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CLINICAL ARTICLE

Recruitment of women in neurosurgery: a 7-year quantitative analysis

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OBJECTIVE The authors aimed to characterize which US medical schools have the most female neurosurgery residents and to identify potential associations between medical school characteristics and successful recruitment of women pursuing a neurosurgery career.

METHODS The authors evaluated a total of 1572 residents in US neurosurgery programs accredited by the Accreditation Council for Graduate Medical Education as of February 2021, representing match cohorts from 2014 to 2020. The authors extracted US medical school characteristics and ranked schools based on the percentages of women graduates entering neurosurgery. They additionally studied yearly trends of the percentage of women constituting incoming neurosurgery resident cohorts as well as associations between female recruitment percentage and medical school characteristics using univariable and stepwise multivariable linear regression (including significant univariable factors).

RESULTS The cohort consisted of 1255 male and 317 (20%) female residents. Yearly trends indicated a significant drop in incoming female residents in 2016, followed by significant increases in 2017 and 2019. On multivariable analysis, the following factors were associated with a higher average percentage of female graduates entering neurosurgery: total affiliated neurosurgery clinical faculty ($\beta = 0.006$, 95% CI 0.001–0.011, $p = 0.01$), allopathic versus osteopathic schools ($\beta = 0.231$, 95% CI 0.053–0.409, $p = 0.01$), and top 10 *U.S. News & World Report* ranking ($\beta = 0.380$, 95% CI 0.129–0.589, $p < 0.01$). When the number of female clinical faculty was added to the model, the variable was not statistically significant. Multivariable bibliometric analyses indicated a higher mean preresidency H-index for men, with an even greater gender difference identified in the 2021 H-index.

CONCLUSIONS This study characterizes which medical schools are most successful at recruiting female students who constituted the total neurosurgery resident workforce of the 2020–2021 academic year. The overall number of clinical neurosurgery faculty rather than faculty gender was independently associated with female recruitment. Gender differences in research productivity persisted with control for confounders and increased between preresidency and 2021 time points. Such understanding of factors that influence the recruitment of women can help improve female representation in neurosurgery residency training moving forward.

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KEYWORDS residency; gender diversity; education; research; recruitment

From 2008 onward, at least half of medical students across the US have been women.[1] Despite nationwide efforts to increase the recruitment of women into surgical fields, gender imbalances persist across a wide spectrum of surgical residencies. In the 2007–2008 academic year, the five specialty residencies with the greatest degree of female underrepresentation were all surgical: otolaryngology, plastic surgery, urology, orthopedic surgery, and neurosurgery, which was the specialty with the least amount of women (11.15%).[2] Neurosurgery remained the specialty with the second least amount of female representation (17.82%) in 2017–2018, and trend analyses projected that gender parity in neurosurgery, measured against female representation in the overall US trainee population, will not be achieved until the year 2056.[2] By the end of 2018, only 53.2% of Accreditation

ABBREVIATIONS ΑΩΑ = Alpha Omega Alpha medical honor society; AAMC = American Association of Medical Colleges; AANS = American Association of Neurological Surgeons; ACGME = Accreditation Council for Graduate Medical Education; IMG = international medical graduate; PGY = postgraduate year; *US News* = *U.S. News & World Report*.

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Council for Graduate Medical Education (ACGME)–accredited neurosurgery residency programs had both female faculty and female residents.[3] Beyond recruitment, the retention of women in surgery represents an additional challenge, with female residents being more likely than male residents to leave their surgical training programs, commonly citing an uncontrollable lifestyle and a desire to transfer to another specialty, such as anesthesiology.[4] In parallel, higher attrition rates were reported among female than male neurosurgery residents in a nationwide study.[5] Likewise, medical student interest in neurosurgery also varies throughout medical school and by gender. For instance, 2.2% of the 2016 entering medical school class was initially interested in neurosurgery.[6] By graduation, only 1.1% of the 2020 medical school class intended to pursue neurosurgery—an attrition rate of 50%.[7] Research also indicates that female medical students are less likely than male students to have an interest in surgery or a surgical subspeciality at the start of medical school (OR 0.42, 95% CI 0.40–0.44). By the end of medical school, female medical students are still less likely than male students to have an interest in surgery or a surgical subspeciality (OR 0.64, 95% CI 0.561–0.727), but by less of a margin.[8] Strategies to address such imbalances and other challenges have been devised and include a focus on mentorship/sponsorship programs and conference scholarships, the establishment of "Women in Surgery" organizations, and awareness efforts regarding burnout.[9] In the absence of multivariable quantitative analyses targeting the early recruitment stage from medical school to residency, the development of an effective plan to bridge gender gaps may prove difficult. In the present study, we explored which US medical schools have been most successful in recruiting female medical students to the traditionally male-dominated specialty of neurosurgery. In our analysis, we also sought to determine medical school characteristics associated with successful recruitment of women. Finally, we aimed to characterize potential bibliometric disparities, given the widespread emphasis placed on research in the field and its importance in career advancement.

Methods

Approval for this project was obtained from the Johns Hopkins Medicine Institutional Review Board.

