# Mapping the global neurosurgery workforce. Part 1: Consultant neurosurgeon density

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**OBJECTIVE** It is unknown whether efforts to expand access to neurosurgery worldwide have translated to an increase in the global neurosurgery workforce, particularly in low- and middle-income countries. The main objective of this study was to quantify the number and distribution of consultant neurosurgeons worldwide, while also identifying temporal and geographic trends in the neurosurgery workforce in different income levels and WHO regions, and analyzing what factors might contribute to the growth of a national workforce.

**METHODS** This study was a subanalysis of an electronic cross-sectional survey administered to participants identified through neurosurgery societies, personal contacts, and online searches of all 193 countries and 26 territories, independent states, and disputed regions as defined by the World Bank (WB) and United Nations between October 2022 and March 2023. Population-weighted statistics for the consultant neurosurgery workforce and resource availability were estimated, and linear regression analysis was conducted to identify correlations with growth in the workforce.

**RESULTS** Data were obtained for 192 countries (99.5%) and 25 additional territories, states, and disputed regions (96.2%). One hundred seventy-seven respondents participated in the survey. There were an estimated 72,967 neurosurgeons worldwide, representing a global pooled density of 0.93 neurosurgeons per 100,000 people and a median country density of 0.44 neurosurgeons per 100,000 people. The authors found an increasing density of consultant neurosurgeons, from low-income countries (0.12 per 100,000 people), to lower-middle-income countries (LoMICs; 0.37), to upper-middle-income countries (UpMICs; 1.13), and to high-income countries (2.44). The WHO African and Southeast Asia regions had the lowest pooled neurosurgeon density, while the Western Pacific region (WPR) had the highest density. There were 29 countries, 14 territories, and 1 independent state with no neurosurgeons. Neurosurgeons in countries with higher income–level designations had more frequent access to resources and equipment. The annual growth rates in workforce density were highest in LoMICs (26.0%) and UpMICs (21.3%), and the most rapid annual growth was in the Southeast Asia region (33.0%). Regression analysis revealed that an increasing population quartile, the Eastern Mediter-

**ABBREVIATIONS** EMR = Eastern Mediterranean region; GDP = gross domestic product; HIC = high-income country; LIC = low-income country; LMIC = low- and middle-income country; LoMIC = lower-middle-income country; TBI = traumatic brain injury; UN = United Nations; UpMIC = upper-middle-income country; USD = US dollars; WB = World Bank; WPR = Western Pacific region.

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ranean region (relative to the WPR), the presence of a national neurosurgery society, increasing global development aid, and national gross domestic product were associated with relative growth in national neurosurgeon density.

**CONCLUSIONS** The authors estimate a global consultant neurosurgeon workforce of nearly 73,000 neurosurgeons, with stark disparities in the density and growth of the workforce in different WB income-level groups and WHO regions. The presence of a neurosurgery society was correlated with the growth of the workforce, and this study identified several regional targets for further intervention to expand access to neurosurgery.

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**KEYWORDS** neurosurgery workforce; capacity building; global neurosurgery; density; global surgery

There are an estimated 5 billion people who lack access to safe, affordable, and timely surgical care worldwide.[1] More than 5 million patients in low- and middle-income countries (LMICs) who would benefit from a neurosurgery operation do not receive this care every year.[2] Neurosurgery is a critical component of any health system, especially in regions with a high incidence of traumatic brain injury (TBI), hydrocephalus, epilepsy, and stroke, which are disproportionately located in LMICs.[3] The neurosurgery workforce has grown from 1 neurosurgeon per 230,000 people in 2000 to 1 neurosurgeon for every 147,000 people in 2016, with the most rapid growth occurring in Southeast Asia.[4–6] More than half of LMICs saw a further increase in their neurosurgical workforce between 2016 and 2018, but the pace of growth has remained slow.[4,5]

Initiatives to improve neurosurgical capacity in LMICs have included efforts to increase training opportunities,[47] transfer of equipment and donations, support of neurosurgeons in politically unstable regions, and the development of novel, context-specific technologies.[4,7,8] However, it remains undetermined regarding what degree these efforts have increased the neurosurgery workforce or improved access to resources.

In this study, we utilize a cross-sectional survey to estimate the total number of neurosurgeons on a global level, the trends in the neurosurgical workforce, and the resources that neurosurgeons have access to. We incorporate indicators from the World Bank (WB) and WHO to query whether any country-level political, economic, and demographic factors are correlated with the expansion of neurosurgery.

## Methods

The primary objective of this study was to quantify the number and distribution of consultant neurosurgeons worldwide. Secondary objectives included identifying temporal and geographic trends in the neurosurgery workforce in different WB income levels and WHO regions, and analyzing what factors might contribute to the growth of a national workforce. This study was exempted from review by the Harvard Medical School IRB.

