Research productivity in neurosurgery: trends in globalization, scientific focus, and funding

A review

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**Object.** While research is important for the survival, growth, and expansion of neurosurgery, little work has been done to quantify the status and trends of neurosurgical publications. The purpose of this bibliometric study was to quantitatively analyze trends in neurosurgical publications, including changes in worldwide productivity, study methodology, subspecialty topic, and funding.

**Methods.** This was a retrospective bibliometric study using MEDLINE to record all publications between 1996 and 2009 by first authors affiliated with neurosurgical departments. Country of origin, MEDLINE-defined methodology, study topic, and funding sources (for US articles) were recorded. Linear regression was used to derive growth rates.

**Results.** Total articles numbered 53,425 during the study period, with leading global contributors including the US with 16,943 articles (31.7%) and Japan with 10,802 articles (20.2%). Countries demonstrating rapid growth in productivity included China (121.9 ± 9.98%/year, \( p < 0.001 \)), South Korea (50.5 ± 4.7%/year, \( p < 0.001 \)), India (19.4 ± 1.8%/year, \( p < 0.001 \)), and Turkey (25.3 ± 2.8%/year, \( p < 0.001 \)). While general research articles, case reports, and review articles have shown steady growth since 1996, clinical trials and randomized controlled trials have declined to 2004 levels. The greatest overall subspecialty growth was seen in spine surgery. Regarding funding, relative contribution of National Institutes of Health (NIH)–funded publications decreased from 30.2% (290 of 959) to 22.5% (356 of 1229) between 1996 and 2009.

**Conclusions.** Neurosurgical publications demonstrate continued increases in productivity as well as in global expansion, although US contributions remain dominant. Two challenges that the neurosurgical community is facing include the preponderance of case reports and review articles and the relative decline in NIH funding for US neurosurgical publications, as productivity has outpaced government financial support. (DOI: 10.3171/2011.8.JNS11857)

**Key Words** • neurosurgery • neuroscience • bibliometrics

**Abbreviations used in this paper:** ISI = Institute for Scientific Knowledge; JIF = journal impact factor; MeSH = Medical Subject Heading; NCI = National Cancer Institute; NCRR = National Center for Research Resources; NHLBI = National Heart, Lung, and Blood Institute; NIA = National Institute on Aging; NIH = National Institutes of Health; NINDS = National Institute of Neurological Disorders and Stroke; RCT = randomized controlled trial.

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In 1973, a provocative article by Bergland appeared in the *New England Journal of Medicine*, "Neurosurgery May Die," discussing the potential fall in growth and innovation within neurosurgery due to a decrease in time and motivation for research activities. However, this fear was not immediately realized as neurosurgeons responded with success and progress through use of technology and expansion of the field into spine, vascular, functional, and tumor surgery. Nonetheless, scholarly activities by neurosurgeons have become increasingly vulnerable given the current state of academic medicine: the increasing time requirements for clinical work at the expense of academic pursuits. These challenges have been manifested in neurosurgery and among other specialties with a decline of American contribution in clinical research.

Without a doubt, research is important for the survival, growth, and expansion of neurosurgery. A survey of research by members of the American Association of Neurological Surgeons (AANS) and Congress of Neurological Surgeons (CNS) member publications in 2001 noted that 62% of the research was conducted outside the US and that a majority of clinical work was based...
on retrospective case series with approximately 1% represented in RCTs. While this presented a snapshot of a moment of activity among neurosurgeons, little has been done to quantify the developments and trends within the field.

The goal of this study is to quantitatively examine the trends in published work by neurosurgeons. Specifically, we seek to examine trends in worldwide research productivity, as measured by publications. Variables examined include study design, overall growth, topics of interest, and NIH influence among articles published in the US.

Methods

This study was a retrospective bibliometric analysis of a publicly available database, the National Library of Medicine’s MEDLINE database, and was exempt from institutional review board approval. Between 1996 and 2009, MEDLINE articles published by first authors affiliated with neurosurgery departments were included. This methodology was described in part previously.

