Measuring Impact in Stereotactic and Functional Neurosurgery: An Analysis of the Top 100 Most Highly Cited Works and the Citation Classics in the Field

Nir Lipsman Andres M. Lozano

Division of Neurosurgery, Toronto Western Hospital, University of Toronto, Toronto, Ont., Canada

Key Words

Functional neurosurgery • Top 100 papers • Citation classics • Literature search • Citation indices

Abstract

Background: Functional neurosurgery is a rapidly expanding field, with an exponentially growing literature. However, as with other fields, it can sometimes be difficult to distinguish between what is incremental and what is transformational. One way of measuring durable impact is examining the number of times a specific piece of scholarship is cited by others in the field. For example, papers that have been cited at least 400 times are designated 'citation classics' or works that, by virtue of very high citations, have been deemed of particular importance by researchers working in related disciplines. **Methods:** We queried a large, web-based scholarly database using 49 pre-selected search terms. The results for each individual query was manually examined for relevance to the functional neurosurgery field in order to arrive at the top 100 most highly cited papers as well as the citation classics. **Results:** The top 100 most cited papers, including 61 citation classics, in the stereotactic and functional neurosurgery field can be divided into 7 categories: functional/anatomic studies, technological innovations, and

papers relevant to movement disorders, pain, psychiatry, radiosurgery and epilepsy. **Conclusions:** We have attempted to ascertain which papers have had, and continue to have, significant impact in our rapidly advancing field. At a minimum, the citation classics in functional neurosurgery provide both trainees and seasoned surgeons with a reading list of the 'must-know' works in the field – works whose influence have helped shape the direction of functional neurosurgery well into the future.

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Background

Technological and conceptual advances in functional neurosurgery have led to a rapidly growing biomedical literature. Given the diversity of diagnoses and number of procedures under the umbrella of 'functional disorders', ranging from movement disorders to psychiatry to radiosurgery, it can often be difficult to keep up and distinguish

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Table 1. Search terms used

Balloon compression	Glycerol	Proton Beam
Brachytherapy	Hemispherectomy	Radiofrequency
Brain-machine interface	Image guidance	Radiosurgery
Brain stimulation	Image-guided surgery	Rhizotomy
Callosotomy	Intrathecal	Spinal cord stimulation
Capsulotomy	Language mapping	Stereotactic
Cingulotomy	Linac	Stereotaxic
Cordotomy	Lobectomy	Stereotaxis
CyberKnife	Localization	Subpial transection
Deep brain stimulation	Mapping	Subthalamotomy
Dorsal root entry zone	Mesencephalotomy	Sympathectomy
DREZ	Microvascular decompression	Temporal lobectomy
Electrical stimulation	Motor cortex stimulation	Thalamotomy
Epidural stimulation	Movement disorder surgery	Tractotomy
Fetal transplantation	Neuronavigation	Vagal nerve
Gamma Knife	Pallidotomy	
Gene transfer	Peripheral nerve stimulation	

between the important and the incremental developments in the field. One way of doing so is examining which publications have been cited most frequently by others within the field and its related disciplines. Whether having a positive impact or a negative one, highly cited works can be viewed, when analyzed as a whole, as an objectively agreed-upon list of work that has influenced the field, given their recognition by others. In bibliometric terms, a citation classic is defined as a work that has been cited at least 400 times by others in the biomedical literature [1, 2]. An examination of citation classics in different fields and even within different diagnoses can yield an interesting snapshot of key papers in that area and provide unique insights into how impact is achieved and changes with time [3, 4]. For example, we have previously shown that the field of Parkinson's disease (PD) contains approximately as many citation classics as the entire field of neurosurgery [5, 6]. The field of major depression, on the other hand, contains more citation classics than both combined [7]. Such lists reflect not only the breadth of work within a field but also the relative impact of specific types of work in that area. An example is that papers that described scales and measures in depression accounted for 8 of the top 10 most highly cited papers in the field.

The list of highly cited papers is valuable for several reasons. Decisions regarding funding, resource allocation and academic priorities can be made by identifying which areas offer most promise and which do not. Citation classics also allow beginner and expert members of the field to keep up with the literature and identify, at a glance, which works have made a lasting impact.

Other papers have examined highly cited works in sub-disciplines within functional neurosurgery, such as radiosurgery [8, 9]. For example, one group has recently analyzed citation and publication patterns specifically in the field of stereotaxy, with a focus on the contemporary era (work since 1993) [8]. The authors sought to describe global trends in stereotactic research and identify particularly prolific and productive surgical centers. Thus far, however, no work has examined the citation classics in the field of stereotactic and functional neurosurgery as a whole. The objective of this paper is to examine which papers in the functional neurosurgery literature have become citation classics and, further, to identify what are the 100 most highly cited works in the field.

