Fellowship, gender, and scholarly productivity: trends among academic neurosurgeons in the US

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OBJECTIVE Current data on fellowship choice and completion by neurosurgical residents are limited, especially in relation to gender, scholarly productivity, and career progression. The objective of this study was to determine gender differences in the selection of fellowship training and subsequent scholarly productivity and career progression.

METHODS The authors conducted a quantitative analysis of the fellowship training information of practicing US academic neurosurgeons. Information was extracted from publicly available websites, the Scopus database, and the Centers for Medicare and Medicaid Services Open Payments website.

RESULTS Of 1641 total academic neurosurgeons, 1403 (85.5%) were fellowship trained. There were disproportionately more men (89.9%) compared to women (10.1%). A higher proportion of women completed fellowships than men ($p = 0.004$). Proportionally, significantly more women completed fellowships in pediatrics ($p < 0.0001$), neurooncology ($p = 0.012$), and critical care/trauma ($p = 0.001$), while significantly more men completed a spine fellowship ($p = 0.012$). Within those who were fellowship trained, the academic rank of professor was significantly more commonly held by men ($p = 0.001$), but assistant professor was held significantly more often by women ($p = 0.017$). The fellowships with the largest mean h -indices were functional/stereotactic, pediatrics, and critical care/trauma. Despite more women completing neurooncology and pediatric fellowships, men had significantly greater h -indices in these subspecialties compared to women. Women had more industry funding awards than men in pediatrics ($p < 0.0001$), while men had more in spine ($p = 0.023$).

CONCLUSIONS Women were found to have higher rates for fellowship completion compared with their male counterparts, yet had lower scholarly productivity in every subspecialty. Fellowship choice remains unequally distributed between genders, and scholarly productivity and career progression varies between fellowship choice.

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KEYWORDS gender; fellowship training; women in neurosurgery; scholarly productivity; industry funding

STRIDES have been made in achieving gender parity as the medical literature has addressed the need for more women in the realm of organized neurosurgery.^{1–11} Even though more than half of the students in US medical schools are women, smaller percentages of those graduates enter neurosurgical training, remain in academic neurosurgery, and complete fellowship training.^{3,12} A white paper regarding neurosurgery residency retention rates by Women in Neurosurgery, called for by the American Association of Neurological Surgeons (AANS),

found that medical students have concerns regarding how gender inequities impact acceptance, income, and promotional opportunities within neurosurgery.³ In addition to the presence of factors “pushing” women from neurosurgery, there may also be factors “pulling” women into neurosurgery. One notable attractant that has been discussed is the presence of other women in the field, as Renfrow et al. reported that female medical students were more likely to pursue programs with higher proportions of women.⁸ In fact, less than one-fifth of neurosurgical residents in

ABBREVIATIONS AANS = American Association of Neurological Surgeons; CMS = Centers for Medicare and Medicaid Services.

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the US are women.^{5,12} Furthermore, women are more likely to leave neurosurgery (17%) compared to their male counterparts (5%).^{5,8} Similar trends are found in other countries, as female neurosurgeons make up only 5.5% of Brazilian neurosurgeons, and Italian female neurosurgical residents are less likely to be hired for an academic position after training compared to males.^{11,13} Previous studies have outlined various factors that influence both the decision to pursue residency training and the specific subspecialty chosen by women in neurosurgery in the US. Key influences that have been described as deterrents for women pursuing training in neurosurgery include the absence of female role models,^{1,3,14} the presence of sexual harassment,^{1,14,15} unconscious bias,¹ discrimination,^{5,15} the challenge of pregnancy and children,^{1,16,17} the length of training,^{8,17} and inadequate maternity and family leave policies.¹²

Subspecialization in neurosurgery is a growing trend,^{18,19} yet differences in fellowship choice and subsequent career trajectory by gender are not well-studied. Prior studies have suggested that although the number of women pursuing neurosurgery has increased, there is a disproportionate number of women in pediatric neurosurgery.^{1,20} Women who pursue surgical fellowships tend to select pediatrics at higher rates than their male counterparts, a phenomenon that not only occurs in neurosurgery,¹⁴ but also in urology,²¹ orthopedic surgery,²² general surgery,²³ and otolaryngology.²⁴ Work-life balance, caregiving duties, relationship status, age, geographic preference,²⁵ prestige, and marketability¹⁸ can also influence fellowship choice.^{8,14,17,26,27}