Articles indexed by MEDLINE include the first author’s departmental location (city, state, and country). This field was used to determine the country of origin. MEDLINE-defined study type and methodology were preserved. Only articles defined as “journal articles” were included, which includes original research articles, reviews, trials, and other scientific reports. Occasionally, journals publish nonscientific information, such as bibliographies, news items, letters, comments, or roll calls of reviewers. These are not indexed as “journal articles” and thus were excluded. Specialized study type and methodology tags were preserved. These tags included clinical trials (including controlled, randomized controlled, and Phase 1–4 trials), case reports, review articles, multicenter studies, process evaluations and validations, therapeutic comparisons, in vitro studies, twin studies, and meta-analyses. Full methodological tag details are available at the National Library of Medicine website. Articles identified as both clinical trials and multicenter studies were given the additional designation of “multicenter trial.” Finally, journal articles that had no additional specialized tags were labeled “general research.”

All MeSH terms were indexed. MeSH terms are assigned by the National Library of Medicine to create a standardized set of labels to describe the subject matter of published articles. They are manually created by trained indexing staff, with error checking performed by computerized programs. They provide a more accurate means of searching for and identifying articles than free text searches. Analysis of focus by topic was performed by grouping MeSH terms according to associated neurosurgical subspeciality. Journal impact factor data were obtained from Thomson Reuters. Articles were assigned the JIF of their publishing journal in the year of publication, from which mean JIF values were calculated. MEDLINE-defined tags relating to receipt of NIH, other US government, and non-US government research support were captured. In addition to the publication data mined through MEDLINE, JIFs were obtained through the ISI Web of Knowledge. All impact factors were from 2009. Of note, several journal articles did not have impact factors calculated through the ISI (such as Neurosurgical Focus, Acta Neurochirurgica Supplementum, and No To Shinkei), and therefore any articles from these journals were excluded from impact factor analysis.

Trend analysis was performed using fitted linear regression to derive growth rates. Significance was set at p < 0.05. The statistical software used included Microsoft Excel and GraphPad Prism.

Results

Worldwide Productivity

Between the years 1996 and 2009, a total of 8,289,413 articles were published, cataloged in MEDLINE, and indexed in PubMed. A total of 53,425 articles (0.64%) authored by first authors self-identified as members of neurosurgery departments were included. The top 22 journals containing articles written by affiliates of a neurosurgery department, along with their 2009 impact factors as assessed by the ISI, are listed in Table 1. Of all neurosurgical articles, 52,370 (98.0%) were assignable to a country. Leading contributors included the US at 16,943 (31.7%) articles and Japan at 10,802 (20.2%) articles, followed by Germany, the United Kingdom, and China numbering 3367 (6.3%), 3284 (6.1%), and 2230 (4.2%) articles, respectively (Fig. 1). Total publication counts for the top 20 producers of neurological literature according to methodology and mean JIF can be found in Fig. 2.

Focus by Article Type

Regarding article type, unspecified general research represented the largest subcategory (23,041 [43.1%]). This was followed by case reports and review articles, which numbered 16,339 (30.6%) and 8317 (15.6%), respectively. Clinical trials numbered 2754 (5.2%).

National focus on article type varied greatly from country to country. Of total output from the US, 6999 review articles and case reports (41.3%) and 710 clinical trials (4.2%) were produced. Japan produced 6090 review articles and case reports (56.4%) and 434 clinical trials (4.02%). In contrast, Germany produced 1005 (29.8%) review articles and case reports and 297 (8.8%) clinical trials. Lastly, the United Kingdom produced 1717 review articles and case reports (52.3%) and 239 clinical trials (7.3%).

Growth

Worldwide, total publication output increased over the study period from 2840 papers/year in 1996 to 4793 articles/year in 2009. A summary of total publication counts and growth rates (from regression analysis) can be found in Table 2. Perhaps most interesting are the trends in publications according to country (Fig. 3). The top 5 producers of neurosurgical publications have been the US, Japan, Germany, the United Kingdom, and China. When comparing the overall publication output of these countries with 1996 levels, only China has emerged as a country with substantial growth (121.9% ± 9.98%/year, p < 0.001). The US, Germany, and the United Kingdom have significantly increased overall publication output,
but this has been in the range of 2%–6%/year. Japan is the only country in the top 5 to no longer experience any significant growth in publication output, and in fact has trended toward a decline (−1.4% ± 0.8%/year, p = 0.08). Notably, marked growth has marked several of the 5th through 10th most productive countries, including South Korea (50.5% ± 4.7%/year, p < 0.001), Turkey (25.3% ± 2.8%/year, p < 0.001), and India (19.4% ± 1.8%/year, p < 0.001).

