Predictors of Citations in Neurosurgical Research: A 5-year Follow-Up

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Abstract

Introduction: Citation rates are an important measure for the impact of publications. This study is the most comprehensive analysis of predictors for scientific neurosurgical research articles.

Methods: Scientific articles published in 13 neurosurgical journals in 2015 were selected. Data collected included: article subject, level of evidence (LOE), journal impact factor (IF), authorship, contributing centers, and study design. Citation counts were collected for each article in the Web of Science (WoS), Google Scholar (GS), and Scopus 2.5 and 5 years after publication. A generalized linear mixed effects model using the predictors of search engine, LOE, number of centers, number of authors, and IF was constructed to predict total citation count at 5 years.

Results: 2867 articles generated 39190 citations in WoS, 61682 in GS, and 43481 in Scopus. The median [interquartile range] number of citations per article was 10 [14] in WoS, 15 [20] in GS, and 11 [15] in Scopus. On average, for every 1 citation in WoS, Scopus and GS identified 1.11 and 1.58 citations, respectively. Significant predictors of citation count in all databases 5 years after publication included search engine, LOE, number of centers, number of authors, number of countries, journal IF, and the month of publication ($p<0.05$). The article subject (tumor, spine, etc.) did not significantly predict citation counts.

Conclusions: In the most thorough analysis of citation predictors in the neurosurgical literature, search engine, LOE, number of centers, number of authors, number of countries, journal impact factor, and month of publication influenced citations 5 years after publication.

Abbreviations List

CI: Confidence Intervals
GS: Google Scholar
IQR: Interquartile Range
IRR: Incidence Rate Ratio
LOE: Level of Evidence
NB: Negative Binomial Regression
SD: Standard Deviation
WoS: Web of Science

Introduction

Citation rates in the neurosurgical literature are instrumental in assessing the impact of academic works. The emphasis on research productivity has led to the growing field of bibliometrics, which aims to measure research quality and quantity.[1] For example, indices such as the h-index are used to quantify productivity of individuals, and these values can even be predictive of National Institutes of Health funding in neurosurgery.[2]

With increasing emphasis on bibliometrics, it is important to determine which factors influence research impact in the field of neurosurgery. A previous study by our group analyzed such factors in approximately 3000 scientific and 1000 editorial articles published in 2015. 2.5 years after publication, level of evidence, number of participating centers, number of authors, and the journal's impact factor were most influential on citation rates of scientific articles in Web of Science (WoS) and Google Scholar (GS).[3] As a continuation of the findings of Oravec et al.[3], this study seeks to explore the predictors of citation rates of nearly 3000 neurosurgical scientific publications in 13 journals 5 years after being published in print.

Methods

All scientific articles published in print from January 2015 to December 2015 in 13 English-language neurosurgical journals were included in this review. The data collection and results methodology has been described in detail in a previous study by our group.[4] In short, authorship, contributing centers, study design, study topic, level of evidence (LOE) (using the modified LOE scale for neurointerventional and neurosurgical research[5]), number of citations, and self-citations at 2.5 years and 5 years were collected from scientific and editorial papers published in neurosurgical journals. We included the following journals: *Acta Neurochirurgica, British Journal of Neurosurgery, European Spine Journal, Journal of Neurosurgery, Journal of Neurosurgery Neurosurgical Focus, Journal of Neurosurgery Pediatrics, Journal of Neurosurgery Spine, Journal of Neurosurgical Sciences, Neurosurgical Review, Neurosurgery,* *Operative Neurosurgery, Spine*, and *World Neurosurgery*. Non-scientific or editorial works were excluded.

Citation rates were collected from Web of Science (WoS; https://apps.webofknowledge.com) and Google Scholar (GS; scholar.google.com) 2.5 years and 5 years after print. Rates were also collected from Scopus (www.scopus.com) 5 years after print. This was temporally standardized by collecting the data within the first week of each month 5 years after publication. For example, articles published in January 2015 had their 5-year data collected during January 1^{st}-7^{th}, 2020. Therefore, all articles had equal time consideration for citation rates. Self-citation rates were also collected from Scopus. Impact factor of the included journals was collected from the 2019 reported journal impact factor in the WoS Journal Citation Reports.[6]

