: Exploring Its Research Hotspots and Frontiers. *Int J Environ Res Public Health*. 2021;18. doi: 10.3390/ijerph182413008
72. Brabenec L, Klobusiakova P, Simko P, Kostalova M, Mekyska J, Rektorova I. Non-invasive brain stimulation for speech in Parkinson's disease: A randomized controlled trial. *Brain Stimul*. 2021;14:571-578. doi: 10.1016/j.brs.2021.03.010
73. Chung CL, Mak MK. Effect of Repetitive Transcranial Magnetic Stimulation on Physical Function and Motor Signs in Parkinson's Disease: A Systematic Review and Meta-Analysis. *Brain Stimul*. 2016;9:475-487. doi: 10.1016/j.brs.2016.03.017
74. Zanjani A, Zakzanis KK, Daskalakis ZJ, Chen R. Repetitive transcranial magnetic stimulation of the primary motor cortex in the treatment of motor signs in Parkinson's disease: A quantitative review of the literature. *Mov Disord*. 2015;30:750-758. doi: 10.1002/mds.26206
75. Li R, He Y, Qin W, Zhang Z, Su J, Guan Q, Chen Y, Jin L. Effects of Repetitive Transcranial Magnetic Stimulation on Motor Symptoms in Parkinson's Disease: A Meta-Analysis. *Neurorehabil Neural Repair*. 2022;36:395-404. doi: 10.1177/15459683221095034
76. Chung CL, Mak MK, Hallett M. Transcranial Magnetic Stimulation Promotes Gait Training in Parkinson Disease. *Ann Neurol*. 2020;88:933-945. doi: 10.1002/ana.25881
77. Chen R, Udupa K. Measurement and modulation of plasticity of the motor system in humans using transcranial magnetic stimulation. *Motor Control*. 2009;13:442-453. doi: 10.1123/mcj.13.4.442
78. Trung J, Hanganu A, Jobert S, Degroot C, Mejia-Constain B, Kibreab M, Bruneau MA, Lafontaine AL, Strafella A, Monchi O. Transcranial magnetic stimulation improves cognition over time in Parkinson's disease. *Parkinsonism Relat Disord*. 2019;66:3-8. doi: 10.1016/j.parkreldis.2019.07.006
79. Chen KS, Chen R. Invasive and Noninvasive Brain Stimulation in Parkinson's Disease: Clinical Effects and Future Perspectives. *Clin Pharmacol Ther*. 2019;106:763-775. doi: 10.1002/cpt.1542
80. Udupa K, Bahl N, Ni Z, Gunraj C, Mazzella F, Moro E, Hodaie M, Lozano AM, Lang AE, Chen R. Cortical Plasticity Induction by Pairing Subthalamic Nucleus Deep-Brain Stimulation and Primary Motor Cortical Transcranial Magnetic Stimulation in Parkinson's Disease. *J Neurosci*. 2016;36:396-404. doi: 10.1523/jneurosci.2499-15.2016
81. Wilson M, Sampson M, Barrowman N, Doja A. Bibliometric Analysis of Neurology Articles Published in General Medicine Journals. *JAMA Netw Open*. 2021;4:e215840. doi:

10.1001/jamanetworkopen.2021.5840