Resident Cohort

We accessed the American Association of Neurological Surgeons (AANS) neurosurgical residency training program directory to obtain a list of ACGME-accredited residency training programs in neurosurgery while excluding Canadian programs. We generated a list of neurosurgery residents (postgraduate years [PGYs] 1 through 7) from publicly available web pages of the included US programs, which were accessed during February 2021. The resident cohort represented successfully matched medical school applicants over the 2014–2020 match cycles.

Resident Characteristics

For every resident, we recorded demographic information including gender, residency program name, PGY, medical school name with year of graduation, international medical graduate (IMG) status, degrees obtained, and Alpha Omega Alpha medical honor society (AΩA) membership (https://www.alphaomegaalpha.org). Website information was supplemented with publicly available data from Google Scholar, LinkedIn, Doximity, and DocInfo.

We compiled bibliometric data for each resident through the author search tool in Web of Science (Clarivate Analytics). We collected the total number of published papers, abstracts, and citations and the H-index during February 2021 and at the preresidency level (by the end of medical school), by filtering according to medical school graduation date. If publications had different names belonging to the same author, Web of Science allowed the merging of multiple author profiles.

Medical School Characteristics

Once we produced a list of feeder medical schools for neurosurgery (2014–2020), we collected characteristics for every feeder school located in the US while excluding international medical schools owing to incomplete data for a large number of schools and because the top feeder schools are US based. We extracted the total number of accredited allopathic and osteopathic medical schools from the American Association of Medical Colleges (AAMC) website (https://www.aamc.org/data-reports/faculty-institutions/report/us-medical-school-revenues) and the American Association of Colleges of Osteopathic Medicine website (https://www.aacom.org/become-a-doctor/u-s-colleges-of-osteopathic-medicine). We obtained medical school class size from the AAMC (https://apps.aamc.org/msar-ui/#/landing) and from the respective school web pages. Geographical data constituted the state in which every medical school was located and the regions (West, Midwest, South, and Northeast) as categorized by the US Census Bureau (https://www.census.gov/geographies/reference-maps/2010/geo/2010-census-regions-and-divisions-of-the-united-states.html). Comparisons with the AANS neurosurgery residency training programs list and supplementary online queries were used to ascertain which medical schools had a neurosurgery residency training program. From department web pages we extracted the total number of clinical neurosurgery faculty as well as the number of female clinical neurosurgery faculty affiliated with each medical school. We additionally determined the presence of a neurosurgery interest group using the AANS directory of medical student chapters (https://www.aans.org/Trainees/Medical-Students/Chapter-Directory) and the medical school websites. We obtained the total reported NIH funding for each medical school in 2020 from the *U.S. News & World Report* (*US News*) website (https://www.usnews.com/best-graduate-schools/top-medical-schools/most-research-money-rankings) and from the Blue Ridge Institute for Medical Research website (http://www.brimr.org/NIH_Awards/2020/default.htm). We recorded information regarding the reputations of affiliated neurosurgery departments by determining whether the affiliated hospital was ever ranked in the top 10 best *US News* rankings for neurology and neurosurgery from 2014 until 2020. Using the Doximity Residency Navigator tool, we

also recorded top 10 reputation rankings for affiliated neurosurgery programs in 2021; moreover, we extracted the top 30–ranked programs in research output according to Doximity, which measures the collective H-index of program alumni.

Statistical Analysis

We summarized resident cohort characteristics using descriptive statistics (number and percentage for categorical variables and mean and standard deviation for continuous variables) while comparing men and women (chi-square and Fisher exact tests used as appropriate). To obtain an estimate of the number of graduating female medical students from each feeder school over the 7-year period, we multiplied the class size by 7 and subsequently divided by 2. This was based on AAMC data extracted from the Medical School Admission Requirements website (https://mec.aamc.org/msar-ui/#/landing), whereby having a subscription account allows the user to query the gender breakdown of every medical school, indicating a 1:1 male-to-female ratio in the vast majority of schools. Subsequently, we ranked the medical schools according to the percentage of female graduates pursuing and matching into neurosurgery over the 7-year period. We evaluated the yearly trend in the percentage of women constituting every incoming neurosurgery resident cohort using a chi-square test with post hoc comparisons between individual years (Bonferroni adjustment). We then created a heat map of the percentage of female graduates entering neurosurgery across the US organized by state. This heat map was created by entering our data into Google Geocharts under the following freely accessible link: https://www.danielpinero.com/how-to-create-heat-map-united-states?lang=en.

Using Pearson's correlation coefficient (PCC) and the independent-samples t-test as appropriate, we evaluated associations between the percentage of female graduates entering neurosurgery and medical school characteristics. We used univariable and stepwise multivariable linear regression of univariable significant factors to identify medical school characteristics that were independently associated with the percentage of female graduates matching into neurosurgery. The absence of multicollinearity between variables in the multivariable model was verified by checking whether the variance inflation factor for all possible variable pairs was less than 3, especially for the total numbers of all neurosurgery clinical faculty and the number of female clinical faculty. To identify the relative importance of every variable, standardized β values were derived. We also performed univariable and multivariable gender comparisons of preresidency and 2021 bibliometric data using the independent-samples t-test and linear regression. We performed statistical analyses using SPSS software (version 25.0; IBM Corp.) with statistical significance set at $p < 0.05$.