### Study Design

This study was a subanalysis of a cross-sectional survey administered by the Global Neurosurgery Initiative at the Program for Global Surgery and Social Change at Harvard Medical School (Supplementary Fig. 1). Participant emails were obtained through personal archives of the coauthors and online searches through Google and PubMed. Potential participants were enrolled with a sequential hierarchical recruitment design. The hierarchical recruitment process was determined using a consensus process among multiple coauthors (S.G., T.S.A., W.É.C., O.E.D., Z.T.G., W.L., R.R., C.Q., and K.B.P.). The survey was designed between August 2022 and September 2022 and was administered between October 2022 and March 2023. All participants were contacted three times to participate over 2 weeks prior to moving to the next potential participant for each country.

A hierarchical data collection strategy was designed to optimize data quality. First, the leadership of national and regional neurosurgery societies was contacted. When there were multiple national or regional societies representing one country, societies with larger memberships were prioritized. Second, personal contacts of the coauthors who were neurosurgeons were contacted to participate. Third, bibliometric and Google searches identified neurosurgeons to contact to participate. If no neurosurgeon could be identified or contacted in a given country, territory, independent state, or disputed region, then attempts were made to obtain information from a neurosurgeon in a neighboring country or from a neurosurgeon who had conducted a volunteer mission trip described in a peer-reviewed publication in that country. Fifteen countries, independent economies, or disputed territories with a population of fewer than 80,000 people with only 1 hospital were assumed to have no neurosurgeons if a description of their hospital's services was publicly available and did not include neurosurgery.

All participants were either attending neurosurgeons, residents/fellows in neurosurgery, or general surgeons (n = 1) with medical doctorate degrees or equivalents (i.e., MBBS, MBBCh, etc.). All participants were adults. An online survey was administered to all participants. Participants were not compensated for their participation.

### Data Sources

An estimate of each country's number of neurosurgeons and the percentage of their neurosurgeons with access to various resources was obtained from study participants. We attempted to include all 193 countries and 26 territories, independent states, and disputed regions as defined by the WB and United Nations (UN), although analyses were conducted solely on countries unless otherwise specified. Subregions were defined through the UN geoscheme. Population data were obtained from the WB; the most recent population estimations from 2021 were utilized, except for Eritrea (2018) and Taiwan (unavailable through the WB, so 2023 UN data were used).[9] Population quartiles were constructed based on country populations and applied across all countries and other regions.

The estimated physicians per capita, health expenditure per capita, urban population proportion, urban population growth, net official development assistance, and gross domestic product (GDP) were also obtained for each country from The World Bank Data Catalog.[10] Countries undergoing a war or major armed conflict (> 1000 casualties in 2022) were identified using publicly available data from the Armed Conflict Location & Event Data Project. Countries were classified into low-income countries (LICs), lower-middle-income countries (LoMICs), upper-middle-income countries (UpMICs), and high-income countries (HICs) using WB designations.[11] All non-HICs are collectively referred to as LMICs. Countries were sorted into WHO regions for geographic analysis.

Survey data on the presence of national neurosurgery societies were corroborated and adjusted post hoc following review of a recent study on neurosurgery societies.[12] Discrepancies between our data and previously published data were resolved through online searches for societies. Through our survey, 7 countries (Benin, Kenya, Madagascar, Malaysia, Oman, Panama, and Zambia) were identified to have neurosurgery or combined neurology/neurosurgery societies that did not have societies listed in the aforementioned study.[12]

Data from 192 countries (all but Tajikistan) and 25 additional regions (all but Macau) were obtained, representing 99.9% of the global population, so data were assumed to be complete and representative of each income-region and WHO region.

### Statistical Analysis and Data Visualization

Statistical analysis was performed in R (version 4.2.1, The R Project). Descriptive, population-weighted estimates were calculated. Temporal trends incorporating previous estimates in the neurosurgery workforce were constructed and fit with linear models.[5,6] Univariate linear regression analysis with pairwise elimination was then used to assess factors associated with the growth of neurosurgery modeled as geometric (relative) and linear (absolute) growth rates from 2016 (using prior estimates) to 2022.[6] Linear and geometric growth were correlated with several factors available publicly through the WHO and WB; they were also correlated with the presence of a neurosurgery society. Categorical variables included population quartile, WHO region, WB income level, and presence of a neurosurgery society; the remainder were linear variables.

All figures were made with Prism (GraphPad Software, Inc.) and Datawrapper (Datawrapper GmbH). The Datawrapper map visualization function incorporates all 193 countries, 4 territories (Andorra, Greenland, Hong Kong, Macau), 2 independent states (Kosovo, West Bank and Gaza), and 1 disputed region (Taiwan).