Statistical Methods

Initially, WoS, GS, and Scopus citation counts were modeled individually by negative binomial regression (NB) using the predictors of LOE, number of countries, number of centers, number of authors, month of publication, and impact factor. Prior to analysis, correlations between the predictors and response variables were examined. Since citation count is a nonnegative integer, its distribution was remarkably skewed, and the conditional variance was larger than the conditional mean (overdispersion). The method for choosing the best fitting model was explained in the previous study.[3] Once it was established that the estimates for the individual search engine models were identical among all engines, a negative binomial generalized linear mixed effects model was constructed to predict citation count including search engine as a factor. Within article correlation in citation count between all search engines was considered and controlled for in the model. Other predictors of study design, subject group, month of publication, and number of countries were considered separately and eliminated after comparison of model fit (AIC). Beta coefficients were converted to incidence rate ratios (IRR) with 95% confidence intervals (CI). Comparison of citation count within search engine in the latter 2.5 years after publication compared with the first 2.5 years was done by related samples Wilcoxon Signed Rank tests. Descriptive statistics were calculated such that mean (SD) were used for normally distributed variables and median [IQR] for count data. All analyses were conducted using R: A language and environment for statistical computing, R Foundation for Statistical Computing, Version 3.4.3, Vienna Austria and RStudio: Integrated Development for R., Version 1.1.383, RStudio, Inc., Boston, MA, USA. Two-tailed hypothesis testing was used with $p<0.05$ interpreted for statistical significance.

Results

There were 2889 articles published in the 13 selected journals in 2015 that were initially reviewed. 22 articles had missing data or were not traceable in the selected databases and were therefore excluded from further analysis. A total of 2867 scientific articles were analyzed for this study.

Data from 2.5 years after publication has been published previously.[3] Five years after publication, 2867 articles generated 39190 citations in WoS, 61682 in GS, and 43481 in Scopus. The median [IQR] number of citations per article was 10 [14] in WoS, 15 [20] in GS, and 11 [15] in Scopus. The *Journal of Neurosurgery* had the highest median number of citations per article in WoS and GS, while *Neurosurgical Focus* had the highest median number of citations in Scopus (**Table 1**).

There were 87 (3%) articles with zero citations in WoS, 39 (1.4%) in GS, and 80 (2.9%) in Scopus over the 5 years. Mean (SD) change in citations from 2.5 to 5 years after publication was 8.7 (10.6) and 12.2 (15.1) in WoS and GS, respectively. Mean (SD) rate of citation change for articles without zero citations in 2017 was 209.4 (215.6)% and 154.9 (155.9)% in WoS and GS, respectively (**Figure 1**). Overall, more citations occurred in the last 2.5 years after publication compared to the first 2.5 years after publication in WoS and GS ($p<0.001$).

Predictors of Citations

Predictors of citations in WoS, GS, and Scopus using a negative binomial linear mixed effects model are included in **Table 2**. Citations across all databases were significantly predicted by search engine, LOE, number of centers, number of authors, number of countries, impact factor of the journal, and the month of publication. Citation count differed by search engine. WoS had fewer citation counts per article than GS and Scopus. On average, for every 1 citation in WoS, Scopus and GS identified 1.11 and 1.58 citations, respectively.

A 1-level increase in LOE (higher quality evidence) was associated with a 14.3% increase of citation counts. For each additional center involved in the study, citation counts increased by 3.8%. For each additional country, there was an associated increase in citation counts by 9.5%. For each additional author, citation counts increased by 2.5%. For each additional impact factor point, there was an associated increase in citation counts by 27.0%. The journals published later in the year tended to have fewer citations.

Study Subject

Tables 3 and 4 demonstrate the breakdown of citations 5 years after publication by study subject. Spine, Tumor, and Trauma articles had the highest median citation rates of all subjects in WoS, GS, and Scopus.

Table 5 demonstrates the change in citation numbers and citation rates 2.5 years to 5 years after publication by subject in WoS and GS. Spine, Trauma, and Tumor had the highest mean change in absolute counts. Spine, "Other", and Tumor had the highest mean rate of citation change.

Study Design

Table 6 reveals the change in citations 2.5 years to 5 years after publication by study design. Systematic reviews/meta-analyses, randomized controlled trials (RCTs), and literature reviews had the highest mean change in absolute counts in WoS and GS. For mean rate of change, WoS and GS differed. Systematic reviews/meta-analyses and databases had highest mean rates of change in WoS, while case series and non-human/imaging studies increased the most in GS.

Top 10 Cited Articles

The supplementary materials reveal the 10 most highly cited articles 5 years after publication in WoS, GS, and Scopus, respectively. Although these articles vary in features, many were published in the *Journal of Neurosurgery*.

Discussion

This is the largest and most extensive analysis of the neurosurgical literature and citation patterns to date. Nearly 3000 scientific articles published in 2015 revealed that citation counts 5 years later were significantly predicted by search engine, higher LOE, number of centers, number of authors, number of countries, impact factor of the journal, and the month of publication. These predictors are similar to those at 2.5 years after publication.[3]

Level of evidence criteria have been adapted in the past from the Canadian Task Force on the Periodic Health Examination in 1979.[7] A recent adaptation has targeted more applicability to neurosurgery, which was utilized in this study.[5] Study design, which directly relates to LOE, has been explored previously as a predictor of citations in other medical specialties. Some studies have found that RCTs and meta-analyses tend to have higher rates of citation, which corroborates our findings in the neurosurgical literature.[8–11] However, some studies suggest study design does not significantly influence the citation rate.[12,13] A higher impact factor of the publishing journal has also been found to be associated with higher citation rates,[13] which is intuitive given impact factor is calculated as the mean number of citations per article annually for the previous 2 years.[14] Collaboration has also been well-studied in other fields, and increased number of authors, centers, and countries have all been found to increase number of citations, as found in the present study.[11,15,16]