Results

Resident Characteristics

The complete resident cohort in US ACGME-accredited neurosurgery programs reflecting matched applicants over the 2014–2020 match periods consisted of 1572 residents. Resident demographic characteristics compared by gender are summarized in Supplemental Digital Appendix 1. There were 317 (20%) women and 113 (7%) IMGs. Degrees held were generally similar between both genders, and there was a trend toward a higher proportion of AΩA members among men (29% vs 24%, $p = 0.08$).

Top Feeder Schools for Women

The 165 US medical schools that contributed at least 1 neurosurgery resident over the 7-year period contributed an average of 1.8 ± 2.1 (median 1, IQR 0–3) female residents per school. These 165 schools included 140 allopathic schools (99% of all allopathic schools [n = 141]) and 25 osteopathic schools (68% of all osteopathic schools [n = 37]). Of these, a total of 112 (68%) schools contributed at least 1 female neurosurgery resident. The mean percentage of female medical graduates going into neurosurgery from 2014 to 2020 among the 165 schools was 0.37% ± 0.44% (median 0.24%, IQR 0–0.54%) per school. The top US feeder schools for female neurosurgery residents are summarized in Table 1. The top 12 schools (7%) in recruitment had more than 1% of their female graduates going into neurosurgery. The percentages of women constituting the yearly incoming neurosurgery resident cohort dropped significantly from 16.5% in 2015 to 13.8% in 2016, after which a significant increase occurred in 2017 and 2019 (Fig. 1). Characteristics of feeder schools are summarized in Supplemental Digital Appendix 2.

The mean number of clinical neurosurgery faculty affiliated with each medical school was 13.0 ± 14.1 (median 9, IQR 0–19). There was a significant correlation between the number of faculty members and the percentage of female graduates going into neurosurgery (PCC = 0.385, $p < 0.01$). On linear regression, an absolute increase of 0.012 percentage points (95% CI 0.008%–0.016%, $p < 0.01$) in female graduates entering neurosurgery was identified per clinical faculty member increase (Supplemental Digital Appendix 3). A similar univariable association was detected with the number of female clinical neurosurgery faculty (Supplemental Digital Appendix 4). Some medical schools with no affiliated female neurosurgery faculty still had a relatively large percentage of female medical graduates entering neurosurgery. A geographic representation of female recruitment into neurosurgery by state is provided in the form of a heat map (Fig. 2). Although all US regions had recruitment hubs, medical schools in the Northeastern states had the highest recruitment rates (84% recruited at least 1 woman) compared to those in Western states, which had the lowest recruitment rates (50% recruited at least 1 woman).

Univariable medical school characteristics significantly associated with percentage of women entering neurosurgery included clinical faculty size, number of female clinical faculty, presence of a neurosurgery interest group and a home neurosurgery residency program at the medical school, allopathic school type, *US News* ranking of affiliated neurology and neurosurgery departments, and Doximity reputation ranking (Table 2). A stepwise linear regression model revealed that the number of clinical neurosurgery faculty (β = 0.006, 95% CI 0.001–0.011, p

TABLE 1. Top feeder American medical schools ranked by percentage of women graduates going into neurosurgery during the 2014–2020 match period

Rank	Medical School	Students Entering NS, %	Women Grads Entering NS, No.	Women Grads Entering NS, %
1	Cleveland Clinic Lerner College of Medicine	3.571	3	2.679
2	Case Western Reserve University School of Medicine	3.106	13	1.736
3	Yale School of Medicine	2.857	6	1.714
4	New York University School of Medicine	3.221	6	1.681
5	Stanford University School of Medicine	3.175	5	1.587
6	Harvard Medical School	2.211	9	1.531
7	Louisiana State University School of Medicine	2.381	8	1.524
8	Johns Hopkins University School of Medicine	2.125	6	1.417
9	University of Illinois College of Medicine, Urbana	0.595	2	1.190
10	Duke University School of Medicine	2.459	5	1.171
11	Rutgers New Jersey Medical School	2.648	7	1.124
12	Washington University in St. Louis School of Medicine	1.786	4	1.099
13	Cooper Medical School of Rowan University	0.812	3	0.974
14	University of Pittsburgh School of Medicine	1.918	5	0.959
15	Geisel School of Medicine at Dartmouth	1.270	3	0.952
16	Vanderbilt University School of Medicine	3.799	3	0.912
17	Albany Medical College	1.786	4	0.893
18	University of California, San Diego, School of Medicine	1.719	4	0.859
19	University of Tennessee College of Medicine	1.176	5	0.840
20	University of Wisconsin School of Medicine	1.003	5	0.835
21	Emory University School of Medicine	1.233	4	0.822
22	Texas Tech University Health Sciences Center El Paso Paul L. Foster School of Medicine	1.429	3	0.779
23	Keck School of Medicine of the University of Southern California	1.152	5	0.768
24	Virginia Commonwealth University School of Medicine	1.306	5	0.768
25	Northeast Ohio Medical University	0.662	4	0.757
26	Rush Medical College	0.922	4	0.737
27	Medical College of Georgia at Augusta University	0.893	6	0.714
28	Georgetown University School of Medicine	1.619	5	0.704
29	University of Kentucky College of Medicine	0.627	5	0.697
30	New York Medical College	1.011	5	0.674
31	Brody School of Medicine at East Carolina University	0.664	2	0.664
32	University of California, Los Angeles, David Geffen School of Medicine	1.388	4	0.653
33	University of Florida College of Medicine	1.481	3	0.635
34	University of Illinois College of Medicine, Chicago	0.952	4	0.635
35	University of Texas Southwestern School of Medicine	1.003	5	0.627
36	Baylor College of Medicine	1.152	4	0.614
37	Wake Forest School of Medicine	0.788	3	0.591
38	Zucker School of Medicine at Hofstra/Northwell	0.577	2	0.577
39	Oregon Health & Science University	0.762	3	0.571
40	Boston University School of Medicine	0.752	3	0.564
41	University of California, Irvine, School of Medicine	0.687	2	0.549
42	University of South Carolina School of Medicine Greenville	0.529	2	0.529
43	University of Connecticut School of Medicine	0.519	2	0.519
44	Robert Wood Johnson Medical School	0.657	3	0.493
45	University of Arizona College of Medicine, Tucson	0.977	2	0.488
46	The University of Toledo College of Medicine	0.812	3	0.487

