JNS

CLINICAL ARTICLE

J Neurosurg 137:283–295, 2022

Which medical schools produce the most neurosurgery residents? An analysis of the 2014–2020 cohort

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OBJECTIVE In this study, the authors sought to determine which US medical schools have produced the most neurosurgery residents and to evaluate potential associations between recruitment and medical school characteristics.

METHODS Demographic and bibliometric characteristics were collected for 1572 residents in US-based and Accreditation Council for Graduate Medical Education (ACGME)–accredited neurosurgery programs over the 2014 to 2020 match period using publicly available websites. US medical school characteristics were collected, including class size, presence of a home neurosurgery program, number of clinical neurosurgery faculty, research funding, presence of a neurosurgery interest group, and a top 10 ranking via *U.S. News & World Report* or Doximity. Correlations and associations were then evaluated using Pearson's correlation coefficient (PCC), independent-samples t-test, and univariable or stepwise multivariable linear regression, as appropriate.

RESULTS Vanderbilt University produced the most neurosurgery residents as a percentage of medical graduates at 3.799%. Case Western Reserve University produced the greatest absolute number of neurosurgery residents (n = 40). The following factors were shown to be associated with a higher mean percentage of graduates entering neurosurgery: number of clinical neurosurgery faculty (PCC 0.509, $p < 0.001$), presence of a neurosurgery interest group (1.022% ± 0.737% vs 0.351% ± 0.327%, $p < 0.001$) or home neurosurgery program (1.169% ± 0.766% vs 0.428% ± 0.327%, $p < 0.001$), allopathic compared with osteopathic school (0.976% ± 0.719% vs 0.232% ± 0.272%, $p < 0.001$), *U.S. News* top 10 ranking for neurology and neurosurgery (1.923% ± 0.924% vs 0.757% ± 0.607%, $p < 0.001$), Doximity top 10 residency program ranking (1.715% ± 0.803% vs 0.814% ± 0.688%, $p < 0.001$), and amount of NIH funding (PCC 0.528, $p < 0.001$).

CONCLUSIONS The results of this study have delineated which medical schools produced the most neurosurgery residents currently in training, and the most important independent factors predicting the percentage of graduates entering neurosurgery and the preresidency *h*-index.

https://thejns.org/doi/abs/10.3171/2021.7.JNS211530

KEYWORDS internship and residency; education; career choice; personnel selection; publishing; research

Neurosurgery is a field that has traditionally tried to recruit the best and brightest students.[1,2] Medical students applying to neurosurgery often have the highest standardized test scores and research productivity compared with those of other medical specialties.[3] Aside from standardized test scores and research productivity, other factors such as where an applicant attends medical school,[4] the ability to connect with supportive mentors,[5] and strong letters of recommendation[6] have also been demonstrated to be important in resident selection. However, less is known about the characteristics of medical schools and the extent to which they influence how medical students become interested in and successfully match into neurosurgery residency programs.

Previous research by Price et al. demonstrated that the number of first author publications by medical students is statistically correlated with neurosurgery department size.[7] Lubelski et al. suggested that the presence of a neurosurgery interest group is correlated with medical student recruitment into the field.[8] In a study reviewing the neu-

ABBREVIATIONS AANS = American Association of Neurological Surgeons; ACGME = Accreditation Council for Graduate Medical Education; AΩA = Alpha Omega Alpha; PCC = Pearson's correlation coefficient; PGY = postgraduate year.

SUBMITTED June 21, 2021. **ACCEPTED** July 27, 2021.

INCLUDE WHEN CITING Published online November 26, 2021; DOI: 10.3171/2021.7.JNS211530.

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rosurgery match between 1990 and 2007, Durham et al. concluded that attending a top 40 NIH-funded medical school was statistically correlated with matching (81% of applicants) into a neurosurgery residency when compared with non–top 40 NIH-funded medical schools (66%).[9]

Critically, however, the literature lacks data delineating which medical schools produce the most neurosurgery residents, both in absolute numbers and in a relative percentage of the graduating class. In this study, we examined 1572 US neurosurgery residents who matched over a 7-year period from 2014 to 2020 and characterized the top feeder medical schools for neurosurgery residencies. Secondarily, we analyzed which medical school parameters were correlated with successful recruitment of students into neurosurgery residency and with preresidency *h*-index, given the emphasis placed on research in the field and the importance of recruiting medical students with academic interest.

Methods

Resident Cohort

A list of Accreditation Council for Graduate Medical Education (ACGME)–accredited residency training programs in neurosurgery was obtained from the American Association of Neurological Surgeons (AANS) neurosurgery residency training program directory. Canadian programs were excluded. The publicly available websites of the included US programs were accessed in February 2021 to acquire a complete list of current residents (postgraduate year [PGY]–1 through PGY-7), which reflected successfully matched medical school applicants in neurosurgery over the 2014 to 2020 match period.

Variables Collected for Residents

This project involved the creation of an IRB-approved database of residents and US medical schools. Consent was waived given the use of publicly available information. For every resident, demographic information was collected, including sex, residency program name, PGY, medical school name and year of graduation, international medical graduate status, degrees obtained (e.g., MD or equivalent, MS or equivalent, MPH, and PhD), and Alpha Omega Alpha (AΩA) Honor Medical Society membership (https://www.alphaomegaalpha.org/ #gsc.tab = 0). Website information was supplemented with publicly available data from Google Scholar, LinkedIn, Doximity, and DocInfo.

Bibliometrics were additionally accrued for each resident by utilizing the author search tool in Web of Science (Clarivate Analytics). The total number of published papers and abstracts, total number of citations, and *h*-index were collected at the preresidency (by the end of medical school) and current time points. If publications had different names belonging to the same author, Web of Science allowed the merging of multiple author profiles.

Medical School Data

Once a list of feeder medical schools for neurosurgery (2014–2020) was generated, characteristics were collected for every feeder school located in the US. International medical schools were excluded from this step given the absence of data availability for most schools and since the top feeder schools are US-based. Medical school class size was obtained from the Association of American Medical Colleges website (https://apps.aamc.org/msar-ui/#/landing) and from the respective school web pages. Cross-referencing with the AANS neurosurgery residency training programs list and supplementary online queries were used to determine which medical schools had a home neurosurgery residency program. The online websites for the neurosurgery departments were used to record the number of clinical neurosurgery faculty affiliated with each medical school. The presence of a neurosurgery interest group was determined using the AANS directory of medical student chapters (https://www.aans.org/Trainees/Medical-Students/Chapter-Directory) and from medical school websites. The total reported NIH funding amount for each medical school in 2020 was obtained from the *U.S. News & World Report* 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). Information regarding affiliated neurosurgery department reputation was recorded by determining whether the affiliated hospital was ever ranked in the *U.S. News* top 10 ranking for neurology and neurosurgery from 2014 to 2020. The 2021 top 10 ranking for affiliated neurosurgery program reputation was also recorded using the Doximity Residency Navigator tool (https://www.doximity.com/residency). Geographical data constituted the state in which each medical school was located and the region (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).