Methods

For our literature search, we used a free, downloadable, publicly available software (Harzing's Publish or Perish 3, PoP3) that utilizes Google Scholar to identify citation indices [10]. Google Scholar is an online search engine that crawls the Internet in search of publications in the biomedical literature, returning results with listed citations. Given the breadth and diversity of the functional neurosurgery field, we sought to be as inclusive as possible with our search criteria and search terms. Our inclusion criteria for papers and studies were the following: (i) functional neurosurgical procedures done in humans; (ii) in one of the main foci of interest of functional neurosurgery (pain, movement disorders, psychiatry, epilepsy and radiosurgery); (iii) discoveries that were made in the course of surgery for any of the preceding indications, and (iv) technology that was developed to facilitate any of the preceding functional neurosurgery procedures.

We identified 49 search terms and searched for each individually anywhere in the paper, title or abstract (table 1). We then manually examined all search results for all search terms individually and gathered all papers with at least 300 citations, a number designed to include all citation classics as well as furnish the final list of the top 100 papers. We excluded (i) patents, books, manuals and non-biomedical publications; (ii) papers dealing with pre-clinical models and experimental (basic science) findings regardless of their relevance to functional neurosurgery, and (iii) literature reviews dealing with specific diagnoses.

Results

Using the above search terms, we identified 61 papers in the functional neurosurgery field with at least 400 citations, the so-called citation classics (table 2). Extending our citation cutoff to 300, we were also able to identify the top 100 most highly cited works in the field (online suppl. table 1; for all online suppl. material, see www.karger.com/doi/10.1159/000337170). The 61 citation classics were found in 25 different journals, with 11 journals having at least 2 papers (table 3). In order to facilitate an analysis of the types of papers that are citation classics and of how trends may have evolved with time, we divided all our results into categories based on the predominant theme of each paper. There were 7 broad categories: functional/anatomic studies, technological advancements, movement disorders, pain, psychiatry, epilepsy and radiosurgery. Table 4 lists the categories, along with the number of citation classics and top 100 papers in each category.

Functional/Anatomic Studies

There were 12 citation classics and 27 top 100 papers in this category. These papers sought to uncover and explore basic functions of central nervous system structures in the course of a functional neurosurgical procedure, or as a consequence of such a procedure. As these types of papers can have broad applicability and relevance to multiple disciplines, from neurology to neurophysiology, they are frequently the most highly cited works, and also some of the oldest papers in the literature. For example, the top 3 papers in the functional neurosurgery field were all in this category. These 3 papers alone account for 47% of all the citations in the top 10. This is likely a function of the early days of the field, where new procedures and their consequences were being developed and explored. Indeed, the oldest paper in the top 100, published in 1937, was an examination of somatic and motor sensation induced by open electrical stimulation [11].

Technology

There were 7 citation classics and 12 top 100 papers in the technology category. Here, we included papers that described new techniques, procedures or equipment with the specific aim of advancing either diagnosis or treatment in functional neurosurgery. As technology is intimately related to the field, it can be difficult to tease out which papers represent technological, as opposed to clinical, advances, and to define where this line should be drawn, if it should be drawn at all. The Limitations section below discusses this in detail. We observed, however, that the most significant advances prior to 1980 were the development of radiosurgery by Leksell in 1951 and the introduction of the stereotactic frame by Spiegel and Wycis in 1947, both fundamental components of modern practice. More recent technological advances have focused on image guidance, the integration of stereotaxy into clinical practice and on interfacing the brain with a machine. Indeed, one of the more impressive and informative results was that a paper dealing with neuronal control of a prosthetic arm in a human, published in 2006, had garnered nearly 1,000 citations in 5 years, suggesting a building momentum in the brain-machine interface field.

Movement Disorders

This field represents, in many ways, the cornerstone of modern functional neurosurgery. There were 31 top 100 papers in the functional neurosurgery literature related to movement disorders, and of these 22 were citation classics, representing the largest proportion of all the categories. Among the citation classics, work relevant to PD made up the vast majority (19 publications), with the remaining 3 works focusing on tremor. Interestingly, in the top 4 works were papers related to each of the areas fetal cell transplantation, stimulation and lesioning, reflecting the diversity of different approaches to PD in the field. Among the 31 top 100 papers, 6 (20%) dealt with lesioning, 12 (38.7%) dealt with stimulation, 1 (3.3%) compared lesioning to stimulation, and 12 (40%) dealt with cell transplantation, including the most highly cited work dealing with movement disorders in the list. For the citation classics, these numbers were 3 (10%) for lesions, 10 (33%) for stimulation, 1 (3.3%) for both, and 8 (26.7%) for transplantation. Put differently, papers examining stimulation had more citation classics, although papers dealing with cell transplantation had a slightly higher representation in the top 100.