Although the topic of women in neurosurgery has been studied for 2 decades, a comprehensive analysis of current fellowship completion and subsequent career trends in relation to gender has not been investigated. In particular, a study by Lawton et al. on career choice found that fellowship completion was significantly associated with pursuing a career in academic medicine, yet this study did not contain any women in their cohort of neurosurgical residents analyzed between 1968 and 2003.²⁵ Lee and Klose, in 1999, discussed the trend of fellowship consideration but did not analyze completion of fellowship in regard to gender and scholarly productivity.¹⁸ To increase the rates of female neurosurgeons in academic medicine, it is crucial that organized neurosurgery develops evidence-based, actionable means of supporting female trainees in their decisions to pursue, and efforts to complete, fellowship training. The primary objective of the present study is to analyze gender differences in fellowship choice among practicing academic neurosurgeons. Our objective is to explore gender differences regarding decisions and ultimately selections of fellowship training in neurosurgery, as well as career trajectories, by measures of scholarly productivity and industry funding after fellowship completion.

Methods

Study Population

The authors used publicly available websites for fellowship training information of American Board of Neurolog-

ical Surgery—certified academic neurosurgeons to conduct a cross-sectional survey of practicing neurosurgeons in the US. Neurosurgeons identified in the American Board of Neurological Surgery were searched online to determine their fellowship training history. Typically, this required visiting academic neurosurgeons' relevant sites of employment, such as hospital or private practice websites. Of the 1641 neurosurgeons identified, fellowship training information was achievable for 1403 (85.5%). Inclusion criteria consisted of all surgeons for whom both gender and fellowship training information were available. Those who did not meet both of these criteria were excluded from the quantitative analysis. Subspecialty choices were grouped into 10 categories: none, multiple, spine (including programs such as orthopedic spine, spinal deformity correction, and scoliosis), pediatrics, vascular (including endovascular, cerebrovascular, and interventional neuroradiology), functional or stereotactic (including deep brain stimulation, epilepsy, and peripheral nerve surgery), neurooncology, skull base, critical care/trauma, and other (including surgery, research fellowships, general neurological surgery, molecular genetics, microbiology, cranial neurosurgery, neurophysiology, neuroradiology, image guidance and minimally invasive surgery, and senior staff fellowships).

Gender Definition

Gender was defined as male or female, based on the name as well as the gender pronoun used or gender expression apparent in publicly available institutional website photos and faculty biographies. We acknowledge a fundamental limitation of this analysis is the subjective categorization of surgeons as "male" or "female" gender. Accordingly, this analysis may hide important distinctions between surgeon-identified sex and surgeon-ascribed gender. It renders other genders, including nonbinary and transgender, invisible. Indeed, neurosurgeon age was also not collected; this limited our ability to perform covariate analyses regarding surgeon age and trends in training. This analysis should therefore serve as an important first step in determining gender differences in neurosurgeon fellowship choice.

Scholarly Productivity and Career Progression

For our subanalyses of scholarly productivity and career progression based on fellowship, we used academic rank, *h*-index, length of publication in years, and industry funding. Faculty name, gender, fellowship training, and academic rank (assistant professor, associate professor, and professor) were collected from the same publicly available institution websites used to determine respective neurosurgeon fellowship training data. Academic rank was defined as assistant professor, associate professor, and professor. The Scopus database (www.scopus.com) was searched to determine each neurosurgeon's publication range, in years, and *h*-index. The "length of publication years" was defined as the number of years elapsed between an author's first identified publication available in the Scopus database through the present (2019), representing their years of experience in research productivity.

FIG. 1. Fellowship completion according to gender (males, **A** and **B**; females, **C** and **D**). Subspecialty fellowship completion is depicted on the *left*, and fellowship distribution on the *right*. An asterisk denotes a statistically significant difference in gender distribution. Figure is available in color online only.