The month of publication was an unexpected significant predictor in our study. Publications later in 2015 tended to have fewer citations than those earlier in the year. Data collection occurred monthly for a year-long basis to avoid the known citation bias favoring citation counts for articles published earlier in the year.[17] After controlling for this confounder, we would expect later months to have increased citations due to database growth and academic productivity over time.[18] The reason for this trend is uncertain but could be due to editorial decisions made by journal editors regarding where in the volume the articles are placed. Despite this trend, there were more citations from 2.5 to 5 years after publication compared to the first 2.5 years, which follows academic productivity trends.

This trend that articles tended to accumulate more citations in the last 2.5 years after publication compared to the first 2.5 years in WoS and GS has been explored previously. A study of 13 American Psychological Association Journals found that after analyzing the citation life cycle of 1,172 articles for 25 years, article yearly citation rate tended to peak between the second and fifth year of publication. Although, "very-high impact articles" (those with 250 or more citations with at least 10 new citations per year) peaked about 11 years after publication.[19] Additionally, Madhugiri et al.[20] found that it takes 6 25 to 7 2 years for neurosurgery articles to reach their peak citation state across all includ d journals after a 13-year follow-up. After this point, articles were still cited often but reached a steady state. This trend, combined with the fact that citation counts tended to be low in he early years after publication, leads to a citation curve that can be mathematically modeled with the form y = ax4 + bx3 + cx2 + dx + e (with variable constants depending on if published in a neurosurgery journal, high-impact medical journal, basic science journal, or non-neurosurgical journal).[20] Our follow-up to 5 years likely has not captured the peak for the most highly cited articles, and future studies could aim to follow citation patterns for a longer time period.

Predictors of citations in the neurosurgical literature have also been explored previously. Harsh et al.[21] assessed 682 articles in *JNS* and *Neurosurgery* (using Scopus, WoS, or GS depending on data availability) and found that increased number of authors, more institutional collaborators, and clinical study design on adult populations were correlated with higher numbers of citations. These findings corroborate our present analyses. Ponce and Lozano[22] investigated the top 100 cited neurosurgical works according to WoS in 2009. Of the 13 neurosurgical journals explored, the top 100 highly cited works were found in only 3 journals (*Neurosurgery, JNS,* and *Journal of Neurology, Neurosurgery, and Psychiatry).* Our group also found a high representation of papers from the *JNS* in our top 10 cited works. In Ponce and Lozano's study, cerebrovascular topics followed by trauma and functional papers were well-represented in the top 100, and the most common study design was clinical case series. An additional study performed by Madhugiri et al.[20] explored 576 neurosurgical articles published in 23 journals and found that neurosurgical articles published in non-neurosurgical journals were more highly cited (utilizing GS) than those published in neurosurgical journals. This is an interesting finding that has not been explored in our paper, as we analyzed the major neurosurgical journals only. Overall, the literature regarding citations of neurosurgical publications has been limited by number of articles included, selection of articles, and/or lack of utilization of multiple databases, and the present study overcomes these limitations.

An additional finding of interest was the differences in citation reporting amongst the three databases queried GS reported 1.58 times greater citations than WoS, and Scopus reported 1.11 times greater citations than WoS. The greater citation counts in GS may be due to the fact that GS includes additional scholarly documents in the citation rates, such as those from websites and professional societies.[3] Therefore, identifying the search engine utilized for calculating citations is very important. Differences in citations in these databases can also heavily influence the highly valued h-index for authors. To illustrate this point, the senior author's h-index varies significantly on each of these databases, with WoS reporting 24, Scopus reporting 25, and GS reporting 33. This can be problematic when interpreting academic impact, and this variability likely becomes more distinct with higher numbers of publications. The h-index has additional weaknesses of excluding very high-impact papers, disadvantaging younger researchers, and confounding authors with the same name.[1] Arguably, the h-index should not be used as a single encompassing view of the scientific impact of an author, and a set of bibliometric indicators is much more preferable.[23] One alternate method to determine author productivity is the m-quotient. The m-quotient is calculated by dividing the h-index by the number of years since first publication, which can reduce the bias against younger researchers. There are other proposed metrics that can be utilized such as the g-index, e-index, and i10 index, but each have their own pitfalls.[1] Many factors need to be considered when assessing author productivity, and the h-index is only one small piece to the puzzle.

Limitations of this study include potential data collection errors when reviewing such a large number of data points. Additionally, although the present study controlled for timing by reviewing citation counts each month 5 years after publication, articles may differ in time published online ahead of print. This could be a contributing confounder when assessing citation counts.

