Taking the next step in publication productivity analysis in pediatric neurosurgery

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OBJECTIVE There has been an increasing interest in the quantitative analysis of publishing within the field of neurosurgery at the individual, group, and institutional levels. The authors present an updated analysis of accredited pediatric neurosurgery training programs.

METHODS All 28 Accreditation Council for Pediatric Neurosurgery Fellowship programs were contacted for the names of pediatric neurosurgeons who were present each year from 2011 through 2015. Faculty names were queried in Scopus for publications and citations during this time period. The 5-year institutional Hirsch index [ih(5)-index] and revised 5-year institutional h-index [ir(5)-index] were calculated to rank programs. Each publication was reviewed to determine authorship value, tier of research, clinical versus basic science research, subject matter, and whether it was pediatrics-specific. A unique 3-tier article classification system was introduced to stratify clinical articles by quality and complexity, with tier 3 being the lowest tier of publication (e.g., case reports) and tier 1 being the highest (e.g., randomized controlled trials).

RESULTS Among 2060 unique publications, 1378 (67%) were pediatrics-specific. The pediatrics-specific articles had a mean of 15.2 citations per publication (median 6), whereas the non-pediatrics-specific articles had a mean of 23.0 citations per publication (median 8; $p < 0.0001$). For the 46% of papers that had a pediatric neurosurgeon as first or last author, the mean number of citations per publication was 12.1 (median 5.0) compared with 22.5 (median 8.0) for those in which a pediatric neurosurgeon was a middle author ($p < 0.0001$). Seventy-nine percent of articles were clinical research and 21% were basic science or translational research; however, basic science and translational articles had a mean of 36.9 citations per publication (median 15) compared with 12.6 for clinical publications (median 5.0; $p < 0.0001$). Among clinical articles, tier 1 papers had a mean of 15.0 citations per publication (median 8.0), tier 2 papers had a mean of 18.7 (median 8.0), and tier 3 papers had a mean of 7.8 (median 3.0). Neuro-oncology papers received the highest number of citations per publication (mean 25.7). The most common journal was the *Journal of Neurosurgery: Pediatrics* (20%). MD/PhD faculty members had significantly more citations per publication than MD faculty members (mean 26.7 vs 14.0; $p < 0.0001$) and also a higher number of publications per author (mean 38.6 vs 20.8). The median ih(5)- and ir(5)-indices per program were 14 (range 5–48) and 10 (range 5.6–37.2), respectively. The mean ir(5)/ih(5)-index ratio was 0.8. The top 5 fellowship programs (in descending order) as ranked by the ih(5)-index corrected for number of faculty members were The Hospital for Sick Children, Toronto; Children's Hospital of Pittsburgh; University of California, San Francisco Benioff Children's Hospital; Seattle Children's Hospital; and St. Louis Children's Hospital.

CONCLUSIONS About two-thirds of publications authored by pediatric neurosurgeons are pediatrics-specific, although non-pediatrics-specific articles averaged more citations. Most of the articles authored by pediatric neurosurgeons are clinical, with basic and translational articles averaging more citations. Neurosurgeons with PhD degrees averaged more total publications and more citations per publication. In all, this is the most advanced and informative analysis of publication productivity in pediatric neurosurgery to date.

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KEY WORDS bibliometrics; pediatric; neurosurgery; ih(5); ranking

ABBREVIATIONS ACPNF = Accreditation Council for Pediatric Neurosurgery Fellowship; h-index = Hirsch index; ih(5)-index = 5-year institutional Hirsch index; ir(5)-index = revised 5-year institutional h-index; r-index = revised h-index.

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RECENTLY, greater attention has been paid to quantifying and comparing publication productivity between individuals and institutions. With this increased focus on objectively measuring and comparing output, many have sought to provide more advanced statistics beyond simply reporting the number of publications and citations. This has resulted in the expansion and evolution of bibliometrics, the science of the statistical analysis of written publications.^{3,4,28} The most popular bibliometric standard is the Hirsch index (*h*-index), which combines the productivity and citation impact of an individual into a single metric.^{1,6,8} Originally applied to individual authors, the *h*-index has also been applied extensively to institutions to compare them for the purposes of ranking and funding allocation.^{2,30} Numerous analyses have since computed individual and institutional *h*-indices for benchmark and comparison in the field of neurosurgery.^{7,9–12,14,16,18,22,25,26,29,31–33}

One limitation of the raw (or unadjusted) *h*-index is that it includes all articles that an author or group of authors has ever published. In 2014, we found the median *h*-index of 312 North American pediatric neurosurgeons to be 10.¹² Because the unadjusted *h*-index is summed, it does not adequately reflect recent productivity and citation impact, or the lack thereof. To account for this in the setting of institutional comparisons, the 5-year institutional *h*-index, or *ih*(5)-index, was created.²⁷ This index captures the *h*-index of a whole group, department, or institution—as determined by the user—over a discrete contemporary 5-year period. It was recently validated and applied to neurosurgical departments with residency training programs in the United States and Canada but has not yet been applied to pediatric neurosurgery fellowship programs.^{17,18,27}

Another limitation of the *h*-index is that it does not take into account the degree of contribution of the author to the publication. For neurosurgical publications, the first, second, and last authors typically contribute disproportionately more to the project than the middle author(s). This contribution may not only be in terms of time, but also in resources (e.g., laboratory space, equipment, funding) and project oversight. On the other hand, “gift” middle authorship is a well-established practice in neurosurgery.¹³ The revised *h*-index (*r*-index), was recently introduced to provide more weight to first or last authorship as compared with middle authorship.²³ More specifically, the *r*-index is simply an *h*-index with first or last authorship weighted 4 times as much as middle authorship.

