The academic productivity and impact of the University of Toronto Neurosurgery Program as assessed by manuscripts published and their number of citations

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OBJECT Recent works have assessed academic output across neurosurgical programs using various analyses of accumulated citations as a proxy for academic activity and productivity. These assessments have emphasized North American neurosurgical training centers and have largely excluded centers outside the United States. Because of the long tradition and level of academic activity in neurosurgery at the University of Toronto, the authors sought to compare that program's publication and citation metrics with those of established programs in the US as documented in the literature. So as to not rely on historical achievements that may be of less relevance, they focused on recent works, that is, those published in the most recent complete 5-year period.

METHODS The authors sought to make their data comparable to existing published data from other programs. To this end, they compiled a list of published papers by neurosurgical faculty at the University of Toronto for the period from 2009 through 2013 using the Scopus database. Individual author names were disambiguated; the total numbers of papers and citations were compiled on a yearly basis. They computed a number of indices, including the *ih*(5)-index (i.e., the number of citations the papers received over a 5-year period), the summed *h*-index of the current faculty over time, and a number of secondary measures, including the *ig*(5), *ie*(5), and *i10*(5)-indices. They also determined the impact of individual authors in driving the results using Gini coefficients. To address the issue of author ambiguity, which can be problematic in multicenter bibliometric analyses, they have provided a source dataset used to determine the *ih*(5) index for the Toronto program.

RESULTS The University of Toronto Neurosurgery Program had approximately 29 full-time surgically active faculty per year (not including nonneurosurgical faculty) in the 5-year period from 2009 to 2013. These faculty published a total of 1217 papers in these 5 years. The total number of citations from these papers was 13,434. The *ih*(5)-index at the University of Toronto was 50.

CONCLUSIONS On the basis of comparison with published bibliometric data of US programs, the University of Toronto ranks first in terms of number of publications, number of citations, and *ih*(5)-index among neurosurgical programs in North America and most likely in the world.

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KEY WORDS *h*-index; *ih*(5)-index; *e*-index; *g*-index; *i10*-index; academic neurosurgery; bibliometrics

NEUROSURGICAL programs can be characterized and ranked using a number of parameters, including clinical volume, patient outcomes, teaching achievements, and the leadership positions held by their faculty in learned and prestigious societies, panels, agencies, and editorial boards as well as their research accomplishments and publications. These attributes, and particu-

larly, the relative weight that one assigns to each individual component, are prone to subjective factors which make it challenging when one attempts to assess how the programs stack up relative to each other.

Given these important caveats, the appraisal of academic productivity in neurosurgery is multifaceted and accurate assessment can be difficult. One objective method,

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however, is an assessment of the number of papers published by a program and their relative influence in the field, with the number of times a work has been cited by others serving as a surrogate for impact.¹³ To this end, groups have now compiled bibliometric indices across neurosurgical training programs as a proxy measure of academic productivity.^{16,19,20,22,42,52,54,55,59} These compilations have emphasized North American programs and particularly programs based in the United States. The accurate compilation of such data is complex and subject to inaccuracy. The work of faculty with common names, for example, can be misattributed, and faculty can be overlooked in search strings or double-counted. It is sometimes difficult to ascertain who within a neurosurgical program is an active neurosurgeon versus, for example, an honorary or a retired member of the faculty, or to distinguish those who are listed as neurosurgical faculty but are not neurosurgeons as occurs when neurologists or PhD scientists hold appointments in neurosurgery departments.

To obtain measures and directly compare the ranking of the University of Toronto Neurosurgery Program's academic productivity, we compiled citation data using manuscripts that could be unambiguously attributed to our faculty. To directly compare our results to those in the literature, we harmonized the time window and methodology used in the analysis to match that available for other programs as recently documented.^{19,20,50} Such an assessment gives an appraisal of the productivity of the University of Toronto Neurosurgery Program in relation to other programs and may be the basis on which to formulate future recommendations and adjustments to neurosurgical programs to enhance or optimize academic productivity. So as to not rely on historical achievements that may be of less relevance today, we focused on recent works, that is, papers published in the last 5 years, as was done for the assessment of all North American neurosurgical programs documented.^{19,20,50}

