

The neurosurgeon workforce: a geographical gender-focused analysis of the trends in representation of neurosurgeons and choices in training over 70 years

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OBJECTIVE Neurosurgeons frequently move throughout their careers, with moves driven by personal and professional factors. In this study, the authors analyzed these migration trends through a dynamic migratory map and statistical review, with a particular focus on differences in education and practice patterns between male and female neurosurgeons.

METHODS A list containing all board-certified and -affiliated US neurosurgeons practicing in 2019 was obtained from the American Association of Neurological Surgeons. The list was augmented to include demographic and location information for medical school, residency, fellowship(s), and current practice for all neurosurgeons with publicly available data. Migration heatmaps were generated, and migration patterns over 10-year intervals were plotted. A web tool was additionally created to allow for dynamic visualization of this database.

RESULTS The database included 5307 neurosurgeons with a mean age of 57.2 ± 11.3 years. The female population made up 8.93% of all neurosurgeons, and were found to be more likely to complete fellowships than their male counterparts, at 54.2% and 39.1%, respectively ($p < 0.0001$). A total of 39.5% of all neurosurgeons completed at least one fellowship. A large proportion of currently practicing US neurosurgeons completed medical school internationally in the 1990s. Recently, there has been a trend in neurosurgeons choosing to practice in the South, emigrating from the Northeast and the Western US Census regions. By population, the Western US region trained the fewest neurosurgeons at 1 per 115,000 residents, and the Northeastern US region trained the most at 1 per 49,000. The web tool provides a simple interface to visualize the database on a world map.

CONCLUSIONS Diversity, equity, and inclusion in neurosurgery have been a strong point of discussion in recent literature, with neurosurgeons comprising one of the most gender-disparate workforces in the US medical system. This study provides additional metrics to assess these disparities to help motivate further action toward a larger, more diverse neurosurgical community.

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KEYWORDS workforce; disparities; geographic; female neurosurgeon; diversity, equity, and inclusion

IN the US there are approximately 3800 board-certified neurosurgeons, which amounts to approximately 1 board-certified neurosurgeon for every 90,000 people in the US as of 2023.^{1,2} This large patient-to-physician ratio creates disparities in access to emergency neurosurgical care based on geographical, socioeconomic, and racial factors.^{3,4} These health disparities are heightened by a lack of diverse representation in the neurosurgical workforce.⁵

The neurosurgeon shortage will worsen in the near future given that 45% of all practicing neurosurgeons are more than 55 years old, and nearly 57% have practiced for more than 20 years.^{2,6} A total of 240 physicians entered neurosurgery training in 2023, which may be sufficient to replace retiring surgeons, but does not allow for the demand for growth of the field.⁷ In 2013, the time needed to fill the 305 neurosurgery vacancies was estimated at 2 years

ABBREVIATIONS AANS = American Association of Neurological Surgeons; ACGME = Accreditation Council for Graduate Medical Education.

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based on the neurosurgeon production rate.⁴ Given the recent calls for an expanded physician workforce in neurosurgery, it is pertinent to quantify the severity of disparity in neurosurgical access across the nation.⁸

The demand for neurosurgery, particularly in the treatment of spine disorders, has seen a nearly threefold increase between 2000 and 2009.⁹ The spine surgery market as a whole continues to expand rapidly, with a projected market capitalization for spinal fusion devices of \$11.4 billion by 2030, driven by the expansion of the aging US population, which is projected to reach 80 million by 2040.^{10,11} As of 2012, the median wait time to see a neurosurgeon was 103 days for elective procedures, which was the most of all medical specialties at the time, indicating a shortage of access.¹² In the US, the mean distance patients need to travel to be seen by a neurosurgeon is 35.68 miles from any county.¹³ Furthermore, the risk of death for a patient with neurotrauma increases by 10% for every 25 miles of distance from the nearest neurosurgeon.¹⁴ This distance remains a barrier to rural populations, leading to negative healthcare outcomes, especially in trauma requiring immediate neurosurgical access. Therefore, there is a need to examine the migratory patterns of neurosurgeons in the US to improve the delivery of neurological services and provide time-sensitive quality of care to patients.

The movement and distribution of neurosurgeons across the US has rarely been studied quantitatively. Many neurosurgeons migrate between geographical locations as they transition between training and practice stages. This migration can be driven by certain personal or professional factors such as monetary incentives, availability of adequate clinical infrastructure in a community, academic and research opportunities, and appropriate working conditions.¹⁵ Although more neurosurgical training positions will ultimately be required to improve access, it is critical to uncover the other factors contributing to the care disparity. Between medical school, residency, and fellowship, neurosurgeons frequently move throughout the country and immigrate to the US. Additionally, some areas of the US have a significantly greater neurosurgeon-to-population ratio than others.

Neurosurgeons often move great distances between each of their training steps on their journey to board-certified practice. To better understand geographical disparities in the neurosurgical workforce, this study explored the migration patterns of neurosurgeons over the past 70 years by using statistical review and a dynamic migratory mapping web tool. This study focuses on trends in neurosurgeons who completed some part of their training in the US. By examining historical data, scholarly research, and anecdotal evidence, in this study we aimed to identify the key drivers and trends that have shaped the movement of neurosurgical talent across different regions and continents. Furthermore, we discuss the impact of migration on the availability and accessibility of neurosurgical services, highlighting the benefits and challenges associated with this phenomenon. We additionally aimed to contribute to the ongoing dialog surrounding the global mobility of medical professionals by comprehensively examining the migration of neurosurgeons. Ultimately, we hope that this research will inform discussions on workforce planning,

policy development, and international collaborations, leading to enhanced healthcare delivery and improved patient outcomes in the field of neurosurgery.

Methods

A list of all neurosurgeon members of the American Association of Neurological Surgeons (AANS) currently practicing in the US was obtained in 2019, and data were collected by the authors (A.D.S., A.L., and A.S.) on the following: age; race; gender; academic education progression through medical school, residency, and fellowship; dates of institutional attendance; location of current practice; and identifying information for all neurosurgeons in the database by using cross-referenced online searches of public databases.