Statistical Analysis

Descriptive statistics were used to summarize the resident cohort characteristics (number and percentage for categorical data and mean ± standard deviation for continuous data). To obtain an estimate of the number of graduating medical students from each feeder school over the 7-year period, the class size was multiplied by 7. Subsequently, the medical schools were ranked according to the percentage of graduates successfully entering neurosurgery from highest to lowest. Associations between the percentage of graduates entering neurosurgery, on one hand, and the number of neurosurgery faculty, amount of NIH funding, presence of a neurosurgery interest group, and reputation ranking, on the other, were evaluated using Pearson's correlation coefficient (PCC) and the independent-samples t-test as appropriate. Graphic representations of these univariable associations were provided using scatterplots and boxplots with labeling of outlier schools. Stepwise multivariable linear regression was used to determine factors that were independently associated with the percentage of graduates entering neurosurgery. Univariable and stepwise multivariable linear regression were also used to identify medical school characteristics that were associated with the preresidency *h*-index of matched applicants. Standardized beta values were derived to identify the relative importance of every variable. Statistical analyses were performed using

IBM SPSS Statistics version 25.0 (IBM Corp.), with statistical significance set at $p < 0.05$.

Results

General Cohort Characteristics

A total of 1572 residents in US-based ACGME-accredited neurosurgery programs reflecting matched applicants over the 2014 to 2020 match periods were identified. The general demographic and bibliometric characteristics of the residents are summarized in Table 1. There were 317 (20%) females and 113 (7%) international medical graduates. The proportions of DO and PhD degree holders were 4% and 11%, respectively, and a total of 434 residents (28%) were AΩA members. The mean preresidency *h*-index was 3.3 ± 3.9 and increased to 4.5 ± 4.3 in 2021.

TABLE 1. Demographic and bibliometric summary for the entire cohort of residents, 2014–2020

Variable	Value
Demographics	
Female sex	317 (20)
International medical graduate	113 (7)
Degrees	
MD	1492 (95)
MBBS	12 (1)
DO	70 (4)
MS	126 (8)
MPH	35 (2)
PhD	167 (11)
AΩA membership	434 (28)
Bibliometrics (n = 1563)	
Preresidency	
Mean no. of published papers & abstracts	8.3 ± 13.0
Mean no. of citations	129.7 ± 315.5
Mean *h*-index	3.3 ± 3.9
2021	
Mean no. of published papers & abstracts	17.2 ± 22.0
Mean no. of citations	175.3 ± 425.8
Mean *h*-index	4.5 ± 4.3

Values represent the number of residents (%) or mean ± SD.

Top Feeder Schools

The subsequent analyses focus on graduates of US medical schools (n = 1459). The 165 US medical schools who contributed ≥ 1 neurosurgery resident over the 7-year period contributed a mean of 8.8 ± 7.2 residents per school. The mean percentage of medical graduates going into neurosurgery from 2014 to 2020 was 0.86% ± 0.72% per school. The top US-based feeder schools for neurosurgery are summarized in Table 2. The top 49 schools (30%) in recruitment had > 1% of their graduates going into neurosurgery. The top 10 recruiting medical schools each year from 2014 to 2020 are displayed in Supplementary Table 1.

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 graduates going into neurosurgery (PCC 0.509, $p < 0.001$). On linear regression, an absolute increase of 0.026 percentage points (95% CI 0.019–0.033, $p < 0.001$) of graduates entering neurosurgery was identified per each clinical faculty member increase (Fig. 1). Some schools were still able to recruit a large percentage of their graduates into the field despite a small department size.

NIH funding data were available for 144 feeder medical schools, and the mean funding amount per school was $171.2 million ± $250.7 million (median $76.6 million [IQR $12.0–$220.1 million]). There was a significant correlation between the total NIH funding amount and the percentage of graduates going into neurosurgery (PCC 0.528, $p < 0.001$). On linear regression, an absolute increase of 0.002 percentage points (95% CI 0.001–0.002, $p < 0.001$) of graduates entering neurosurgery was identified per every $1 million increase in funding (Fig. 2).

Of 165 feeder schools, 126 (76%) had a neurosurgery interest group, 97 (59%) had a home neurosurgery program, and 25 (15%) were osteopathic schools. Only 4 (16%) osteopathic schools had a neurosurgery interest group, compared with 122 (87%) allopathic schools ($p < 0.001$). Medical schools with a neurosurgery interest group had a higher mean percentage of graduates entering neurosurgery (1.022% ± 0.737% vs 0.351% ± 0.327%, $p < 0.001$; Fig. 3A). The mean percentage of graduates entering neurosurgery was around three times higher in medical schools with a home neurosurgery program (1.169% ± 0.766% vs 0.428% ± 0.327%, $p < 0.001$; Fig. 3B) and more than four times higher in allopathic compared with osteopathic schools (0.976% ± 0.719% vs 0.232% ± 0.272%, $p < 0.001$; Fig. 3C). Some schools still had a relatively larger number of graduates entering neurosurgery despite lacking an interest group or home residency program.

A *U.S. News* top 10 ranking (2014–2020) for neurology and neurosurgery was significantly associated with a higher mean percentage of graduates entering neurosurgery (1.923% ± 0.924% vs 0.757% ± 0.607%, $p < 0.001$; Fig. 4), with similar results obtained for a Doximity top 10 (2021) residency program ranking (1.715% ± 0.803% vs 0.814% ± 0.688%, $p < 0.001$; Fig. 4).

With respect to geographical region, medical schools in the Northeast (n = 38) had the highest average recruitment (1.091% of graduates), followed by southern schools (n = 62, 0.825%), midwestern schools (n = 41, 0.820%), and western schools (n = 24, 0.694%). On linear regression, medical schools in the Northeast had significantly higher recruitment than those in the West (β 0.4, 95% CI 0.1–0.8; $p = 0.036$).

A stepwise linear regression model demonstrated the following factors to be independently associated with the percentage of medical graduates entering neurosurgery: neurosurgery faculty size, presence of a home neurosurgery program, being an allopathic medical school, and having a *U.S. News* top 10 ranking (Table 3). Based on standardized beta values, having an affiliated hospital rank in the top 10 for neurology and neurosurgery had the greatest effect on the percentage of graduates entering neurosurgery.