Pain

Papers dealing with pain neurosurgery accounted for 12 of the top 100 papers, of which 8 were citation classics.

Table 2. The 61 citation classics

Rank	Citations	Paper	Category
1	3,209	Scoville WB, Milner B: Loss of recent memory after bilateral hippocampal lesions. <i>J Neurol Neurosurg Psychiatry</i> 1957;20:11–21.	Func/Ana
2	1,472	Milner B: Interhemispheric differences in the localization of psychological processes in man. <i>Br Med Bull</i> 1971;27:272–277.	Func/Ana
3	1,394	Penfield W, Boldrey E: Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. <i>Brain</i> 1937;60:389–443.	Func/Ana
4	1,299	Freed CR, Greene PE, Breeze RE, Tsai WY, DuMouchel W, Kao R, Dillon S, Winfield H, Culver S, Trojanowski JQ, Eidelberg D, Fahn S: Transplantation of embryonic dopamine neurons for severe Parkinson's disease. <i>N Engl J Med</i> 2001;344:710–719.	MD
5	1,008	Limousin P, Krack P, Pollak P, Benazzouz A, Ardouin C, Hoffmann D, Benabid AL: Electrical stimulation of the subthalamic nucleus in advanced Parkinson's disease. <i>N Engl J Med</i> 1998;339:1105–1111.	MD
6*	971	Hochberg LR, Serruya MD, Friehs GM, Mukand JA, Saleh M, Caplan AH, Branner A, Chen D, Penn RD, Donoghue JP: Neuronal ensemble control of prosthetic devices by a human with tetraplegia. <i>Nature</i> 2006;442:164–171.	Tech
7*	910	Mayberg HS, Lozano AM, Voon V, McNeely HE, Seminowicz D, Hamani C, Schwab JM, Kennedy SH: Deep brain stimulation for treatment-resistant depression. <i>Neuron</i> 2005;45:651–660.	Psych
8	899	Leksell L: The stereotaxic method and radiosurgery of the brain. <i>Acta Chir Scand</i> 1951;102:316–319.	Tech
9*	870	Krack P, Batir A, Van Blercom N, Chabardes S, Fraix V, Ardouin C, Koudsie A, Limousin PD, Benazzouz A, LeBas JF, Benabid AL, Pollak P: Five-year follow-up of bilateral stimulation of the subthalamic nucleus in advanced Parkinson's disease. <i>N Engl J Med</i> 2003;349:1925–1934.	MD
10	779	Laitinen LV, Bergenheim AT, Hariz MI: Leksell's posteroventral pallidotomy in the treatment of Parkinson's disease. <i>J Neurosurg</i> 1992;76:53–61.	MD
11	725	Benabid AL, Pollak P, Gervason C, Hoffmann D, Gao DM, Hommel M, Perret JE, de Rougemont J: Long-term suppression of tremor by chronic stimulation of the ventral intermediate thalamic nucleus. <i>Lancet</i> 1991;337:403–406.	MD
12	709	Ojemann G, Ojemann J, Lettich E, Berger M: Cortical language localization in left, dominant hemisphere. An electrical stimulation mapping investigation in 117 patients. <i>J Neurosurg</i> 1989;71:316–326.	Func/Ana