Importantly, an author's first manuscripts may have been published well before dedicated neurosurgery training, such as in undergraduate, graduate, or medical school. This represents a limitation to data stratification, as the Scopus database does not include a tool to stratify these publications by author stage in neurosurgical training. The Scopus database *h*-index has been used by various medical fields,^{28,29} including neurosurgery,^{30,31} as an accurate resource for bibliometric analyses of peer-reviewed journals and author research productivity. We further analyzed industry funding received in 2018 as a proxy of career progression and scholarly productivity of those neurosurgeons who had completed fellowships and who are currently in practice.^{32,33} Industry contributions during the year 2018 were collected from the Centers for Medicare and Medicaid Services (CMS) Open Payments website (<https://www.cms.gov/OpenPayments>). We collected data on payments classified as general payments (i.e., honoraria/speaking fees, consulting fees), research payments, and associated research funding. Total industry payment awards summing these classifications were analyzed in this analysis.

Statistical Analysis

IBM SPSS Statistics for Windows (version 23.0, IBM Corp.) was used to analyze data. Tests of association were performed with Fisher's exact, chi-square, and independent t-tests. Any *p* values ≤ 0.05 were considered significant.

Results

Fellowship Data

Of the 1641 academic neurosurgeons identified from publicly available websites, fellowship information was attainable for 1403 (85.5%). The sample size consisted of a greater proportion of males compared to females (1261 males [89.9%], 142 females [10.1%]). A significantly greater proportion of women completed a fellowship (74.4% of men vs 85.2% of women, *p* = 0.004; Fig. 1). Of the neurosurgeons reviewed, 24.5% did not complete a fellowship. Of the remaining surgeons, the most common fellowship choices were spine (16.6%), multiple (14.1%), vascular (10.8%), pediatrics (9.8%), functional or stereotactic (8.3%), and neurooncology (7.7%). The least

TABLE 1. Associations between gender and fellowship completion

Variable	Total (%), n = 1403	Males (%), n = 1261	Females (%), n = 142	p Value
Any fellowship completion	1059 (75.48)	938 (74.39)	121 (85.21)	0.004
Multiple fellowship completions	198 (14.11)	183 (14.51)	15 (10.56)	0.252
Subspecialty completed				
None	344 (24.51)	323 (25.61)	21 (14.79)	0.004
Spine	232 (16.55)	219 (17.37)	13 (9.15)	0.012
Pediatrics	138 (9.83)	102 (8.09)	36 (25.35)	<0.0001
Vascular	151 (10.76)	142 (11.26)	9 (6.34)	0.085
Functional or stereotactic	117 (8.34)	101 (8.01)	16 (11.27)	0.199
Other	37 (2.64)	36 (2.85)	1 (0.70)	0.169
Neurooncology	108 (7.70)	89 (7.06)	19 (13.38)	0.012
Skull base	49 (3.49)	46 (3.65)	3 (2.11)	0.471
Critical care/trauma	29 (2.07)	20 (1.59)	9 (6.34)	0.001

Boldface type indicates statistical significance.

common were skull base (3.5%), other (2.6%), and critical care/trauma (2.1%). Complete data are displayed in Table 1. The male-female gender distributions differed between specialties, with some specialties displaying more significant extremes relative to others. For example, significantly more male than female neurosurgeons completed spine fellowships (94.4% male vs 5.6% female, $p = 0.012$). The vascular-only subspecialty choice approached but did not achieve a significant difference in fellowship completion between genders (94.0% male vs 6.0% female, $p = 0.085$). Proportionally, there were significantly more female than

male neurosurgeons in the specialties of pediatrics (73.9% male vs 26.1% female, $p < 0.0001$), critical care/trauma (69.0% male vs 31.0% female, $p = 0.001$), and neurooncology (82.4% male vs 17.6% female, $p = 0.012$) relative to the male-female distributions in other specialties (Fig. 2). The remaining subspecialties analyzed did not have significantly different gender distributions from other specialties analyzed (Table 1). When stratified by gender, the top fellowship choices by male neurosurgeons were spine (17%) and vascular (11%), whereas the top fellowship choices by female neurosurgeons were pediatrics (25%) and neuroon-

FIG. 2. Gender distribution among subspecialties. An asterisk denotes statistically significant differences in gender distribution. Figure is available in color online only.

