OBJECTIVE: Deep brain stimulation (DBS) allows for direct electrical stimulation of neural circuitry and recording of local field potentials (LFPs). A bibliometric analysis can be implemented to identify studies that have shaped a research field and influenced future study; however, no such analysis investigating the implementation of LFPs in DBS has been performed. The objective of the present study was to identify the most highly cited articles pertaining to DBS LFPs to identify and evaluate the research that has contributed the most to this growing field.

METHODS: The Science Citation Index of the Web of Science was implemented to identify the top 84 most cited articles pertaining to DBS LFPs. Information regarding the publication, including author information and study aims, was extracted.

RESULTS: The most highly cited articles had had a mean of 109 citations and had been published between 2002 and 2019, with a mode in 2016. The articles had predominantly investigated the subthalamic nucleus (68% of clinical studies) in humans (83.8% of clinical studies). The studies of humans had recruited a mean of 12.5 subjects. Most of the identified articles (56.0%) had reported class III clinical evidence.

CONCLUSIONS: The implementation of DBS LFPs is a novel field that is rapidly growing. However, a need exists for more studies with larger patient cohorts and more randomized controlled trials to further elucidate the benefits of this technology. These results will allow for the identification and recognition of the most influential studies pertaining to DBS LFPs, appreciation of the current and future research trends, and inform us regarding areas warranting further investigation.

INTRODUCTION

Deep brain stimulation (DBS) is a promising neurosurgical procedure that allows for direct electrical stimulation to modulate the underlying brain circuitry for a variety of conditions, including Parkinson disease (PD), essential tremor, and obsessive-compulsive disorder. Although the precise acute and chronic mechanisms of DBS are still relatively unknown, the ability to directly modulate distinct neural networks has provided an exciting possibility for a wide array of other neurological conditions, including epilepsy, post-traumatic stress disorder, depression, and dementia.

Recent advances in DBS technology have enabled the recording of local field potentials (LFPs), a signal representing the activation of neuronal populations by capturing local synaptic activity. LFPs can be recorded during surgery (for which it has been widely implemented for planning and lead optimization), in the acute postoperative period (the signal can be passed through an external digital amplifier), and in the months and years after implantation owing to advances in DBS and implantable pulse generator technology. Progress has occurred in the implementation of this technology for clinical use, including localization of the brain networks and structures. However, LFP signals can also provide direct insights into the underlying mechanisms of the brain and its neurocircuitry. Compared with noninvasive alternatives, including electroencephalography and magnetoencephalography, LFPs can provide direct functional...
recordings with a high temporal resolution that can be used to identify the biomarkers of disease, understand the neural mechanisms, identify connectivity, evaluate the effects of direct electrical stimulation, and more.

Bibliometric analysis is a research modality for evaluating scientific research in a given field and can be implemented to examine the impact of previous studies, including medical literature.7 Several such analyses have been performed in the field of neurosurgery,9-10 including analysis of invasive neuro-modulation,11 stereotactic and functional neurosurgery,12 and DBS as a modality.13 The implementation of LFPs in DBS has also been investigated14; however, to the best of our knowledge, no analysis has yet investigated the most frequently cited articles specifically related to DBS LFP research. The purpose of the present study was to identify the most highly cited articles pertaining to DBS LFPs to identify and evaluate the research that has contributed the most to this growing field.

METHODS

To tabulate the most cited articles relating to LFPs in DBS, we queried the Web of Science database on March 31, 2022. We used the following search terms: DBS local field potential, direct brain stimulation local field potential, and direct brain stimulation LFP. No additional filters or restrictions were implemented. The search returned a total of 484 articles, with 421 having ≥1 citation. The top 20% (n = 84) of these identified articles were obtained and reviewed. Studies that were not directly related to DBS or its effects (n = 2) were removed from subsequent analysis, and the next 2 articles were then included. The article title, names of all the authors and their institutions, year of publication, journal of publication, journal impact factor, SCImago journal rank, journal source-normalized impact per paper, number of citations annually, total citation count, country of first author, and study primary aims were collected. Each article was further categorized as described by the Oxford Centre for Evidence-based Medicine (OCEM) to determine the level of evidence, which includes randomized controlled trials (RCTs) or systematic reviews of RCTs (level I), prospective cohort trials or nonrandomized control trials (level II), retrospective cohort studies (level III), case series (level IV), and expert opinion or literature review (level V). Nonclinical studies were not classified. The journal impact factor was obtained using the Web of Science Journal Citation reports database (updated in 2021). The SCImago journal rank was obtained from the SCImago database (2020). Finally, the source-normalized impact per paper was collected from the CWTS (Centre for Science and Technology Studies) journal indicators database in 2021.