TABLE 2. The top feeder US medical schools for neurosurgery in the match period of 2014–2020

Rank	Medical School	Total No. of Residents	% of Graduates
1	Vanderbilt University School of Medicine	25	3.799
2	New York University School of Medicine	24	3.361
3	Stanford University School of Medicine	21	3.333
4	Cleveland Clinic Lerner College of Medicine	7	3.125
5	Case Western Reserve University School of Medicine	40	3.106
6	Columbia University Vagelos College of Physicians and Surgeons	30	3.061
7	Yale School of Medicine	21	3.000
8	Rutgers New Jersey Medical School	33	2.648
9	Duke University School of Medicine	22	2.576
10	Louisiana State University School of Medicine	25	2.381
11	Johns Hopkins University School of Medicine	19	2.243
12	Harvard Medical School	26	2.211
13	University of Pittsburgh School of Medicine	21	2.013
14	University of California, San Diego, School of Medicine	17	1.826
15	Albany Medical College	16	1.786
16	Washington University School of Medicine in St. Louis	13	1.786
17	Weill Cornell Medicine	13	1.752
18	Georgetown University School of Medicine	24	1.689
19	University of Alabama at Birmingham School of Medicine	21	1.613
20	Mayo Clinic Alix School of Medicine	11	1.497
21	University of Florida College of Medicine	14	1.481
22	Perelman School of Medicine at the University of Pennsylvania	16	1.475
23	Texas Tech University Health Sciences Center El Paso, Paul L. Foster School of Medicine	11	1.429
24	University of Miami Miller School of Medicine	20	1.401
25	University of Rochester School of Medicine	10	1.401
26	David Geffen School of Medicine at University of California, Los Angeles	17	1.388
27	Nova Southeastern University College of Osteopathic Medicine	5	1.374
28	Rosalind Franklin University/Chicago Medical School	18	1.361
29	Baylor College of Medicine	17	1.306
30	Virginia Commonwealth University School of Medicine	17	1.306
31	Warren Alpert Medical School of Brown University	13	1.290
32	Geisel School of Medicine at Dartmouth	8	1.270
33	University of Chicago, Pritzker School of Medicine	8	1.270
34	Emory University School of Medicine	12	1.233
35	Keck School of Medicine of the University of Southern California	16	1.229
36	Virginia Tech Carilion School of Medicine	4	1.190
37	University of Tennessee College of Medicine	14	1.176
38	University of Texas Health Science Center at San Antonio	17	1.146
39	University of California, San Francisco, School of Medicine	14	1.124
40	University of Virginia School of Medicine	12	1.106
41	University of Nebraska College of Medicine	10	1.091
42	The Ohio State University College of Medicine	15	1.045
43	Icahn School of Medicine at Mount Sinai	10	1.020
44	University of Cincinnati College of Medicine	13	1.020
45	McGovern Medical School at the University of Texas Health Science Center at Houston	17	1.012
46	New York Medical College	15	1.011
47	Sidney Kimmel Medical College, Thomas Jefferson University	19	1.005
48	University of Texas Southwestern Medical School	16	1.003
49	University of Wisconsin School of Medicine	12	1.003

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TABLE 2. The top feeder US medical schools for neurosurgery in the match period of 2014–2020

Rank	Medical School	Total No. of Residents	% of Graduates
50	Lewis Katz School of Medicine at Temple University	15	0.983
51	University of Arizona College of Medicine, Tucson	8	0.977
52	University of Oklahoma College of Medicine	11	0.958
53	Florida State University College of Medicine	4	0.952
54	Loyola University Chicago Stritch School of Medicine	11	0.952
55	University of Illinois College of Medicine at Chicago	12	0.952
56	University of Maryland School of Medicine	10	0.940
57	Indiana University School of Medicine	24	0.939
58	Tufts University School of Medicine	13	0.929
59	Rush Medical College	10	0.922
60	Larner College of Medicine at the University of Vermont	8	0.922
61	University of South Florida Morsani College of Medicine	12	0.907
62	University of Louisville School of Medicine	10	0.898
63	Florida Atlantic University Charles E. Schmidt College of Medicine	4	0.893
64	Marshall University Joan C. Edwards School of Medicine	5	0.893
65	Augusta University Medical College of Georgia	15	0.893
66	Northwestern Feinberg School of Medicine	10	0.893
67	State University of New York Upstate Medical University	10	0.893
68	University of Illinois College of Medicine at Peoria	4	0.879
69	University of Arizona College of Medicine Phoenix	6	0.857
70	Pennsylvania State University College of Medicine	9	0.846
71	University of Colorado School of Medicine	9	0.829
72	Cooper Medical School of Rowan University	5	0.812
73	The University of Toledo College of Medicine	10	0.812
74	University of Utah School of Medicine	7	0.800
75	Wake Forest School of Medicine	8	0.788
76	Oregon Health & Science University	8	0.762
77	Boston University School of Medicine	8	0.752
78	University of Iowa Carver College of Medicine	8	0.752
79	Wayne State University School of Medicine	15	0.736
80	Albert Einstein College of Medicine	9	0.703
81	George Washington University School of Medicine	9	0.699
82	Florida International University Herbert Wertheim College of Medicine	6	0.697
83	University of Missouri–Kansas City School of Medicine	6	0.691
84	University of California, Irvine, School of Medicine	5	0.687
85	Michigan State University College of Osteopathic Medicine	14	0.680
86	University of Michigan Medical School	8	0.680
87	Uniformed Services University	8	0.676
88	Brody School of Medicine at East Carolina University	4	0.664
89	Northeast Ohio Medical University	7	0.662
90	Medical University of South Carolina College of Medicine	8	0.661
91	Drexel University College of Medicine	12	0.659
92	Robert Wood Johnson Medical School	8	0.657
93	Stony Brook University School of Medicine	6	0.630
94	University of Kentucky College of Medicine	9	0.627
95	Tulane University School of Medicine	8	0.602
96	University of Central Florida College of Medicine	5	0.595
97	Carle Illinois College of Medicine at the University of Illinois at Urbana-Champaign	2	0.595

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TABLE 2. The top feeder US medical schools for neurosurgery in the match period of 2014–2020