TABLE 2. Fellowship-trained neurosurgeons and their association of gender with academic rank, publication years, and *h*-indices

Variable	Males, n = 1033	Females, n = 109	p Value
Rank, n (%)			
Assistant professor	314 (30.40)	46 (42.20)	0.017
Associate professor	198 (19.17)	22 (20.18)	0.799
Professor	321 (31.07)	17 (15.60)	0.001
Other	165 (15.97)	18 (16.51)	0.891
Academic (mean $\pm$ SD)			
Publication yrs	20.81 $\pm$ 12.32	15.25 $\pm$ 9.64	<0.0001
<i>h</i> -index	18.98 $\pm$ 16.64	10.39 $\pm$ 8.87	<0.0001

Boldface type indicates statistical significance.

cology (14%), followed by functional or stereotactic (11%). Complete data are displayed in Fig. 1. Distribution of gender according to subspecialty is depicted in Fig. 2.

Scholarly Productivity and Career Progression

We examined 1403 fellowship-trained neurosurgeons to analyze scholarly productivity and career progression, which reduced the cohort to 1142 neurosurgeons with information readily available for analysis. Within those neurosurgeons who were fellowship trained, the academic rank of professor was significantly more commonly held by a man than a woman ($p = 0.001$). In contrast, the rank of assistant professor was held significantly more often by women than men ($p = 0.017$). All other academic ranks were not significant between genders (Table 2). To examine subspecialties with higher rates of women compared to men, we examined pediatrics and neurooncology in terms of gender and academic rank. In these subgroup analyses, professor was a rank that was still significantly more likely to be held by male neurosurgeons in both pediatrics and neurooncology ($p < 0.001$ and $p = 0.02$, respectively). Similarly, within these two specialties, assistant professor was a rank more significantly likely to be held by male neurosurgeons as well ($p = 0.024$ and $p = 0.002$, respectively).

We hypothesized that these differences by gender in terms of academic rank may be associated with scholarly activity, which is used in assessing academic surgeons' suitability for promotion. Publication years for each surgeon were compared between men and women who had completed fellowships. Between genders, men had significantly greater mean publication years than women (20.8 vs 15.3 years, $p < 0.0001$). This may reflect the more recent influx of women into neurosurgery. Similarly, men had significantly higher mean *h*-indices than women (19.0 vs 10.4, $p < 0.0001$), which could be related to their greater number of years publishing. The fellowship type with the highest mean *h*-indices were functional/stereotactic, pediatrics, and critical care/trauma (Table 3). When stratifying by gender, men had greater *h*-indices and length of publication years than women in every subspecialty (Table 3).

Scholarly productivity between genders according to fellowship type was significantly different in pediatrics, spine, and functional/stereotactic fellowships. Men in pediatric fellowships had significantly higher mean *h*-indices ($p < 0.001$) and publication years ($p < 0.001$) than women. Spine had significantly higher *h*-indices for men ($p < 0.001$), but there were no measurable differences between publication years. The stereotactic/functional fellowship also had significant differences in *h*-indices ($p = 0.016$) between men and women but not publication years. The fellowships with the least amount of difference between genders in scholarly productivity were vascular and critical care/trauma. Because women in neurosurgery had shorter publication years, we stratified range of publication years to ≤ 20 years to assess *h*-indices between genders. Statistical differences between *h*-indices in relation to gender disappeared when publication years were ≤ 20 years, yet statistical power was omitted due to the small sample sizes of the female cohort. As a result, this analysis is warranted in the future for men and women with lower publication years through variables such as years in practice, as more women have been entering neurosurgery within the last few decades.

The trajectory of a neurosurgeon's career by industry funding in 2018 was then compared, as previous literature has described industry funding as it is related to career progression and scholarly productivity in academic sur-

TABLE 3. Fellowship type and their association of gender with publication years and *h*-indices

Fellowship	<i>h</i> -index		p Value	Publication Years		p Value
	Females	Males		Females	Males	
Pediatrics	8.69	20.83	<0.001	13.81	23.49	<0.001
Spine	8.1	16.3	<0.001	16.6	18.46	0.592
Vascular	13.89	18.76	0.368	17.56	18.58	0.808
None	9.05	18.17	<0.001	15.65	24.11	0.003
Neurooncology	14.06	24.4	0.025	11.28	21.11	<0.001
Functional/stereotactic	14.33	21.68	0.016	18.13	21.11	0.235
Multiple	14.21	18.69	0.317	18.29	19.66	0.67
Skull base	7.33	19.29	0.207	9.33	19.81	0.154
Critical care/trauma	16.86	23.06	0.529	17	23.33	0.201

Boldface type indicates statistical significance.