Global growth trends according to methodology can be found in Fig. 4. While there has been a sustained global increase in general research articles, case reports, and review articles (Fig. 4A), the trends in clinical trials and, in particular, RCTs have been considerably more dynamic. Both were fitted to higher order polynomial regression to increase the amount of variability accounted for in the model. Clinical trials increased in number during the first 9 years, peaking in 2005 and exhibiting a steady decline since. Similarly, RCTs increased and peaked at 2007, with a notable decline in number over the last 2 years of the study period. Both have resumed levels seen in 2004.

Focus by Topic

While all subspecialty areas have shown growth since 1996, some have experienced explosive increases while others have seen only modest changes (Fig. 5). The greatest expansion in overall productivity was seen in spine publications (12.7% ± 0.9%/year, p < 0.0001), with increases in hydrocephalus publications (9.0% ± 1.4%/year, p < 0.0001) showing the second-highest average growth rate. This must be interpreted with caution, however, since hydrocephalus also had the lowest number of overall publications and thus growth rate could be leveraged by a small bump in productivity.

Functional neurosurgery and traumatic brain injury productivity had lower overall growth rates (5.9% ± 0.6%/year and 5.2% ± 0.9%/year, respectively, both p < 0.001) and fewer total reports than the other specialties. Interestingly, when looking at publications labeled with MeSH terms related to deep brain stimulation, the growth rate is 116% ± 10.7%/year (p < 0.001). Vascular and tumor neurosurgery also had lower growth rates (4.1% ± 0.5%/year and 5.4% ± 0.5%/year, respectively, both p < 0.001), but also had the greatest numbers of publications. Thus, a much larger increase in absolute productivity would be necessary to impact the growth rate of these specialties. A closer inspection of vascular neurosurgery papers labeled with MeSH terms specific for endovascular neurosurgery, however, reveals a growth rate of 22.7% ± 2.1%/year (p < 0.0001).

Funding

During the study period, the NIH supported 4257 publications (25.1%) by neurosurgeons in the US. Specifically, the NIH funded 32 (19.2%) of multicenter clinical trials, 152 (21.4%) of clinical trials, and 49 (29.0%) of RCTs. Leading branches of NIH support for neurosurgical research include the NINDS (3046 articles [71.6%],

<table>
<thead>
<tr>
<th>TABLE 1: The top 22 journals containing articles written by affiliates of a neurosurgery department between 1996 and 2009</th>
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<tr>
<td>Journal Title</td>
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<tr>
<td>Neurosurgery</td>
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<tr>
<td>J Neurosurg</td>
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<tr>
<td>Acta Neurochir (Wien)</td>
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<tr>
<td>Surg Neurol</td>
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<tr>
<td>No Shinkei Geka</td>
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<td>Neur Med Chir (Tokyo)</td>
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<tr>
<td>Childs Nerv Syst</td>
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<tr>
<td>J Clin Neurosci</td>
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<tr>
<td>Neurosurg Focus</td>
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<tr>
<td>Pediatr Neurosurg</td>
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<tr>
<td>Br J Neurosurg</td>
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<tr>
<td>Acta Neurochir Suppl</td>
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<tr>
<td>J Neurooncol</td>
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<tr>
<td>Neurol Res</td>
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<tr>
<td>Minim Invasive Neurosurg</td>
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<tr>
<td>J Neurosurg Spine</td>
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<td>Spine (Phila Pa 1976)</td>
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<tr>
<td>Brain Res</td>
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<tr>
<td>Neurosurg Rev</td>
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<td>Stereotact Funct Neurosurg</td>
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NCI (812 articles [19.1%]), NHLBI (283 articles [6.6%]), NIA (197 articles [4.6%]), and NCRR (174 articles [4.1%]) (Fig. 6A). With regard to growth, both the NINDS and NCI have shown modest growth in neurosurgical support, with the NINDS supporting an additional $3 \pm 1$ (p < 0.01) and the NCI supporting an additional $2.5 \pm 0.5$ (p < 0.01) papers each year. This modest growth is substantiated by the increasing trend in US publications without stated support from the NIH relative to those claiming NIH funding (Fig. 6B).