The articles were categorized by their study aims into the following categories: understanding oscillatory activity, stimulation effects on oscillatory activity, brain—computer interface (“adaptive DBS”), pharmacologic function/co-function, clinical effects, connectivity (using magnetoencephalography, functional magnetic resonance imaging, diffusion tensor imaging, single units, electrocorticography, etc.), and review articles.

RESULTS

The top 84 most highly cited articles related to DBS LFPs were identified and had been cited a combined 9131 times, with a mean ± standard deviation of 108.7 ± 93.4 citations (range, 49–633 citations). The top article had received 633 citations,15 and the least highly cited articles had received 49 citations.16-18 The top 10 most highly cited articles, along with their journal, year, total number of citations, and annual number of citations, are presented in Table 1.15-19-27 All articles had been published in journals in the English language.

Year of Publication

The articles had been published between 2002 and 2019. Seven studies had been published before 2005, 28 between 2006 and 2010, 26 between 2011 and 2015, and 23 between 2016 and 2021. A peak in the publication year for the most highly cited articles was found in 2016 (Figure 1). The aggregated number of annual citations across the identified articles had increased for most years, with an attenuation noted in 2014.

Country and Institution of Origin

The top 84 most highly cited articles had originated from 9 countries (Figure 2). Most of the articles were from the United States (n = 32), followed by England (n = 18), Italy (n = 16), Germany (n = 9), Canada (n = 4), Switzerland (n = 2), Australia (n = 1), France (n = 1), and the Netherlands (n = 1). The articles were attributed to a mean of 2.63 ± 1.60 institutions, with a maximum number of 10 unique institutions.28

Journal Distribution

The top 84 most highly cited articles had been published in 38 journals. Most articles had appeared in Experimental Neurology (n = 13), followed by the Journal of Neuroscience (n = 9) and Movement Disorders (n = 6). Brain (n = 4) was the highest impact factor journal in the list (Table 2).

Fields and Aims of Study

Of the 84 articles, 16 were review articles (19.0%) and 68 were experimental studies (81.0%). The experimental studies had had more overall citations (mean, 111.2 ± 101.1) compared with the review articles (mean, 95.1 ± 50.6). However, the difference was not statistically significant (t(13,83) = 0.6172; P = 0.539).

Of the 68 experimental studies, DBS LFP had been investigated most often in humans (n = 57 studies; Table 3). These human studies had included an average of 12.51 ± 9.57 patients. The study with the highest number of participants had recruited 54 subjects.29 The most investigated DBS target was the subthalamic nucleus (STN; n = 48; Table 4).

Aims of Study and Evidence

Of the 84 articles, 30 (35.7%) had sought to understand neural activity, 22 (26.2%) had examined the effects of stimulation on neural activity, 11 (13.1%) had investigated the clinical effects, 9 (10.7%) had investigated connectivity with other brain regions, 8 (9.5%) had examined the implementation of brain—computer
Table 1. Top 10 Most Highly Cited DBS LFP Articles