In this study, we applied, for the first time, the *ih*(5)-index to the 28 Accreditation Council for Pediatric Neurosurgery Fellowship (ACPNF)-approved pediatric neurosurgery fellowship programs in North America to capture and compare contemporary publication productivity. Previously, we ranked the 26 ACPNF-approved programs that were in existence in 2014 by summing the number of publications and citations from those publications from 2008 through 2013 and found that the top 2 institutions were Harvard University (Boston Children’s Hospital) and University of Toronto (The Hospital for Sick Children).¹² In this report, we also introduce the revised 5-year institutional *h*-index (*ir*(5)-index), which is analogous to the *ih*(5)-index but takes into account au-

thorship value using the *r*-index formula and uses this metric to quantify and compare program output. Lastly, in an attempt to provide programs with guidance as to how to allocate resources and attention when seeking to improve citation impact, we analyzed article and faculty member variables that correlate to productivity.

Methods

Selection of Programs and Collection of Faculty Information

A list of the 28 currently accredited US and Canadian pediatric neurosurgery fellowship programs was obtained from the ACPNF website (www.acpnf.org). All programs were successfully contacted in May 2017 to obtain a list of pediatric neurosurgeons who practiced at their institutions on a year-by-year basis from 2011 through 2015. The academic rank and advanced degrees of the faculty members were also collected. The number of cases per program per year was also obtained from the ACPNF website or from direct contact with the program.

Collection of Publication and Citation Data

Faculty names were queried in Scopus using a methodology similar to that used in our previous publications,^{17,27} with some notable methodologic improvements. Results were filtered to include only those articles published during the time frame in which the faculty member was present at the particular institution in question. Both original articles and review articles were included, whereas review articles were excluded in our previous publications.^{12,17,27} Each publication result was then reviewed to confirm the correct affiliation for the author search. Great care was taken to capture every article for each faculty member. Finally, the number of citations per article was collected from the time of article publication through June 2017. This is a departure from our previous methodology and was modified to allow 18 months of additional time for citation accumulation, which is particularly important for those articles published in 2015—the last year of the publication time period.

An article with multiple pediatric neurosurgeon authors was attributed to an institution and the individuals as follows: 1) if 2 or more authors were from the same institution, the article was counted only once for that institution in the institutional comparison analysis; 2) if 2 or more authors were from 2 or more institutions, each institution received credit for that article but only once and only if the faculty member was affiliated with the institution during the year of publication; and 3) each faculty author of a publication received credit for that publication in the analysis of individual faculty members that considered rank, degree, and so on (Table 1).

Defining Article Characteristics

To analyze the article characteristics, all publications from each faculty member included in this analysis were pooled into a single database. Duplicates (e.g., 2 authors who contributed to the same article) were removed so that an article was not double counted, which would skew the statistics for a particular variable.

TABLE 1. Top 10 most common journals

Characteristic	Impact Factor*	Citations per Publication		Publications		Citations	
		Mean*	Median*	No.	Percentage	No.	Percentage
<i>Journal of Neurosurgery: Pediatrics</i>	2.17	8.8	6	421	20	3713	10
<i>Child's Nervous System</i>	1.081	6.0	3	162	8	972	3
<i>Neurosurgery</i>	4.889	13.0	10	85	4	1101	3
<i>World Neurosurgery</i>	2.592	5.8	3	56	3	326	1
<i>Neurosurgical Focus</i>	3.139	7.3	3.5	50	2	366	1
<i>Journal of Neuro-Oncology</i>	2.980	12.4	8	47	2	583	2
<i>Journal of Neurosurgery</i>	4.059	15.1	9	41	2	618	2
<i>Pediatric Neurosurgery</i>	0.550	2.9	2	36	2	105	<1
<i>Pediatric Blood & Cancer</i>	2.513	11.5	8	33	2	379	1
<i>Neuro-Oncology</i>	7.786	28.7	20	31	2	891	2
Top 10 journals		9.4	6.0	962	47	9054	25
All journals (n = 407)		17.8	7.0	2060	100	36,584	100

* There was a statistically significant correlation between both the mean and median citations per publication and the impact factor among the top 10 journals according to the linear regression analysis (R^2 mean 0.87, $p < 0.0001$; R^2 median 0.85, $p < 0.001$).

For each article, we determined the following characteristics: whether a pediatric neurosurgeon was first or last author (compared with middle authorship status), the article tier (Table 2), the article subject, whether it was a pediatric-neurosurgery-specific publication, where it was published and the 2017 impact factor of that journal, and whether it was a clinical, basic science, or translational study. The impact factor was obtained from the journal websites and cross-referenced with www.scijournal.org. As shown in Table 2, clinical articles were subdivided into 3 tiers based on the quality or complexity of the research in question. Tier 1 mostly consisted of controlled, high-quality, primary studies, tier 2 consisted of either secondary research (i.e., the study used previously collected or published data) or lower quality primary studies, and tier 3 consisted of the lowest quality and least complex publications including case reports, small series, survey-based studies, and technical reports. Articles that did not easily fit into one of these tiers were categorized by consensus. Basic and translational science articles were not subdivided by tier.