Methods

The surgically active neurosurgery faculty at the University of Toronto (defined as individuals who are board certified in neurosurgery, have “on call” responsibilities, and perform surgery with greater than 25% of activity dedicated to clinical effort) were identified and verified for the 5-year period from 2009 through 2013. The number of active years in this 5-year period for each of these individual “authors” was compiled. The years of active contribution for those who left the program for reasons of retirement, relocation, or death were determined. Similarly, for new hires, only the years of active participation within this 5-year period were counted. Manuscripts published and citations obtained prior to being appointed or after leaving the Toronto program were not included. So as not to confound the issue of academic productivity by discipline, we did not include publications by nonneurosurgeons who may be appointed to the neurosurgery faculty when these publications did not include at least 1 active faculty-appointed neurosurgeon.

We then performed a Scopus author search (www.scopus.com) using the author names and imposing the search

limit of “University of Toronto” as an affiliation parameter. From this generated list of authors, we selected those who were confirmed to be active Toronto neurosurgical faculty. Faculty names were manually verified, and their authorship was unambiguously validated (for example, by correcting for multiple individuals having the same surname and initials and by correcting errors, omissions, and duplications by cross-referencing to papers that appeared listed in their individual curricula vitae). The total number of papers published by these authors in the 2009–2013 time windows was compiled. Duplicates were identified and papers authored by more than 1 faculty member were counted once with attribution to a single author based on the rank order of appearance in authorship (first, then second, then last, then third, and so on). A citation report was then created based on these publications using the Scopus database. Only papers published between 2009 and 2013 were considered, and only the citations to these papers in this 5-year window were counted. The papers were then sorted by citation number and *ih(5)*-index; namely, the number of papers published in this 5-year interval that were cited *h* or more times was determined. Secondary indices were similarly calculated, including the *ig(5)*-index, *ie(5)*-index, and *il0(5)*-index. We also calculated the Gini coefficient for publications and citations as a measure of equality of contribution of individual faculty to these metrics. All calculations were carried out during the month of July 2014. The definition and significance of these various measures are shown in Table 1.

Results

The number of active neurosurgeons on faculty at the University of Toronto in the 2009–2013 period ranged from 28 to 31 per year, with a mean number of 29.2 (Table 2). The total number of publications by these neurosurgeons in this time period was 1217, increasing from 185 to 289 per year over the 5 years. The mean number of publications per neurosurgeon also increased—from 6.6 to 9.3 per year, a 41% increase—with a mean of 8.3 publications per author per year over the 5-year period. The total number of citations for papers published in this 5-year window was 13,434, or 89.68 per surgeon per year.

These 1217 papers were sorted by their total number of citations to generate the *ih(5)*-index. The *ih(5)*-index for the faculty was 50—i.e., in this 5-year period there were 50 papers published which were cited 50 or more times within the same 5 years. These works are shown in Tables 31–6, 8–12, 14, 15, 17, 18, 21, 23–41, 43–49, 51, 52, 56–58, 60–62 and 4. Review, consensus, and guideline works featured prominently among the most highly cited papers, as did original works in the field of tumor biology and functional neurosurgery.

Twelve faculty members (approximately 40%) published papers that contributed to the *ih(5)*-index. The contributions were not equal, however, and generally followed the Pareto principle (also known as the 80–20 rule) where approximately 80% of papers in the *ih(5)*-index came from 20% of the faculty. Another measure of the principle of relative contribution or factor sparsity, the Gini coefficient, was calculated to be 0.61 for publications and 0.72 for citations where 0 indicates total equality and 1 indicating total