The location names for all migration steps, including medical school, residency, fellowship, and current practice were extracted from the data, and the geopy package using the Google Geocoding API¹⁶ in Python 3.11¹⁷ was used to convert semantic locations into latitude and longitude for each educational institution and location of current practice. These geographical locations were associated with dates of attendance to portray migration patterns over 10-year periods. These migration trends were then compared across the four US Census regions¹⁸ to determine if the time-series data had a trend toward any particular region of the US throughout training by using a chi-square test of independence between training steps. A comparison between migration distances of women and men was analyzed using Student t-tests and plotted across decades to assess periodicity of geographical migration between the genders. Each of the migration heatmaps were generated using the *rworldmap* package in R.¹⁹

Fellowship data were subcategorized into the eight existing fellowships available to neurosurgeons. Categories included spine, vascular, pediatric, functional, neuro-oncology, skull base, trauma, peripheral, and unspecified. A demographic comparison between all fellowship-trained neurosurgeons was made to characterize the different patterns in fellowship behavior between male and female, and US-native and international neurosurgeons. Chi-square tests of independence were used to assess the differences between groups. The means are reported $\pm$ 1 SD. Neurosurgeons who trained in any international medical school were considered international neurosurgeons for the purpose of this study.

Due to the potential for these data to be further analyzed, R Shiny²⁰ and the leaflet R package²¹ was used to provide the reader with an open-access web tool for dynamic visualization of the database (available at https://mostafa-lab.shinyapps.io/Neurosurgery_Migration_Visualization/).

Results

Participant Demographics and Fellowship Subspecialization

The database included 5307 neurosurgeons. For 4638 (87.39%), age was reported, and the mean age was 57.2 ± 11.3 years. For 5162 (97.27%), gender was reported, and

TABLE 1. Basic demographics of the database, subdivided by gender

	Total, n = 5307*	Women, n = 461	Men, n = 4701
Mean age in yrs (SD)	57.2 (11.3)	52.1 (9.2)	57.7 (11.3)
Reported race	2980	215	2765
Asian	369 (12.4)	38 (17.7)	331 (12.0)
Native American	1 (0.03)	0 (0)	1 (0.04)
Middle Eastern	1 (0.03)	0 (0)	1 (0.04)
Black	98 (3.3)	10 (4.7)	88 (3.2)
Hispanic	127 (4.3)	8 (3.7)	119 (4.3)
White	2309 (77.5)	151 (70.2)	2158 (78.0)
Other	76 (2.6)	8 (3.7)	68 (2.5)
No. of reported first medical schools in each location	4058	369	3686
International	884 (21.8)	98 (26.6)	785 (21.3)
US	3174 (78.2)	271 (73.4)	2901 (78.7)
No. of reported first residencies in each location	5010	444	4561
International	412 (8.22)	45 (10.1)	363 (7.96)
US	4598 (91.8)	399 (89.9)	4198 (92.0)
Fellowship-trained neurosurgeons	2096 (39.5)	250 (54.2)	1837 (39.1)
No. of reported fellowships completed in each location	2053	240	1804
International	231 (11.3)	31 (12.9)	199 (11.0)
US	1822 (88.7)	209 (87.1)	1605 (89.0)
No. of reported fellowships in subspecialties completed	2008	251	1750
Spine	498 (24.8)	23 (9.16)	473 (27.0)
Vascular	476 (23.7)	36 (14.3)	436 (24.9)
Pediatric	321 (16.0)	95 (37.8)	226 (12.9)
Functional	226 (11.3)	30 (12.0)	196 (11.2)
Neuro-oncology	166 (8.27)	35 (13.9)	130 (7.43)
Skull base	165 (8.22)	11 (4.38)	154 (8.8)
Trauma	27 (1.34)	3 (1.20)	24 (1.37)
Peripheral	18 (0.90)	5 (1.99)	13 (0.74)
Unspecified	111 (5.53)	13 (5.18)	98 (5.6)
Current practice locations	5301	460	4698
International	54 (1.0)	0 (0)	53 (1.1)
US	5247 (99)	460 (100)	4645 (98.9)

Details race, medical school, residency, fellowship training locations, and types of fellowships pursued between the genders. Unless otherwise indicated, values are expressed as the number (%).

* The overall total is correct—gender was not reported for all neurosurgeons. To avoid double counting, only the first program attended is reported.

8.93% of neurosurgeons were female. A total of 2096 (39.5%) neurosurgeons completed at least one fellowship. The most common fellowships were spine (24.8%), followed by vascular (23.7%). However, when stratified by gender, pediatrics was the most common fellowship (37.8%) completed by female neurosurgeons. Female neurosurgeons were additionally more likely to complete fellowship training compared to male neurosurgeons (54.2% vs 39.1%, $p < 0.0001$). Table 1 provides the basic demographic information regarding the data included in the completed database.

Locations of Training and Current Practice

Locations for medical school attended and current

practice were reported for 76.5% and 99.9% of the neurosurgeons, respectively. Residency and fellowship data were available for 94.4% and 38.7%, respectively. The most common state to complete medical school and residency was New York. The most common state to complete fellowships was Ohio, and California is the state where most neurosurgeons currently practice (Fig. 1). A total of 2096 neurosurgeons completed at least one fellowship, and of those, the mean number of fellowships completed was 1.37 ± 0.82 .

Migration of Neurosurgeons

Between medical school and residency, 41.83% moved to a different US Census region. Of those who completed