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TABLE 1. Top feeder American medical schools ranked by percentage of women graduates going into neurosurgery during the 2014–2020 match period

Rank	Medical School	Students Entering NS, %	Women Grads Entering NS, No.	Women Grads Entering NS, %
47	Wright State University School of Medicine	0.363	2	0.484
48	Saint Louis University School of Medicine	0.546	3	0.468
49	University of Alabama at Birmingham School of Medicine	1.613	3	0.461
50	University of Missouri–Kansas City School of Medicine	0.691	2	0.461
51	Oakland University William Beaumont School of Medicine	0.571	2	0.457
52	Florida Atlantic University Charles E. Schmidt College of Medicine	0.893	1	0.446
53	University of Illinois College of Medicine, Peoria	0.879	1	0.440
54	University of Nebraska College of Medicine	1.091	2	0.436
55	Columbia University College of Physicians and Surgeons	2.959	2	0.408
56	Icahn School of Medicine at Mount Sinai	0.918	2	0.408
57	University of Texas Health Science Center at San Antonio	1.146	3	0.404
58	East Tennessee State University James H. Quillen College of Medicine	0.397	1	0.397
59	City University of New York Medical School (Sophie Davis School of Biomedical Education)	0.376	1	0.376
60	University of Pennsylvania Perelman School of Medicine	1.475	2	0.369
61	University of Virginia School of Medicine	1.106	2	0.369
62	University of Louisville School of Medicine	0.898	2	0.359
63	Marshall University Joan C. Edwards School of Medicine	0.893	1	0.357
64	Northwestern Feinberg School of Medicine	0.714	2	0.357
65	Loyola University of Chicago Stritch School of Medicine	0.952	2	0.346
66	Drexel University College of Medicine	0.659	3	0.330
67	Texas A&M University Health Science Center College of Medicine	0.490	2	0.327
68	University of California, San Francisco, School of Medicine	1.043	2	0.321
69	Sidney Kimmel Medical College at Thomas Jefferson University	1.005	3	0.317
70	University of Cincinnati College of Medicine	1.020	2	0.314
71	Indiana University School of Medicine	0.939	4	0.313
72	Albert Einstein College of Medicine	0.703	2	0.312
73	George Washington University School of Medicine	0.699	2	0.311
74	Quinnipiac University–Frank H. Netter School of Medicine	0.456	1	0.304
75	Rosalind Franklin University/Chicago Medical School	1.361	2	0.302
76	Michigan State University College of Osteopathic Medicine	0.680	3	0.292
77	University of Miami Miller School of Medicine	1.401	2	0.280
78	University of Rochester School of Medicine	1.401	1	0.280
79	Ohio State University College of Medicine	0.976	2	0.279
80	Central Michigan University College of Medicine	0.277	1	0.277
81	Mayo Medical School	1.224	1	0.272
82	Lewis Katz School of Medicine at Temple University	0.983	2	0.262
83	Howard University College of Medicine	0.238	1	0.238
84	University of Texas Medical School at Houston	0.952	2	0.238
85	University of Minnesota Medical School	0.593	2	0.237
86	Florida International University Herbert Wertheim College of Medicine	0.697	1	0.232
87	University of Vermont College of Medicine	0.922	1	0.230
88	University of Utah School of Medicine	0.800	1	0.229
89	University of Missouri School of Medicine	0.223	1	0.223
90	Touro University College of Osteopathic Medicine, New York	0.317	1	0.212
91	University of Pikeville–Kentucky College of Osteopathic Medicine	0.212	1	0.212

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TABLE 1. Top feeder American medical schools ranked by percentage of women graduates going into neurosurgery during the 2014–2020 match period