| Rank | First Author         | Title                                                                 | Journal                | Year | Total Citations (n) | Annual Citations (n) |
|------|----------------------|----------------------------------------------------------------------|------------------------|------|---------------------|----------------------|
| 1    | Little S             | Adaptive deep brain stimulation in advanced Parkinson disease        | Ann Neurrol             | 2013 | 633                 | 63.3                 |
| 2    | Kühn A              | High-frequency stimulation of the subthalamic nucleus suppresses oscillatory beta activity in patients with Parkinson’s disease in parallel with improvement in motor performance | J Neurosci             | 2013 | 481                 | 32.07                |
| 3    | Weinberger M         | Beta oscillatory activity in the subthalamic nucleus and its relation to dopaminergic response in Parkinson’s disease | J Neurophysiol         | 2006 | 368                 | 21.65                |
| 4    | Priori A             | Rhythm-specific pharmacological modulation of subthalamic activity in Parkinson’s disease | Exp Neurrol             | 2004 | 363                 | 19.11                |
| 5    | Eusebio A            | Deep brain stimulation can suppress pathological synchronisation in parkinsonian patients | J Neurol Neurosur Psychiatry | 2011 | 226                 | 18.83                |
| 6    | Priori A             | Adaptive deep brain stimulation (aDBS) controlled by local field potential oscillations | Exp Neurrol             | 2013 | 194                 | 19.4                 |
| 7    | Bronte-Stewart H     | The STN beta-band profile in Parkinson’s disease is stationary and shows prolonged attenuation after deep brain stimulation | Exp Neurrol             | 2009 | 185                 | 13.21                |
| 8    | Li S                 | Resonant antidromic cortical circuit activation as a consequence of high-frequency subthalamic deep-brain stimulation | J Neurophysiol         | 2007 | 183                 | 11.44                |
| 9    | Herrington T         | Mechanisms of deep brain stimulation                                  | J Neurophysiol         | 2016 | 180                 | 25.71                |
| 10   | Wingeier B           | Intra-operative STN DBS attenuates the prominent beta rhythm in the STN in Parkinson’s disease | Exp Neurrol             | 2006 | 173                 | 10.18                |

DBS, deep brain stimulation; LFP, local field potential; STN, subthalamic nucleus.

DISCUSSION

Bibliometric analysis is the statistical analysis of published media, and its role in literature has become increasingly important owing to its ability to assess the scientific impact of publications, individuals, and institutions. A bibliometric study can elucidate the progress and direction of a field of study by examination of the most highly cited publications. A bibliometric study investigating the top 100 articles in DBS has been previously performed. The recording and implementation of LFPs has blurred the line between basic science, clinical science, and engineering investigations, although DBS, as a system, pertains to the improvement in patient condition, the examination of neuronal network activation leaves away from the clinical realm toward a mechanistic, basic science domain—and a great potential also exists to introduce neural engineering principles in the implementation of these signals. As such, most of the identified highly cited articles were published in journals such as Experimental Neurology, Journal of Neuroscience, and Movement Disorders. These journals emphasize the mechanistic and translational aspects of scientific advancements and allow for a wider variety of research approaches. LFP trend was positive. This was likely because of the rapidly advancing DBS technology, because the required hardware and software for, and widespread commercialization of, LFPs has recently emerged. The Medtronic PC (Medtronic Inc., Minneapolis, Minnesota, USA) is a DBS system that has the capability to record LFPs chronically. This will allow for greater scientific investigation of DBS technology, especially in the temporal dimension.

Most of the identified highly cited papers had originated from first authors from the United States. This is similar to the U.S. dominance of neurosurgical publications as a whole. However, similar to previous bibliometric analyses of DBS, international articles represented a large proportion of the overall articles (62%). This globalization of neurosurgical research is promising, and further examination of this trend is warranted in subsequent studies.

The recording and implementation of LFPs has blurred the line between basic science, clinical science, and engineering investigations, although DBS, as a system, pertains to the improvement in patient condition, the examination of neuronal network activation leaves away from the clinical realm toward a mechanistic, basic science domain—and a great potential also exists to introduce neural engineering principles in the implementation of these signals. As such, most of the identified highly cited articles were published in journals such as Experimental Neurology, Journal of Neuroscience, and Movement Disorders. These journals emphasize the mechanistic and translational aspects of scientific advancements and allow for a wider variety of research approaches. LFP
recordings have great relevance to neurosurgeons, neurologists, neuroscientists, physicists, and engineers alike, and future technological advancement will likely occur at the intersection of these disciplines. However, the niche nature of this field might underlie the lack of presence in broadly applicable, typically higher impact journals that can reach wider audiences.\textsuperscript{11,13}

LFP recordings have been implemented to elucidate differences in neuronal population activity, especially between structures and by frequency. The implementation of underlying neural activity to modify DBS parameters and optimize stimulation is known as “adaptive DBS.” Thus far, adaptive DBS has been most investigated for PD. Specifically, beta frequency activity (12–30 Hz) in the STN has been found to correlate with bradykinesia and rigidity, and stimulation can be applied relative to this activity.\textsuperscript{3,15,28,36} In the most highly cited article that we identified, Little et al.\textsuperscript{15} demonstrated the feasibility of adaptive DBS in humans and showed that by applying stimulation in a closed-loop system, the stimulation can be more efficacious and stimulator battery life could be improved. That article had been cited a total of 633 times and had had the highest rate of annual citations, at 63.3 citations annually.