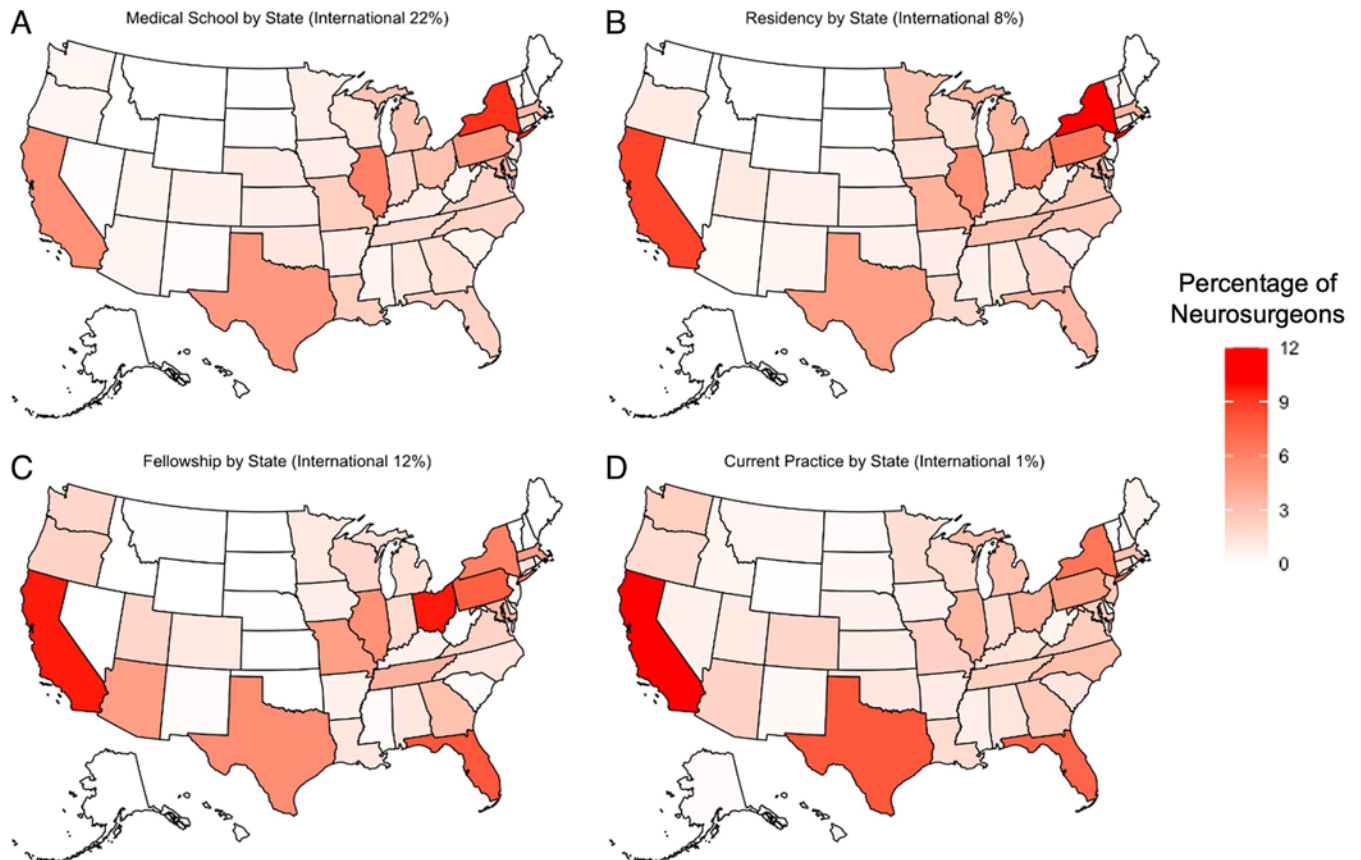


FIG. 1. Maps illustrate the percentage of neurosurgeons who trained in each state for medical school (A), residency (B), fellowship (C), and current practice (D). Darker regions indicate a larger proportion of the workforce. Maps were created using the *rworldmap* package in R.¹⁹

fellowship training, 51.29% traveled to a different region following residency. Between residency and current practice, 44.59% moved to a different region. Adjusted for population, the western US region trained the fewest neurosurgeons at 8.712 per million people, or approximately 1 per 115,000 residents; and the northeastern US region trained the most at 20.539 per million, or approximately 1 per 49,000 residents. Despite migration, the change in overall neurosurgeon population at each training stage was nonsignificant ($p = 0.192$).

Trends in Migration From the 1950s to 2019

Based on combined training data for each decade, there is no consistent movement of neurosurgeons into or out of any particular region. A list of the total number of trainees across the decades is described in Table 2. In the 1990s there was a significant increase in international medical students who were accepted into neurosurgical training and eventually began practice in the US. Residency training has remained fairly consistent, with more residents training in the South, Midwest, and Northeast regions compared to residents in the western US and international trainees. In the past 20 years, there has been a significant increase in neurosurgeons pursuing subspecialization through fellowships ($p < 0.001$) (Fig. 2). Migration pat-

terns for medical school, residency, and fellowship are visually portrayed in Fig. 3.

The number of total moves between the four US Census regions was significant, with female neurosurgeons moving approximately 0.2 times more than male neurosurgeons on average ($p < 0.0001$). However, female neurosurgeons had nonsignificantly increased total distance traveled, at 6 km more than men on average ($p = 0.1037$). Female-to-male ratio is visualized in Fig. 4, with positive numbers indicating increased female-to-male ratio and negative numbers indicating a decreased female-to-male ratio.

Dynamic Visualization Web Tool

The web tool uses our database to display neurosurgeon locations per training step around the world. The user can select what to plot based on a combination of seven drop-down menus. The first two menu options, "Choose an input" and "Choose a state," allow the user to specify the state(s) where the neurosurgeons attended medical school, their first residency, their first fellowship, or current practice. The states menu allows for multiple selections, enabling users to query neurosurgeons from one or more states to be displayed on the map (Fig. 5).

The additional filter menus allow the user to narrow the

TABLE 2. Metrics for location and migration based on training stage from the 1950s to 2019

Stage of Training	Medical School	Residency	Fellowship
No. of trainees w/ detailed location data	4058	5010	2053
Percentage of training location data available	86.77%	99.25%	53.85%
No. of locations w/ date of attendance data	3883	5177	1389
1950s	35 (0.90)	12 (0.23)	1 (0.07)
1960s	133 (3.43)	87 (1.68)	0 (0)
1970s	583 (15.0)	397 (7.67)	3 (0.22)
1980s	1099 (28.3)	1037 (20.03)	26 (1.87)
1990s	1199 (30.9)	1385 (26.75)	95 (6.84)
2000s	824 (21.2)	1707 (32.97)	836 (60.2)
2010s	10 (0.26)	552 (10.66)	428 (30.8)
No. of neurosurgeons who immigrated to US after training stage	881 (21.7)	265 (5.29)	260 (12.7)
No. of neurosurgeons who emigrated from US after training stage	45 (1.11)	57 (1.14)	19 (0.93)
No. of neurosurgeons who trained at >1 institution during training stage	114 (2.81)	223 (4.45)	549 (26.74)

Unless otherwise indicated, values are expressed as the number (%).

results by race (Asian, Black, Hispanic, White, other); gender (male, female); and whether the first residency or fellowship was completed in the US or internationally. Multiple selections are available for these menus as well. The final menu, "Display Location," provides the locations to display, with the same four options as the first menu. For example, the default selections are "Medical School" and "IL" for the first two menus, female selected for the Gender menu, all selections First Residency, First Fellowship, and Race, and "Current" for the "Display Location" menu. This map will show the current location of all female neurosurgeons who attended medical school in Illinois.