Growth rates of US NIH-funded publications were less than that of overall productivity (Fig. 6C–E). This has resulted in a decrease of relative contribution from NIH-funded articles from 30.2% (290 of 959) to 22.5% (356 of 1229). Regression of growth rate in NIH funding normalized to 1996 levels reveals an increase in NIH support of $2.3 \pm 0.4$ (p < 0.001). Despite large fluctuations in support, there has not been significant growth in support of clinical trials. Furthermore, overall neurosurgical productivity has been outpacing increases in NIH support.

**Fig. 1.** Top producers of neurosurgical publications in terms of contribution to the entire neurosurgical canon. **A:** Thirteen-year trend in country publication records in terms of percentage of all neurosurgical literature. In the 1st year of the study period, the total number of neurosurgical articles indexed was 2840. At the end of the study period, the total number of neurosurgical articles indexed was 4796. The US has consistently produced between 30% and 40% of the global neurosurgical literature, remaining dominant in total neurosurgical publications despite rapid growth in global neurosurgical productivity over the study period. Germany and the United Kingdom have produced between 5% and 10% of global neurosurgical publication output. Japanese contributions to the global neurosurgical literature have been declining since the later 1990s, while Chinese production has been increasing primarily over the past 3–4 years. **B–F:** Top contributors to global neurosurgical publications according to publication type.
since 1999 (Fig. 6E). When comparing mean JIFs of US articles with and without NIH support, those with stated support consistently had higher impact factors (Fig. 6F).

**Discussion**

**Worldwide Productivity**

The US was the largest single-nation contributor to neurosurgical productivity. Analyses of the radiology and emergency medicine literature had a similar result, where the US contributes 43.2% and 58.5%, respectively, to the published literature. While the US remains the largest overall contributor, its relative contribution is less than in radiology and emergency medicine. This suggests that neurosurgical publications are more globally distributed and less concentrated in the US than in other medical specialties.

The prominence of the US may be due to the high ratio of neurosurgeons to overall population. This has been estimated at about 1:62,000. Therefore, the lower productivity of countries in which the ratio is considerably lower, such as the United Kingdom, the Netherlands, France, and countries of Eastern Europe may reflect the greater clinical needs of these physicians that supplant time for research. Research productivity of these countries may reflect a greater clinical demand.

Publications from the US, the United Kingdom, and Canada had high mean JIFs, suggesting many were published in high-impact journals. An important caveat, however, is that the JIF is reflective of the journal and not the paper itself. A better measure of individual articles’ impacts would be the h-index, g-index, or Eigenfactor score. The Netherlands, Switzerland, and Sweden also have notably high JIFs but significantly fewer publications. Some of mean JIFs for lower-producing countries may be skewed by smaller numbers of publications within extremely high–impact journals. Therefore, when assessing the productivity and impact factors, it is important to weigh the mean JIF by the number of total publications generated by a particular country.
Global neurosurgical publications