When examining the most highly cited articles stratified by the DBS target, we found that most of the identified articles had examined LFPs in PD patients and that the most common target had been the STN. PD was the first U.S. Food and Drug Administration—approved condition for DBS (approved in 2002), and the number of patients with PD receiving DBS treatment has increased since then.\textsuperscript{37} Furthermore, 2 predominant target sites for PD are available: the STN and globus pallidus internus.\textsuperscript{38}
This might be attributable to older publications having had more time to accumulate citations, causing them to be more highly represented in most highly cited article lists. However, we also found DBS applications for a variety of other conditions, including multiple sclerosis (n = 1 study), obsessive-compulsive disorder and alcohol addiction (n = 4 studies), chronic pain (n = 2 studies), major depressive disorder (n = 1 study), Tourette syndrome (n = 1 study), major depressive disorder (n = 1 study), and epilepsy (n = 1 study). It is exciting that such articles have penetrated the literature landscape. For DBS to be implemented for the treatment of these conditions, a thorough knowledge of the underlying neurocircuitry is needed, and LFPs can provide a window to examine this. Additional studies will continue to add to the current knowledge and enable continued progress toward the expansion of DBS applications.

The OCEM class is an important factor in determining the magnitude of the data and evidence provided within an article and is the driver of evidence-based medicine. Recently, neurological journals have started to include this information in the metadata associated with an article (e.g., Rutka, 2016). Of the 77 studies for which the OCEM evidence class was available or could be assigned, we found that most articles were of class III evidence (i.e., retrospective cohort studies, case-controlled studies, or meta-analyses [e.g., systematic reviews]). Few of the studies had

### Table 2. Journals with Most Highly Cited DBS LFP Articles with Accompanying Journal Citation Information

| Top Represented Journals | Studies (n) | Impact Factor | SJR  | SNIP |
|--------------------------|------------|---------------|------|------|
| Exp Neurol               | 13         | 4.691         | 1.779| 1.18 |
| J Neurosci               | 9          | 5.673         | 3.483| 1.7  |
| Mov Dis                  | 6          | 8.679         | 3.352| 2.5  |
| Neurobiol Dis            | 5          | 5.332         | 2.205| 1.19 |
| Brain                    | 4          | 11.337        | 5.142| 3.05 |
| J Neurol Neurosurg Psychiatry | 3    | 8.234         | 3.391| 2.5  |
| J Neurophysiol           | 3          | 2.225         | 1.302| 0.95 |
| Neurology                | 3          | 8.77          | 2.91 | 2.48 |
| Brain Stimulat           | 2          | 6.585         | 2.685| 1.79 |
| Clinical Neurophysiol    | 2          | 3.214         | 1.478| 1.48 |
| J Clin Neurophysiol      | 2          | 1.434         | 0.657| 1.06 |
| J Physiol                | 2          | 4.547         | 1.802| 1.33 |
| Neuroimage               | 2          | 5.902         | 3.259| 1.9  |
| Neurosurgery             | 2          | 4.853         | 1.455| 1.73 |
| PLoS One                 | 2          | 2.74          | 0.99 | 1.35 |

DBS, deep brain stimulation; LFP, local field potential; SJR, Scimago Journal Rank; SNIP, journal source-normalized impact per paper.

*Impact factor was retrieved from Web of Science group ranking (2020); the SJR was retrieved from Scimago (2020); and SNIP was retrieved from CWTS Journal Indicators (2021).

### Table 3. Study Population of Top 84 Most Highly Cited DBS LFP Articles

| Study Population        | Studies (n) |
|-------------------------|-------------|
| Human                   | 57          |
| Nonhuman primate        | 1           |
| Rodent                  | 4           |
| Model/computational     | 6           |

DBS, deep brain stimulation; LFP, local field potential.