Discussion

Geographical Disparities

Medical schooling represented the greatest geographical heterogeneity of our neurosurgical cohort, with most neurosurgeons attending medical school in New York, Texas, Illinois, and California. This distribution is probably driven by state populations, tuition incentives for attending local medical schools, and the fact that nearly 30% of all medical schools are within these four states.^{22,23} The majority (58.17%) of incoming residents remained within the same geographical region as their medical school. This may be due to geographical familiarity, connections to surrounding academic institutions, and understanding of state-based grants. We observed a decline in migration

as the neurosurgeon progresses through their training. This may be attributed to the surgeon establishing vocational and nonvocational ties to their geographical locale over time.

We hypothesize that the increase in neurosurgeons in southern US regions is driven by private practice due to tax and medical liability laws. The tax burden in southern states is significantly lower than in states of the West and Northeast.²⁴ For that reason, neurosurgeons in the West and Northeast are potentially leaving due to the higher taxes. Political affiliation may also have some bearing on the practice location decisions that neurosurgeons make.²⁵ Additionally, we hypothesize that neurosurgeons may favor warmer climates common to states in the southern US, leading to a trend toward the South, particularly with older neurosurgeons.

Neurosurgical outcomes are significantly correlated to the geographical distribution of the neurosurgical workforce.²⁶ Of the studied neurosurgeons with reported locations ($n = 4163$), states in the central US host the lowest neurosurgical density. In 2009, Mukherjee et al. correlated low neurosurgeon density to the lack of pediatric neurosurgical critical care services, highlighting the disequilibrium between patient safety and physician coverage.²⁷ Recognizing the inherent limitation of self-reporting, future work should be done to build predictive models for neurosurgeon migration. Furthermore, it is important that we understand a neurosurgeon's motivations for moving to different programs so that we can better anticipate trends in migration. This will allow us to identify care gaps and mitigate disparities in access to neurosurgical care.

Women in Neurosurgery

Neurosurgery has historically been a male-dominated field, with women being underrepresented. Although progress has been made in recent years, gender disparities persist.^{28,29} Several factors contribute to this disparity, including stereotypes and bias, work/life balance considerations, and a general lack of women applying to neurosurgery programs, with less than 27% of applicants in the past 5 years identifying as female.³⁰ When surveyed, female medical students showed interest in surgical specialties; however, 88.5% expressed concern for inequality and adversity in their pursuit of male-dominated fields like neurosurgery.³¹ Female medical students also cited challenges and inadequate policy around family leave, pregnancy, and breastfeeding as an important factor in their career decision.³¹

Neurosurgical societies are an important means to connect the neurosurgical community, foster mentorship, and facilitate academic growth. Currently, only 28% of board positions are held by women. The lack of female leaders and mentors in neurosurgery may discourage women from entering the field or hinder their career progression.³² All of these factors coalesce to result in fewer numbers of women than men currently applying to neurosurgery.

Efforts to address these disparities include promoting diversity and inclusion, creating supportive work environments, and providing mentorship opportunities for aspiring female neurosurgeons. Increasing awareness about

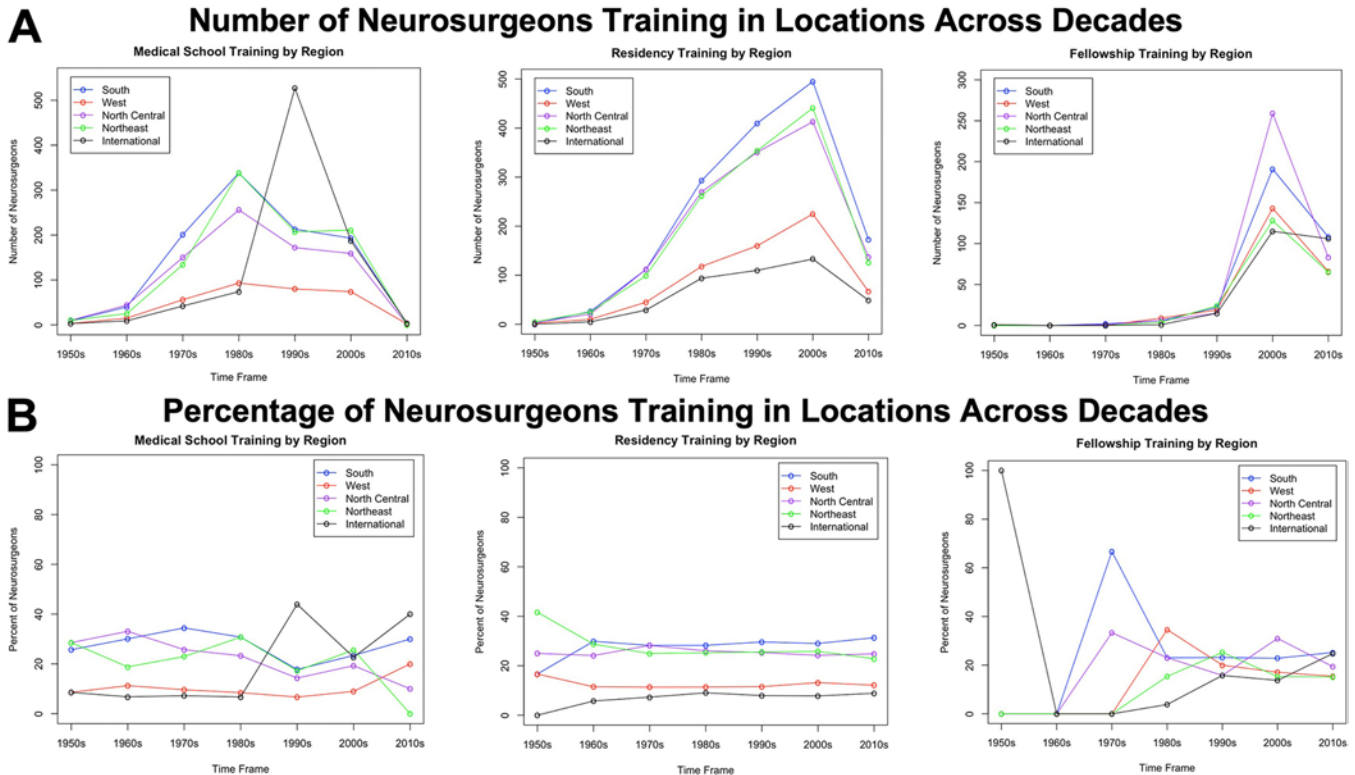


FIG. 2. Comparative plots of the training locations over time for neurosurgeons. **A:** Number of trainees in medical school, residency, and fellowship across decades (from left to right). **B:** Percentage of trainees in medical school, residency, and fellowship across decades (from left to right).