**Table 2: Total numbers and growth rates of neurosurgical publications, grouped by methodology**

<table>
<thead>
<tr>
<th>Article Type/Methodology</th>
<th>No. of Articles</th>
<th>% of All</th>
<th>Mean JIF</th>
<th>Growth Rate (%/yr)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>journal articles, all</td>
<td>53,425</td>
<td>100.0</td>
<td>2.2</td>
<td>5.599 ± 0.3159</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>general research articles</td>
<td>23,041</td>
<td>43.1</td>
<td>2.6</td>
<td>2.674 ± 0.6566</td>
<td>0.0015</td>
</tr>
<tr>
<td>case reports</td>
<td>16,339</td>
<td>30.6</td>
<td>1.4</td>
<td>5.767 ± 0.3420</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>review articles</td>
<td>8,317</td>
<td>15.6</td>
<td>1.9</td>
<td>7.788 ± 1.191</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>multicenter studies</td>
<td>381</td>
<td>0.7</td>
<td>3.0</td>
<td>27.57 ± 3.306</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>clinical trials, all</td>
<td>2,754</td>
<td>5.2</td>
<td>2.3</td>
<td>13.46 ± 3.299</td>
<td>0.0015</td>
</tr>
<tr>
<td>controlled clinical trials</td>
<td>251</td>
<td>0.5</td>
<td>2.4</td>
<td>5.875 ± 2.755</td>
<td>0.0543</td>
</tr>
<tr>
<td>RCTs</td>
<td>604</td>
<td>1.1</td>
<td>2.7</td>
<td>8.996 ± 1.486</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>multicenter trials</td>
<td>199</td>
<td>0.4</td>
<td>3.3</td>
<td>10.73 ± 3.693</td>
<td>0.0132</td>
</tr>
<tr>
<td>clinical trials (Phases 1–4)</td>
<td>172</td>
<td>0.3</td>
<td>12.8</td>
<td>15.70 ± 4.846</td>
<td>0.0071</td>
</tr>
</tbody>
</table>

**Article Type**

Over two-thirds of all general research articles, case reports, and reviews originated from the US and Japan. However, the US and Japan published a disproportionately large number of review articles and case reports, respectively. Clinical trials and RCTs are relatively evenly distributed among the top 8 producing countries, suggesting a more even global contribution in these areas. In fact, Germany, the United Kingdom, China, and Japan have generated over half of the global published RCTs. In multicenter clinical trials, the US has dominated the literature, claiming 43.8% of these publications. The nation’s large size and numerous large medical centers may convey an advantage in organizing this type of research.

Another interesting observation is in the field of clinical trials, particularly RCTs. The United Kingdom, has consistently produced work in high-impact journals that has exceeded the US, Japan, and Germany. This suggests that the United Kingdom is focused on clinical trials of high quality. The US has also been productive in this area, nearly doubling the efforts on the next-highest producer. The lower mean JIFs may signify more heterogeneity in the quality of these studies. Given that both countries have been very productive overall in clinical trials, it is not likely that dominance of the United Kingdom in mean JIF is a statistical aberrancy. Several of the lower-producing countries, including Belgium, Switzerland, the Netherlands, and France, produced much fewer publications in these areas, but those publications have succeeded in leveraging the mean JIF higher. This is not surprising, given that many RCTs are published in journals with high impact factors, with impact factors serving as a rough indicator of study quality.

Despite these trends in clinical trials, the overwhelming majority of articles were review articles and case reports with only 5.2% in clinical trials and 1.1% in RCTs. This parity in RCTs has been previously described. This number is alarming given that RCTs allow investigation and new therapeutic interventions and their safety and efficacy with minimal bias. This is increasingly important in an era where techniques in functional, endovascular, and oncology neurosurgery are in constant evolution.

**Growth**

Overall, growth in neurosurgery literature has steadily increased, from 2840 to 4796 articles per year over the study period between 1996 and 2009. Of the top 5 producing nations, China exhibited the strongest growth rate, almost doubling yearly. Conversely, the US, Germa-
ny, and the United Kingdom experienced a more modest growth rate, while Japan showed a small decline in overall output. The small decline in Japan is interesting given the abundance of neurosurgeons when compared with other countries, including the US and China, because the neurosurgical workforce is relatively robust. Modest growth in US productivity is likely multifactorial. One major global event that could have dampened US growth was the economic downturn, reflected as a reduction in US gross domestic product (GDP). This financial strain may have stressed the neurosurgical workforce, academic institutions, and government and private funding sources. This event did have international impact and may be reflected in many countries’ academic productivity. Of course, it is also possible that full effects of economic change have yet to be fully realized.

Even though US growth was moderate, this is particularly interesting given the decline in US neurosurgical workforce seen in the middle of this study period. Given that the US neurosurgical workforce has been estimated at about 3000 to 3500 physicians (about 10%–12% of the global neurosurgical workforce), this modest growth has kept this small percentage of the global neurosurgical community contributing more than a third of the significant new neurosurgical literature annually.