Rank	Medical School	Total No. of Residents	% of Graduates
98	University of Minnesota Medical School	10	0.593
99	University of North Carolina at Chapel Hill School of Medicine	8	0.592
100	Zucker School of Medicine at Hofstra/Northwell	4	0.577
101	Eastern Virginia Medical School	6	0.571
102	Oakland University William Beaumont School of Medicine	5	0.571
103	Jacobs School of Medicine and Biomedical Sciences	7	0.556
104	Saint Louis University School of Medicine	7	0.546
105	Southern Illinois University School of Medicine	3	0.536
106	University of South Carolina School of Medicine Greenville	4	0.529
107	University of Connecticut School of Medicine	4	0.519
108	University of Illinois College of Medicine at Rockford	2	0.519
109	University of Mississippi School of Medicine	6	0.519
110	University of Texas Medical Branch at Galveston, School of Medicine	8	0.497
111	Texas A&M University Health Science Center College of Medicine	6	0.490
112	Medical College of Wisconsin	9	0.483
113	SUNY Downstate Health Sciences University, College of Medicine	7	0.483
114	Creighton University School of Medicine	5	0.461
115	Quinnipiac University, Frank H. Netter MD School of Medicine	3	0.456
116	University of New Mexico School of Medicine	3	0.442
117	University of North Dakota School of Medicine and Health Sciences	2	0.426
118	University of Arkansas for Medical Sciences College of Medicine	5	0.413
119	East Tennessee State University Quillen College of Medicine	2	0.397
120	West Virginia University School of Medicine	3	0.383
121	Sophie Davis School of Biomedical Education at the City University of New York School of Medicine	2	0.376
122	University of Hawaii, John A. Burns School of Medicine	2	0.371
123	Wright State University School of Medicine	3	0.363
124	University of Kansas School of Medicine	5	0.339
125	Philadelphia College of Osteopathic Medicine	6	0.317
126	Touro College of Osteopathic Medicine	3	0.317
127	University of Texas at Austin, Dell Medical School	1	0.286
128	Lake Erie College of Osteopathic Medicine	5	0.286
129	Midwestern University Chicago College of Osteopathic Medicine	4	0.279
130	Central Michigan University College of Medicine	2	0.277
131	Morehouse School of Medicine	2	0.272
132	Rocky Vista University College of Osteopathic Medicine	3	0.265
133	University of Washington School of Medicine	5	0.265
134	University of Puerto Rico School of Medicine	2	0.260
135	Loma Linda University School of Medicine	3	0.255
136	Meharry Medical College	2	0.248
137	Howard University College of Medicine	2	0.238
138	Edward Via College of Osteopathic Medicine	3	0.232
139	Mercer University School of Medicine	2	0.229
140	San Juan Bautista School of Medicine	1	0.227
141	Midwestern University Arizona College of Osteopathic Medicine	4	0.225
142	University of California, Davis, School of Medicine	2	0.225
143	University of Missouri School of Medicine	2	0.223
144	New York Institute of Technology College of Osteopathic Medicine	4	0.212
145	University of Pikeville, Kentucky College of Osteopathic Medicine	2	0.212

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TABLE 2. The top feeder US medical schools for neurosurgery in the match period of 2014–2020

Rank	Medical School	Total No. of Residents	% of Graduates
146	University of South Dakota Sanford School of Medicine	1	0.207
147	University of Nevada, Reno, School of Medicine	1	0.204
148	University of Massachusetts Chan Medical School	2	0.176
149	Kirksville College of Osteopathic Medicine, A.T. Still University	2	0.168
150	Southwest College of Naturopathic Medicine & Health Sciences	1	0.150
151	University of South Carolina School of Medicine Columbia	1	0.144
152	School of Osteopathic Medicine in Arizona, A.T. Still University	1	0.143
153	College of Osteopathic Medicine of the Pacific, Western University of Health Sciences	3	0.131
154	Des Moines University College of Osteopathic Medicine	2	0.129
155	Texas College of Osteopathic Medicine, University of North Texas Health Science Center	2	0.124
156	Touro University College of Osteopathic Medicine in California	1	0.105
157	Campbell University School of Osteopathic Medicine	1	0.095
158	Ponce Health Sciences University School of Medicine	1	0.095
159	Liberty University College of Osteopathic Medicine	1	0.092
160	William Carey University College of Osteopathic Medicine	1	0.090
161	University of New England College of Osteopathic Medicine	1	0.087
162	Touro University Nevada College of Osteopathic Medicine	1	0.085
163	West Virginia School of Osteopathic Medicine	1	0.071
164	Kansas City University College of Osteopathic Medicine	1	0.053
165	Lincoln Memorial University–DeBusk College of Osteopathic Medicine	1	0.039

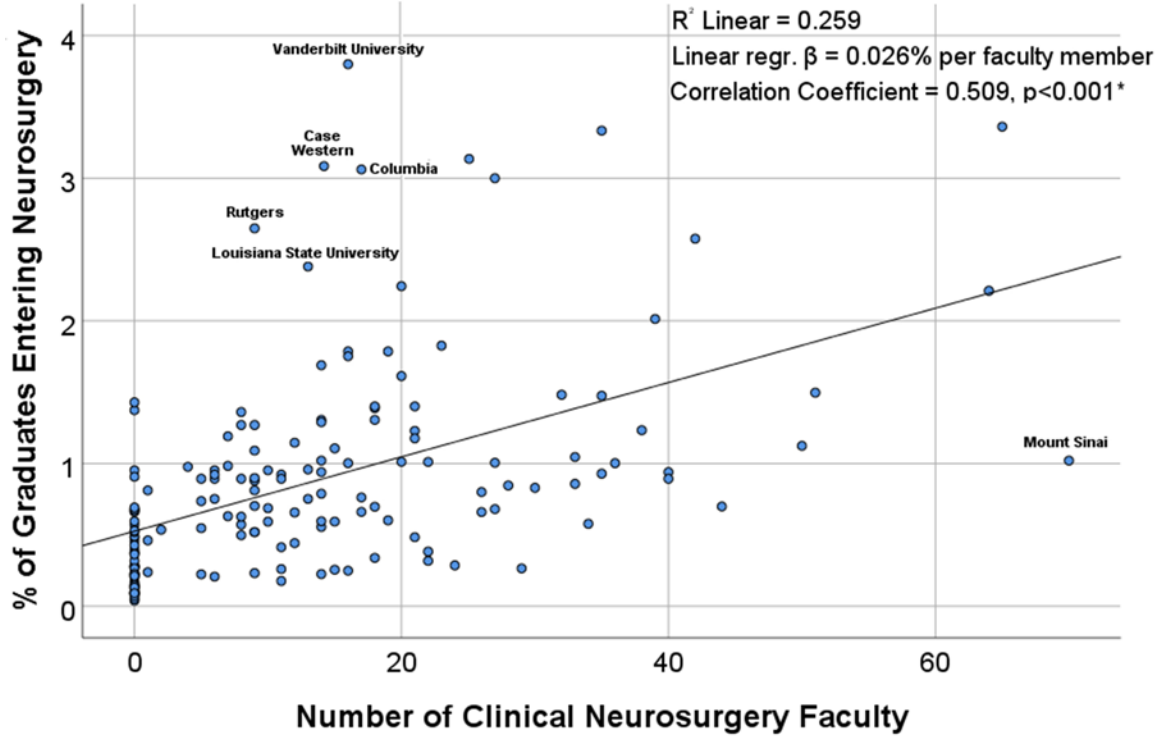

FIG. 1. Scatterplot showing the relationship between the number of clinical neurosurgery faculty and the percentage of graduates entering neurosurgery (n = 165). *Blue circles* indicate the individual medical schools. *Statistically significant ($p < 0.050$). regr. = regression. Figure is available in color online only.