13	697	Limousin P, Pollak P, Benazzouz A, Hoffmann D, Le Bas JF, Broussolle E, Perret JE, Benabid AL: Effect of parkinsonian signs and symptoms of bilateral subthalamic nucleus stimulation. <i>Lancet</i> 1995;345:91–95.	MD
14	665	Olanow CW, Goetz CG, Kordower JH, Stoessl AJ, Sossi V, Brin MF, Shannon KM, Nauert GM, Perl DP, Godbold J, Freeman TB: A double-blind controlled trial of bilateral fetal nigral transplantation in Parkinson's disease. <i>Ann Neurol</i> 2003;54:403–414.	MD
15*	646	Wiebe S, Blume WT, Girvin JP, Eliasziw M, Effectiveness and Efficiency of Surgery for Temporal Lobe Epilepsy Study Group: A randomized, controlled trial of surgery for temporal-lobe epilepsy. <i>N Engl J Med</i> 2001;345:311–318.	Epi
16	632	Andrews DW, Scott CB, Sperduto PW, Flanders AE, Gaspar LE, Schell MC, Werner-Wasik M, Demas W, Ryu J, Bahary JP, Souhami L, Rotman M, Mehta MP, Curran WJ Jr: Whole brain radiation therapy with or without stereotactic radiosurgery boost for patients with one to three brain metastases: phase III results of the RTOG 9508 randomised trial. <i>Lancet</i> 2004;363:1665–1672.	Radio
17	625	Brindley GS, Lewin WS: The sensations produced by electrical stimulation of the visual cortex. <i>J Physiol</i> 1968;196:479–493.	Func/Ana
18	589	Benabid AL, Pollak P, Gao D, Hoffmann D, Limousin P, Gay E, Payen I, Benazzouz A: Chronic electrical stimulation of the ventralis intermedius nucleus of the thalamus as a treatment of movement disorders. <i>J Neurosurg</i> 1996;84:203–214.	MD
19	588	Shealy CN, Mortimer JT, Reswick JB: Electrical inhibition of pain by stimulation of the dorsal columns: preliminary clinical report. <i>Anesth Analg</i> 1967;46:489–491.	Pain
20	583	Lindvall O, Brundin P, Widner H, Rehnström S, Gustavii B, Frackowiak R, Leenders KL, Sawle G, Rothwell JC, Marsden CD, et al: Grafts of fetal dopamine neurons survive and improve motor function in Parkinson's disease. <i>Science</i> 1990;247:574–577.	MD
21	551	Mayer DJ, Liebeskind JC: Pain reduction by focal electrical stimulation of the brain: an anatomical and behavioral analysis. <i>Brain Res</i> 1974;68:73–93.	Pain
22	546	Kordower JH, Freeman TB, Snow BJ, Vingerhoets FJ, Mufson EJ, Sanberg PR, Hauser RA, Smith DA, Nauert GM, Perl DP, et al: Neuropathological evidence of graft survival and striatal reinnervation after the transplantation of fetal mesencephalic tissue in a patient with Parkinson's disease. <i>N Engl J Med</i> 1995;332:1118–1124.	MD