Rank	Medical School	Students Entering NS, %	Women Grads Entering NS, No.	Women Grads Entering NS, %
92	Warren Alpert Medical School of Brown University	1.290	1	0.198
93	Campbell University School of Osteopathic Medicine	0.095	1	0.190
94	Pennsylvania State University College of Medicine	0.846	1	0.188
95	University of Colorado School of Medicine	0.829	1	0.184
96	State University of New York Upstate Medical University	0.893	1	0.179
97	University of Oklahoma College of Medicine	0.958	1	0.174
98	Uniformed Services University	0.676	1	0.169
99	Medical University of South Carolina College of Medicine	0.661	1	0.165
100	Jacobs School of Medicine and Biomedical Sciences	0.556	1	0.159
101	Edward Via College of Osteopathic Medicine	0.232	1	0.154
102	University of South Florida Morsani College of Medicine	0.907	1	0.151
103	Tulane University School of Medicine	0.526	1	0.150
104	University of North Carolina at Chapel Hill School of Medicine	0.592	1	0.148
105	Tufts University School of Medicine	0.929	1	0.143
106	Midwestern University–Chicago College of Osteopathic Medicine	0.279	1	0.139
107	University of Kansas School of Medicine	0.339	1	0.135
108	University of Texas Medical School at Galveston	0.497	1	0.124
109	Lake Erie College of Osteopathic Medicine	0.286	1	0.114
110	New York Institute of Technology College of Osteopathic Medicine	0.212	1	0.106
111	University of Washington School of Medicine	0.265	1	0.106
112	Western University of Health Sciences College of Osteopathic Medicine	0.131	1	0.087

Grads = graduates; NS = neurosurgery.

= 0.01), allopathic school type (β = 0.231, 95% CI 0.053–0.409, p = 0.01), and top 10 *US News* ranking (β = 0.380, 95% CI 0.148–0.612, p < 0.01) were independently and positively associated with the percentage of women entering neurosurgery. Upon adding the number of female clinical neurosurgery faculty to this model, this variable was not significantly associated with the percentage of female graduates entering neurosurgery. None of the following variables exhibited collinearity: neurosurgery clinical faculty, number of female clinical neurosurgery faculty, allopathic versus osteopathic school type, and *US News* top 10 ranking (variance inflation factor < 3 in all pairs).

Bibliometric Characteristics

Bibliometric comparisons by gender are summarized in Table 3 for 1563 residents with available data. The average preresidency H-index was 0.5 points higher for men (3.4 ± 4.0 vs 2.9 ± 3.1, p = 0.03). This difference increased to 0.8 points when the 2021 H-index was assessed (4.7 ± 4.5 vs 3.9 ± 3.3, p < 0.01). On multivariable analysis, the gender difference persisted for preresidency H-index when we controlled for IMG status, PhD degree, MS degree, and graduating from a medical school affiliated with a top 30 Doximity research output program (preresidency H-index less in women by 0.5 [95% CI 0.02–0.9], p = 0.04). Concerning H-index values in 2021, women still had a significantly lower H-index with a wider difference compared to preresidency after we adjusted for IMG status, PhD degree, MS degree, graduating from a medical school affiliated with a top 30 Doximity research output program, going to a top 30 Doximity research output residency program, and PGY (H-index lower by 0.7 [95% CI 0.2–1.2] for women, p < 0.01).

Discussion

Our results clarify which medical schools are most successful in recruiting female medical students into a traditionally male-dominated surgical specialty. Standardizing our metrics to class size was necessary in order to capture medical school recruitment efforts; larger medical schools will naturally have more women entering the field regardless of recruitment efforts. Medical school characteristics that were independently associated with female recruitment included the number of affiliated clinical neurosurgery faculty, allopathic school type, and *US News* top 10 ranking. A gender gap in publications existed at the preresidency time period and increased by 2021, even with adjustment for confounding variables. While it appears that female medical student recruitment may be trending up over time, our analysis suggests that this pro-