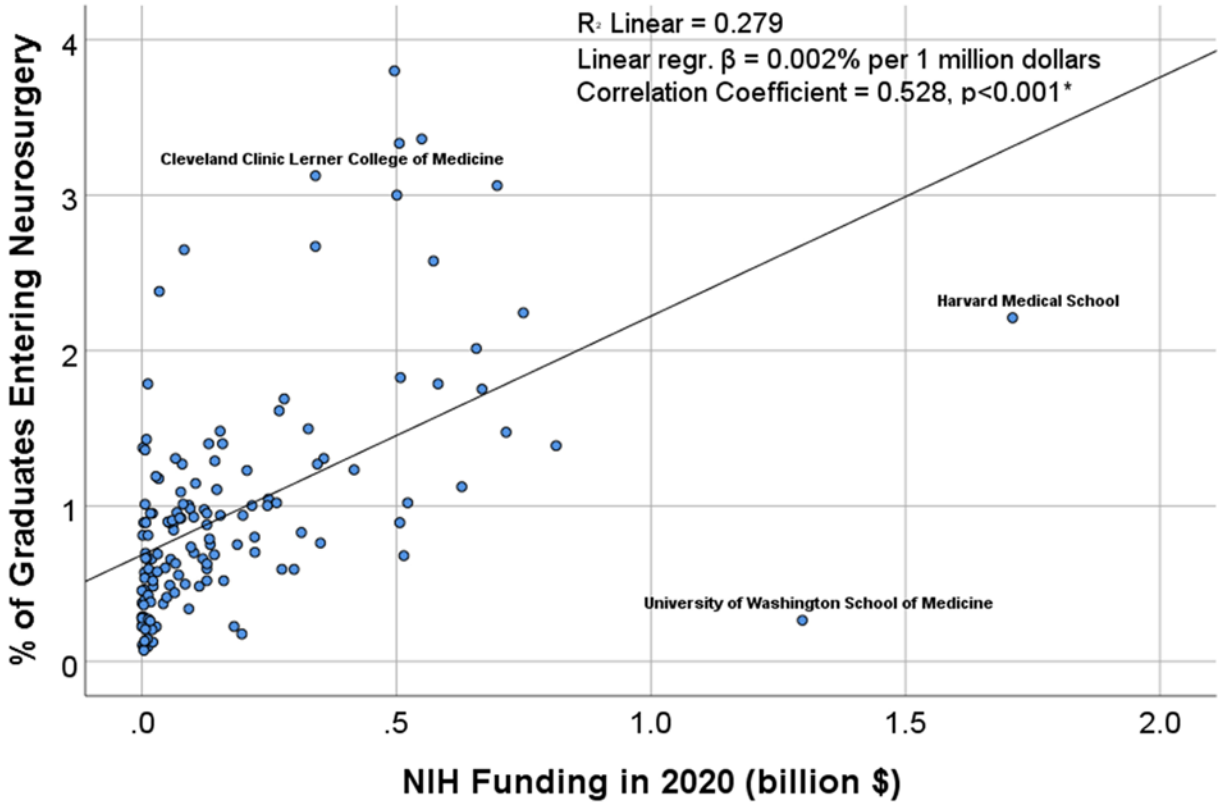

FIG. 2. Scatterplot showing the relationship between the amount of NIH funding in 2020 and the percentage of graduates entering neurosurgery (n = 144). *Blue circles* indicate the individual medical schools. *Statistically significant ($p < 0.050$). Figure is available in color online only.

Preresidency *h*-Index

The univariable and stepwise multivariable linear regression analyses of factors associated with the average preresidency *h*-index per school are summarized in Table 4. Larger neurosurgery faculty size, *U.S. News* top 10 ranking, and a higher percentage of graduates entering neurosurgery were independently associated with a higher preresidency *h*-index. Based on the standardized beta values, the size of the affiliated neurosurgery department had the greatest effect on preresidency *h*-index.

Discussion

Our study is the first of its kind to delineate which medical schools produce the most neurosurgery residents, both as an absolute number and as a relative percentage of class size. Of the 165 medical schools in our sample, Vanderbilt University School of Medicine (faculty size of 16, 2022 *U.S. News* medical school rank of 13, and 2021 Doximity residency rank of 30) had the highest percentage of its class entering the field of neurosurgery, with 25 medical students over the past 7 years, comprising 3.799% of graduates. Case Western Reserve University School of Medicine (faculty size of 14, 2022 *U.S. News* medical school rank of 25, and 2021 Doximity residency rank of 39) had the highest absolute number of medical students entering the field within the past 7 years, with 40 medical students (3.106% of graduates). While several medical schools in the top 10 of our recruitment ranking were expected and traditionally ranked in the top 10 best programs or hospitals by reputation and outcome/research metrics, others such as Louisiana State University School of Medicine (2022 *U.S. News* "unranked") and Rutgers New Jersey Medical School (2022 *U.S. News* rank of 66) were not expected.