Conclusions

This is the largest and most thorough analysis of predictors of citations in the neurosurgical literature. On average, for every 1 citation in WoS, Scopus and GS identified 1.11 and 1.58 citations, respectively. Factors that influenced citation counts in WoS, GS, and Scopus 5 years after publication were the level of evidence, number of centers, number of authors, number of countries, impact factor of the journal, and month of publication.

Figures

Figure 1. Trends of Median Number of Citations Overall and by Subject at 2.5 and 5 Years After Publication

Tables

Table 1. Number of Articles and Citations at 5 Years by Journal

Journal	# Articles	Median Citations [IQR]		
		WoS	**GS**	**Scopus**
Acta Neuro.	238	7.0 [9.0]	10.0 [13.0]	7.5 [10.3]
BJN	166	3.0 [5.0]	6.5 [8.0]	3.0 [6 0]
Euro Spine	444	9.0 [11.0]	15.0 [18.0]	10 0 [13.0]
JNS	350	14.5 [19.0]	24.0 [29.0]	15 5 [21.0]
JNSNF	86	14.0 [11.3]	22.0 [10.3]	16.0 [11.5]
JNSP	198	9.0 [14.0]	14 0 [20 3]	10.0 [15.0]
JNSS	199	11.0 [16.0]	18.0 [26.0]	12.0 [18.0]
JNSSci	14	3.0 [6.5]	6.5 [14.3]	4.5 [10.3]
Neurosurg Review	77	8.0 [9.0]	12.0 [15.0]	9.0 [9.5]
Neurosurgery	203	14.0 [18.0]	21.0 [23.0]	14.0 [17.0]
Operative N	71	7 0 [9.0]	9.0 [12.0]	8.0 [9.0]
Spine	432	11.0 [14.0]	18.0 [21.8]	12.5 [16.0]
World N	389	8.0 [11.5]	13.0 [16.0]	9.0 [11.0]
TOTAL	**2867**			

Abbreviations: Acta Neuro = Acta Neurochirurgica; BJN = British Journal of Neurosurgery; Euro Spine = European Spine; JNS = Journal of Neurosurgery; JNSNF = Journal of Neurosurgery Neurosurgical Focus; JNSP = Journal of Neurosurgery Pediatrics; JNSS = Journal of Neurosurgery Spine; JNSSci = Journal of Neurosurgical Sciences; Neurosurg Review = Neurosurgical Review; Operative N = Operative Neurosurgery; World N = World Neurosurgery; NCNA = Neurosurgical Clinics of North America

Table 2. Negative Binomial Generalized Linear Mixed Effects Model

Dependent: Citation Count	**IRR**	**95% CI**	**P-Value**
Search engine (ref = Web of Science)			

Google Scholar	1.577	(1.494, 1.664)	<0.001
Scopus	1.113	(1.054, 1.175)	<0.001
Level of evidence	0.857	(0.839, 0.876)	<0.001
Number of centers	1.038	(1.019, 1.057)	<0.001
Number of countries	1.095	(1.051, 1.141)	<0.001
Number of authors	1.025	(1.016, 1.034)	<0.001
Impact factor	1.270	(1.240, 1.302)	<0.001
Month of publication	0.982	(0.976, 0.988)	<0.001

Table 3. Number of Citations by General Article Subject

Subject Group	# Articles	Median Citations IQR]			
		WoS	GS	Scopus	Self-Citations (Scopus)
Pediatric	148	6.0 [12.0]	11.5 [16.8]	8.0 [12.0]	0 [2.0]
Trauma	170	10.0 [14.0]	16.0 [24.3]	10.0 [15.0]	1.0 [2.8]
Vascular	446	9.0 [13.0]	14.0 [17.0]	10.0 [14.0]	1.0 [3.0]
Tumor	467	10.0 [13.0]	16.0 [19.0]	11.0 [13.0]	1.0 [2.0]
Spine	943	11.0 [14.0]	18.0 [22.0]	12.0 [16.0]	1.0 [3.0]
Functional	253	8.0 [11.0]	13.0 [18.0]	9.0 [12.0]	1.0 [3.0]
General Neurosurgery	260	8.5 [13.0]	14.0 [21.0]	10.0 [16.0]	1.0 [3.0]
Other	180	8.0 [12.0]	11.5 [19.0]	8.0 [14.0]	1.0 [2.0]

Table 4. Number of Citations by Individual Subject Subclassification

Individual Subject Sub-Group	# Articles	Median Citations IQR]			
		WoS	GS	Scopus	Self-Citations (Scopus)
Pediatric brain tumor	40	4.0 [7.8]	7.0 [13.3]	5.0 [9.3]	0 [1.0]