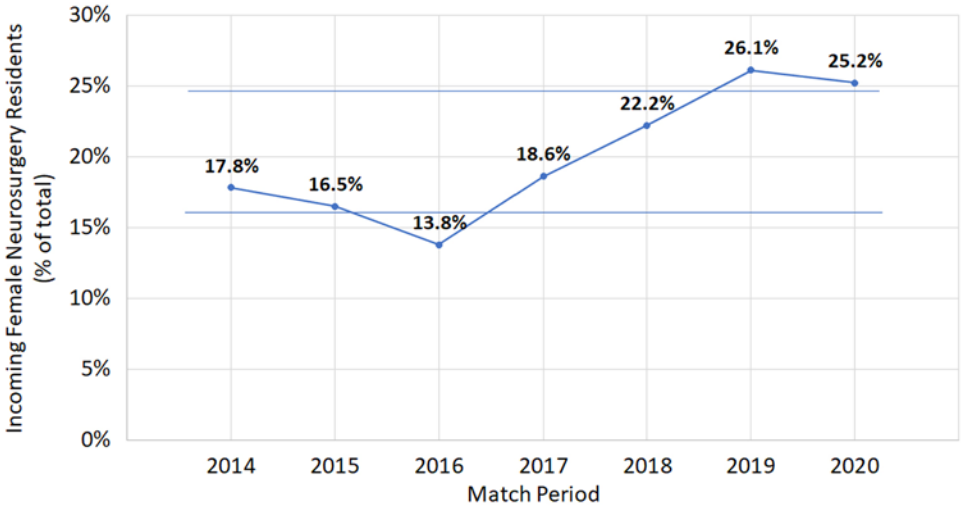

FIG. 1. Yearly trend in the percentage of women in incoming neurosurgery cohorts (n = 1572). Overall chi-square $p < 0.01$; *horizontal lines* separate years with significantly different female student enrollment. Figure is available in color online only.

cess may be happening far too slowly. Alternatively, female recruitment may be oscillating around a mean, with 2017 and 2019 recruitment data acting as outliers. This situation is occurring despite concerted recruitment efforts already implemented. Given these findings, we suggest that more disruptive mechanisms may be necessary to increase female recruitment. One potential avenue to pursue includes recruitment and exposure efforts directed toward female medical students at matriculation, when interest in a surgical specialty is widest among students of both genders.[8]

Affiliated Departmental Faculty: Does Gender Matter?

Although a higher number of affiliated clinical neurosurgery faculty was independently associated with increased female recruitment, the number of women faculty

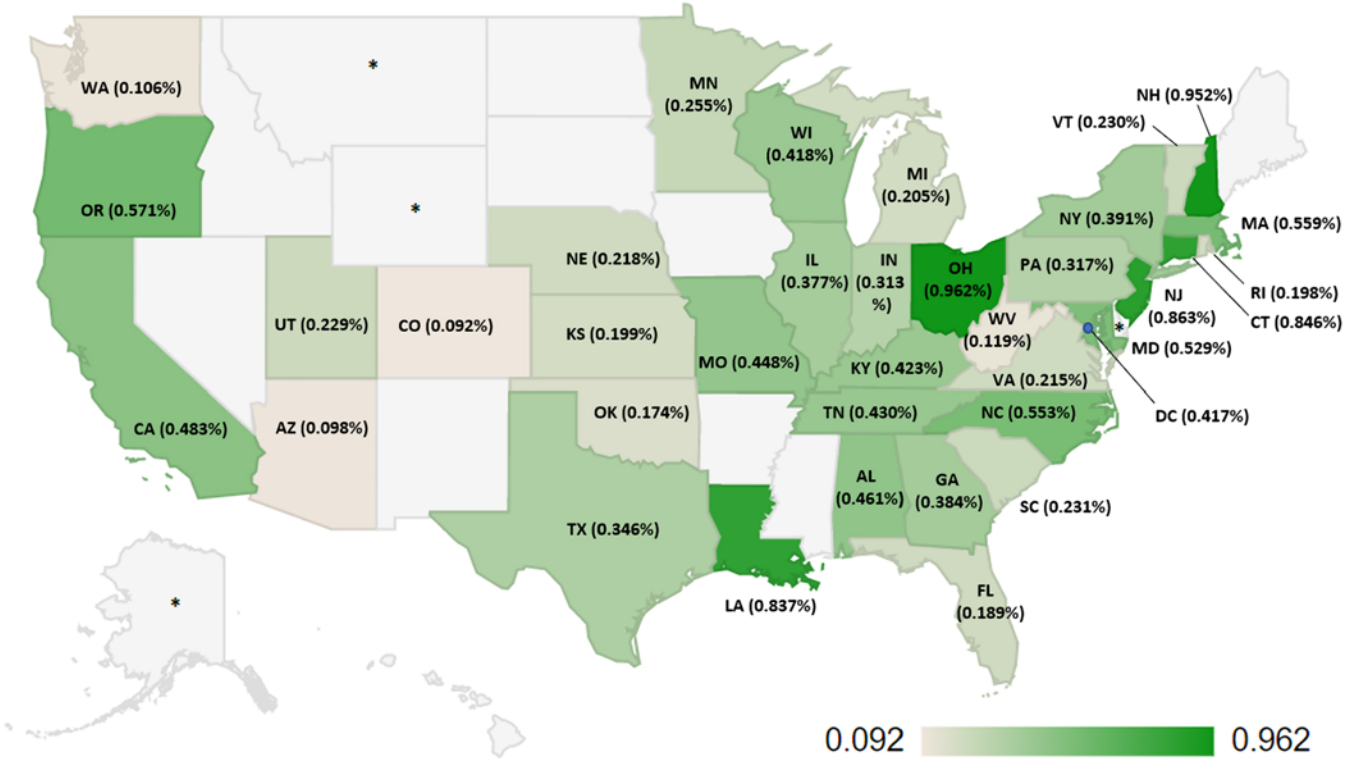

FIG. 2. A heat map by state for average percentages of female graduates entering neurosurgery. *Indicates states without medical schools. This map was created using Google GeoCharts. Figure is available in color online only