To determine if an article was pediatric-neurosurgery-specific, the following criteria were used. For clinical articles, the publication methodology was reviewed to determine the age range of the study participants. If the age range included only pediatric patients (age range 0–21 years), then it was considered pediatrics-specific. For basic and translational science papers, this distinction was more difficult. Many disease processes are inherently pediatrics-specific, such as craniosynostosis and myelomeningocele, and were thus classified as pediatrics-specific on that basis (unless specifically stated otherwise). If the topic was a disease process that occurs predominantly in children (e.g., medulloblastoma), then it was generally included as pediatrics-specific. Most articles classified as pediatrics-specific, however, were clearly designated as such in the title or paper methodology, similar to clinical articles. Two different authors (R.P.L. and the author assigned to primary data collection for that institution) reviewed each article and the senior author (P.K.) settled discrepancies.

To classify articles as clinical, basic science, or translational research, we used previously published definitions.²⁴ In brief, clinical articles were patient oriented and included the following characteristics: “(a) mechanism of disease, (b) therapeutic interventions, (c) clinical trials, or (d) development of new technologies.” Clinical articles also included the use of human tissues and specimens “for which an investigator (or colleague) directly interact[ed] with human subjects.” Basic science research, on the other hand, centers on the “acquisition of knowledge without obligation to apply it to practical ends.” Translational research lies in between and serves to bridge the gap by applying basic science discoveries to the clinical realm. Giv-

TABLE 2. Clinical article tiers

Tier 1
Prospective & retrospective controlled cohort
Case-control study
Randomized controlled trial
Multicenter non-industry-sponsored study
Tier 2
Secondary research
Systematic review w/ meta-analysis
Big database or registry based
Uncontrolled case series (>10 patients)
Multicenter but industry sponsored
Observational
Guidelines
Tier 3
Case reports
Review article
Uncontrolled case series (≤10 patients)
Other (e.g., surgical simulation, cadaver studies, technology or instrument design, survey)

TABLE 3. Citation counts by article subject

Characteristic	Citations per Publication*		p Value	Publications		Citations	
	Mean	Median		No.	Percentage of Total†	No.	Percentage of Total†
Tumor	25.7	10.0	<0.0001	731	35	18,782	51
Clinical	12.1	6.0		422	20 (58)	5108	14 (27)
Basic science or translational	44.3	18.0		309	15 (42)	13,674	37 (73)
Spine	10.6	5.0	0.67	220	11	2337	6
Clinical	10.7	5.0		216	10 (98)	2305	6 (99)
Basic science or translational	8.0	8.0		4	<1 (2)	32	<1 (1)
Hydrocephalus	8.7	5.0	0.13	191	9	1661	5
Clinical	9.0	5.0		177	9 (93)	1597	4 (96)
Basic science or translational	4.9	2.5		13	1 (7)	64	<1 (4)
Functional/epilepsy	15.5	6.0	0.04	237	12	3684	10
Clinical	14.9	6.0		194	9 (82)	2895	8 (79)
Basic science or translational	18.8	11.0		41	2 (18)	789	2 (21)
Vascular	11.7	6.0	0.006	169	8	1981	5
Clinical	11.4	5.0		159	8 (94)	1806	5 (91)
Basic science or translational	17.5	15.0		10	<1 (6)	175	<1 (9)
Trauma	12.4	8.0	0.85	174	8	2156	0.06
Clinical	12.5	8.0		153	7 (88)	1915	0.05 (89)
Basic science or translational	11.5	10.0		21	1 (12)	241	0.01 (11)
Chiari malformation	9.2	4.0	0.30	65	3	595	2
Clinical	9.2	4.5		64	3 (98)	590	2 (99)
Basic science or translational	2.0	3.0		2	<1 (2)	4	<1 (1)
Craniosynostosis	9.5	4.0	0.88	77	4	735	2
Clinical	9.7	4.0		75	4 (97)	725	2 (99)
Basic science or translational	5.0	5.0		2	<1 (3)	10	<1 (1)
Total	17.8	7.0		2060	100	36,584	100

* The p value represents the comparison of the mean citations per publication between clinical versus basic or translational science publications within subjects.

† Number in parentheses represents the percentage of that particular subject, as opposed to the percentage of the total publications or citations.

en the difficulty in separating basic science research and translational research articles in many cases, we grouped them together in this analysis.

Articles were also classified into 1 of 8 subjects, if applicable: tumor, spine, hydrocephalus, functional/epilepsy, vascular, trauma, Chiari malformation, and craniosynostosis. An article could fall under multiple subjects, or none at all. Further subclassification was used to compare clinical articles with basic science and translational articles within each subject (Table 3).