Pediatric spine surgery	24	5.5 [12.8]	9.5 [14.8]	7.5 [10.8]	0 [2.0]
Pediatric traumatic injury/TBI	23	19.0 [15.0]	30.0 [32.0]	19.0 [17.0]	1.0 [5.0]
Other Pediatric	61	7.0 [11.0]	12.0 [13.0]	8.0 [10.5]	0 [2.0]
Adult traumatic brain injury	57	11.0 [15.5]	20.0 [26.5]	12.0 [19.0]	1.0 [2.0]
Adult traumatic spine	92	9.0 [13.0]	15.0 [24.0]	10.0 [16.0]	0 [3.3]
Other Trauma	21	8.0 [9.5]	14.0 [17.5]	9.0 [9.0]	1.0 [2.0]
Aneurysm	194	10.5 [13.5]	16.0 [19.0]	11.0 [15.0]	1.0 [3.0]
Arteriovenous malformation/fistula	96	10.0 [14.0]	15.0 [19.0]	11.0 [15.8]	1.0 [4.0]
Ischemic stroke	19	6.0 [11.0]	10.0 [17.0]	6.0 [10.0]	0 [1.0]
Hemorrhagic stroke	38	9.0 [9.3]	15.0 [15.0]	9.0 [9.3]	0 [1.0]
Other Vascular	99	8.0 [10.0]	11.0 [16.0]	8.0 [11.0]	1.0 [2.0]
Intrinsic brain tumor	75	12.0 [18.0]	21.0 [25.0]	13.0 [19.0]	2.0 [3.0]
Meningioma	60	12.0 [13.8]	18.0 [18.8]	12.0 [15.8]	0 [1.8]
Brain metastases	79	9.0 [13.0]	13.0 [19.0]	9.5 [13.3]	0.5 [2.0]
Other Brain tumor	173	7.0 [11.5]	13.0 [17.0]	9.0 [11.0]	1.0 [2.5]
Spinal cord tumor	57	10.0 [10.5]	18.0 [15.0]	12.0 [12.0]	0 [1.0]
Spinal column tumor	23	10.0 [16.0]	21.0 [23.0]	11.0 [19.0]	1.0 [2.0]
Cervical myelopathy/surgery	243	9.0 [15.0]	16.0 [23.0]	11.0 [17.0]	1.0 [3.0]
Artificial disk	13	9.0 [20.5]	17.0 [36.5]	9.0 [19.0]	1.0 [4.5]
Fusion of thoracic or lumbar spine	152	12.0 [18.5]	21.5 [25.8]	15.5 [17.0]	1.0 [3.0]
Spinal deformity and scoliosis	277	11.0 [13.0]	18.0 [22.0]	12.0 [16.0]	1 [3.8]
Spinal infection	32	10.5 [15.8]	16.5 [26.8]	11.0 [16.8]	0 [2.0]
Other Spine	226	12.0 [11.3]	18 [19.3]	13.0 [12.0]	1.0 [2.0]

Deep brain stimulation	44	9.5 [10.8]	12.0 [15.8]	9.5 [10.5]	1.0 [2.8]
Epilepsy/seizure	45	8.0 [15.5]	16.0 [19.0]	10.0 [16.5]	1.0 [3.0]
Pain/spasticity	149	9.0 [11.0]	14.0 [19.0]	9.5 [12.0]	1.0 [3.0]
Other functional	15	5.0 [3.0]	8.0 [4.0]	6.0 [5.0]	1.0 [1.0]
Hydrocephalus/CSF disorders	117	7.0 [12.0]	11.0 [18.5]	8.0 [14.5]	0 [2.0]
Other Infection	30	9.5 [11.3]	15.5 [17.8]	10.0 [9.8]	0 [1.0]
Operating room	4	2.0 [5.0]	3.5 [5.3]	2.5 [4.8]	0.5 [1.0]
Residency training	17	14.0 [21.5]	21.0 [24.0]	15.0 [22.0]	1.0 [3.5]
Socioeconomic	19	15.0 [19.0]	18.0 [27.0]	16.0 [24.0]	1.0 [3.0]
Anatomy	73	10.0 [15.5]	16.0 [24 0]	12.0 [17.5]	2.0 [4.0]
Other	180	8.0 [12.0]	11.5 [19.0]	8.0 [14.0]	1.0 [2.0]

Abbreviations: TBI = traumatic brain injury; CSF = cerebrospinal fluid

Table 5. Increase in Citation Rates by Subject Group

	Absolute Change (Count) Mean [SD]		Rate of Change (%) Mean [SD]	
Subject Group	**WoS**	**GS**	**WoS**	**GS**
Pediatric	6.90 [8.84]	9.85 [12.51]	190.61 [186.37]	138.36 [104.28]
Trauma	9.05 [13.86]	13.89 [20.51]	201.23 [162.57]	151.99 [136.54]
Vascular	7.87 [9.08]	10.13 [11.80]	191.70 [220.92]	128.66 [107.44]
Tumor	8.73 [10.43]	12.11 [15.12]	207.59 [190.44]	168.05 [180.64]
Spine	10.02 [11.03]	14.34 [16.14]	233.57 [247.41]	167.21 [180.41]
Functional	7.85 [12.72]	11.34 [17.24]	180.37 [161.97]	148.29 [150.08]
General Neurosurgery	7.75 [8.12]	10.91 [11.64]	190.53 [179.11]	141.60 [113.61]
Other	7.83 [9.29]	10.48 [12.26]	216.18 [243.32]	163.48 [150.32]