TABLE 2. Univariable and stepwise multivariable linear regression analysis of the percentages of female graduates entering neurosurgery (n = 165 medical schools)

Variable	Univariable		Multivariable	
	β (95% CI)	p Value	β (95% CI)†	p Value
No. of neurosurgery clinical faculty	0.012 (0.008 to 0.016)	<0.01*	0.006 (0.001 to 0.011)	0.013*
No. of female clinical neurosurgery faculty	0.063 (0.034 to 0.091)	<0.01*	—	—
Neurosurgery interest group	0.309 (0.158 to 0.461)	<0.01*	—	—
Home neurosurgery program	0.317 (0.189 to 0.445)	<0.01*	—	—
Allopathic vs osteopathic school	0.360 (0.181 to 0.540)	<0.01*	0.231 (0.053 to 0.409)	0.01*
US News top 10 (2014–2020)	0.559 (0.340 to 0.777)	<0.01*	0.380 (0.129 to 0.589)	<0.01*
Doximity top 10 (2021)	0.428 (0.138 to 0.718)	<0.01*	—	—
NIH funding in 2020, per $1 billion	0.728 (0.454 to 1.002)	<0.001*		
Geographic region (West as reference)		0.28	—	—
Northeast	0.195 (−0.030 to 0.420)	0.09	—	—
Midwest	0.133 (−0.089 to 0.355)	0.24	—	—
South	0.057 (−0.150 to 0.264)	0.59	—	—

* Statistically significant ($p < 0.05$).
† Standardized β coefficients: clinical faculty size (0.206), allopathic school (0.190), *US News* ranking (0.250).

members was not. The univariable association between the number of women faculty and recruitment was likely the result of confounding: larger and more highly ranked affiliated neurosurgery departments were more likely to have an increased number of employed female faculty. One possible explanation for our findings, put forward by Benzil et al. in a 2008 White Paper Committee article, is that female faculty have yet to reach a "critical mass" of 15%, whereby under this threshold they act more as isolated individuals as opposed to a unified minority group.[10] This effect may have an impact on the influence of women faculty on female medical students interested in neurosurgery. One possibility is that female medical students may view female neurosurgery faculty as isolated, an observation that may discourage them from pursuing the field. Moreover, with fewer female faculty to act as mentors, less diversity among the cohort of women neurosurgeons is expected, which may impact the ability of female medical students to connect with mentors. We hypothesize that a larger and more diverse female workforce would positively impact the recruitment of female medical students into the field. Another possibility is that female medical students seek high-quality mentorship, regardless of faculty gender. A greater number of available mentors may have increased the likelihood of finding and establishing mentor-mentee relationships that promoted interest in the field of neurosurgery. Finally, gender bias may lead to male faculty being relatively better able to successfully match mentees into neurosurgery, a situation that might offset the benefit of having more access to female neurosurgeons as possible mentors.

TABLE 3. Bibliometric characteristics (n = 1563) by gender (2014–2020 match cycles)

Variable	Men (n = 1247)	Women (n = 316)	p Value
Preresidency			
Published papers & abstracts	8.6 ± 13.7	7.5 ± 10.0	0.11
Citations	137.7 ± 336.2	97.9 ± 212.3	<0.01*
H-index†	3.4 ± 4.0	2.9 ± 3.1	0.03*
2021			
Published papers & abstracts	18.2 ± 23.3	13.3 ± 15.0	<0.01*
Citations	188.1 ± 460.6	125.0 ± 238.4	<0.01*
H-index†	4.7 ± 4.5	3.9 ± 3.3	<0.01*

* Statistically significant ($p < 0.05$).
† Gender differences persisted on multivariable linear regression with adjustment for IMG status, PhD and MS degrees for preresidency H-index, and graduating from medical schools affiliated with top 30 Doximity research output residency programs, and with adjustment for IMG status, PhD degree, MS degree, graduating from medical schools affiliated with top 30 Doximity research output residency programs, being in a top 30 Doximity research output residency program, and PGY for 2021 H-index.

These findings mirror survey-based data published in 2020 by McNutt et al.[11] Among 105 active female neurosurgery residents in 2019 (44% response rate among female residents), the residency program characteristics considered least important when choosing a residency program were gender diversity of faculty and residents, number of female residents, number of female faculty, and attitudes toward maternity leave. The most important attributes were caseload and variety, resident happiness and well-being, early surgical experience, and academic reputation.[11] Similar results were reported in 2020 by Goss et al. in the field of orthopedic surgery based on a survey of 158/305 (52% response rate) female residents. Gender diversity of faculty and residents, number of female residents, and number of female faculty were reported to be among the least influential factors in deciding on a residency program.[12] These findings, taken together, suggest that overall mentorship quality and opportunity in surgical

fields ought to be emphasized in addition to gender diversity in order to maximize female medical student interest and successful recruitment.