TABLE 4. Total industry funding awards by gender and neurosurgical subspecialty

Subspecialty	Total (%)	Males (%)	Females (%)	p Value
Pediatrics	74 (7.81)	53 (71.62)	21 (28.38)	<0.0001
Spine	172 (18.14)	164 (95.35)	8 (4.65)	0.023
Vascular	116 (12.24)	111 (95.69)	5 (4.31)	0.053
Neurooncology	74 (7.81)	63 (85.13)	11 (14.86)	0.078
Functional/stereotactic	91 (9.60)	79 (86.81)	12 (13.19)	0.163
Skull base	35 (3.69)	33 (94.29)	2 (5.71)	0.470
Trauma/critical care	17 (1.79)	11 (64.71)	6 (35.29)	<0.0001
Multiple	140 (14.77)	133 (95.00)	7 (5.00)	0.064
None	209 (22.05)	195 (93.30)	14 (6.70)	0.160
Other	20 (2.11)	19 (95.00)	1 (5.00)	0.160

Boldface type indicates statistical significance.

gery.^{32–34} There was significantly more industry funding allocated to the spine subspecialty (18.1%), followed by the vascular subspecialty (12.2%; Table 4). Within these subspecialties, women were funded significantly less than men, most noticeably in spine ($p < 0.023$), trauma/critical care ($p < 0.0001$), and neurovascular ($p < 0.053$). However, women received significantly more funding in pediatrics ($p < 0.0001$). No significant differences were found between genders in other subspecialty funding analyses (Table 4).

Discussion

Although women in the US complete medical school at higher rates than men, they nonetheless face barriers when pursuing careers in surgery. Gender differences in neurosurgery are evident, with significantly more men than women in the field. In addition, previous data on the neurosurgery match process showed that women appeared less likely to match into neurosurgery compared to men.¹ The reasons for this continued discrepancy are not well-elucidated, but data from neurosurgery and other specialties suggest that deterrents for women pursuing neurosurgery include factors such as 1) physician mothers are often subjected to emotional and physical challenges during pregnancy, maternity leave, and in caregiving roles;²⁷ 2) there are fewer female role models in the field;^{3,7} and 3) sexual harassment¹⁵ and bias. Fellowship completion is an important metric of a neurosurgeon's abilities to advance professionally within his or her field, and has been found to significantly predict an academic neurosurgical career.²⁵ In 2013, Agarwal et al. found that the *h*-index, as a measure of scholarly productivity, did not differ significantly between fellowship- and non-fellowship-trained neurosurgeons until stratified by academic rank, thereby associating fellowship and academic rank with productivity success.³⁵ These authors also found significant differences in scholarly productivity by subspecialty. Because research about neurosurgical fellowships is scant, our study was conducted to first describe the current quantitative distribution of fellowship-trained academic neurosurgeons, with subsequent analyses of gender, academic rank, *h*-index, publication years, and industry funding. We sought to unravel gender differences regarding selection of

fellowship training in neurosurgery. Furthermore, we postulated how gender plays a role in differential professional advancement and achievement within academic neurosurgery through scholarly productivity as assessed by fellowship completion. The authors nonetheless acknowledge the overall lack of granular data regarding decision-making by female neurosurgeons in training. Our study only further elucidates areas of uncertainty remaining in the literature. Therefore, as well as discussing our study's findings within the context of past analyses, we also intentionally and frequently highlight opportunities for further research.