TABLE 1. Definition of bibliometric indices

Metric	Definition
<i>h</i> -index	The <i>h</i> -index is equal to a number, <i>h</i> , where an author has <i>h</i> number of publications with at least <i>h</i> number of citations, as originally proposed by Hirsch. ¹³ It was manually calculated from data obtained using the Scopus author search. The <i>h</i> -index serves as a basic indicator of publication productivity and can be used to compare authors across disciplines.
<i>ih</i> (5)-index	The <i>ih</i> (5)-index is an institution's <i>h</i> -index over a defined 5-year period, as proposed by Taylor et al. ⁵⁰ It was manually calculated from data obtained using Scopus author searches by arranging a list of the institution's publications from 2009–2013 in decreasing order of citation count; the <i>ih</i> (5)-index is the point where the publication number equals its citation count.
Summed <i>h</i> -index	The summed or cumulative <i>h</i> -index is the aggregate of the <i>h</i> -indices of all individuals in an institution (e.g., all faculty in neurosurgical program). It is not restricted to a 5-year period. Since at the time of manuscript preparation Scopus data were restricted to 1996 and later, the summed <i>h</i> -index was calculated using Scopus data for post-1996 publications and data from Reuters Web of Science for pre-1996 publications.
<i>g</i> -index	The <i>g</i> -index is equal to a number, <i>g</i> , such that <i>g</i> number of publications cumulatively received at least <i>g</i> ² number of citations, as proposed by Egghe. ⁷ It was manually calculated from data obtained using the Scopus author search. The <i>g</i> -index places more emphasis on highly cited papers and thus complements the <i>h</i> -index when comparing authors.
<i>ig</i> (5)-index	The <i>ig</i> (5)-index is an institution's <i>g</i> -index over a defined 5-year period, as proposed by Taylor et al. ⁵⁰ It was manually calculated from data obtained using Scopus author searches.
<i>e</i> -index	The <i>e</i> -index is the square root of the excess citations over those used for calculating the <i>h</i> -index, as proposed by Zhang. ⁶³ It is calculated by determining the total number of citations from papers that make up an <i>h</i> -index, then subtracting the minimum number of citations required to reach that <i>h</i> -index squared (<i>h</i> ²). The square root of this excess is the <i>e</i> -index. The <i>e</i> -index is used to evaluate highly cited authors or to compare groups having identical <i>h</i> -indices, thus complementing the <i>h</i> -index.
<i>ie</i> (5)-index	The <i>ie</i> (5)-index is an institution's <i>e</i> -index over a defined 5-year period, as proposed by Taylor et al. ⁵⁰ It was manually calculated from data obtained using Scopus author searches.
<i>i10</i> -index	The <i>i10</i> -index is an author's number of publications that have acquired 10 or more citations, and was initially introduced by Google Scholar.
<i>i10</i> (5)-index	The <i>i10</i> (5)-index is an institution's <i>i10</i> -index over a defined 5-year period, as proposed by Taylor et al. ⁵⁰
Gini coefficient	The Gini coefficient is a measure of equality ranging from 0 (which indicates total equality) and 1 (which indicates total inequality). In our study, it is used to quantify the relative contribution of faculty members to institutional number of publications and citations.

inequality (Table 5). This finding indicates that a few individuals contributed disproportionately to the number of publications and citations. This trend is illustrated in Fig. 1, which shows the number of publications and citations on a per faculty member basis, grouped by the number of citations received from 2009 to 2013.

One of the most important purposes for conducting this study was to ascertain and provide a verifiable assessment

of where our academic productivity stands in relation to other neurosurgical programs. We took advantage of the appraisal of the training programs in the United States as published in the accompanying article in this issue⁵⁰ and tailored our analysis methods, metrics, and period of evaluation to closely match so as to allow for meaningful comparisons.

The performance metrics of the neurosurgery program

TABLE 2. University of Toronto Neurosurgery Program yearly bibliometric indices, 2009–2013

Characteristic	2009	2010	2011	2012	2013	Total	Yearly Average
Total faculty	28	29	28	30	31	146	29.2
Total publications	185	256	232	255	289	1217	243.4
Total citations	146	979	2291	4147	5871	13,434	2686.8
5-Year Average							
Average papers/faculty	6.6	8.8	8.3	8.5	9.3		8.3
Average citations/faculty	5.2	33.8	81.8	138.2	189.4		89.68
5-Year Measure							
<i>ih</i> -index	4	13	22	29	32	<i>ih</i> (5)	50
<i>ig</i> -index	8	20	30	41	45	<i>ig</i> (5)	80
<i>ie</i> -index	6.24	12.49	17.29	24.3	27.66	<i>ie</i> (5)	54.77
<i>i10</i> -index	2	23	53	107	139	<i>i10</i> (5)	336