Calculation of Metrics and Ranking of Programs

The first metric calculated and used for interdepartmental comparison was the *ih*(5)-index.⁶ It was calculated as follows: *ih*(5) = the *h* number of publications with $\geq h$ number of citations. The pool of publications used for this metric included all those published by all authors from the institution in question during the 5-year period between January 1, 2011, and December 31, 2015. The citations for each publication were calculated cumulatively from January 1, 2011, through June 30, 2017.

This metric has been previously used to analyze the publication output from all US and Canadian neurosurgical programs.^{17,27}

The *ih*(5)-index corrected for the number of faculty members was also calculated for each institution. We also corrected the *ih*(5)-index for authorship value using the *r*-index formula, which yielded the novel *ir*(5)-index. The *r*-index formula values the first and last authorship positions at 4 times more than middle authorship: $r = (1.2 \times a) + (0.4 \times h)$, where *a* equals the subset of articles *h* in which an author from the institution or program was first or last author. Programs were ranked by these 4 bibliometric measures: 1) *ih*(5)-index; 2) *ih*(5)-index/(number of faculty members); 3) *ir*(5)-index; and 4) *ir*(5)-index/(number of faculty members). The primary ranking used was *ih*(5)-index/(number of faculty members).

Statistical Analysis

All statistical analyses were carried out using JMP Pro (version 13, SAS Institute, Inc.). The mean and median numbers of citations per publication were calculated for each category or characteristic. The mean number of citations per publication was compared between characteristics using the Wilcoxon rank-sum test. The *ih*(5)-index and *ir*(5)-index were compared with linear regression. The impact factors of the top 10 journals were also compared

TABLE 4. Overview of article characteristics

Characteristic	Citations per Publication		p Value	Publications		Citations	
	Mean	Median		No.	Percentage of Total	No.	Percentage of Total
Pediatrics-specific			<0.001				
Yes	15.2	6.0		1378	67	20,892	57
No	23.0	8.0		682	33	15,692	43
Authorship			<0.0001				
First or last	12.1	5.0		940	46	11,368	31
Middle	22.5	8.0		1120	54	25,216	69
Article Type			<0.0001				
Clinical	12.6	5.0		1619	79	20,325	56
Basic science or translational	36.9	15.0		441	21	16,259	44
Clinical article tier							
1	15.0	8.0	0.47*	398	25§	5974	29
2	18.7	8.0	<0.0001†	440	27§	8234	41
3	7.8	3.0	<0.0001‡	781	48§	6117	30
Total	17.8	7.0		2060	100	36,584	100

* Tier 1 versus tier 2.

† Tier 2 versus tier 3.

‡ Tier 1 versus tier 3.

§ The percentage of clinical articles (n = 1619) is shown, not the percentage of the total number of articles.

with the mean and median numbers of citations per article for each journal using linear regression; $p \leq 0.05$ denoted significance for all statistical tests.

Results

Article Characteristics

Among the 28 programs, there were 2060 unique publications counted in this analysis during the 5-year period (January 1, 2011, to December 31, 2015) with a total of 36,584 citations (from January 1, 2011, to June 30, 2017) (Table 4). The mean and median numbers of citations per publication were 17.8 and 7.0, respectively. There were 123 articles that had authors from multiple institutions counted in this comparison. Duplicates were excluded from the analysis of the article characteristics.

Of the 2060 total publications, 1378 (67%) were pediatrics-specific. The mean and median numbers of citations per publication for pediatrics-specific articles were 15.2 and 6.0, respectively, compared with 23.0 and 8.0 for non-pediatrics-specific articles ($p < 0.0001$).

Approximately 79% of articles were clinical, with mean and median numbers of citations per publication of 12.6 and 5.0, respectively. By contrast, the other 21% of articles, classified as basic or translational, had a mean of 36.9 and median of 15.0 ($p < 0.0001$). Forty-eight percent of the clinical articles were categorized as tier 3, with a mean of 7.8 citations per publication (median 3.0). Tier 2 articles, which were 27% of the total, averaged 18.7 citations per publication (median 8.0). Tier 1 articles were 25% of total articles and averaged 15.0 citations per publication (median 8.0). Tier 1 and 2 articles each averaged significantly more citations than tier 3 articles ($p < 0.0001$) but neither averaged more than the other ($p = 0.47$).

Pediatric neurosurgeons (affiliated with one of the 28 study institutions) were the first or last author for 46% of publications. The mean and median numbers of citations per publication for articles with a pediatric neurosurgeon as the first or last author were 12.1 and 5, respectively. For the other 54% of publications, for which the pediatric neurosurgeon was a middle author, there were on average 22.5 citations per publication with a median of 8.0 ($p < 0.0001$).

Article Subject

As shown on Table 3, we classified each article according to subject matter. "Tumor" was the most commonly published subject in this analysis and comprised approximately 35% of articles. The next most common subject was functional/epilepsy, which only made up 12% of articles. Tumor articles also had the highest number of citations per publication (mean 25.7; median 10), and they made up over half of all citations among all papers. Tumor articles also accounted for over 70% of all basic and translational science articles.