Table 2 (continued)

Rank	Citations	Paper	Category
23	528	Penfield W, Milner B: Memory deficit produced by bilateral lesions in the hippocampal zone. <i>AMA Arch Neurol Psychiatry</i> 1958;79:475–497.	Func/Ana
24	526	Wolpaw JR, McFarland DJ: Control of a two-dimensional movement signal by a noninvasive brain-computer interface in humans. <i>Proc Natl Acad Sci USA</i> 2004;101:17849–17854.	Tech
25	515	Flickinger JC, Kondziolka D, Lunsford LD, Coffey RJ, Goodman ML, Shaw EG, Hudgins WR, Weiner R, Harsh GR 4th, Sneed PK, et al: A multi-institutional experience with stereotactic radiosurgery for solitary brain metastasis. <i>Int J Radiat Oncol Biol Phys</i> 1994;28:797–802.	Radio
26	512	Milner B: Visual recognition and recall after right temporal-lobe excision in man. <i>Neuropsychologia</i> 1968;6:191–209.	Func/Ana
27	511	Barker FG 2nd, Jannetta PJ, Bissonette DJ, Larkins MV, Jho HD: The long-term outcome of microvascular decompression for trigeminal neuralgia. <i>N Engl J Med</i> 1996;334:1077–1083.	Pain
28	509	Spiegel EA, Wycis HT, Marks M, Lee AJ: Stereotaxic apparatus for operations on the human brain. <i>Science</i> 1947;106:349–350.	Tech
29	505	Wall PD, Sweet WH: Temporary abolition of pain in man. <i>Science</i> 1967;155:108–109.	Pain
30	499	Kondziolka D, Patel A, Lunsford LD, Kassam A, Flickinger JC: Stereotactic radiosurgery plus whole brain radiotherapy versus radiotherapy alone for patients with multiple brain metastases. <i>Int J Radiat Oncol Biol Phys</i> 1999;45:427–434.	Radio
31	495	Milner B: Psychological defects produced by temporal lobe excision. <i>Res Publ Assoc Res Nerv Ment Dis</i> 1958;36:244–257.	Func/Ana
32	482	Deuschl G, Schade-Brittinger C, Krack P, Volkmann J, Schäfer H, Bötzel K, Daniels C, Deuschländer A, Dillmann U, Eisner W, Gruber D, Hamel W, Herzog J, Hilker R, Klebe S, Kloss M, Koy J, Krause M, Kupsch A, Lorenz D, Lorenzl S, Mehdorn HM, Moringlane JR, Oertel W, Pinski MO, Reichmann H, Reuss A, Schneider GH, Schnitzler A, Steude U, Sturm V, Timmermann L, Tronnier V, Trottenberg T, Wojtecki L, Wolf E, Poewe W, Voges J, German Parkinson Study Group, Neurostimulation Section: A randomized trial of deep-brain stimulation for Parkinson's disease. <i>N Engl J Med</i> 2006;355:896–908.	MD
33	479	Roberts DW, Strohbehn JW, Hatch JF, Murray W, Kettenberger H: A frameless stereotaxic integration of computerized tomographic imaging and the operating microscope. <i>J Neurosurg</i> 1986;65:545–549.	Tech
34	472	Schuurman PR, Bosch DA, Bossuyt PM, Bonsel GJ, van Someren EJ, de Bie RM, Merkus MP, Speelman JD: A comparison of continuous thalamic stimulation and thalamotomy for suppression of severe tremor. <i>N Engl J Med</i> 2000;342:461–468.	MD
35	465	Ojemann GA: Brain organization for language from the perspective of electrical stimulation mapping. <i>Behav Brain Sci</i> 1983;6:189–206.	Func/Ana
36	461	Smith ML, Milner B: The role of the right hippocampus in the recall of spatial location. <i>Neuropsychologia</i> 1981;19:781–793.	Func/Ana
37	459	Alexander E 3rd, Moriarty TM, Davis RB, Wen PY, Fine HA, Black PM, Kooy HM, Loeffler JS: Stereotactic radiosurgery for the definitive, noninvasive treatment of brain metastases. <i>J Natl Cancer Inst</i> 1995;87:34–40.	Radio
38	458	Basser LS: Hemiplegia of early onset and the faculty of speech with special reference to the effects of hemispherectomy. <i>Brain</i> 1962;85:427–460.	Func/Ana
39	453	Handforth A, DeGiorgio CM, Schachter SC, Uthman BM, Naritoku DK, Tecoma ES, Henry TR, Collins SD, Vaughn BV, Gilmartin RC, Labar DR, Morris GL 3rd, Salinsky MC, Osorio I, Ristanovic RK, Labiner DM, Jones JC, Murphy JV, Ney GC, Wheless JW: Vagus nerve stimulation therapy for partial-onset seizures: a randomized active-control trial. <i>Neurology</i> 1998;51:48–55.	Epi
40	448	Penfield W, Welch K: The supplementary motor area of the cerebral cortex; a clinical and experimental study. <i>AMA Arch Neurol Psychiatry</i> 1951;66:289–317.	Func/Ana
41	445	Hosobuchi Y, Adams JE, Linchitz R: Pain relief by electrical stimulation of the central gray matter in humans and its reversal by naloxone. <i>Science</i> 1977;197:183–186.	Pain
42	443	Piccini P, Brooks DJ, Björklund A, Gunn RN, Grasby PM, Rimoldi O, Brundin P, Hagell P, Rehncrona S, Widner H, Lindvall O: Dopamine release from nigral transplants visualized in vivo in a Parkinson's patient. <i>Nat Neurosci</i> 1999;2:1137–1140.	MD
43	443	Lunsford LD, Kondziolka D, Flickinger JC, Bissonette DJ, Jungreis CA, Maitz AH, Horton JA, Coffey RJ: Stereotactic radiosurgery for arteriovenous malformations of the brain. <i>J Neurosurg</i> 1991;75:512–524.	Radio
44	440	Engel J Jr: Surgery for seizures. <i>N Engl J Med</i> 1996;334:647–652.	Epi

Table 2 (continued)