## Results

### Survey Respondents

Data were obtained from 192 (99.5%) of 193 countries and 25 of 26 additional territories, independent states, and disputed regions. One hundred seventy-seven participants provided data for at least 1 country or territory. The median age of the participants was 43 (interquartile range 36–55) years and 13.6% of respondents were women. Data were obtained from the leaders of national/regional neurosurgery organizations (n = 4, 2.3%), chairs of neurosurgery departments (n = 30, 16.9%), consultant neurosurgeons (n = 107, 60.5%), and residents and fellows (n = 31, 17.5%), among others. Most respondents (64.0%) practiced in LMICs and approximately half (51.1%) trained in LMICs. Most respondents (80.9%) were affiliated with a national/regional neurosurgery society.

### Workforce and Equipment

There were 72,967 estimated neurosurgeons worldwide, representing a pooled density of 0.93 neurosurgeons per 100,000 people and a median national density of 0.44 neurosurgeons per 100,000 people (Fig. 1). The neurosurgeon densities in HICs, UpMICs, LoMICs, and LICs were 2.44, 1.13, 0.37, and 0.12 per 100,000 people, respectively. When including independent states, territories, and disputed regions, these densities remain relatively consistent at 2.51, 1.13, 0.37, and 0.12 per 100,000 people, respectively. The target of 1 neurosurgeon per 100,000 people was met by 50.8%, 32.1%, 7.7%, and 0% of HICs, UpMICs, LoMICs, and LICs, respectively.

Africa (0.11 neurosurgeons per 100,000 people) and Southeast Asia (0.34 per 100,000) had the lowest neurosurgeon density, while the Western Pacific region (WPR) had the highest (1.58 per 100,000), which was largely driven by Japan (7.95 per 100,000) and South Korea (6.76 per 100,000). Among countries with available data, 124 (64.9%) of 191 countries had national neurosurgery societies and 119 (65.7%) of 181 countries had certification processes for new neurosurgeons (Supplementary Fig. 2).

There were 29 countries, 14 territories, and 1 independent state with no neurosurgeons, representing a total population of 35,753,949 people without access to a neurosurgeon within their borders. Among the 29 countries with no neurosurgeons, 21 were LMICs (72.4%), and most were either in the WPR (n = 10, 34.5%) or African region (n = 9, 31.0%).

Generally, neurosurgeons in LMICs had less access to blood transfusion, ventriculoperitoneal shunts, microscopes, angiography, neuronavigation, and endoscopes (Fig. 2). The differences in availability of spinal instrumentation were variable, but data on the division of spine cases between neurosurgeons and orthopedic surgeons were not obtained. The absolute differences in equipment availability for HICs and LICs were highest for biplane angiography (67.2% vs 4.5%) and intraoperative neuronavigation (63.9% vs 5.5%).

### Temporal Trends

There was growth in the neurosurgical workforce across all WHO regions and income groups over time (Fig. 3). Annual growth rates between 2016 and current estimates in 2022 were 5.5% in HICs, 21.3% in UpMICs, 26.0% in LoMICs, and 9.4% in LICs. The greatest growth