Top Journals

The top 10 journals from the analysis are shown in Table 1. More than 400 journals were captured in this analysis, but almost half of the articles were published in just 10 journals. Notably, 20% of articles were published in just 1 journal, *Journal of Neurosurgery: Pediatrics*. The top 10 journals accounted for 47% of the total publications and 25% of the total citations and had a mean and median number of citations per publication of 9.4 and 6.0, respectively. Both the mean and median numbers of citations per publication for the top 10 journals were correlated with the journal impact factor on the linear regression analysis (R^2 mean 0.87, $p < 0.0001$; R^2 median 0.85, $p < 0.001$).

Program Comparison and Ranking

The median *ih*(5)-index per program was 14.0 with a range of 5 to 48 (Table 5). The top 5 fellowship programs based on the *ih*(5)-index corrected for number of faculty members (our primary ranking measure) were the following: 1) The Hospital for Sick Children; 2) Children's Hospital of Pittsburgh; 3) University of California, San Francisco Benioff Children's Hospital; 4) Seattle Children's Hospital; and 5) St. Louis Children's Hospital. Rankings were also calculated and are shown in Table 5 for uncorrected *ih*(5)-index values.

We also created a novel bibliometric index, based on the *r*-index, which is a modified *h*-index and gives more weight to the first or last author of a publication. This new index, called the *ir*(5)-index, is the institutional *r*-index over the previous 5 years. Table 5 includes rankings based on the *ir*(5)-index and corrected *ir*(5)-index. The top 5 fellowship programs based on the *ir*(5)-index corrected for number of faculty members were the following: 1) The Hospital for Sick Children; 2) Children's Hospital of Pittsburgh; 3) St. Louis Children's Hospital; 4) Doernbecher Children's Hospital; and 5) University of California, San Francisco Benioff Children's Hospital. The *ir*(5)-index was correlated with the *ih*(5)-index on the linear regression analysis ($R^2 = 0.88$; $p < 0.001$).

Table 5 also includes a statistic that compares the value of the *ir*(5)-index with the *ih*(5)-index, the *ir*(5)-index/*ih*(5)-index ratio. This statistic attempts to quantify the relative change in the program's index when first and last authorship are more heavily weighted. On average, the ratio was 0.8, meaning that the *ir*(5)-index was 80% that of the *ih*(5)-index for the typical program. Doernbecher Children's Hospital had the highest *ir*(5)-index/*ih*(5)-index ratio at 1.24, meaning the *ir*(5)-index was 124% of the *ih*(5)-index.

There was a notable variability among the metrics as seen in Table 5. However, The Hospital for Sick Children and Children's Hospital of Pittsburgh were consistently ranked first and second, respectively, in every metric. Comparing the uncorrected to the corrected *ih*(5)-index, the mean change in rank was 3.8 (range -14 to 8). For the uncorrected to corrected *ir*(5)-index, the mean change in rank was 3.5 (range -10 to 8). Between the corrected *ih*(5) and corrected *ir*(5), the mean change in rank was 4 (range -14 to 12).

Academic Rank and Degree

The articles authored by MD/PhD faculty members had a significantly higher mean number of citations per publication than those authored by MD-only (or DO-only) faculty members (26.7 vs 14.0; $p < 0.0001$) (Table 6). Each MD author on average produced 20.8 publications compared with 38.6 for each MD/PhD author. As academic rank increased from assistant professor to associate professor to professor, the faculty member had significantly more citations per publication (8.5 vs 13.6 vs 21.7, respectively; $p < 0.001$). The mean number of publications was also greater at each level of more highly ranked faculty members (9.7 vs 26.0 vs 35.9, respectively). Interestingly, almost 40% of the pediatric neurosurgeons in these 28 programs were full professors.

Discussion

Methodology

Several major methodological changes were implemented in the data collection process for this paper compared with previous publications.^{12,15,27} First, citations were counted for 18 months after the discrete 5-year period ended—in this case through mid-2017—as opposed to ending citation collection concurrently with publication collection as in our previous reports. Madhugiri et al. demonstrated that the time for neurosurgical articles to peak in citations is about 6.25 years after publication.¹⁹ Therefore, later articles in the discrete publication collection time period do not have adequate time to accumulate citations. We felt that adding approximately 18 months was a fair compromise that allowed us to present a metric that encompassed a contemporary time frame and also allowed later articles in the discrete time frame to accumulate citations so as to more adequately reflect the impact or interest generated by that article. Therefore, early articles have approximately 5–6 years and later articles have 2–3 years of citation follow-up by using this new methodology. Moreover, it has also been demonstrated that the time to peak citation does not differ between articles in neurosurgical journals compared with those in nonneurosurgical high-impact journals, so there should be no bias in our methodology against either.¹⁹

The second methodological improvement was to directly contact every program to obtain faculty affiliations for each year in the discrete time frame. Previously, faculty names were collected from program websites. However, this led to a limitation in that, if a faculty member left an institution before the website was accessed at the end of the 5-year period, the individual's contributions may not have been credited to the institution he or she just left even if that individual had been there for all of the 5 years. To overcome this limitation, we asked programs to provide a year-by-year listing of which faculty members were present so that each institution with whom a faculty member was affiliated during the 5-year period would get credit for the publications published during those years.

Third, we took a critical step by factoring in authorship value. This was accomplished by incorporating the *r*-index, which is a modified version of the *h*-index that weighs first or last authorship 4 times more than middle authorship. The *ir*(5)-index is introduced as an analogous index to the *ih*(5)-index for this very purpose.