Several programs in the top 15 recruitment positions, such as Vanderbilt, Stanford, University of Pittsburgh, Johns Hopkins, and Rutgers, have published about the implementation of early-exposure programs for medical students to stimulate early interest in the field. For example, at Vanderbilt, faculty in 2012 and 2013 offered 1st- and 2nd-year medical students the opportunity to enroll in a neurosurgery elective that combined clinical experience with faculty discussions.[10] After the elective, students responded that they were more likely to consider neurosurgery as a future career ($p < 0.0001$), perceive the personalities of attending physicians to be more collegial and friendly ($p = 0.0002$), perceive attending quality of life to be higher ($p < 0.0001$), and believed it was achievable to be a neurosurgeon and have a family ($p < 0.0001$). At Stanford, the third highest-ranked medical school as a relative percentage of neurosurgery residents produced in relation to class size, a similar program has been established.[11] There, faculty created an introductory surgical skills training course for preclinical students that combined clinical exposure to the field and access to neurosurgery faculty as mentors.[11] The University of Pittsburgh Medical Center offered a preclini-

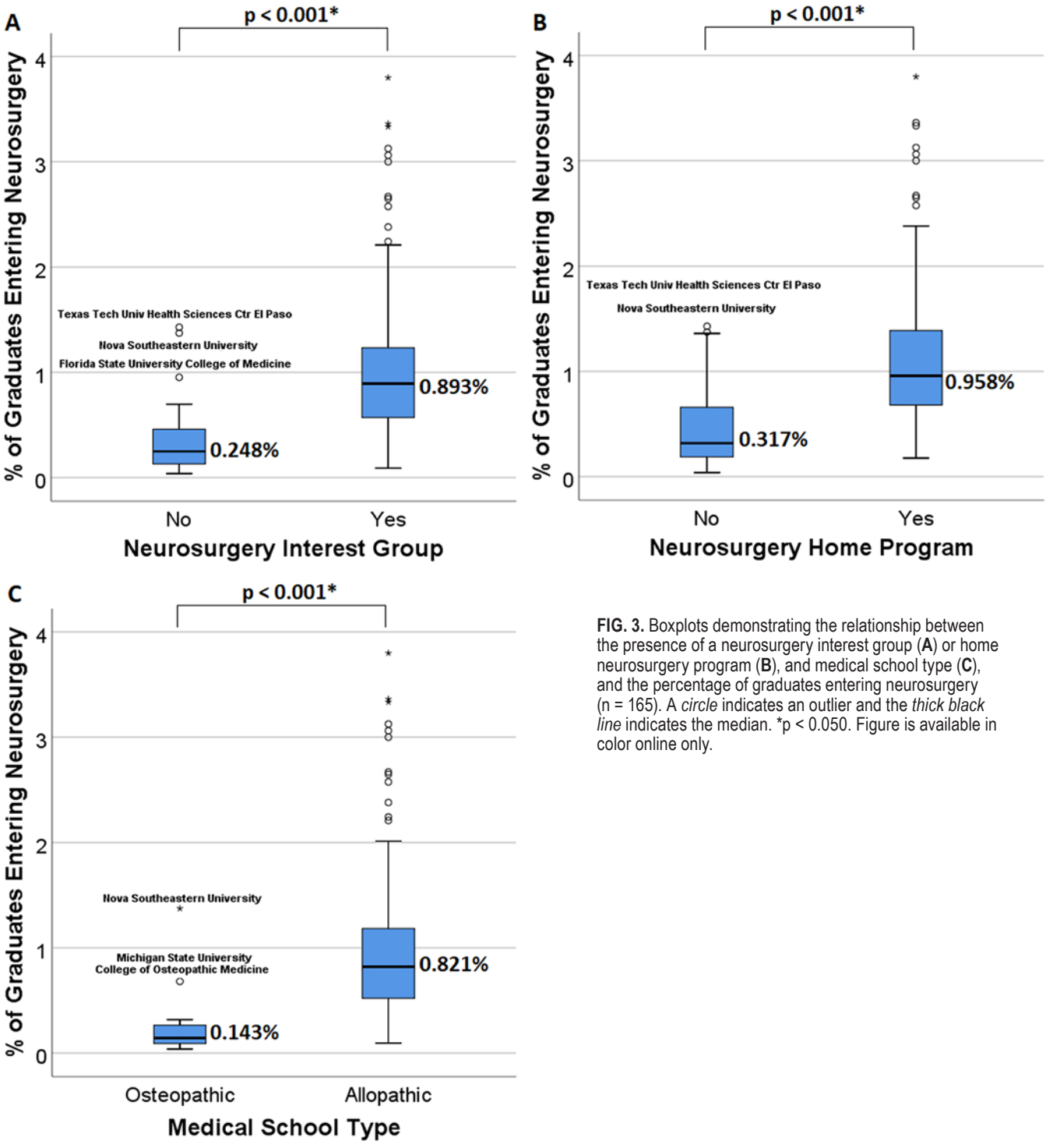

FIG. 3. Boxplots demonstrating the relationship between the presence of a neurosurgery interest group (**A**) or home neurosurgery program (**B**), and medical school type (**C**), and the percentage of graduates entering neurosurgery (n = 165). A *circle* indicates an outlier and the *thick black line* indicates the median. *p < 0.050. Figure is available in color online only.

cal elective course for 2nd-year medical students, which was organized by residents, senior students, and attendings, that culminated with a higher chance of selecting neurosurgery as a career, an increased understanding of the field, and improved knowledge scores at the postcourse time point.[12] The Johns Hopkins Department of Neurosurgery launched a neuroanatomy lab initiative for 1st-year medical students that resulted in their becoming more knowledgeable about the field and starting to perceive faculty and residents as more pleasant, affable, and satisfied with their careers.[13] Finally, at Rutgers, a phased early-exposure program was added in 2002, consisting of earlier and more expansive neurosurgery electives, a summer neurosurgery research experience for medical students and undergraduates, and a neurosurgery interest group.[14] All the schools with published early-exposure programs are ranked highly