Rank	Citations	Paper	Category
45	438	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. <i>Appl Neurophysiol</i> 1987;50:344–346.	MD
46	431	Kumar R, Lozano AM, Kim YJ, Hutchison WD, Sime E, Halket E, Lang AE: Double-blind evaluation of subthalamic nucleus deep brain stimulation in advanced Parkinson's disease. <i>Neurology</i> 1998;51:850–855.	MD
47	431	Blomgren H, Lax I, Näslund I, Svanström R: Stereotactic high dose fraction radiation therapy of extracranial tumors using an accelerator. Clinical experience of the first thirty-one patients. <i>Acta Oncol</i> 1995;34:861–870.	Radio
48	430	Krack P, Pollak P, Limousin P, Hoffmann D, Xie J, Benazzouz A, Benabid AL: Subthalamic nucleus or internal pallidal stimulation in young onset Parkinson's disease. <i>Brain</i> 1998;121:451–457.	MD
49	430	Rodriguez-Oroz MC, Obeso JA, Lang AE, Houeto JL, Pollak P, Rehnrcrona S, Kulisevsky J, Albanese A, Volkmann J, Hariz MI, Quinn NP, Speelman JD, Guridi J, Zamarbide I, Gironell A, Molet J, Pascual-Sedano B, Pidoux B, Bonnet AM, Agid Y, Xie J, Benabid AL, Lozano AM, Saint-Cyr J, Romito L, Contarino MF, Scerrati M, Fraix V, Van Blercom N: Bilateral deep brain stimulation in Parkinson's disease: a multicentre study with 4 years follow-up. <i>Brain</i> 2005;128:2240–2249.	MD
50	423	McLaughlin MR, Jannetta PJ, Clyde BL, Subach BR, Comey CH, Resnick DK: Microvascular decompression of cranial nerves: lessons learned after 4,400 operations. <i>J Neurosurg</i> 1999;90:1–8.	Pain
51	417	Freed CR, Breeze RE, Rosenberg NL, Schneck SA, Kriek E, Qi JX, Lone T, Zhang YB, Snyder JA, Wells TH, et al: Survival of implanted fetal dopamine cells and neurologic improvement 12 to 46 months after transplantation for Parkinson's disease. <i>N Engl J Med</i> 1992;327:1549–1555.	MD
52	413	Lutz W, Winston KR, Maleki N: A system for stereotactic radiosurgery with a linear accelerator. <i>Int J Radiat Oncol Biol Phys</i> 1988;14:373–381.	Tech
53	411	Backlund EO, Granberg PO, Hamberger B, Knutsson E, Mårtensson A, Sedvall G, Seiger A, Olson L: Transplantation of adrenal medullary tissue to striatum in parkinsonism. First clinical trials. <i>J Neurosurg</i> 1985;62:169–173.	MD
54	408	Lozano AM, Lang AE, Galvez-Jimenez N, Miyasaki J, Duff J, Hutchinson WD, Dostrovsky JO: Effect of GPi pallidotomy on motor function in Parkinson's disease. <i>Lancet</i> 1995;346:1383–1387.	MD
55	406	Jannetta PJ, Abbasy M, Maroon JC, Ramos FM, Albin MS: Etiology and definitive microsurgical treatment of hemifacial spasm. Operative techniques and results in 47 patients. <i>J Neurosurg</i> 1977;47:321–328.	Pain
56	405	Donoghue JP: Connecting cortex to machines: recent advances in brain interfaces. <i>Nat Neurosci</i> 2002;5(suppl):1085–1088.	Tech
57	404	Marsden CD, Obeso JA: The functions of the basal ganglia and the paradox of stereotaxic surgery in Parkinson's disease. <i>Brain</i> 1994;117(Pt 4):877–897.	Func/Ana
58	403	Baron MS, Vitek JL, Bakay RA, Green J, Kaneoke Y, Hashimoto T, Turner RS, Woodard JL, Cole SA, McDonald WM, DeLong MR: Treatment of advanced Parkinson's disease by posterior GPi pallidotomy: 1-year results of a pilot study. <i>Ann Neurol</i> 1996;40:355–366.	MD
59	401	Sweet WH, Wepsic JG: Controlled thermocoagulation of trigeminal ganglion and rootlets for differential destruction of pain fibers. 1. Trigeminal neuralgia. <i>J Neurosurg</i> 1974;40:143–156.	Pain
60	401	Madrazo I, Drucker-Colin R, Díaz V, Martínez-Mata J, Torres C, Becerril JJ: Open microsurgical autograft of adrenal medulla to the right caudate nucleus in two patients with intractable Parkinson's disease. <i>N Engl J Med</i> 1987;316:831–834.	MD
61	400	Auchter RM, Lamond JP, Alexander E, Buatti JM, Chappell R, Friedman WA, Kinsella TJ, Levin AB, Noyes WR, Schultz CJ, Loeffler JS, Mehta MP: A multiinstitutional outcome and prognostic factor analysis of radiosurgery for resectable single brain metastasis. <i>Int J Radiat Oncol Biol Phys</i> 1996;35:27–35.	Radio

Papers marked with an asterisk have had more than 100 citations per year since the year of their publication (until November 2011).