Last, we included review articles in the analysis, whereas previously they were excluded. These reports, while not primary research, can still require significant time and effort that should be acknowledged. They are appropriately classified in the lowest tier to account for the lack of primary research, unless they included a meta-analysis, which would upgrade them to tier 2.

Article Characteristics

There were over 300 more articles across this updated 5-year time period compared with our previous articles for 2009–2013.¹² This increase is due to a combination of globally increased academic productivity within pediatric neurosurgery and the addition of 2 new fellowship pro-

TABLE 5. Fellowship program metrics and rankings

Program	ih(5)-index/ (faculty members)			Median No. of Faculty	ih(5)-index			(ir(5)- index)/ (ih(5)- index)			ir(5)-index/ (faculty members)			ir(5)-index			Citations per Publication	Percentage Pediatrics- Specific*	Percentage Clinical†	Case Vol‡
	Rank	No.	Members		Rank	No.	index	Rank	No.	index	Rank	No.	Rank	No.	Publications	Citations				
The Hospital for Sick Children	1	9.6	5	1	48	0.78	1	7.4	1	37.2	314	10,434	33.2	83	51	525				
Children's Hospital of Pittsburgh	2	7.5	4	2	30	0.80	2	6.0	2	24.0	136	3455	25.4	71	76	851				
UCSF Benioff Children's Hospital	3	5.8	4	5	23	0.66	5	3.8	8	15.2	77	3067	39.8	60	67	700				
Seattle Children's Hospital	4	5.4	5	4	27	0.58	10	3.1	7	15.6	115	4577	39.8	46	63	682				
St. Louis Children's Hospital	5	5.0	4	7	20	0.88	3	4.4	5	17.6	102	1620	15.9	34	85	836				
NYU Langone Medical Center	6	4.7	3	13	14	0.74	7	3.5	13	10.4	42	640	15.2	64	95	640				
Lucile Packard Children's Hospital at Stanford	6	4.7	3	13	14	0.57	12	2.7	18	8.0	51	754	14.8	81	69	711				
Le Bonheur Children's Hospital/St. Jude Children's Research Hospital	8	4.3	4	8	17	0.75	9	3.2	11	12.8	101	1288	12.8	66	91	800				
Children's Hospital of Philadelphia	8	4.3	3	16	13	0.58	17	2.5	20	7.5	50	1449	29.0	84	88	958				
Johns Hopkins Hospital	8	4.3	3	16	13	0.40	22	1.7	27	5.2	101	1709	16.9	57	87	581				
Primary Children's Hospital	11	4.0	4	9	16	0.93	6	3.7	9	14.8	76	799	10.5	92	97	820				
Children's Hospital of Denver	12	3.8	4	11	15	0.48	21	1.8	22	7.2	46	591	12.8	78	59	702				
Rady Children's Hospital	13	3.7	6	6	22	0.95	7	3.5	4	20.8	128	2415	18.9	16	77	631				
Children's Hospital of Los Angeles	13	3.7	3	19	11	0.84	10	3.1	16	9.2	37	298	8.1	95	87	635				
Barrow Neurological Institute at Phoenix Children's Hospital	15	3.5	4	13	14	0.74	15	2.6	13	10.4	50	542	10.8	74	76	735				
Doernbecher Children's Hospital	16	3.3	3	22	10	1.24	4	4.1	12	12.4	41	359	8.8	61	100	762				
Boston Children's Hospital	16	3.3	9	2	30	0.80	12	2.7	2	24.0	209	3522	16.9	65	81	900				
Children's Hospital of Alabama/UAB	18	3.0	5	11	15	0.88	15	2.6	10	13.2	110	1117	10.2	73	98	827				
Ann & Robert H. Lurie Children's Memorial Hospital	18	3.0	4	18	12	0.80	18	2.4	15	9.6	52	511	9.8	69	65	1132				
Duke Children's Hospital & Health Center	18	3.0	3	23	9	0.53	23	1.6	28	4.8	32	555	17.3	42	58	626				
Children's National Medical Center	21	2.8	4	19	11	0.84	19	2.3	16	9.2	43	455	10.6	81	93	538				
Texas Children's Hospital	22	2.7	6	9	16	1.00	12	2.7	6	16.0	141	1079	7.7	84	96	900				
Cincinnati Children's Hospital Medical Center	23	2.2	5	19	11	0.62	27	1.4	23	6.8	48	414	8.6	96	90	700				
Miami Children's Health System/Nicklaus Children's Hospital	24	2.0	4	24	8	0.93	20	1.9	21	7.4	29	241	8.3	97	79	500				
James Whitcomb Riley Hospital for Children	25	1.8	4	26	7	0.91	23	1.6	24	6.4	42	199	4.7	79	98	930				
Children's Healthcare of Atlanta at Egleston and Scottish Rite	26	1.6	5	24	8	1.00	23	1.6	18	8.0	34	187	5.5	91	94	1148				
Nationwide Children's Hospital	27	1.5	4	27	6	1.00	26	1.5	25	6.0	13	76	5.8	69	75	640				
Children's Medical Center Dallas	28	1.0	5	28	5	1.12	28	1.1	26	5.6	12	68	5.7	92	100	966				
Cumulative mean	NA	3.8	4.3	NA	15.9	0.8	NA	2.9	NA	12.3	79.7	1515	15.1	67	79	770.2				
Cumulative median	NA	3.6	4	NA	14	0.8	NA	2.7	NA	10	50.5	697	11.8			735				

NA = not applicable.