Disparity in Research Productivity

Our findings demonstrate a greater H-index for male neurosurgery residents, with disparity starting during medical school and increasing with time throughout residency. In 2017, a bibliometric analysis of 1506 neurosurgical residents in North America conducted by Khan et al. indicated that men had higher overall and intraresidency H-indices than women, but no multivariable analysis was conducted.[13] Preresidency bibliometric analyses have been conducted in neurosurgery, but no gender comparisons were performed.[14,15] On univariable analysis, preresidency total publications were associated with a PhD degree and attending a medical school affiliated with a department that was highly ranked in research; no multivariable analysis was conducted.[14] A positive univariable correlation between medical student first-author publications and the number of affiliated neurosurgery faculty was also previously described.[15] Our analysis confirms that gender disparities arise at an early stage in medical training independently from differences in degree attainment, IMG status, or affiliated institution research ranking. It remains unclear, however, if preresidency publication metrics accurately predict performance and academic success during and after residency, and this topic deserves further study. Bibliometric profiles *during* residency are significantly associated with a future academic career path, attaining full professorship, and becoming a departmental chair or chief.[16] Critically, it is not enough to simply recruit more female medical students into neurosurgery; it is also necessary to enable them to attain prominent, visible positions of leadership in order to positively influence the field from the top down. Hence, a deeper understanding is required of the contributing factors (e.g., comparatively lower interest in research among women vs fewer mentorship and funding opportunities available to women) behind the start and perpetuation of gender disparity in surgical academic productivity and its downstream effects.

Implications Moving Forward

For stakeholders interested in improving the recruitment of female medical students into neurosurgery and likely other surgical subspecialties, the data presented herein may serve as a guide. Medical schools in several states, such as New Mexico, Nevada, Idaho, North and South Dakota, Iowa, Arkansas, Mississippi, and Maine, have not had female medical students join the total neurosurgery resident workforce of the 2020–2021 academic year. Medical schools in the West, as a whole, have the most potential to increase female recruitment. As such, organizational efforts aimed at promoting recruitment of women may have the most to gain from focusing on such regions. It is, however, important to note that educational missions may vary among medical schools, with some schools aiming to recruit students into primary care as opposed to neurosurgery. Such motivations must be taken into account when engaging in recruitment efforts.

Additionally, larger departments have a higher chance of recruiting female medical students by offering more opportunities for strong partnerships with mentors to develop. Departments that emphasize mentorship qualities and skills in their clinical faculty hiring practices, in addition to gender diversification strategies, may maximize the chances of attracting more women medical students into the field. Similar quantitative analyses centered on recruitment patterns in other surgical subspecialties, such as plastic surgery, orthopedic surgery, and otolaryngology, remain warranted. In recognition of the crucial role that women have played in the progress of neurosurgery abroad, including regions such as Asia, Australasia, Latin America, and India,[17–19] comparable analyses and data curation efforts must be established internationally.

Overall, based on our findings, we suggest three recommendations that we believe may have an immediate impact on female recruitment and career advancement. First, efforts should be focused on introducing the field of neurosurgery to female medical students at matriculation, when the gender gap in surgical specialty interest is widest.[8] In turn, these efforts may encourage female students who otherwise may not have been interested in neurosurgery to begin exploring the field, thus enabling them to get an early start in developing more competitive applications and dispelling negative notions they may have had about the field. Second, research fellowships and opportunities should be specifically targeted to female neurosurgery residents, as our data show that gender disparities in research productivity widen during residency. Finally, concerted efforts should be made to create female neurosurgery groups comprising faculty, residents, and medical students at each institution. Groups such as these may enable female medical students to view women neurosurgeons as a unified minority as opposed to dispersed individuals and may help minimize the 15% critical mass threshold described by Benzil et al.,[10] which may be required for more robust recruitment of women neurosurgeons.

Study Limitations

Our findings must be interpreted with caution. Data regarding applicants who were interested in neurosurgery but who failed to match during the 7-year study period were missed. Addition of this information to percentage entry into the field would reflect not only interest in the field, but also the ability to match successfully. Arguably, however, successful recruitment of medical students into surgical fields is more important as an outcome measure than merely promoting interest in pursuing surgical training. In addition, our data captured female neurosurgery residents who trained during the 2020–2021 academic year; it did not, however, account for residents who may have matched in positions beyond PGY-1 or who may have matched but subsequently discontinued training, possibilities to which a small amount of attrition may be attributed. Another limitation is our assumption that all medical school male-to-female student ratios are exactly one to one. While this is generally true for the vast majority of medical schools, in some programs the ratios may vary by a small percentage. Our study was also limited in its inability to capture nonbinary individuals or to confirm the gender identity that each resident associates with; this shortcoming was

primarily due to the heterogeneity of data for each resident profile on different program websites. Finally, our data only represent contemporary trends; it may be worthwhile to track even larger cohorts over a longer period of time.

Conclusions

This study characterizes which medical schools are most successful at recruiting female students into the current resident workforce of a traditionally gender-imbalanced specialty. The overall number of clinical faculty rather than faculty gender was independently associated with female recruitment. Gender differences in research productivity persisted with control for confounders and increased between preresidency and 2021 time points. Increased understanding of the manifestations of gender disparities can help improve female representation in neurosurgery residency training moving forward, a need that remains crucially unmet, while providing a data curation and analysis model that can be used to address disparities in other surgical subspecialties.

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Disclosures

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