gender bias and implementing policies to promote work/life balance can also help bridge the gender gap. Recent changes, including increased female applicants, Accreditation Council for Graduate Medical Education (ACGME) changes, and more residency positions have probably allowed for the apparent narrowing of this disparity.^{7,33} The female workforce in neurosurgery increased from 11.15% to 17.82% between 2008 and 2018.³⁴ This may be attributed to the changes in ACGME residency requirements, particularly after the 80-hour work week was implemented by the ACGME in 2003, with revisions in 2011.³³ As of May 2021, 8.85% of neurosurgery program directors were female, which is consistent with the overall representation of female neurosurgeons seen in this study.³⁵ Additionally, female program directors were more likely to be appointed to the position earlier in their careers following residency compared to their male counterparts (8.6 vs 14.7 years, respectively; $p = 0.013$).³⁵

Of the neurosurgeons who reported fellowship training, a greater proportion of women were fellowship trained than men (54.2% vs 39.1%, $p < 0.0001$). Fellowship completion by neurosurgeons has had a 10-fold increase since 2000. Furthermore, there has been an increase in the rate of women entering the field of neurosurgery in the last decade. The female fellowship rates may be falsely elevated by this simultaneous influx in fellowship popularity due to the larger population of older men who completed residency before the 2000s. However, there may

also be differences in perceived competence, motivating a female neurosurgeon to pursue advanced training.³⁶ We hypothesize that women's choice of residency and fellowship—and particularly their geographical stasis between their residency and fellowship—may be related to community (mentorship, faculty, colleagues), policy (family leave, length of training), and cohort representation (race, gender, ethnicity).

Outlook for the Future of Neurosurgery

Like most other medical specialties, the neurosurgery workforce exhibits disparities in gender representation and geographical distribution. These disparities are a subject of concern and study within the medical community. However, the further quantification of these disparities and a deeper understanding of their causes will assist in creating a holistic and diverse neurosurgical workforce.

There are two important approaches to consider when working to reduce the gender disparity in the neurosurgical workforce: a top-down marketing approach by programs, mentors, and accreditation associations, and a bottom-up approach in the education of women in the possibilities of a neurosurgical career and the importance of a diverse workforce in medical specialties.³ We propose that in the top-down approach, programs, mentors, and associations should give special consideration to regions that have a lower enrollment of female neurosurgeons in residency. The workforce has been significantly changing

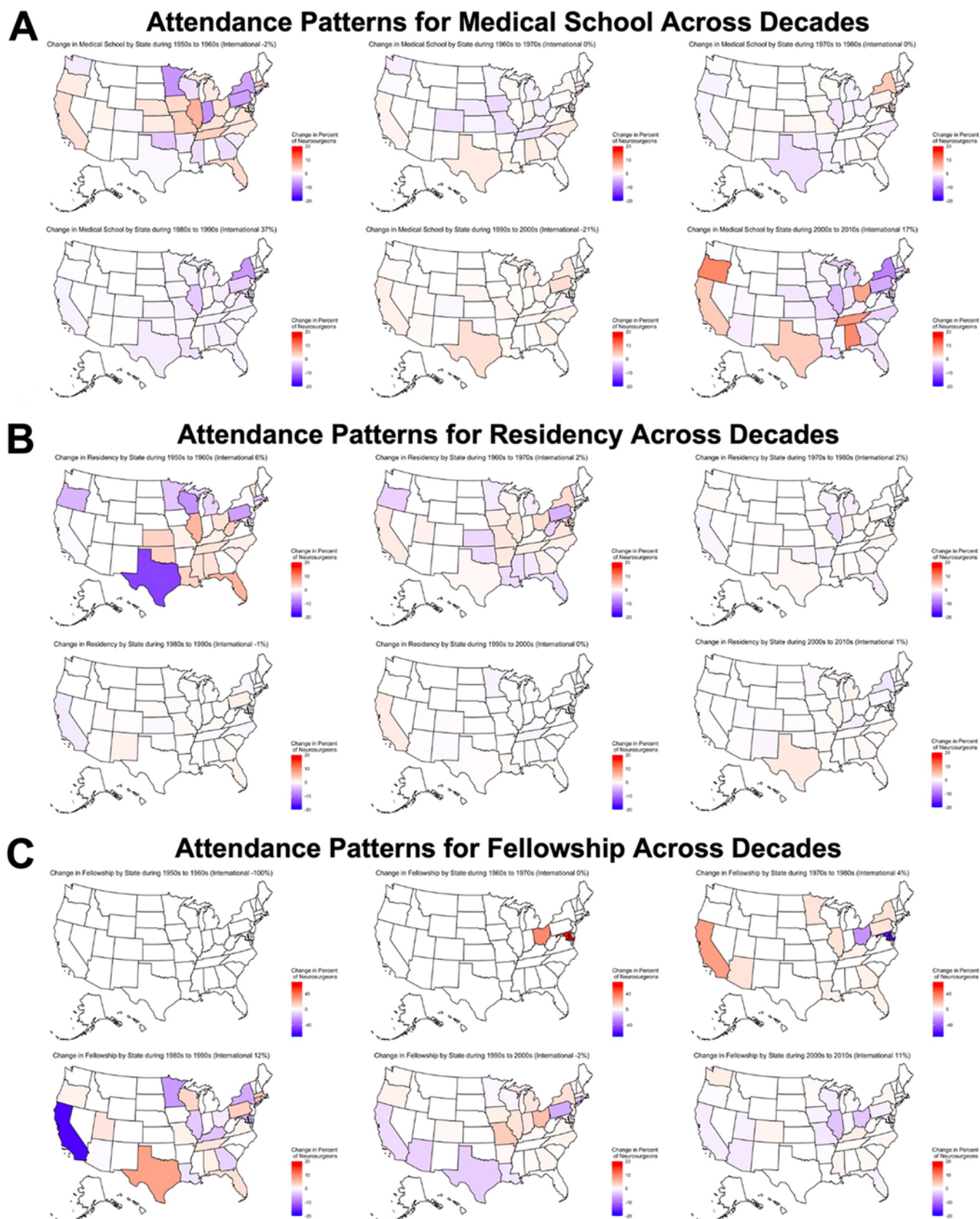


FIG. 3. Migration dynamics over 10-year intervals assessed using migration heatmaps (*cold* = emigration, *warm* = immigration) for first medical school (**A**), first residency (**B**), and first fellowship (**C**). Migration from international locations is reported as positive for immigration and negative for emigration. Maps were created using the *rworldmap* package in R.¹⁹