* Percentage of articles that are pediatrics-specific.

† Percentage of articles that are clinical as opposed to basic and translational science.

‡ Case volumes were determined from <http://www.acpnf.org/> or by directly contacting the program.

TABLE 6. Dependence of citation impact on academic rank and degree

Characteristic	Citations per Publication		p Value	Publications	Publications per Author	Citations
	Mean	Median				
Degree			<0.0001			
MD/PhD (n = 21; 17%)	26.7	10.0		811	38.6	21,690
MD or DO (n = 101; 83%)	14.0	6.0		2103	20.8	29,503
Academic rank						
Professor (n = 47; 39%)	21.7	8.0	<0.0001*	1688	35.9	36,551
Associate professor (n = 34; 29%)	13.6	6.0	0.0007†	884	26.0	11,992
Assistant professor (n = 38; 32%)	8.5	4.0	<0.0001‡	370	9.7	3132

* Professor versus associate professor.

† Associate professor versus assistant professor.

‡ Professor versus assistant professor.

grams. Although two-thirds of the articles in this analysis were pediatric-neurosurgery-specific, adult and mixed adult and pediatric studies averaged significantly more citations per publication (Table 4). This is likely due to the much larger readership and applicability of adult medicine compared with pediatric medicine, especially within neurosurgery and the neurosciences. This finding also shows that the average pediatric neurosurgeon does not exclusively publish papers on pediatric topics.

While about half of the articles in this analysis had a pediatric neurosurgeon as the first or last author, those articles in which the pediatric neurosurgeon was a middle author had significantly greater citation impact. Perhaps this finding is attributable to scenarios in which pediatric neurosurgeons contribute to non-neurosurgery-specific projects that have an overall greater impact, such as clinical neuro-oncology or basic science projects on tumor biology. This also represents the notable frequency of collaboration among pediatric neurosurgeons, either in place of—or in addition to—serving as a principal investigator. Collaborative research, in fact, has been consistently shown to lead to higher citations than if one publishes alone.^{5,20,21}

As was expected, basic science and translational research papers had significantly higher mean and median numbers of citations per publication—in this case 3 times higher. Whether this ratio of citation impact is proportional to the increased time and resources required for the typical basic or translational project compared with a clinical project is unclear.

When looking just at clinical research, tier 3 articles, which represent in general the lowest quality and least complex research, averaged about half as many citations per publication as tier 1 and 2 articles. This is also expected because research of higher quality and greater complexity (i.e., in terms of the time and resources needed) is more likely to be cited in the future. There was no difference between tier 1 and tier 2, however, which was somewhat unexpected. One contributing factor to this finding is that meta-analyses were classified as tier 2 because they are not original research. Meta-analyses, though, represent high-quality evidence and are likely to be cited frequently. Furthermore, there may be a “ceiling” to citation counts in the very small field of pediatric neurosurgery, mean-

ing that even the highest-quality studies may not garner proportionally more citations as they would in other larger fields.

The strong plurality of publications in this analysis was focused on tumor, which accounted for 35% of all publications and 51% of all citations. Over 70% of all basic and translational science articles were tumor focused. Part of this finding may be due to a disproportionate amount of contemporary funding going to neuro-oncology. However, it can also likely be attributed to the fact that this is a subject that crosses over to nonneurosurgery clinicians and scientists. The same applies to spine, epilepsy, and trauma, whereas those subjects that are more neurosurgery-specific—namely Chiari malformation, craniosynostosis, and hydrocephalus—had relatively lower citation impacts.

When looking at tumor, functional/epilepsy, and vascular papers, basic science and translational publications did have a significantly greater number of citations per publication than clinical articles on the same subject. There was no difference in this comparison for spine, trauma, Chiari malformation, or craniosynostosis. However, it is difficult to reliably compare citation impact between clinical versus basic and translational science papers within these latter subjects because only a small number of basic and translational articles were included on each subject.

Author Characteristics

Faculty members with dual degrees (MD and PhD) were significantly more productive than their MD- or DO-only counterparts. This may be due to some combination of more research training among PhD-trained neurosurgeons and a greater interest in research. It also may be due to MD/PhD faculty members publishing more basic science or translational studies, which we have shown to garner more citations per publication, or publishing more papers on topics that have a great citation impact like neuro-oncology.

Consistent with previous reports in both general and pediatric neurosurgery, greater publication productivity is positively correlated with more advanced academic rank.^{9,11} However, the causality in this relationship remains unclear. Rank may progress secondary to reaching a productivity threshold. Alternatively, increased rank may

lead to more collaborative opportunities (i.e., research networks) or gift authorships as highlighted previously. Likely there is an element of both.