TABLE 3. The most highly cited publications, University of Toronto Neurosurgery Program, 2009–2013*

Number	Attributed Author	Year	Article	Citations Per Year					5-Year Total
				2009	2010	2011	2012	2013	
1	Macdonald	2010	Guidelines for the management of spontaneous intracerebral hemorrhage: a guideline for health-care professionals from the American Heart Association/American Stroke Association. <i>Stroke</i> 41:2108–2129, 2010 ³¹	0	10	77	128	161	376
2	Dirks	2009	Tumour-initiating cells: challenges and opportunities for anticancer drug discovery. <i>Nat Rev Drug Discov</i> 8:806–823, 2009 ³²	0	49	69	65	66	249
3	Taylor	2011	The genetic landscape of the childhood cancer medulloblastoma. <i>Science</i> 331:435–439, 2011 ³⁹	0	0	42	93	83	218
4	Taylor	2011	Medulloblastoma comprises four distinct molecular variants. <i>J Clin Oncol</i> 29:1408–1414, 2011 ³⁶	0	0	32	102	82	216
5	Dirks	2009	Glioma stem cell lines expanded in adherent culture have tumor-specific phenotypes and are suitable for chemical and genetic screens. <i>Cell Stem Cell</i> 4:568–580, 2009 ⁴¹	9	34	49	54	61	207
6	Tymianski	2010	Glutamate receptors, neurotoxicity and neurodegeneration. <i>Pflügers Arch</i> 460:525–542, 2010 ²⁵	0	3	39	98	67	207
7	Taylor	2009	Multiple recurrent genetic events converge on control of histone lysine methylation in medulloblastoma. <i>Nat Genet</i> 41:465–472, 2009 ³⁷	12	34	38	52	26	162
8	Rutka	2010	Nanomedicine. <i>N Engl J Med</i> 363:2434–2443, 2010 ²¹	0	0	30	58	71	159
9	Rutka	2009	The miR-17/92 polycistron is up-regulated in sonic hedgehog-driven medulloblastomas and induced by N-myc in sonic hedgehog-treated cerebellar neural precursors. <i>Cancer Res</i> 69:3249–3255, 2009 ³⁵	7	46	25	43	29	150
10	Lozano	2010	A phase I trial of deep brain stimulation of memory circuits in Alzheimer's disease. <i>Ann Neurol</i> 68:521–534, 2010 ²⁶	0	2	24	44	66	136
11	Tymianski	2010	Calcium, ischemia and excitotoxicity. <i>Cell Calcium</i> 47:122–129, 2010 ⁴⁹	0	11	36	46	41	134
12	Lozano	2011	Deep brain stimulation for Parkinson disease an expert consensus and review of key issues. <i>Arch Neurol</i> 68:165, 2011 ³	0	0	21	56	47	124
13	Lozano	2010	Gene delivery of AAV2-neurturin for Parkinson's disease: a double-blind, randomised, controlled trial. <i>Lancet Neurol</i> 9:1164–1172, 2010 ³⁹	0	2	41	36	44	123
14	Lozano	2010	Unilateral pedunculopontine stimulation improves falls in Parkinson's disease. <i>Brain</i> 133:215–224, 2010 ³²	0	16	37	33	30	116
15	Macdonald	2009	Cerebral vasospasm following subarachnoid hemorrhage: time for a new world of thought. <i>Neurol Res</i> 31:151–158, 2009 ⁴⁰	3	21	33	29	27	113
16	Macdonald	2010	Definition of delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage as an outcome event in clinical trials and observational studies proposal of a multidisciplinary research group. <i>Stroke</i> 41:2391–2395, 2010 ⁵⁶	0	0	21	43	46	110
17	Lozano	2010	Long-term results of a multicenter study on subthalamic and pallidal stimulation in Parkinson's disease. <i>Mov Disord</i> 25:578–586, 2010 ³³	0	7	30	42	29	108
18	Spears	2011	International guidelines for the diagnosis and management of hereditary haemorrhagic telangiectasia. <i>J Med Genet</i> 48:73–87, 2011 ⁸	0	0	18	43	46	107
19	Taylor	2012	Genome sequencing of pediatric medulloblastoma links catastrophic DNA rearrangements with TP53 mutations. <i>Cell</i> 148:59–71, 2012 ⁴⁴	0	0	0	42	64	106
20	Taylor	2009	MicroRNA-199b-5p impairs cancer stem cells through negative regulation of HES1 in medulloblastoma. <i>PLoS ONE</i> 4:e4998, 2009 ¹⁰	3	21	33	27	20	104