The numbers of total journal articles, general research articles, case reports, and reviews have all significantly increased since 1996. While the numbers of clinical trials and, in particular, RCTs have also increased since 1996, fitting these trends to a higher-order polynomial (which substantially increases R²) demonstrates a recent drop-off in productivity, both of which seem to have returned to approximately 2004 levels (Fig. 4). This is a concerning trend of unclear etiology. It is possible that reductions in clinical trials and RCTs may be reflective of changes in research priority, neurosurgical workforce, or funding (both public and private). It is also possible that barriers related to publication have stifled growth of clinical trials and RCTs. These barriers could include language and writing issues (with regard to international work being published in English-language journals), varying publishers’ requirements (including fees associated with publication), and limitations of peer review (particularly with the rising numbers of articles requiring refereeing). Judging from the globalization of neurosurgical literature, however, it seems that many of these challenges are being met.

This increasing internationalization of the neurosurgery literature has been well described in other medical subspecialties with respect to declining US relative contribution in the scientific literature and other medical subspecialties including medicine, radiology, and surgery. While this is likely multifactorial, one possible contributing factor is the increasingly difficult environment for academic neurosurgeons. These may include the increasing pressures for clinical work and decrease in funding for scholarly activity.

Research Focus

All areas of neurosurgery have seen expansion in the literature, although some greater than others. We found that the greatest expansion of neurosurgical publications was in the area of spine surgery. This is not surprising, given the recent explosion in number of spine procedures relative increases in overall research spending to research and development. This growth was also observed in other emerging nations including South Korea, Turkey, and India.

Fig. 4. Growth of the entire neurosurgical canon according to publication type. A: Increases in review articles have outpaced all other types of journal articles. Case reports have also expanded at a greater rate than general neurosurgical research articles, keeping pace with overall productivity. B: Trend in all clinical trials since 1996. Numbers of clinical trials increased from 1996 and peaked in 2005–2006. Since then, clinical trial numbers have undergone a steady decline. C: Randomized controlled trials have undergone a similar trend as all clinical trials. Currently, RCT numbers are in a decline, and in 2009 they approached levels of 5 years ago.
Global neurosurgical publications

being performed and the emerging markets for spinal implants.\textsuperscript{4,35} Hydrocephalus, which continues to be a major problem (particularly in the field of pediatric neurosurgery), has also seen growth but maintains overall small numbers of publications. While functional and vascular neurosurgery have only experienced modest growth overall, expansion of publications in the subfields of deep brain stimulation and endovascular techniques demonstrate innovation and high productivity, respectively, with regard to novel approaches and techniques. One area that could possibly use more scientific attention is neurotrauma. Traumatic brain injury continues to be a major part of neurosurgical practice, yet has only seen mild expansion in research productivity in recent years.

**Funding**

During the study period, the NIH supported nearly one-quarter of US publications. While the number of NIH-supported articles increased from 290 to 356 over the study period, its relative contribution has decreased from 30\% to 25\%, suggesting that the number of NIH-funded articles is not keeping pace with the rate of publication among US neurosurgeons. This is a concerning trend that needs to be investigated further to determine its causes. While it is possible that reductions in NIH spending and the recent economic downturn are to blame (in part), the fact is that NIH funding of neurosurgical journals has remained relatively static for over a decade. This is particularly surprising considering that NIH-funded papers appear to have the greatest impact and thus have the greatest potential to shape neurosurgical science. While it is possible that this decline in relative support reflects a greater number of unfunded publications, it is also possible that the relative decline is merely due to a greater number of industry-supported publications. It is also possible that the preponderance of review articles and case studies, both of which have driven growth in US publications, are reducing the percentage of NIH-funded articles since these articles are not typically funded. That being said, a relative reduction in NIH funding could dampen expansion of clinical trials and RCTs, which tend to be expensive and require many resources.