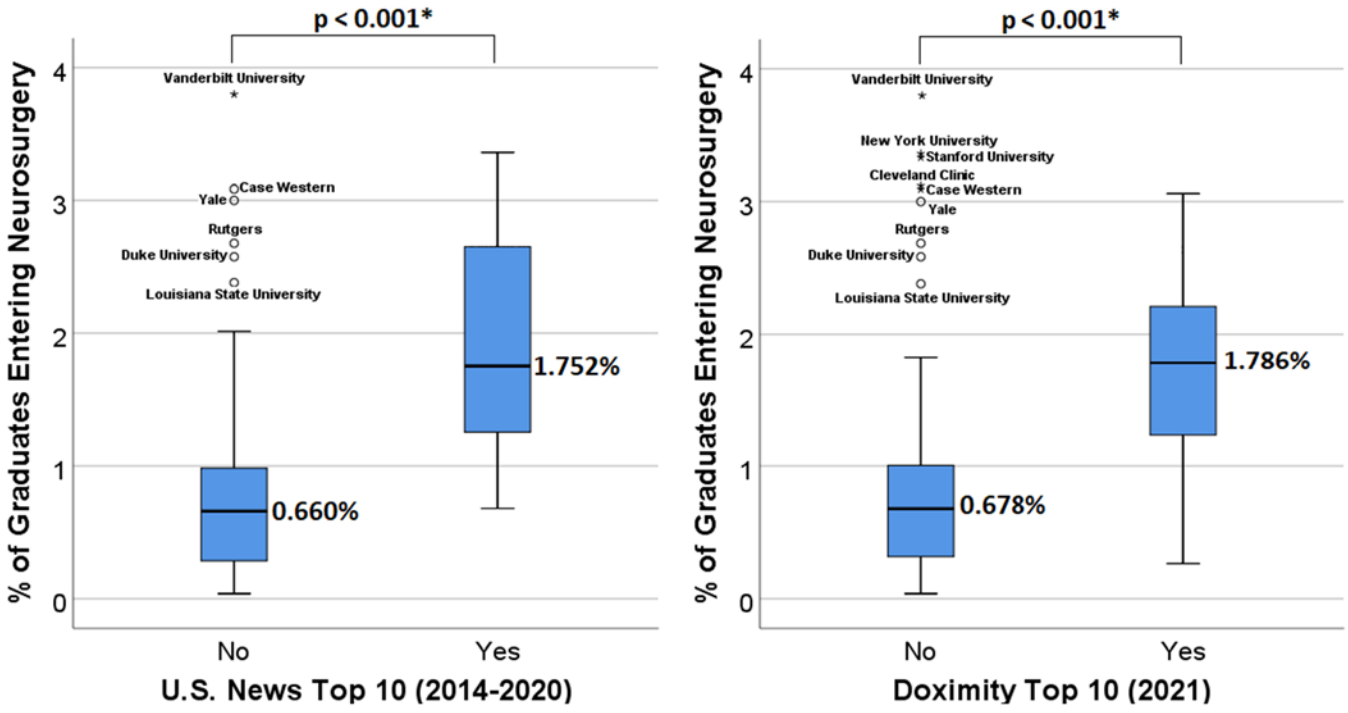

FIG. 4. Boxplots demonstrating the relationship between a top 10 *U.S. News* neurology and neurosurgery ranking from 2014 to 2020 (**left**) or Doximity residency program ranking for 2021 (**right**) and the percentage of graduates going into neurosurgery (n = 165). A *circle* indicates an outlier and the *thick black line* indicates the median. *p < 0.050. Figure is available in color online only.

on the recruitment list, which reinforces the efficacy and utility of such efforts, and indicates that more research about optimal timing, curricular structure, and delivery methods is warranted.

Our data also provided a descriptive sense of the 7-year cohort with some expected and unexpected findings. For example, it was of little surprise that 95% of residents held an MD as opposed to a DO degree, given previous research on the preference for allopathic as opposed to osteopathic graduates.[15] In our data set, graduates of allopathic medical schools had an almost fourfold higher rate of entry into neurosurgery compared with those of osteopathic schools.

Another unsurprising finding, given prior research,[16] was the percentage of female neurosurgery residents in the cohort—a mere 20%. Significant efforts have been made to address this gender gap in the field, with slow, but positive, trends.[15] Our findings also helped quantify how research productivity changes over time. Neurosurgery residents had a mean preresidency number of abstracts and publications of 8.3 ± 13.0, reflecting roughly 2 abstracts or publications produced for each year of medical school. That mean number increased to 17.2 ± 22.0 total abstracts or publications at the 2021 intraresidency time point. This was unsurprising, given that research productivity increases over time as trainees gain more experience.[17] The mean *h*-index also increased from a preresidency value of 3.3 ± 3.9 to a 2021 intraresidency value of 4.5 ± 4.3. Taken as a whole, these data may be of use to neurosurgery applicants and departments to gauge the research productivity of trainees in relation to the national cohort.

Regarding medical school and neurosurgery department characteristics, our data set corroborated previous research,[18] but, perhaps equally as important, quantified these relationships. For instance, we found a statistically significant correlation between the percentage of medical school graduates entering the field of neurosurgery and the clinical neurosurgery department size (PCC 0.509). For each additional clinical neurosurgery faculty member, an increase of 0.026% of graduates entering neurosurgery was observed. This was an independently associated factor in a multivariable model controlling for potential confounders such as the presence of a neurosurgery home program, type of medical school, or *U.S. News* top 10 ranking. In our model evaluating preresidency *h*-index, clinical neu-

TABLE 3. Stepwise multivariable linear regression model with percentage of graduates entering neurosurgery as the outcome (n = 165)

Variable	β (95% CI)	Standardized β Value	p Value
Neurosurgery faculty size, per faculty member	0.009 (0.001 to 0.017)	0.175	0.032*
Home neurosurgery program	0.378 (0.141 to 0.615)	0.256	0.002*
Allopathic school	0.280 (−0.005 to 0.564)	0.138	0.054
U.S. News top 10 (2013–2020)	0.746 (0.405 to 1.088)	0.295	<0.001*

* p < 0.050.

TABLE 4. Univariable and stepwise multivariable linear regression analysis of average preresidency *h*-index (n = 165)

Variable	Univariable		Multivariable	
	β (95% CI)	p Value	β (95% CI)	p Value
Clinical neurosurgery faculty size†	0.07 (0.05–0.09)	<0.001*	0.05 (0.02– 0.07)	<0.001*
Neurosurgery interest group	1.3 (0.6–2.0)	<0.001*	—	—
Home neurosurgery program	1.6 (1.0–2.2)	<0.001*	—	—
Allopathic vs osteopathic school	1.4 (0.6–2.3)	0.001*	—	—
U.S. News top 10 (2014–2020)†	2.9 (1.9–3.9)	<0.001*	1.3 (0.2–2.3)	0.019*
Doximity top 10 (2021)	2.4 (1.1–3.8)	<0.001*	—	—
% of graduates entering neurosurgery†	1.2 (0.8–1.6)	<0.001*	0.6 (0.1–1.0)	0.014*

* $p < 0.050$.