### Table 4. Target Structure of Top 84 Most Highly Cited DBS LFP Articles

| Target                                         | Studies (n) |
|------------------------------------------------|-------------|
| STN (PD)                                       | 48          |
| GPI (PD/ET)                                    | 3           |
| PPN (PD)                                       | 3           |
| VPL (PD/ET)                                    | 3           |
| NAc (OCD/alcohol addiction)                    | 3           |
| PVG (chronic pain)                             | 2           |
| BNST (OCD)                                     | 1           |
| SCC (major depressive disorder)                | 1           |
| CM/VO (Tourette syndrome)                      | 1           |
| Anterior thalamic/hippocampal (epilepsy)       | 1           |
| ZI (MS)                                        | 1           |
| Other/nonspecific                              | 3           |

DBS, deep brain stimulation; LFP, local field potential; STN, subthalamic nucleus; PD, Parkinson disease; GPI, globus pallidus internus; ET, essential tremor; PPN, pedunculopontine nucleus; VPL, ventral posterolateral nucleus; NAc, nucleus accumbens; OCD, obsessive-compulsive disorder; PVG, periventricular gray; BNST, bed nucleus of the stria terminalis; SCC, subgenual cingulate cortex; CM, centromedian thalamic nucleus; VO, nucleus ventrooralis; ZI, zona incerta; MS, multiple sclerosis.

### Table 5. Primary Aim of 84 Most Highly Cited DBS LFP Articles

| Study Aim                                                                 | Studies (n; %) |
|--------------------------------------------------------------------------|---------------|
| Understanding oscillatory activity                                       | 30 (35.7)     |
| Stimulation effects on neural activity                                  | 22 (26.2)     |
| Brain computer interface (“adaptive DBS”)                               | 8 (9.5)       |
| Pharmacologic function/co-function                                       | 3 (3.6)       |
| Clinical effect                                                          | 11 (13.1)     |
| Connectivity (MEG, fMRI, DTI, single units, etc.)                        | 9 (10.7)      |
| Review                                                                  | 16 (19.0)     |

MEG, magnetoencephalography; fMRI, functional magnetic resonance imaging; DTI, diffusion tensor imaging.

*The total count may exceed the number of studies because of multiple identified aims.
been of class I or II evidence, and no large RCTs were identified. Furthermore, of the 58 studies investigating DBS LFPs in humans, the studies had averaged only 13 subjects. Designing and executing DBS RCTs will be challenging owing to the stringent inclusion and exclusion criteria for surgical implantation and the limited number of potential participants. However, the number of patients who have received DBS has been increasing each year, and the overall research footprint of the field has also been increasing annually. A previous study indicated that the quality of RCTs in functional neurosurgery has been improving. Hence, we are hopeful to see studies with a higher number of subjects and more RCTs. Thus, it might be beneficial for future projects to recruit or include additional centers, similar to the identified article with the highest recruitment (54 subjects), which had had affiliations with 6 institutions. The reasons for low study participation might involve the low number of annual DBS implantations (studies investigating DBS usage in China across centers found that most centers had implanted <15 leads per annum) and ethical considerations to maintain patient autonomy, beneficence, and transparency.

The present study had several limitations, including those common to the bibliometric analysis technique. First, older articles and research media will have had more time to be exposed to the scientific community. Although most highly cited articles had been published in 2016 and DBS LFP technology is still in its relative infancy, newer studies might not have had more time to acquire high numbers of citations. Second, only articles in English (or those for which an English-translated version was available) were considered. It is known that a language discrepancy exists in scientific literature, one that biases toward the English language and can cause discrepancies in the citation rates. Hence, articles that were not in English could have been underrepresented in our analysis. Third, highly cited articles do not necessarily reflect research of good quality; it is possible that research can have increased citations for negative reasons (e.g., disagreement with the results). Finally, a bibliometric analysis cannot substitute for a thorough and comprehensive literature review, because the former will simply identify the most cited articles and not specifically inform regarding the complete status of a field. Such wide-ranging reviews and in-depth study are required, especially for modern DBS implementations and technologies, including multiple electrode recordings, awake versus asleep surgery, adaptive DBS, and directional DBS.