Our cross-sectional analysis of academic neurosurgeons, as expected, was male dominated, comprising 89.9% of our sample. In addition, only one-quarter of the cohort was not fellowship trained, supporting the theory that subspecialization in academic neurosurgery is trending upwards.¹⁹ Yet, intriguingly, a statistically significant higher proportion of academic female neurosurgeons were fellowship trained compared to their male counterparts (74.4% of men vs 85.2% of women, $p = 0.004$). Female neurosurgeons in our cohort likely have higher rates of fellowship completion relative to their male counterparts due to the fact that our analysis was cross-sectional and was conducted among practicing academic neurosurgeons of all ages in the US. Older neurosurgeons in the sample population, predominantly likely to be men, would have started their careers in the 1970s and 1980s, when fellowship completion was less common among academic neurosurgeons. The rate of female fellowship completion may therefore appear higher because women were less likely to enter neurosurgery in previous decades. As a result, the greater influx of women entering the field in recent years may artificially increase rates of fellowship completion, aligning with the increasing popularity of pursuing fellowship training. Another possibility could be that residents perceive weaknesses in certain areas of neurosurgical care during training,¹⁹ as it has been documented that women, more so than men, underestimate themselves in terms of confidence and ability.^{36,37} Other factors may exist that differentially motivate male and female neurosurgeons to pursue further training. This would be interesting, given that previous authors have observed that women are more likely than men to leave neurosurgery.^{5,8} Factors that have

already been described in the literature may include interest in specialty training, job market forces, specialty prestige, and perceived weakness in providing clinical care.^{19,30} A longitudinal study of women in neurosurgical residency, fellowship, and career progression is warranted to further explore these theories. Qualitative data would be particularly beneficial.

Historically, women in neurosurgery specialize in pediatrics more so than any other subspecialty.^{8,20} Our data support this, as female neurosurgeons were best represented in pediatrics (26.1%), critical care/trauma (31.0%), and neurooncology (17.6%). Conversely, female neurosurgeons comprised 5.60% of those with spine fellowship completion, and 5.96% of those with vascular fellowship completion. The current literature suggests that rates of women receiving neurosurgical training are increasing overall. It is unclear whether more women entering the field will ultimately result in an equal distribution of women within each neurosurgical subspecialty. Importantly, the gender differences found in this study may not be entirely due to gender inequities. Men were more likely to pursue no fellowship training ($p = 0.004$) and fellowship training in the spine subspecialty ($p = 0.012$). Women were more likely to pursue fellowship training in pediatrics ($p \leq 0.001$), neurooncology ($p = 0.012$), and critical care/trauma ($p = 0.001$). Female neurosurgeons may simply tend to be attracted to features of certain neurosurgical subspecialties relative to others. Given current research on gender differences in neurosurgical training,^{1-3,5,9,10,12,14} however, we believe the reasons for this distribution are multifactorial. Existing literature cites many reasons why women enter and stay or leave neurosurgery in general, including intrapersonal (work-life balance and interest in discipline), interpersonal (relationship status, the presence or absence of mentors and advisors, and colleague and patient relationships), organizational (length of training, and family and maternity leave policies), community (prestige and marketability), and political (altruism, race, gender, and ethnicity).^{1,3-5,12,20,34,38-43} Importantly, these studies describe women in neurosurgical residency programs, not fellowships. If any of these factors also contribute to fellowship choice, some would constitute true and modifiable inequities (presence of mentors, sexual harassment), and others would constitute mere differences between genders (interest in discipline). For instance, fields such as neurooncology, pediatrics, and critical care/trauma may attract more female neurosurgeons due to both interest in content, more favorable work-life balance, and presence of mentors, reasons that may also deter women from spine, vascular, and skull-base subspecialties.¹⁴ It is even possible that the spine field, known for its sense of mechanical and physical labor, could have deterred women for this very reason. These are suppositions and may propagate gender stereotypes, and further work is necessary to both understand fellowship choice and to try to mitigate any existing barriers. With our spine example, the physical labor may be perceived as more difficult for women who have smaller hands and muscle mass. Yet, the effect of these differences may be reduced with power tools and instruments that are more amenable to the use of those with smaller hands (both male and female). However, as these are simply observa-

tions, we recommend further investigations and we encourage an expansion of our data to include granular data through surveys of female neurosurgeons and reasons for their fellowship choices, which is beyond the scope of our present study.