Func/Ana = Functional/anatomic study; MD = movement disorder study; Tech = technology study; Psych = psychiatry study; Epi = epilepsy study; Radio = radiosurgery study; Pain = pain study.

Besides the functional/anatomy category, the pain group had the largest representation prior to 1980, with 6 papers in that era. Five (41.7%) of the top 100 papers, of which 4 were citation classics, dealt with trigeminal or facial pain, while 4 (33.3%) dealt with spinal cord stimulation.

Psychiatry

There were 2 publications dealing with psychiatric neurosurgery in the top 100, of which 1 can be designated a citation classic. Interestingly, both papers dealt with stimulation, either vagal nerve or deep brain, and both

Fig. 1. The top 100 papers over time (citations per year).

were related to major depressive disorder. There were no papers dealing with ablative psychiatric surgery on the list, despite its relatively long history in the realm of functional neurosurgery.

Epilepsy

There were 3 publications in the top 100 that dealt primarily with epilepsy, and all 3 had over 400 citations. Two papers evaluated a therapy (vagal nerve stimulation and temporal lobectomy), and the third was a prominent and highly cited commentary on surgery for seizures. Of note, these papers dealt exclusively with the treatment of seizures with surgery and so were included in a distinct category. Several publications in the functional/anatomic category also involved patients with epilepsy who were tested intra- and postoperatively in order to highlight the functional impact observed during and after seizure surgery. We distinguished these two categories by the primary intent of the articles rather than by the subject population per se.

Radiosurgery

For this category, we included all clinical articles using any form of radiosurgery, including Gamma Knife and linear accelerator. As such, the technological advances, most notably Leksell's 1951 paper, were not included here, but instead in the technology category. There were 13 clinical radiosurgery papers in the top 100, of which 7 were citation classics. Among these 13, 10 dealt with oncologic applications and 3 with arteriovenous malformations (the figures were 6 and 1, respectively, for citation classics). All of the citation classics in the clinical radiosurgery category were published after 1990.

Table 3. Journals containing 2 or more citation classics

<i>NEJM</i>	11
<i>Journal of Neurosurgery</i>	9
<i>Brain</i>	5
<i>International Journal of Radiation Oncology, Biology, Physics</i>	4
<i>Science</i>	4
<i>The Lancet</i>	4
<i>Annals of Neurology</i>	2
<i>Archives of Neurology and Psychiatry</i>	2
<i>Nature Neuroscience</i>	2
<i>Neuropsychologia</i>	2
<i>Neurology</i>	2

Table 4. Categories of articles

Category	Top 100	Citation classics
Epilepsy	3	3
Functional/anatomy	27	13
Movement disorders	31	22
Pain	12	8
Psychiatry	2	1
Radiosurgery	13	7
Technology	12	7
Total	100	61

Discussion

We identified the top 100 most highly cited papers in the functional neurosurgery literature, of which 61 publications can be designated as citation classics.

Trends over Time

Convention would dictate that older publications, by virtue of having more years to accumulate citations, would necessarily be overrepresented in the top 100 and citation classic lists. However, this is not typically the case. As is illustrated in figure 1, there was a clear crescendo in highly cited works per year until the mid-1990's, at which point the rate declined. This is likely due to two factors. First, the 1990's were particularly active years in functional neurosurgery, marked most significantly by the success of deep brain stimulation clinical trials. Second, the '90's peak' may be a fundamental feature of contemporary research with a combination of not viewing as necessary the referencing of older publications that established basic principles but have since been replicated and newer publications that have not had time to

Table 5. Number of citation classics by epoch in each category

	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009
Epilepsy							2	1
Functional/anatomy	1		4	3	1	3	1	
Movement disorders						3	13	6
Pain				2	4		2	
Psychiatry								1
Radiosurgery							6	1
Technology		1	1			2		3

establish themselves as citation classics. Indeed we noted a similar ‘90’s peak’ in previous analyses that examined the citation classics in the major depression field [7]. It should be noted, however, that among the citation classics, 3/5 papers with over 1,000 citations were published in 1971 or before.

Trends of categories over time are particularly informative as these provide insights into the fluctuations of research interests over the years (table 5). For example, functional/anatomic studies, where cranial surgery was used as a laboratory of sorts to study the response to either electrical stimulation or cortical resection, were more common prior to 1970 than after. For example, Dr. Brenda Milner, whose practice grew primarily out of such anatomic investigations following cortical resections, has 7 publications in the top 100, including numbers 1 and 2. It is also interesting to note, although not entirely surprising as this likely grew out of an increasing sophistication in trial design, that the clinical epilepsy papers on the citation classic list were all published after 1990.