Table 6. Increase in Citation Rates by Study Design

	Absolute Change (Count) Mean [SD]		Rate of Change (%) Mean [SD]	
Study Design	**WoS**	**GS**	**WoS**	**GS**
RCT	14.73 [19.29]	21.82 [26.43]	210.93 [229.08]	155.71 [94.13]
Prospective	10.00 [9.61]	13.90 [13.88]	204.61 [202.63]	134.45 [100.30]
Retrospective	9.55 [9.13]	13.24 [12.67]	214.19 [205.63]	152.68 [128.18]
Case Series (2-9 Patients)	4.91 [4.82]	7.23 [6 65]	186.98 [185.52]	170.62 [184.80]
Case Report	2.70 [3.41]	3 67 [4.51]	163.79 [176.56]	156.34 [213.10]
Animal Study	7.97 [15.11]	10.19 [19.96]	213.85 [306.87]	125.83 [92.01]
Non-human Study or Imaging Study	8.17 [10 36]	11.50 [14.53]	214.84 [227.43]	166.35 [188.84]
Systematic Review	15.84 [12.08]	23.48 [19.33]	238.37 [232.24]	159.66 [127.12]
State/Nationwide Database	12.53 [9.88]	17.07 [13.69]	236.48 [265.02]	151.28 [144.91]
Literature Review	13.91 [19.55]	20.77 [29.50]	208.69 [168.64]	156.33 [136.25]

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Tables

Table 1. Number of Articles and Citations at 5 Years by Journal

Journal	# Articles	Median Citations [IQR] WoS	GS	Scopus
Acta Neuro.	238	7.0 [9.0]	10.0 [13.0]	7.5 [10.3]
BJN	166	3.0 [5.0]	6.5 [8.0]	3.0 [6.0]
Euro Spine	444	9.0 [11.0]	15.0 [18.0]	10.0 [13.0]
JNS	350	14.5 [19.0]	24.0 [29.0]	15.5 [21.0]
JNSNF	86	14.0 [11.3]	22.0 [10.3]	16.0 [11.5]
JNSP	198	9.0 [14.0]	14.0 [20.3]	10.0 [15.0]
JNSS	199	11.0 [16.0]	18.0 [26.0]	12.0 [18.0]
JNSSci	14	3.0 [6.5]	6.5 [14.3]	4.5 [10.3]
Neurosurg Review	77	8.0 [9.0]	12 0 [15 0]	9.0 [9.5]
Neurosurgery	203	14.0 [18.0]	21.0 [23.0]	14.0 [17.0]
Operative N	71	7.0 [9.0]	9.0 [12.0]	8.0 [9.0]
Spine	432	11.0 [14.0]	18.0 [21.8]	12.5 [16.0]
World N	389	8.0 [11.5]	13.0 [16.0]	9.0 [11.0]
TOTAL	**2867**			

Abbreviations: Acta Neuro = Acta Neurochirurgica; BJN = British Journal of Neurosurgery; Euro Spine = European Spine; JNS = Journal of Neurosurgery; JNSNF = Journal of Neurosurgery Neurosurgical Focus; JNSP = Journal of Neurosurgery Pediatrics; JNSS = Journal of Neurosurgery Spine; JNSSci = Journal of Neurosurgical Sciences; Neurosurg Review = Neurosurgical Review; Operative N = Operative Neurosurgery; World N = World Neurosurgery; NCNA = Neurosurgical Clinics of North America

Table 2. Negative Binomial Generalized Linear Mixed Effects Model

Dependent: Citation Count	IRR	95% CI	P-Value
Search engine (ref = Web of Science)			
Google Scholar	1.577	(1.494, 1.664)	<0.001
Scopus	1.113	(1.054, 1.175)	<0.001
Level of evidence	0.857	(0.839, 0.876)	<0.001

Number of centers	1.038	(1.019, 1.057)	<0.001
Number of countries	1.095	(1.051, 1.141)	<0.001
Number of authors	1.025	(1.016, 1.034)	<0.001
Impact factor	1.270	(1.240, 1.302)	<0.001
Month of publication	0.982	(0.976, 0.988)	<0.001

Table 3. Number of Citations by General Article Subject

		Median Citations IQR]			
Subject Group	**# Articles**	**WoS**	**GS**	**Scopus**	**Self-Citations (Scopus)**
Pediatric	148	6.0 [12.0]	11.5 [16.8]	8.0 [12.0]	0 [2.0]
Trauma	170	10.0 [14.0]	16.0 [24.3]	10.0 [15.0]	1.0 [2.8]
Vascular	446	9.0 [13.0]	14.0 [17.0]	10.0 [14.0]	1.0 [3.0]
Tumor	467	10.0 [13.0]	16.0 [19.0]	11.0 [13.0]	1.0 [2.0]
Spine	943	11.0 [14.0]	18.0 [22.0]	12.0 [16.0]	1.0 [3.0]
Functional	253	8.0 [11.0]	13.0 [18.0]	9.0 [12.0]	1.0 [3.0]
General Neurosurgery	260	8.5 [13.0]	14.0 [21.0]	10.0 [16.0]	1.0 [3.0]
Other	180	8.0 [12.0]	11.5 [19.0]	8.0 [14.0]	1.0 [2.0]