When analyzing career progression and scholarly productivity, differences were most notable in pediatrics, spine, and functional/stereotactic subspecialties. Even though women were most represented in pediatrics, they were most significantly lagging behind their male counterparts in this fellowship group compared to all others. An intriguing finding in spine and functional/stereotactic (Table 3) subspecialties revealed that women had significantly lower *h*-indices than men, yet publication years were not significantly different. Both spine (5.6%) and vascular (6.0%) had extremely low representation of women, yet spine had significant differences in scholarly productivity that were not present in the vascular group. It could be possible that male neurosurgeons in these subspecialties may be more likely to present the findings of their research in a positive light than their female counterparts, ultimately resulting in greater future citations by both themselves and by other researchers.⁴⁴ Finally, our data showed a relationship between the fellowship chosen and industry funding awards. Women in pediatrics had significantly more industry funding awards than their male counterparts, while the opposite was found in spine and vascular. Therefore, a female neurosurgeon's choice in subspecialty may have implications for her future attainment of industry funding based on current marketplace values of medical devices in neurosurgical subspecialties. These differences may also be linked to availability of men versus women to be involved in device development and testing, which may be influenced by caregiver responsibilities and perception of available time.

We remain curious about fellowship acceptance, as our study only reported on neurosurgeons who ultimately completed fellowship training. A study of orthopedic surgery fellowship match data from 2010 to 2014 found female applicants had higher rates of match success compared to men (96% vs 81%, $p < 0.001$).²² It remains unclear whether differences in fellowship completion rates in neurosurgery may also be determined by differential acceptance of male and female neurosurgeons into these prestigious training programs. For example, a neurosurgeon may have been denied acceptance to fellowship training in his or her first-choice specialty field, leading that person to then apply for a fellowship in a different field. If he or she completed that fellowship, our study would have only coded that individual as completing a fellowship in the second-choice specialty. We also did not assess attrition rates in fellowship training. Therefore, all data points in this analysis should be evaluated realistically: successful fellowship completion may not necessarily imply unsuccessful fellowship applications, and no fellowship completion may not necessarily imply no interest in receiving fellowship training. Experiences by male and female neurosurgeons in the fellowship application may be similar or different.

Study Limitations

This study has a few limitations. Because cross-sec-

tional analysis was conducted to obtain a first look at gender distributions in neurosurgery fellowships, rates and trends in fellowship completion may have been subject to change over the years; these could not be detected in our study. It would be interesting for future analyses to collect data on surgeon age to determine trends in training by generational cohort; we could not reliably procure surgeon age with this analysis. Similarly, our study did not stratify data based on years in practice since fellowship completion. These two variables of age, for stratification of generational cohorts and years in practice, are encouraged in further studies, but out of scope of the data currently presented. Additionally, aggregate data were collected from online sources of practicing academic neurosurgeons. The accuracy of said data is subject to the accuracy of data entry by relevant neurosurgical organizations, hospitals, and practices. Ultimately, fellowship data were available for 85% of academic neurosurgeons listed online. To detect gender differences, we needed to make crude assessments of gender, conflating it with binary definitions of sex, for each neurosurgeon. Finally, our tests of association represent correlation of variables, not causation.

Conclusions

Because investigating the demographics of current practicing neurosurgeons is vital, our study offers the most up-to-date and comprehensive analysis of recent data in neurosurgical fellowship training. There are evident gender differences in neurosurgery; overall, more female neurosurgeons were fellowship trained, yet distribution of fellowship type differed. Female neurosurgeons were more likely to be fellowship trained in pediatrics, critical care/trauma, and neurooncology compared to their male counterparts; male neurosurgeons were more likely to complete spine fellowships. Most significant scholarly productivity gender differences were found in pediatrics, spine, neurooncology, and functional/stereotactic subspecialties. Men received more industry funding in spine and vascular, while pediatrics industry funding was significantly higher for women. These results raise many questions regarding experiences of male and female neurosurgeons. We suggest further longitudinal studies to build on our work by investigating factors influencing neurosurgical choice in fellowship applications, training, attrition, and career progression.

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Author Contributions

Conception and design: Behmer Hansen, Cuevas, Richardson. Acquisition of data: Behmer Hansen, Cuevas. Analysis and interpretation of data: Behmer Hansen, Silva, Cuevas, Cerasiello. Drafting the article: Behmer Hansen, Silva. Critically revising the article: Nanda, Silva, Richardson, Mammis. Reviewed submitted version of manuscript: Nanda, Silva, Mammis. Study supervision: Nanda, Silva.

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