Rankings

This is the first ranking of pediatric neurosurgery programs that used a contemporary measure of productivity rather than summed career metrics as we used in our prior report. As we have more recently posited, it is much more informative to examine publication productivity through a contemporary lens rather than looking at summed metrics over a faculty member's or institution's lifetime. Using a contemporary discrete 5-year period may highlight recent productivity in historically less-productive programs or stagnation in programs with strong historical reputations. Contemporary metrics and descriptive analyses, as we have done, are far more informative than simply the total number of publications. This goes for all stakeholders, including administrators, department leadership, funding bodies, and program applicants.

In this report, we provide 4 rankings for the 28 programs. Our primary ranking is the $ih(5)$ -index corrected for the number of faculty members [$ih(5)$ -index/(number of faculty members)] (Table 5). Correcting for the number of authors is important in the setting of pediatrics where an increase in 1 faculty member can change the program size by 25%–33%. Compared with our previous ranking of pediatric fellowship programs by using the cumulative h -index, only 1 program (The Hospital for Sick Children) remained in the top 5 and only 4 remained in the top 10 (Seattle Children's Hospital, St. Louis Children's Hospital, and Children's Hospital of Pittsburgh).

We also presented rankings based on our novel metric, the $ir(5)$ -index, which is both corrected and uncorrected for the number of faculty members. The faculty-corrected $ir(5)$ -index was used as the secondary ranking metric. There were only 3 fellowship programs within the top 10

faculty-corrected $ih(5)$ -index list that were not present in the top 10 corrected $ir(5)$ -index list: Lucile Packard Children's Hospital, Children's Hospital of Pennsylvania, and Johns Hopkins were replaced with Primary Children's Hospital, Rady Children's, and Children's Hospital of Los Angeles. This finding implies that, in general, upper-tier programs are highly productive both as collaborators and primary investigators. We feel that the ratio of these 2 faculty-adjusted metrics— $ir(5)$ -index to $ih(5)$ -index—is an important measure going forward. As shown in Fig. 1, there is considerable variability in the ratio of these 2 metrics, and on average the authorship-weighted index is lower than the nonweighted index.

Moving forward, more emphasis should be placed on the subject of publication authorship value, particularly because the number of authors has increased significantly in neurosurgical publications, including gift authorship.¹³ Middle authorship represents an unknown when it comes to assessing productivity. There is no question that middle authors invest less time and intellectual effort into a project than the primary, secondary, and senior authors, but not much more can be said beyond that. There is also often significant variability in the contributions of middle authors. For many projects, some middle authors have contributed significantly whereas others contribute minimally or are given authorship as a “gift.”

In general, we intentionally did not overemphasize any implications of ranking and we provided multiple methods of ranking to give readers information that can be interpreted and used as appropriate per the situation. Bibliometric indices are only a proxy of departmental productivity, and each has inherent biases and flaws. Furthermore, publication productivity is only 1 of many critical factors that contributes to the strength of an academic training environment. However, given the noticeably increased attention to quantifying and comparing program productivity, we have attempted to incrementally improve the process and provide the most advanced analysis yet produced.

There was no specific face validation performed on these rankings because there is no comparison metric that would serve as a gold standard. The well-publicized *US News and World Report* rankings incorporate a wide variety of factors and include neurology departments, thereby making comparison with our rankings more “apples-to-oranges” than “apples-to-apples.”¹¹ Ranking programs by National Institutes of Health funding would provide a more compatible comparison because both focus on research and our previous work would suggest a positive correlation.³⁰

Limitations

There were 2060 unique articles counted with at least 1 author from a pediatric neurosurgery fellowship program included in this analysis. This amounts to roughly 400 articles per year. However, this does not include all articles in the pediatric neurosurgery literature or even all articles published by pediatric neurosurgeons. This publication selection bias is a limitation of the article characteristics analysis because the collected data are restricted to those faculty members working at these 28 institutions. There are many more pediatric neurosurgeons working at other academic centers whose work was not included in this

FIG. 1. Comparison of the $ih(5)$ -index and $ir(5)$ -index. The x-axis corresponds to the program rankings by the uncorrected $ih(5)$ -index. Figure is available in color online only.

study. There are also pediatric neurosurgeons in nontraditional academic settings who were not included, which adds additional bias to these results. We used a 3-tier classification system to acknowledge that publications are not equal in terms of effort and complexity; nevertheless, we accept some criticism of this system.

Conclusions

This iteration further advances the analysis of publication productivity in pediatric neurosurgery to date. We provide an updated methodology that more appropriately weighs authorship value to accurately quantify and compare contemporary productivity among programs. We used both previously validated metrics and a proposed new metric. We also provide a novel analysis of article and author characteristics that correlate with citation impact. Regular assessment of academic productivity with continual methodological refinement is important to our small field.

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Disclosures

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Conception and design: Klimo, Lee, Venable, Khan, Taylor. Acquisition of data: Lee, Xu, Dave, Ajmera, Lillard, Wallace, Broussard, Motiwala, Norrdahl, Howie, Akinduro, Vaughn. Analysis and interpretation of data: Klimo, Lee. Drafting the article: Klimo, Lee. Critically revising the article: Klimo, Lee, Venable. Reviewed submitted version of manuscript: Klimo, Lee, Venable, Vaughn. Approved the final version of the manuscript on behalf of all authors: Klimo. Statistical analysis: Lee. Study supervision: Klimo.

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