Table 4. Number of Citations by Individual Subject Subclassification

		Median Citations IQR]			
Individual Subject Sub-Group	**# Articles**	**WoS**	**GS**	**Scopus**	**Self-Citations (Scopus)**
Pediatric brain tumor	40	4.0 [7.8]	7.0 [13.3]	5.0 [9.3]	0 [1.0]
Pediatric spine surgery	24	5.5 [12.8]	9.5 [14.8]	7.5 [10.8]	0 [2.0]
Pediatric traumatic injury/TBI	23	19.0 [15.0]	30.0 [32.0]	19.0 [17.0]	1.0 [5.0]
Other Pediatric	61	7.0	12.0	8.0	0 [2.0]

		[11.0]	[13.0]	[10.5]	
Adult traumatic brain injury	57	11.0 [15.5]	20.0 [26.5]	12.0 [19.0]	1.0 [2.0]
Adult traumatic spine	92	9.0 [13.0]	15.0 [24.0]	10.0 [16.0]	0 [3.3]
Other Trauma	21	8.0 [9.5]	14.0 [17.5]	9.0 [9.0]	1.0 [2.0]
Aneurysm	194	10.5 [13.5]	16.0 [19.0]	11.0 [15.0]	1.0 [3.0]
Arteriovenous malformation/fistula	96	10.0 [14.0]	15.0 [19.0]	11.0 [15.8]	1.0 [4.0]
Ischemic stroke	19	6.0 [11.0]	10.0 [17.0]	6.0 [10.0]	0 [1.0]
Hemorrhagic stroke	38	9.0 [9.3]	15.0 [15.0]	9.0 [9.3]	0 [1.0]
Other Vascular	99	8.0 [10.0]	11.0 [16.0]	8.0 [11.0]	1.0 [2.0]
Intrinsic brain tumor	75	12.0 [18.0]	21 0 [25.0]	13.0 [19.0]	2.0 [3.0]
Meningioma	60	12.0 [13.8]	18.0 [18.8]	12.0 [15.8]	0 [1.8]
Brain metastases	79	9.0 [13.0]	13.0 [19.0]	9.5 [13.3]	0.5 [2.0]
Other Brain tumor	173	7.0 [11.5]	13.0 [17.0]	9.0 [11.0]	1.0 [2.5]
Spinal cord tumor	57	10.0 [10.5]	18.0 [15.0]	12.0 [12.0]	0 [1.0]
Spinal column tumor	23	10.0 [16.0]	21.0 [23.0]	11.0 [19.0]	1.0 [2.0]
Cervical myelopathy/surgery	243	9.0 [15.0]	16.0 [23.0]	11.0 [17.0]	1.0 [3.0]
Artificial disk	13	9.0 [20.5]	17.0 [36.5]	9.0 [19.0]	1.0 [4.5]
Fusion of thoracic or lumbar spine	152	12.0 [18.5]	21.5 [25.8]	15.5 [17.0]	1.0 [3.0]
Spinal deformity and scoliosis	277	11.0 [13.0]	18.0 [22.0]	12.0 [16.0]	1 [3.8]
Spinal infection	32	10.5 [15.8]	16.5 [26.8]	11.0 [16.8]	0 [2.0]
Other Spine	226	12.0 [11.3]	18 [19.3]	13.0 [12.0]	1.0 [2.0]
Deep brain stimulation	44	9.5 [10.8]	12.0 [15.8]	9.5 [10.5]	1.0 [2.8]
Epilepsy/seizure	45	8.0 [15.5]	16.0 [19.0]	10.0 [16.5]	1.0 [3.0]
Pain/spasticity	149	9.0	14.0	9.5	1.0 [3.0]

		[11.0]	[19.0]	[12.0]	
Other functional	15	5.0 [3.0]	8.0 [4.0]	6.0 [5.0]	1.0 [1.0]
Hydrocephalus/CSF disorders	117	7.0 [12.0]	11.0 [18.5]	8.0 [14.5]	0 [2.0]
Other Infection	30	9.5 [11.3]	15.5 [17.8]	10.0 [9.8]	0 [1.0]
Operating room	4	2.0 [5.0]	3.5 [5.3]	2.5 [4.8]	0.5 [1.0]
Residency training	17	14.0 [21.5]	21.0 [24.0]	15.0 [22.0]	1.0 [3.5]
Socioeconomic	19	15.0 [19.0]	18.0 [27.0]	16.0 [24.0]	1.0 [3.0]
Anatomy	73	10.0 [15.5]	16.0 [24.0]	12.0 [17.5]	2.0 [4.0]
Other	180	8.0 [12.0]	11.5 [19.0]	8 0 [14.0]	1.0 [2.0]