(continued)

TABLE 3. The most highly cited publications, University of Toronto Neurosurgery Program, 2009–2013* (continued)

Number	Attributed Author	Year	Article	Citations Per Year					5-Year Total
				2009	2010	2011	2012	2013	
21	Taylor	2012	Molecular subgroups of medulloblastoma: the current consensus. <i>Acta Neuropathol</i> 123:465–472, 2012 ⁵¹	0	0	0	37	65	102
22	Fehlings	2010	Synergistic effects of transplanted adult neural stem/progenitor cells, chondroitinase, and growth factors promote functional repair and plasticity of the chronically injured spinal cord. <i>J Neurosci</i> 30:1657–1676, 2010 ¹⁷	0	6	28	29	38	101
23	Kulkarni	2009	Comparisons of citations in Web of Science, Scopus, and Google Scholar for articles published in general medical journals. <i>JAMA</i> 302:1092–1096, 2009 ²⁴	2	18	24	13	41	98
24	Dirks	2012	Cancer stem cells: an evolving concept. <i>Nat Rev Cancer</i> 12:133–143, 2012 ²⁴	0	0	0	37	60	97
25	Taylor	2012	Dissecting the genomic complexity underlying medulloblastoma. <i>Nature</i> 488:100–105, 2012 ¹⁵	0	0	0	11	83	94
26	Macdonald	2011	Clazosentan, an endothelin receptor antagonist, in patients with aneurysmal subarachnoid haemorrhage undergoing surgical clipping: a randomised, double-blind, placebo-controlled phase 3 trial (CONSCIOUS-2). <i>Lancet Neurol</i> 10:618–625, 2011 ²⁸	0	0	7	41	44	92
27	Lozano	2011	Deep brain stimulation for treatment-resistant depression: follow-up after 3 to 6 years. <i>Am J Psychiatry</i> 168:502–510, 2011 ¹⁸	0	0	18	31	42	91
28	Taylor	2010	Cross-species genomics matches driver mutations and cell compartments to model ependymoma. <i>Nature</i> 466:632–636, 2010 ¹⁴	0	1	28	29	30	88
29	Gentili	2009	Expanded endoscopic endonasal approach for anterior cranial base and suprasellar lesions: indications and limitations. <i>Neurosurgery</i> 64:677–689, 2009 ⁶	2	23	22	18	22	87
30	Taylor	2009	YAP1 is amplified and up-regulated in hedgehog-associated medulloblastomas and mediates Sonic hedgehog-driven neural precursor proliferation. <i>Genes Dev</i> 23:2729–2741, 2009 ⁹	1	16	22	29	15	83
31	da Costa	2009	The natural history and predictive features of hemorrhage from brain arteriovenous malformations. <i>Stroke</i> 40:100–105, 2009 ⁵	4	11	20	29	17	81
32	Taylor	2012	Medulloblastoma exome sequencing uncovers subtype-specific somatic mutations. <i>Nature</i> 488:106–110, 2012 ⁴³	0	0	0	10	70	80
33	Taylor	2012	Hotspot mutations in H3F3A and IDH1 define distinct epigenetic and biological subgroups of glioblastoma. <i>Cancer Cell</i> 22:425–437, 2012 ⁴⁷	0	0	0	2	75	77
34	Tymianski	2009	Suppression of hippocampal TRPM7 protein prevents delayed neuronal death in brain ischemia. <i>Nat Neurosci</i> 12:1300–1307, 2009 ⁴⁸	2	17	19	15	22	75
35	Fehlings	2011	A systematic review of cellular transplantation therapies for spinal cord injury. <i>J Neurotrauma</i> 28:1611–1682, 2011 ⁵²	0	0	8	30	35	73
36	Lozano	2011	Priorities in Parkinson's disease research. <i>Nat Rev Drug Discov</i> 10:377–393, 2011 ³⁰	0	0	5	34	34	73
37	Macdonald	2010	Cognitive and functional outcome after aneurysmal subarachnoid hemorrhage. <i>Stroke</i> 41:e519–536, 2010 ¹	0	1	14	24	34	73
38	Taylor	2012	Clonal selection drives genetic divergence of metastatic medulloblastoma. <i>Nature</i> 482:529–533, 2012 ⁶¹	0	0	0	22	51	73
39	Lozano	2010	Antidepressant-like effects of medial prefrontal cortex deep brain stimulation in rats. <i>Biol Psychiatry</i> 67:117–124, 2010 ¹¹	0	13	14	17	28	72