There is clearly, however, a recent decline in the number of NIH-funded clinical trials and RCTs in the US that parallels the decline in global productivity seen in Fig. 4. The question then becomes whether the decline is independent of changes in US funding, particularly since the US has contributed over one-third of the global literature in these fields. The results are interesting. Examination of the trend in US production of clinical trials demonstrates modest growth from 1996 to 2004, a sharp peak in 2005, and an annual decline since that has brought the numbers back down near 1996 levels (Fig. 6E). Superimposed on this trend is the change in percentage of NIH-funded clinical trials, which dramatically rose between 1996 and 1999 and peaked. Since 1999, there has been a steady decline in the percentage of NIH-funded clinical trials. This suggests a lag between decline in percentage of NIH funding and overall clinical trial productivity of about 5 years. If this is the case, it is expected that US clinical trial output will continue to decline in coming years unless NIH funding percentages begin to rise.

When examining the broader context of overall NIH funding per year,\textsuperscript{1} government support of the NIH peaked in 2004 and has undergone a gradual decline since. Thus, the ability of the NIH to keep pace with neurosurgical productivity has been further dampened by its own decline in financial support. Given that NIH funding has not kept pace with the growth in the neurosurgical literature, other avenues must be explored. One potential funding source would be to expand beyond the NINDS, the NIH branch that has traditionally funded the majority of neurosurgical articles. The static funding from branches such as the NCI, NHLBI, NIA, and NCRR may be resources waiting to be tapped. Of course, the other potential solution would be to accept industry grants for neurosurgical research. Many of the papers that did not have NIH fund-
ing may very well have been funded by industry. This could also be a pitfall, however; others have raised concerns regarding bias and conflicts of interest.\textsuperscript{20,34}

**Limitations**

When interpreting the results of this study, several limitations should be kept in mind. First, this study is limited to only articles indexed within MEDLINE, which does not encompass all types of research. Specifically, meeting abstracts, new ongoing device development and emerging techniques, and unpublished halted and/or terminated studies would not be captured and represent a potential source of bias. Nonetheless, MEDLINE is a comprehensive resource that includes 17.4 million articles from more than 5200 journals in 37 languages.\textsuperscript{22,23} There is also a possible bias within MEDLINE toward English-language and Western journals. Some national journals, particularly in non–English-speaking countries such as China or Japan, may have been excluded from our analysis. Second, utilizing the affiliation of the first author to assign departmental affiliation and country of origin represents another consideration. Instances in which

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**Fig. 6.** Changes in identified funding sources for US neurosurgical publications.  
**A:** The top 5 branches of the NIH that are identified sources of funding for neurosurgical research include the NINDS, NCI, NHLBI, NIA, and NCRR.  
**B:** The number of publications with stated NIH funding have remained relatively constant, while the number of non–NIH-funded (unfunded) publications are rising.  
**C and D:** The NIH-funded US publications by methodology.  
**E:** Comparison of growth of total US publications and those with stated NIH funding.  
**F:** Journal impact factors for publications with stated NIH funding compared with overall US neurosurgical publications.
neurosurgeons were involved but whose department was not represented by the first author would not have been included. This can be a particular concern in multidisciplinary areas of neurosurgery, such as functional neurosurgery. Therefore, contributions to the literature may be excluded if they pertained to deep brain stimulation, for example, but were written by neurologists or psychiatrists. Thus, it is expected that the “capture rate” for papers in multidisciplinary fields will be lower than in fields that are predominantly represented by neurosurgeons only. Another corollary of this limitation is in cases in which collaborators from multiple nations coauthor papers. Only the primary author’s country would receive credit, thus potentially undercounting the contribution of non-first authors from different countries. However, previous studies have shown that in most multiauthor scenarios the first authors make the most meaningful contribution and are the most deserving of credit.10,20

Conclusions

While neurosurgery continues to experience increases in overall academic productivity and increasing globalization, academic neurosurgical productivity continues to face challenges. One issue is that the neurosurgical literature tends to be dominated by case reports and review articles, suggesting that increases in publications may not necessarily be accompanied by an equivalent increase in growth of global scientific impact. A second issue is that the recent downturn in numbers of clinical trials and RCTs needs to be addressed. This may be in part due to the fact that NIH funding has not been able to keep pace with neurosurgical productivity. This potentially can be addressed by increasing funding for neurological projects through the NIH and its branches as well as partnering with industry. It may be necessary to have more neurosurgeons involved within the NIH to help promote funding programs and initiatives within neurosurgery.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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