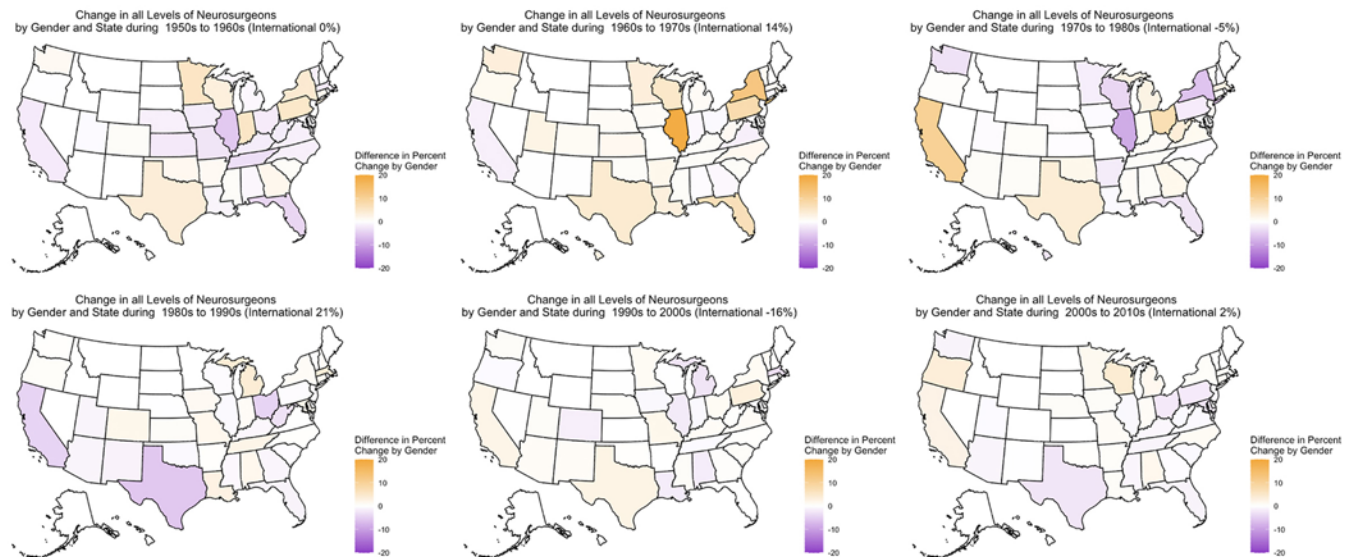


FIG. 4. Comparative maps characterize the state-level female-to-male ratio across the decades, pooling all training steps including current practice. *Orange* indicates an increase in female-to-male ratio, and *purple* indicates a decrease in female-to-male ratio. Maps were created using the *rworldmap* package in R.¹⁹

in recent years, with the current number of female neurosurgical residents approaching 20%; however, this figure remains far from the overall female population (approximately 50.8%).³⁷ This study provides a potential method of approaching the need for improved diversity in the neurosurgical workforce through targeting regions where females are underrepresented and less likely to participate in neurosurgical training.

Limitations

Our study was primarily limited by the AANS database, which is derived from the active neurosurgeon workforce in the US in 2019. Reliance on publicly available data resulted in inconsistent self-reporting of race, education, location, age, specialty, and advanced training. These data may be incomplete or inaccurate due to the self-reporting of information obtained through web searches. Specific factors for why a neurosurgeon may choose to migrate were not available from this database. Furthermore, the AANS database is limited to American surgeons. Thus, our study does not follow the surgeons who train in a medical school, residency, and/or fellowship in the US, but who currently practice internationally.

This study would be improved through a centralized collection and storage of neurosurgeon affiliations with the AANS. Before this study, there was no such centralized database containing neurosurgeons' training locations, information regarding their fellowships, and movement across their practice locations. Because current practice does not include any prior jobs, it is difficult to assess the journey neurosurgeons take between their final stage in training and their current practice today. Some statistics that would benefit from this information would include the total distance moved by neurosurgeons throughout their careers, whether there was a journey that was undetect-

ed in the 55.4% of neurosurgeons who currently practice in the same region as their residency training, and better quantification of when neurosurgeons choose to train in fellowships after residency.

This study could benefit from expansion to a global scale. Although the workforce in the US indicates a need for improved access, particularly in the western US region, the metrics described in this study do not correlate well with the demands for neurosurgical care across the globe. A 2019 study by Corley et al. estimates that, for low- and middle-income countries, there should be access to at least 1 neurosurgeon per 212,000 people, indicating a much greater shortage in access to care compared to the US.³⁸ Therefore, further research is required to quantify the geographical neurosurgical disparities on a global scale.

Conclusions

In this study we explored the trends in neurosurgeon practice types, migration patterns, and chronology of education, with a comparative analysis between the two genders. This study highlighted the fact that women are more likely than men to train in fellowships, showed that fellowships have had a rapid increase in popularity over the past 20 years, and that there was a sudden influx in internationally trained medical students from the 1990s who became American neurosurgeons. Many of the statistics uncovered in this database recapitulate existing knowledge as well, particularly the limited size of the female neurosurgeon workforce, and the trend in increased fellowship training, validating our data as representative of the existing literature.