(continued)

TABLE 3. The most highly cited publications, University of Toronto Neurosurgery Program, 2009–2013* (continued)

Number	Attributed Author	Year	Article	Citations Per Year					5-Year Total
				2009	2010	2011	2012	2013	
40	Taylor	2012	Molecular subgroups of medulloblastoma: an international meta-analysis of transcriptome, genetic aberrations, and clinical data of WNT, SHH, Group 3, and Group 4 medulloblastomas. <i>Acta Neuropathol</i> 123:473–484, 2012 ²³	0	0	0	20	52	72
41	Guha	2011	Hexokinase 2 is a key mediator of aerobic glycolysis and promotes tumor growth in human glioblastoma multiforme. <i>J Exp Med</i> 208:313–326, 2011 ⁶⁰	0	0	10	25	35	70
42	Dirks	2009	Multipotent CD15+ cancer stem cells in Patched-1-deficient mouse medulloblastoma. <i>Cancer Res</i> 69:4682–4690, 2009 ⁵⁸	3	16	22	12	16	69
43	Lozano	2009	Stimulation of the subthalamic nucleus and impulsivity: release your horses. <i>Ann Neurol</i> 66:817–824, 2009 ²	1	8	24	12	23	68
44	Taylor	2012	Subgroup-specific structural variation across 1,000 medulloblastoma genomes. <i>Nature</i> 488:49–56, 2012 ³⁸	0	0	0	8	51	59
45	Lozano	2011	Stimulation of entorhinal cortex promotes adult neurogenesis and facilitates spatial memory. <i>J Neurosci</i> 31:13469–13484, 2011 ⁴⁶	0	0	2	28	27	57
46	Lozano	2011	The subcallosal cingulate gyrus in the context of major depression. <i>Biol Psychiatry</i> 69:301–308, 2011 ¹²	0	0	3	24	30	57
47	Tymianski	2012	Treatment of stroke with a PSD-95 inhibitor in the gyrencephalic primate brain. <i>Nature</i> 483:213–217, 2012 ⁴	0	0	0	21	34	55
48	Taylor	2009	Frequent amplification of a chr19q1341 microRNA polycistron in aggressive primitive neuroectodermal brain tumors. <i>Cancer Cell</i> 16:533–546, 2009 ²⁷	0	5	15	24	10	54
49	Guha	2010	Poor drug distribution as a possible explanation for the results of the PRECISE trial. <i>J Neurosurg</i> 113:301–309, 2010 ⁴⁵	0	5	12	19	17	53
50	Lozano	2009	Long-term effects of pallidal or subthalamic deep brain stimulation on quality of life in Parkinson's disease. <i>Mov Disord</i> 24:1154–1161, 2009 ⁵⁷	0	12	11	11	17	51

* 50 publications were cited 50 or more times in this period resulting in an *h*(5)-index of 50.