CONCLUSIONS

Our analysis has provided insight into the literature landscape of DBS LFP research. These most highly cited research articles indicate the progress in the field, major advances, and prominent trends in this research discipline. The present analysis has also provided insight for future directions of research and identified current deficiencies in the literature.

CONFLICT OF INTEREST STATEMENT

The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Akash Mishra: Conceptualization, Methodology, Data curation, Formal analysis, Writing—original draft, Writing—review & editing. Harshal A. Shah: Conceptualization, Methodology, Data curation. Joshua D. McBriar: Data curation, Writing—original draft, Writing—review & editing. Chris Zamor: Data curation, Writing—review & editing. Antonios Mammis: Conceptualization, Methodology, Writing—review & editing, Supervision.
8. Ponce FA, Lozano AM. Highly cited works in neurosurgery. Part I: the 100 top-cited papers in neurosurgical journals: a review. J Neurosurg. 2010;112:233-232.

9. Kamounye US, Robertson FC, Sebogelo LA, et al. Bibliometric analysis of the 200 most cited articles in World Neurosurgery. World Neurosurg. 2021;149:226-231.e7.

10. Lepard JR, Walters BC. A bibliometric analysis of neurosurgical practice guidelines. Neurosurgery. 2020;86:607-614.

11. Ward M, Doran J, Paskhover B, Mamiss A. The 30 most cited articles in invasive neuromodulation. World Neurosurg. 2018;114:2420-2426.

12. Lipsman N, Lozano AM. Measuring impact in stereotactic and functional neurosurgery: an analysis of the top 100 most highly cited works and the citation classics in the field. Stereotact Funct Neurosurg. 2012;90:201-209.

13. Hu K, Moses ZB, Xu W, Williams Z. Bibliometric profile of deep brain stimulation. Br J Neurosurg. 2017;31:987-992.

14. Yin Z, Zhu G, Zhao B, et al. Local field potentials in Parkinson’s disease: a frequency-based review. Neurobiol Dis. 2021;155:105372.

15. Little S, Pogosyan A, Neal S, et al. Adaptive deep brain stimulation in advanced Parkinson disease. Ann Neurol. 2017;74:449-457.

16. Widge AS, Ellard KK, Paulk AC, et al. Treating refractory mental illness with closed-loop brain stimulation: progress towards a patient-specific translational approach. Exp Neurol. 2017;287:461-472.

17. Neumann WJ, Staub F, Horn A, et al. Deep brain recordings using an implanted pulse generator in Parkinson’s disease. Neuro modulation. 2016;19:20-24.

18. Sypulkowski PH, Stanisłaski SR, Jensen RM, Denison TJ, Gifkins JE. Brain stimulation for epilepsy—local and remote modulation of network excitability. Brain Stimulat. 2014;7:530-538.

19. Kühn AA, Kempf F, Brucke C, et al. High-frequency stimulation of the subthalamic nucleus suppresses oscillatory activity in patients with Parkinson’s disease in parallel with improvement in motor performance. J Neurosci. 2008;28:6065-6073.

20. Weinberger M, Mahant N, Hutchison WD, et al. Beta oscillatory activity in the subthalamic nucleus and its relation to dopaminergic response in Parkinson’s disease. J Neurophysiol. 2006;96:3748-3756.

21. Priore A, Foffani G, Pesenti A, et al. Rhythm-specific pharmacological modulation of subthalamic activity in Parkinson’s disease. Exp Neurol. 2004;193:399-379.

22. Eusebio A, Thevathasan W, Doyle Gaynor L, et al. Deep brain stimulation can suppress pathological synchronisation in parkinsonian patients. J Neurol Neurosurg Psychiatry. 2012;83:569-573.

23. Priore A, Foffani G, Rossi L, Marcellig S. Adaptive deep brain stimulation (aDBS) controlled by local field potential oscillations. Exp Neurol. 2013;245:77-86.

24. Bronste-Stewart H, Barberini C, Koep MM, Hill BC, Henderson JM, Wingeir B. The STN beta-band profile in Parkinson’s disease is stationary and shows prolonged attenuation after deep brain stimulation. Exp Neurol. 2009;225:20-28.