The analysis of these trends may be interesting for a variety of purposes, from helping surgeons interested in finding underserved populations, to service, to identifying gaps in care that might benefit from increased targeted

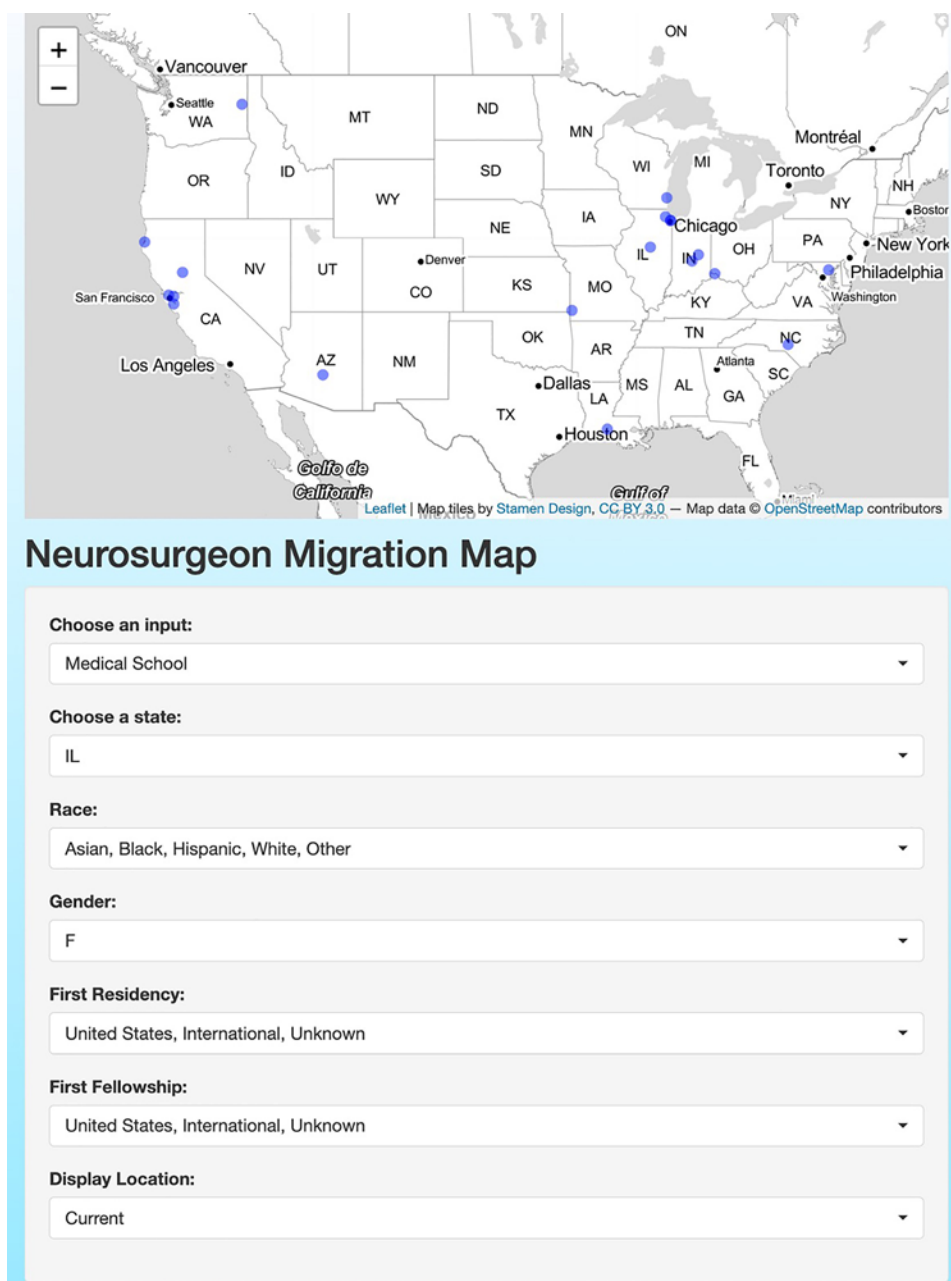


FIG. 5. Web tool visualization for state-level migration. An example is plotted, showing the current practice location of all female neurosurgeons who attended medical school in Illinois. Made in R using R Shiny and leaflet packages.^{20,21} Map generated using Leaflet, an open-source JavaScript library. Map tiles by Stamen Design, CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/>). Map data © OpenStreetMap contributors (<https://openstreetmap.org/copyright>).

recruitment for specific geographical locations. Working alongside the World Federation of Neurosurgical Societies and our global partnerships are a critical next step to assessing the global trends in neurosurgeon migration. The web tool proposed here will serve as a critical resource for those analyzing the trends in neurosurgeons, particularly when comparing disparities in access to care. The web tool may be applicable to uncovering disparities in other medical specialties as well in the future.

As exemplified by recent calls for an improved work-

force, the existing pool of neurosurgeons falls short of meeting the current and growing demand, driven by the increasing US population. The challenges posed by an aging neurosurgical profession and the difficulties in recruiting enough physicians to replace them have further exacerbated the already existing shortage of access to essential care. Continued measures are needed to expand the neurosurgical workforce and address disparities in geographical access to neurosurgical care, and to reduce gender disparities in the neurosurgical workforce nationwide.