TABLE 4. Comparison of neurosurgery department rankings based upon institutional and summed *h*-index, total publications, and total citations*

Institution	<i>ih</i> (5)-Index		Summed <i>h</i> -Index		Total Publications		Total Citations		Faculty Number
	Rank	Number	Rank	Number	Rank	Number	Rank	Number	
University of Toronto	1	50	1	1117	1	1217	1	13,434	29.2
University of California, San Francisco	2	42	2	625	2	680	2	9048	33
University of California, Los Angeles	3	36	6	467	6	360	3	6038	23
University of Pittsburgh	4	31	5	471	4	388	6	4065	34
Brigham & Women's Hospital	4	31	17	289	11	263	5	4250	16
Johns Hopkins University	6	29	4	509	3	557	4	4795	31
University of Virginia	7	28	9	361	7	328	8	3552	14
Duke University Hospital	8	27	14	298	11	263	7	3783	15
Ohio State University	8	27	23	258	13	261	12	3013	22
St. Joseph's Hospital/Barrow Neurological Institute	10	26	3	513	5	365	9	3547	29
Stanford University	10	26	10	342	9	279	10	3534	26

* Data from centers other than Toronto were compiled from Table 3 in Taylor et al.⁵⁰

at the University of Toronto in relation to the top 10 programs with respect to publications is shown in Tables 4 and 5 (data from centers other than Toronto are compiled from Taylor et al.,⁵⁰ more specifically, Table 3 and Appendix 1 in that publication). As shown in Table 4, compared with other neurosurgical programs in North America, for the period of the last 5 years, the program in Toronto ranks first for total publications, total citations and *ih*(5)-index. The 1217 publications over the 5-year period are almost double those of the next closest ranking program, the University of California, San Francisco (UCSF). This was not related to having a larger program since the University of Toronto has 29 faculty compared with 33 at UCSF. With 13,434 citations, the University of Toronto also led in total number of citations for papers published in the last 5 years. On the other hand, the mean number of citations per paper over the last 5 years was higher at UCSF 13.3 versus 11.0 in Toronto. In removing the emphasis on the last 5 years

and assessing career-long contributions as reflected by the summed *h*-index, current faculty at the University of Toronto had the highest summed *h*-index among programs in North America.

Discussion/Conclusions

The University of Toronto Neurosurgery Program generates a high number of publications that receive a large number of citations. When compared with the output of other neurosurgery programs in the United States,⁵⁰ the University of Toronto ranks first in papers, in number of citations or in *ih*(5), that is the institutional *h*-index over the last 5 years.

Given the absence of intimate knowledge concerning the make-up of foreign neurosurgical programs and the technical challenges and limitations that exist, we have not made a comprehensive and validated appraisal of world-

TABLE 5. Comparison of neurosurgery department rankings based upon remaining bibliometric indices*

Institution	<i>ig</i> (5)-Index		<i>ie</i> (5)-Index		<i>i10</i> (5)-Index		Publication Gini Coefficient	Citation Gini Coefficient
	Rank	Number	Rank	Number	Rank	Number		
University of Toronto	1	80	1	55	1	336	0.61	0.72
University of California, San Francisco	3	66	3	43	2	243	0.52	0.62
University of California, Los Angeles	2	69	2	52	6	104	0.57	0.74
University of Pittsburgh	11	48	14	31	4	119	0.66	0.74
Brigham & Women's Hospital	4	58	3	43	9	84	0.50	0.59
Johns Hopkins University	6	50	11	34	3	135	0.48	0.60
University of Virginia	14	44	17	28	5	107	0.53	0.42
Duke University Hospital	5	54	5	41	10	83	0.41	0.70
Ohio State University	13	46	13	32	11	76	0.65	0.74
St. Joseph's Hospital and Medical Center/Barrow Neurological Institute	9	49	8	37	11	76	0.61	0.65
Stanford University	9	49	9	36	8	86	0.61	0.74

* Data from centers other than Toronto were compiled from Appendix Table 1 in Taylor et al.⁵⁰