25. Li S, Aebasmnott GW, Jutras MJ, Goldberg JA, Jaeger D. Resonant antidromic cortical circuit activation as a consequence of high-frequency subthalamic deep-brain stimulation. J Neurophysiol. 2007;98:3325-3337.

26. Herrington TM, Cheng JJ, Eskandar EN. Mechanisms of deep brain stimulation. J Neurophysiol. 2011;105:939-953.

27. Wingeir B, Tcheng T, Koep MM, Hill BC, Heit G, Bronste-Stewart HM. Intra-operative STN DBS attenuates the prominent beta rhythm in the STN in Parkinson’s disease. Exp Neurol. 2006;207:244-251.

28. Areti M, Marcellig S, Foffani G, et al. Eight-hours adaptive deep brain stimulation in patients with Parkinson disease. Neurology. 2018;90:97:1-97:8.

29. Horn A, Neumann WJ, Degen K, Schneider GH, Kühn AA. Toward an electrophysiological “sweet spot” for deep brain stimulation in the subthalamic nucleus: subcortical mapping of “beta” band activity in Parkinson’s disease. Hum Brain Mapp. 2017;38:3377-3390.

30. Pritchard A. Statistical bibliography or bibliometrics. J Doc. 1996:35:348-349.

31. Priore A. Technology for deep brain stimulation at a gallop. Mov Disord. 2015;30:1206-1213.

32. Cummins DD, Kochanski RB, Gilron R, et al. Chronic sensing of subthalamic local field potentials: comparison of first and second generation implantable bidirectional systems within a single subject. Front Neurosci. 2021;15:735:97.

33. Hauptman JS, Chow DS, Martin NA, Itagiaki MW. Research productivity in neurosurgery: trends in globalization, scientific focus, and funding: a review. J Neurosurg. 2011;115:262-272.

34. Sarica C, Egemen E. Contribution of countries to scientific output in subthalamic neurostimulation. Front Integr Neurosci. 2011;5:17.

35. Elaissmith C, Anderson CH. Neural Engineering: Computational, Representation, and Dynamics in Neurobiological Systems. Cambridge, MA: MIT Press; 2004.

36. Little S, Brown P. What brain signals are suitable for feedback control of deep brain stimulation in Parkinson’s disease? Ann N Y Acad Sci. 2012;1255:9-24.

37. Gardner J. A history of deep brain stimulation: technological innovation and the role of clinical assessment tools. Sur Surf Stud. 2013;44:709-728.

38. Wagle Shukla A, Okun MS. Surgical treatment of Parkinson’s disease: patients, targets, devices, and approaches. Neurotherapeutics. 2014;11:57-95.

39. Rutka JT. Editorial: classes of evidence in neurosurgery. J Neurosurg. 2016;125:674-747.

41. Bronte-Stewart H, Taira T, Valdeoroña F, et al. Inclusion and exclusion criteria for DBS in dystonia: inclusion and exclusion criteria. Mov Disord. 2012;26:suppl 1:55-516.

42. Munhob RP, Picillo M, Fox SH, et al. Eligibility criteria for deep brain stimulation in Parkinson’s disease, tremor, and dystonia. Can J Neurol Sci. 2016;43:462-471.

43. Lozano AM, Lipsman N, Bergman H, et al. Deep brain stimulation: current challenges and future directions. Nat Rev Neurol. 2010;6:143-146.

44. Azad TD, Feng AY, Mehta S, et al. Randomized controlled trials in functional neurosurgery—association of device approval status and trial quality. Neuro modulation. 2020;23:496-501.

45. Zhang C, Ramirez-Zamora A, Feng F, et al. An international survey of deep brain stimulation utilization in Asia and Oceania: the DBS think tank east. Front Hum Neurosci. 2020;14:162.

46. Schermer M. Ethical issues in deep brain stimulation. Front Integr Neurosci. 2011;5:17.

49. van Bergeijk D, Risseeuw M. The International Translations Centre: the language barrier in the dissemination of scientific information and the role of the ITC. J Inf Sci. 1980;2:37-42.

50. Ren S, Zu G, Wang HF. Statistics hide impact of non-English journals. Natur. 2002;415:732.

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