† Standardized β values: 0.314 for department size, 0.182 for *U.S. News* ranking, and 0.197 for percentage of graduates entering neurosurgery.

rosurgery faculty size was also a significantly associated variable. Taken together, this suggests that a large neurosurgery clinical faculty size may, in part, be important for recruiting medical students to the field by providing more opportunities for research. It may additionally maximize the chances of pairing up interested medical students with mentors with whom they can identify and from whom they can derive a meaningful mentor-mentee relationship. In addition to the number of clinical faculty, linear regression demonstrated that the amount of NIH funding received by a medical school was also significantly and modestly correlated (PCC 0.528) with an increase in the relative percentage of graduates entering the field. Each additional $1 million in funding was correlated with an absolute increase of 0.002% of graduates pursuing neurosurgery residency. This validated prior research by Durham et al. regarding the importance of selecting a highly NIH-funded medical school for neurosurgery residency.[9]

Moreover, our multivariable linear model further quantified other factors that were independently associated with the percentage of graduates entering neurosurgery. Standardized beta values also provided a measure of the relative importance of associated factors. Neurosurgery faculty size (standardized β 0.175), a home neurosurgery program (standardized β 0.256), and, most importantly, a *U.S. News* top 10 ranking (standardized β 0.295) were all independently correlated with the percentage of graduates entering neurosurgery. This suggests that having a highly ranked home neurosurgery program is among the most important factors for recruitment of medical students into the field, likely due to strong research and mentorship opportunities. Top-ranked affiliated programs and departments may also help provide reassurance for interested medical students that their chances of matching into a competitive specialty such as neurosurgery are higher. Furthermore, the presence of a neurosurgery home program was also demonstrated to be important for recruitment into the specialty. This is likely due a combination of factors, including a more productive research environment, increased access to mentors, the ability to procure strong letters of recommendation, and available positions for graduating home program medical students. As demonstrated by Dallas et al., early-exposure programs at schools without a home program, facilitated by neighboring academic institutions, can improve student perceptions of the field and help foster mentorship relationships that would have been otherwise difficult to establish.[19] When 17 Meharry Medical College students (no home program) participated in an early-exposure program at Vanderbilt, they began to view neurosurgery as less emotionally draining, more collegial and permissive of work-life balance, and were more likely to consider neurosurgery as a future career.[19] Participating remotely in research projects with mentors from outside academic institutions represents another avenue for students at schools without a home program.[20]

Other factors, such as the presence of a neurosurgery interest group, were also associated with recruitment into the field. Medical schools with an interest group recruited 1.022% of their graduates into neurosurgery compared with 0.351% of graduates from medical schools without an interest group. This corroborated a study by Lubelski et al., who suggested that the presence of a neurosurgery interest group was correlated with medical student recruitment into the field.[8] This variable was not included in the final stepwise multivariable model, possibly because interest groups were more likely present in schools with a home program and in allopathic schools. Also, not all interest groups are created equal, as those in top-ranked medical schools have been shown to have greater research activity and national conference attendance.[21] This emphasizes the notion that simply creating a group may not produce the intended effect if not provided with ample support and opportunities for academic productivity.

Beyond recruitment into the field, our bibliometric analysis determined which characteristics helped medical schools produce academically inclined neurosurgery residents. We found that clinical neurosurgery faculty size (standardized β 0.314), *U.S. News* top 10 ranking (standardized β 0.182), and percentage of graduates entering neurosurgery (standardized β 0.197) were all independently correlated with the preresidency *h*-index. Based on standardized β values, we found that clinical neurosurgery faculty size was the most important factor in predicting the preresidency *h*-index. This suggests that having a larger department is more important than having a highly ranked department in promoting a higher preresidency *h*-

index, although the latter still plays a role. The percentage of graduates entering the field was correlated with a higher preresidency *h*-index of matched students, potentially indicating that departments that are better at recruiting students are also more likely to recruit academically inclined students. The reverse directionality, however, is not as readily apparent; medical schools having matched students with higher *h*-indices may not necessarily predict higher recruitment percentages for that school.

Findings emerging from this study may be used by several stakeholders, including undergraduate or medical students, neurosurgery departments, as well as neurosurgical leadership societies. For the prospective medical student with an early interest in neurosurgery, selecting a medical school with a highly rated home neurosurgery program that has a large faculty and that fosters early involvement and exposure to the field may be critical for their future orientation. Nonetheless, as the study results have indicated, being in smaller institutions that may even lack a home program does not completely eliminate mentorship opportunities; however, it will likely require more active engagement on the student's part. Given that programs with early-exposure efforts appeared to be the most successful in recruitment, medical student bodies such as neurosurgery interest groups should advocate for such programs at their institutions. From the perspective of neurosurgery departments, recruiting more students into the field will require focus on both active student engagement at an early stage and provision of as many mentorship opportunities as possible by perhaps seeking mentorship qualities in new faculty hires. For neurosurgical leadership societies, our data suggest that there is marked potential for increasing recruitment in western medical schools. The list of individual school rankings also provides a granular summary of recruitment patterns across the nation. Facilitating crosstalk between higher- and lower-rated medical schools on this list may help bolster recruitment in the future.

Limitations

Our findings provide a snapshot of the current neurosurgery residency cohort. Still, these findings must be interpreted in relation to other research in the field. Most notably, our data represent medical students who succeeded in matching into neurosurgery, not those who were interested in the field but did not match. Despite this, it is important for medical schools not just to generate interest in the field, but also to successfully match their students. Another shortcoming is the limitations presented by the size of the data set, dictated by the small size of the neurosurgery field. Although our findings were based on a 7-year cohort, at times, we ran into data that were trending toward statistical significance but did not reach it (such as the type of medical school in our multivariable analysis related to the percentage of recruitment). Future research should aim to study larger neurosurgery cohorts to elucidate trends that may not be evident in smaller samples. Finally, our data represent neurosurgery residents in training, most of whom successfully matched at the end of medical school. However, due to a small attrition during residency, some neurosurgery residents may have matched in positions beyond the PGY-1 year of training. Moreover, some applicants who matched in the 2014–2020 match periods may have dropped out later and were not captured. This distinction was not made as we did not have match list data available for each medical school.

Conclusions

This study characterizes which medical schools are most successful at recruiting medical students into the current neurosurgery residency workforce. A *U.S. News* top 10 ranking was the most important independent factor predicting the percentage of graduates entering neurosurgery. Neurosurgery faculty size was the most important independent factor predicting preresidency *h*-index. This information may aid various stakeholders in increasing medical student recruitment into the field. The methodology can additionally serve as an analytical model for other surgical subspecialties interested in quantifying and ameliorating recruitment.

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Disclosures

Dr. Brem: consultant for Acuity Bio Corp., InSightech, Accelerating Combination Therapies, Catalio Nexus Fund II, LikeMinds, Galen Robotics, and Nurami Medical.

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Conception and design: Huang, Feghali. Acquisition of data: Antar, Wicks, Sattari, Li. Analysis and interpretation of data: Antar, Feghali. Drafting the article: Antar, Feghali. Critically revising the article: Huang, Antar, Feghali, Witham, Brem. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Huang. Statistical analysis: Feghali. Study supervision: Huang.

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

Supplementary Table 1. https://thejns.org/doi/suppl/10.3171/2021.7.JNS211530.

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