FIG. 1. University of Toronto Neurosurgery Program publications and citations by faculty member. The total number of publications and total number of citations for each individual Toronto neurosurgery faculty member in the 2009–2013 period were plotted in increasing order of citations. Faculty members were grouped according to number of citations in the 5-year period as follows: 1) < 100 citations; 2) 100–499 citations; 3) 500–999 citations; and 4) > 1000 citations.

wide programs. To derive an estimate of world rankings, we arbitrarily surveyed the top 20 ranked universities in the world according to the Times Higher Education 2013–2014 World University Rankings⁵³ and assumed that the top universities may be home to the highest academically productive neurosurgery programs. Such an analysis revealed that 5 of the 20 top ranked universities, including the University of Toronto, are outside the US. The other 4 top ranked universities have a relatively small neurosurgical faculty according to their websites (Cambridge University, $n = 7$; Imperial College London, $n = 8$; Oxford University, $n = 14$; Swiss Federal Institute of Technology Zurich, $n = 0$). Largely for this reason, an analysis of their publication and citation numbers does not place them at the top of the neurosurgery rankings. A recently appearing article in this journal ranking the productivity of neurosurgeons in Great Britain and Ireland also supports this assertion.⁵⁹ With the body of data we have in hand, it is therefore likely that the neurosurgery program at the University of Toronto ranks first in the world in academic output as measured here.

A limitation of our work is that publications and citations are but isolated measures of academic productivity and impact. As the old adage goes, “Not everything that matters can be measured and not everything that can be measured matters.” Several other factors that may be important drivers of impact are not captured by this analysis. Nevertheless, using the number and citation data for manuscripts validated for our program provides a practical, operational and easily quantifiable measure of academic output which can be readily ascertained and benchmarked. We have not emphasized the techniques used in our measures nor their attributes and limitations as they are well covered in the recent work analyzing academic productivity in North American neurosurgical programs in an accompanying article.⁵⁰

We cannot be certain of what factors were the most

important drivers of academic productivity. Reaching this high level of academic activity in the Toronto program is multifactorial and includes setting the course of our program and assembling the residents and faculty that can execute. Among the factors that may contribute are: 1) a longstanding interest and tradition of advancing the field of neurosurgery; 2) a mission to be academic leaders; 3) a policy of selecting residents who have a strong interest in research; 4) the allocation of the time in research and financial support of our residents and their encouragement to obtain a graduate degree in the context of our surgeon-scientist program; and 5) an emphasis on the recruitment of neurosurgeon-scientists to our faculty.

There are also “softer” factors which may have contributed. For example we function in a largely single-payer, predictable reimbursement environment and have stable funding for our clinical activities. A likely important factor also resides in the centralization of academic activity in Toronto. While Toronto is ranked as the fourth largest city by population in North America behind Mexico City, New York, and Los Angeles, we have a single medical school and a single neurosurgery program. This avoids duplication; reduces dilution of programs for complex, rare, or uncommon conditions; drives high-volume subspecialization and enables critical mass in various areas of neurosurgery; and facilitates patient recruitment for clinical trials and reduces internal competition for caseload.

The consequences of this high-level academic activity are difficult to quantify. We can speculate that they may include attracting and retaining residents and faculty, securing preferred academic and industrial partnerships, securing grants and awards, and driving philanthropy. In discussions with our residents, it is clear that academic opportunities in the residency program figure prominently in their choice of residency program. Here, the ability to access research opportunities, the training in a program with a strong research tone and environment, and the feeling that exposure and opportunities in research will make them attractive in an increasingly competitive job market are factors which influence their selection of where to train.

The ultimate goal of research in our specialty is to solve the important problems that our patients face across all fields of neurosurgery. Each subspecialty in neurosurgery has formidable and intractable challenges: malignant tumors, spinal cord injury, subarachnoid hemorrhage, head injury, and so on. Who better to take on these problems and discover treatments which change the way we practice and improve the lives of our patients than neurosurgeons? Albeit not the sole source, academic programs are the prime repository of innovation in neurosurgery. We encourage the programs to use this information as a benchmark to track their performance and evolution. As the old adage goes, if it is worth doing it is worth measuring.

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Supplemental Information

Companion Paper

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