In general, as shown in table 5, there is a clustering of citation classics after 1980, with 71% published after that year. Papers in the movement disorder category accounted for 50% of these, indicating that this field, and particularly PD research, dominated the functional neurosurgery research for the last 30 years.

Absolute Number versus Velocity

Whereas the absolute number of citations may provide an indication of where the field has been and is currently at, the velocity of accumulating citations, or the citations per year since publication, can provide an indication of where the field is going. Among the 61 citation classics, for example, only 4 had more than 100 citations per year since the date of their publication (until November 2011) (asterisks in table 2). These publications deal with brain-machine interface technology [12], deep brain stimulation for depression [13], deep brain stimulation for PD

[14], and temporal lobectomy for epilepsy [15]. There can be several reasons for the relative success and impact of these publications, not least of which is their significant overlap with other disciplines, which are substantially larger with a corresponding large literature, such as psychiatry and neurology. The velocity of growth of individual categories is also informative, and here, radiosurgery has made substantial strides, with 7 citation classics in the last 20 years, second only to movement disorders.

Journals

The 61 citation classics were published in 25 different journals, with 11 journals publishing at least 1 citation classic in the functional neurosurgery field. When the list is expanded to the top 100, 37 journals are included in the list, of which 14 have published 2 or more top 100 papers. *Stereotactic and Functional Neurosurgery*, the flagship publication of the functional neurosurgery field, has published 1 citation classic. As with other disciplines, such as PD and major depression, citation classics in functional neurosurgery tend to cluster in broadly applicable, typically higher impact publications, such as the *New England Journal of Medicine* and *Brain*. Again, as with citation velocity, this is largely a function of the wide applicability of research in functional neurosurgery, which is often easily relevant to neurologists, psychiatrists, neurophysiologists, other neuroscientists and, in some instances, to general practitioners.

Limitations

Studies such as this have several real and theoretical limitations. Most important is the possibility that our search strategy did not truly identify all the citation classics in functional neurosurgery. This may be a function of the search terms we used, although we attempted to be as inclusive as possible, or of the inclusion criteria we used to define relevant papers, although we attempted to keep these relatively broad. Nevertheless, there remains the

possibility that there are highly cited papers relevant to the field of functional neurosurgery that were not included in the list. The list presented is a 'snapshot' in time that literally changes on a week-to-week basis, as the literature evolves. Citation classics will remain classics, but the constitution of the list and the relative 'rank' of publications are both dynamic and subject to constant change. In some ways, the citation classic and top 100 lists are saddled by the inherent obstacles of the functional neurosurgery field itself, which is quite broad and expansive. For example, publications in disciplines that are very active, popular and large will be more widely read and cited than those in fields that are highly specialized and small.

The optimal search algorithm and database are also a matter of debate as each will have unique advantages and disadvantages. Briefly, although discussed in a previous publication, Google Scholar's less restrictive criteria for journal archiving, its broad scope and the fact that it is publicly available and free influenced our decision to use it as the primary access point to the biomedical literature [7]. The relative merits of Google Scholar and our search software Publish or Perish versus other scholarly databases such as ISI Web of Science remain debatable and are largely subject to user preference and objective (for example, see [8] for an alternative strategy). Our aim was not to compare the results between databases, but to use a single database consistently to answer our research question. An additional limitation stems from our preferred means of categorization of retrieved results. For example, we decided to cluster functional investigations

following cortical resection in epilepsy in a unique category rather than include these in the epilepsy category. These decisions were made according to the general theme and intent of the publication and to facilitate an analysis of trends over time. Nevertheless, they are individual preferences that are subject to debate (and controversy).

Ultimately, every aspect of the study described here, from the methodology to the results, is a matter of academic debate. We argue that, for such studies, debate is not only healthy but should be encouraged, so that by working as a community, a clearer picture can emerge of the work in the field that is truly influential and important.

Conclusions

We have attempted to identify the top 100 works and the citation classics in the functional neurosurgery field using citation indices as a proxy for their impact. Functional neurosurgery is a broad and rapidly growing field with the potential to influence the management of diseases across many disciplines. The publications highlighted in this paper represent particularly important contributions to the field and provide residents, beginner and experienced surgeons with a snapshot in time of the 'must-know' works in the field. The list is also an education in where our field has been as a whole and where it is currently at, and provides us with clues about where it is going next.

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