References

1. The demographic outlook: 2023 to 2053. Congressional Budget Office. Published January 24, 2023. Accessed September 21, 2023. <https://www.cbo.gov/publication/58612>
2. Parent A. Physician shortage spikes demand in several specialties. NEJM CareerCenter Resources. Published November 30, 2017. Accessed September 21, 2023. <https://resources.nejmcareercenter.org/article/physician-shortage-spikes-demand-in-several-specialties/>
3. Kim EE, Klein AL, Lartigue JW, Hervey-Jumper SL, Rosseau G. Diversity in neurosurgery. *World Neurosurg*. 2021;145:197-204.
4. Rosman J, Slane S, Dery B, Vogelbaum MA, Cohen-Gadol AA, Couldwell WT. Is there a shortage of neurosurgeons in the United States? *Neurosurgery*. 2013;73(2):354-366.
5. Silver JK, Bean AC, Slocum C, et al. Physician workforce disparities and patient care: a narrative review. *Health Equity*. 2019;3(1):360-377.
6. Singh R, Parikh PP, De La Peña NM, et al. Trends in the neurosurgical workforce and implications in providing for an aging population. *World Neurosurg*. 2022;160:e261-e266.
7. Main residency match data and reports. NRMP. Accessed September 21, 2023. <https://www.nrmp.org/match-data-analytics/residency-data-reports/>
8. *Ensuring an Adequate Neurosurgical Workforce for the 21st Century*. American Association of Neurological Surgeons, American Board of Neurological Surgery, Congress of Neurological Surgeons, Society of Neurological Surgeons; 2012. Accessed September 21, 2023. <https://www.aans.org/-/media/Files/AANS/Advocacy/2012-News/NeurosurgeryIOMGMEPaper121912.ashx>
9. Yoshihara H, Yoneoka D. National trends in the surgical treatment for lumbar degenerative disc disease: United States, 2000 to 2009. *Spine J*. 2015;15(2):265-271.
10. Amol P, Onkar S. Spinal fusion devices market size & growth forecast - 2030. Allied Market Research. Accessed September 21, 2023. <https://www.alliedmarketresearch.com/spinal-fusion-devices-market>
11. *2021 Profile of Older Americans*. ACL; 2022. Accessed September 21, 2023. https://acl.gov/sites/default/files/Profile%20of%20OA/2021%20Profile%20of%20OA/2021ProfileOlderAmericans_508.pdf
12. Thind A, Stewart M, Manuel D, et al. What are wait times to see a specialist? an analysis of 26,942 referrals in southwestern Ontario. *Health Policy*. 2012;8(1):80-91.
13. Pugazenthi S, Hernandez-Rovira MA, Fabiano AS, et al. Mapping the geographic migration of United States neurosurgeons across training and current practice regions: associations with academic productivity. *J Neurosurg*. Published online March 17, 2023. doi: 10.3171/2023.1.JNS222269
14. Ratliff H, Korst G, Moth J, Jupiter D. Geographical variation in traumatic brain injury mortality by proximity to the nearest neurosurgeon. *J Surg Res*. 2021;259:480-486.
15. Rafiei S, Arab M, Rashidian A, Mahmoudi M, Rahimi-Movaghar V. Factors influencing neurosurgeons' decision to retain in a work location: a qualitative study. *Glob J Health Sci*. 2015;7(5):333-351.
16. Geocoding API overview. Google for Developers. Accessed September 21, 2023. <https://developers.google.com/maps/documentation/geocoding/overview>
17. Van Rossum G, Drake FL. *Python 3 Reference Manual*. CreateSpace; 2009.
18. US census data. US Census Bureau. Accessed July 1, 2023. <https://www.census.gov/data.html>
19. South A. rworldmap: a new R package for mapping global data. *R J*. 2011;3(1):35-45.
20. Shiny: web application framework for R. Accessed September 21, 2023. <https://shiny.rstudio.com/>
21. Leaflet for R. Accessed September 21, 2023. <https://rstudio.github.io/leaflet/>
22. U.S. and World Population Clock. US Census Bureau. Accessed July 1, 2023. <https://www.census.gov/popclock/>
23. Accredited MD Programs in the United States. LCME. July 31, 2023. Accessed September 21, 2023. <https://lcme.org/directory/accredited-u-s-programs/>
24. York E, Walczak J. State and local tax burdens, calendar year 2022. Tax Foundation. Published April 7, 2022. Accessed September 21, 2023. <https://taxfoundation.org/tax-burden-by-state-2022/>
25. Singh R, Richter KR, Pollock JR, Haglin JM, Richter RA, Meyer FB. An analysis of political contributions from neurosurgeons in the United States. *World Neurosurg*. 2021;148:e130-e137.
26. Perera S, Hervey-Jumper SL, Mummaneni PV, et al. Do social determinants of health impact access to neurosurgical care in the United States? A workforce perspective. *J Neurosurg*. 2022;137(3):867-876.
27. Mukherjee D, Kosztowski T, Zaidi HA, et al. Disparities in access to pediatric neurooncological surgery in the United States. *Pediatrics*. 2009;124(4):e688-e696.
28. Butkus R, Serchen J, Moyer DV, et al. Achieving gender equity in physician compensation and career advancement: a position paper of the American College of Physicians. *Ann Intern Med*. 2018;168(10):721-723.
29. Durham SR, Donaldson K, Grady MS, Benzil DL. Analysis of the 1990–2007 neurosurgery residency match: does applicant gender affect neurosurgery match outcome? *J Neurosurg*. 2018;129(2):282-289.
30. ERAS® statistics. AAMC. Accessed September 21, 2023. <https://www.aamc.org/data-reports/data/eras-statistics-data>
31. Dixon A, Silva NA, Sotayo A, Mazzola CA. Female medical student retention in neurosurgery: a multifaceted approach. *World Neurosurg*. 2019;122:245-251.
32. Balasubramanian SC, Palanisamy D, Bakhti S, et al. Women in Neurosurgery (WIN): barriers to progress, World WIN Directory and the way forward. *Asian J Neurosurg*. 2020;15(4):828-832.
33. Nacsa TJ. Well-being and work hour requirements. Accreditation Council for Graduate Medical Education. Published January 9, 2019. Accessed September 21, 2023. <https://www.acgme.org/newsroom/2019/1/well-being-and-work-hour-requirements/>
34. Bennett CL, Baker O, Rangel EL, Marsh RH. The gender gap in surgical residencies. *JAMA Surg*. 2020;155(9):893-894.
35. Ryan CA, Sciscent BY, Bhanja D, Tucker J, Daggubati LC. Female neurosurgery residency program directors in the United States: a cross-sectional descriptive analysis. *World Neurosurg*. 2023;169:52-56.
36. Mast MS, Kadji KK. How female and male physicians' communication is perceived differently. *Patient Educ Couns*. 2018;101(9):1697-1701.
37. Gabriel PJ, Alexander J, Kärklipa A. Diversity in neurosurgery: trends in gender and racial/ethnic representation among applicants and residents from U.S. neurological surgery residency programs. *World Neurosurg*. 2021;150:e305-e315.
38. Corley J, Lepard J, Barthélemy E, Ashby JL, Park KB. Essential neurosurgical workforce needed to address neurotrauma in low- and middle-income countries. *World Neurosurg*. 2019;123:295-299.

Disclosures

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Author Contributions

Conception and design: Hassaneen, Smith, Arnold. Acquisition of data: Smith, Siddiqui. Analysis and interpretation of data: Hassaneen, Smith, Lauinger, Siddiqui, Arnold, Pappu, Yu. Drafting the article: Smith, Lauinger, Arnush, Shaffer, Nayak. Critically revising the article: Hassaneen, Smith, Arnush, Shaffer, Siddiqui, Nayak, Arnold, Pappu, Yu, Stroink. Reviewed submitted version of manuscript: Hassaneen, Smith, Arnush, Siddiqui, Arnold, Pappu, Stroink. Approved the final version of the manuscript on behalf of all authors: Hassaneen. Statistical analysis: Smith, Yu. Administrative/technical/material support: Smith, Shaffer, Arnold. Study supervision: Hassaneen, Smith, Arnold.

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