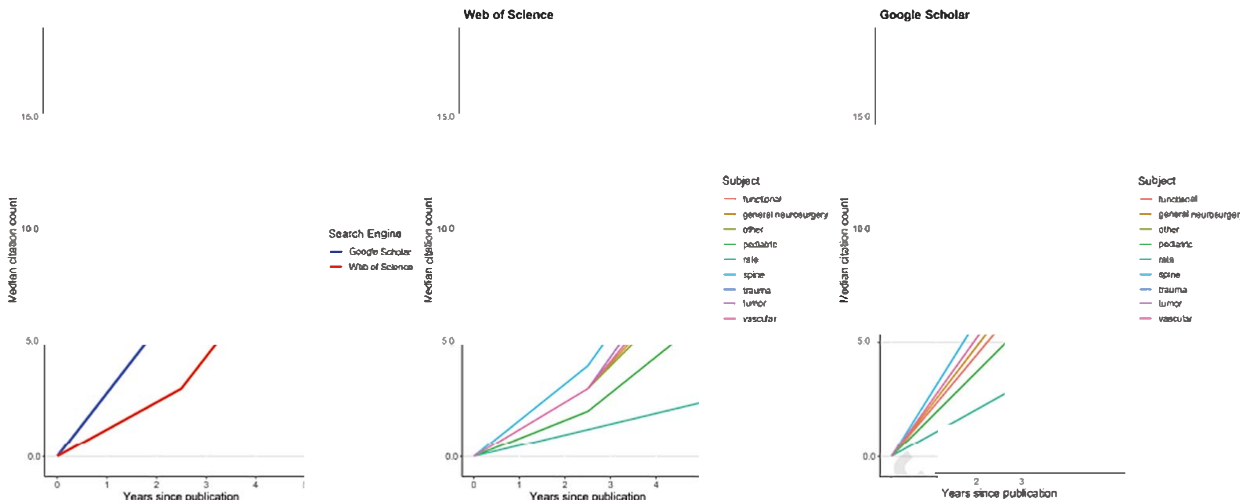
Abbreviations: TBI = traumatic brain injury; CSF = cerebrospinal fluid

Table 5. Increase in Citation Rates by Subject Group

	Absolute Change (Count) Mean [SD]		Rate of Change (%) Mean [SD]	
Subject Group	**WoS**	**GS**	**WoS**	**GS**
Pediatric	6.90 [8 84]	9.85 [12.51]	190.61 [186.37]	138.36 [104.28]
Trauma	9.05 [13.86]	13.89 [20.51]	201.23 [162.57]	151.99 [136.54]
Vascular	7.87 [9.08]	10.13 [11.80]	191.70 [220.92]	128.66 [107.44]
Tumor	8.73 [10.43]	12.11 [15.12]	207.59 [190.44]	168.05 [180.64]
Spine	10.02 [11.03]	14.34 [16.14]	233.57 [247.41]	167.21 [180.41]
Functional	7.85 [12.72]	11.34 [17.24]	180.37 [161.97]	148.29 [150.08]
General Neurosurgery	7.75 [8.12]	10.91 [11.64]	190.53 [179.11]	141.60 [113.61]
Other	7.83 [9.29]	10.48 [12.26]	216.18 [243.32]	163.48 [150.32]

Table 6. Increase in Citation Rates by Study Design

	Absolute Change (Count) Mean [SD]		Rate of Change (%) Mean [SD]	
Study Design	**WoS**	**GS**	**WoS**	**GS**
RCT	14.73 [19.29]	21.82 [26.43]	210.93 [229.08]	155.71 [94.13]
Prospective	10.00 [9.61]	13.90 [13.88]	204.61 [202.63]	134.45 [100.30]
Retrospective	9.55 [9.13]	13.24 [12.67]	214.19 [205.63]	152.68 [128.18]
Case Series (2-9 Patients)	4.91 [4.82]	7.23 [6.65]	186.98 [185.52]	170.62 [184.80]
Case Report	2.70 [3.41]	3.67 [4.51]	163.79 [176.56]	156.34 [213.10]
Animal Study	7.97 [15.11]	10.19 [19 96]	213.85 [306.87]	125.83 [92.01]
Non-human Study or Imaging Study	8.17 [10.36]	11.50 [14.53]	214.84 [227.43]	166.35 [188.84]
Systematic Review	15.84 [12.08]	23.48 [19.33]	238.37 [232.24]	159.66 [127.12]
State/Nationwide Database	12.53 [9.88]	17.07 [13.69]	236.48 [265.02]	151.28 [144.91]
Literature Review	13 91 [19.55]	20.77 [29.50]	208.69 [168.64]	156.33 [136.25]



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