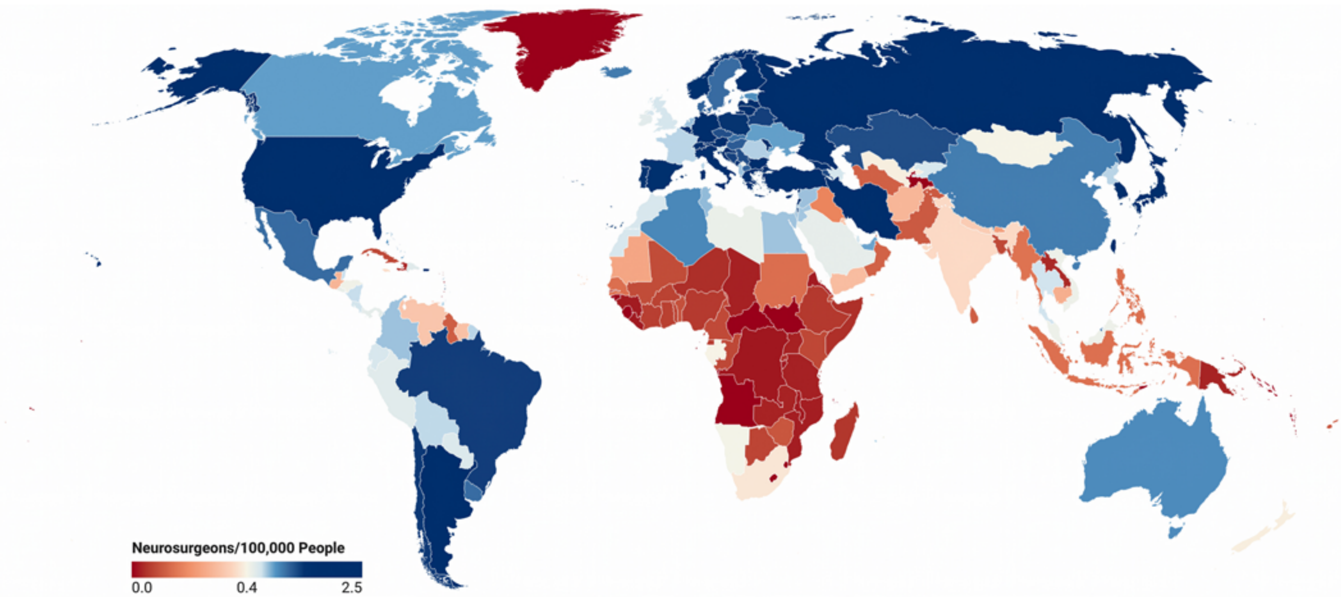


**FIG. 1.** Map demonstrating the global neurosurgeon density. Countries near the average national median density (0.44 neurosurgeons per 100,000 people) are demonstrated in *white*, those increasingly above the median are demonstrated in increasingly *dark blue*, and those increasingly below the median are demonstrated in increasingly *dark red*. This figure was created with Datawrapper (Datawrapper GmbH).

was in the Southeast Asia region (33.0% per year), while the slowest growth was in the African region (2.0% per year; Supplementary Fig. 3).

Univariate regression analyses were conducted to identify WHO and WB indicators and additional factors correlated with the relative and linear growth of the workforce in countries with sufficient data (Supplementary Fig. 4A and B). The strongest predictors of annual relative growth in neurosurgery density were increasing population quartile (30.1% for the 4th quartile relative to the 1st, 12.6% for the 3rd quartile, and 10.8% for the 2nd quartile, all $p < 0.05$), the presence of a national neurosurgery society (17.2%, $p < 0.005$), location in the WHO Eastern Mediterranean region (EMR; 14.2% relative to the WPR, $p = 0.042$), development aid (5% per 1,000,000,000 US dollars [USD], $p = 0.002$), and national GDP (0.004% per 10,000 USD per capita, $p < 0.001$). Increasingly higher population quartiles, the presence of a national neurosurgery society, and the WHO EMR (relative to the reference WPR) were also predictors of absolute growth.

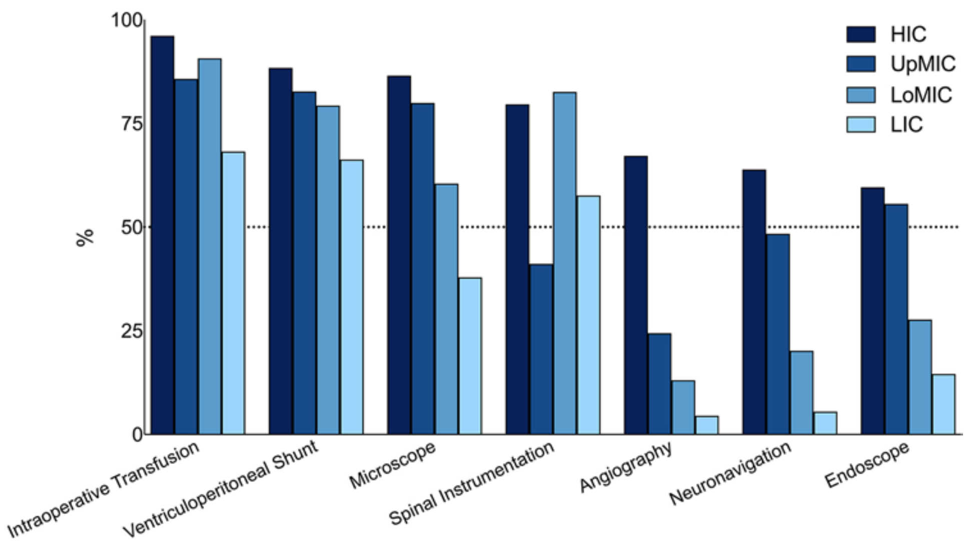


**FIG. 2.** Graph of the availability of various resources and equipment that are helpful or necessary for advanced neurosurgery, in percentage availability for neurosurgeons in countries sorted by WB income categories. In general, lower-income countries have less access to resources than higher-income countries, and the differences are largest for microscopes, angiography, and neuronavigation. Figure is available in color online only.

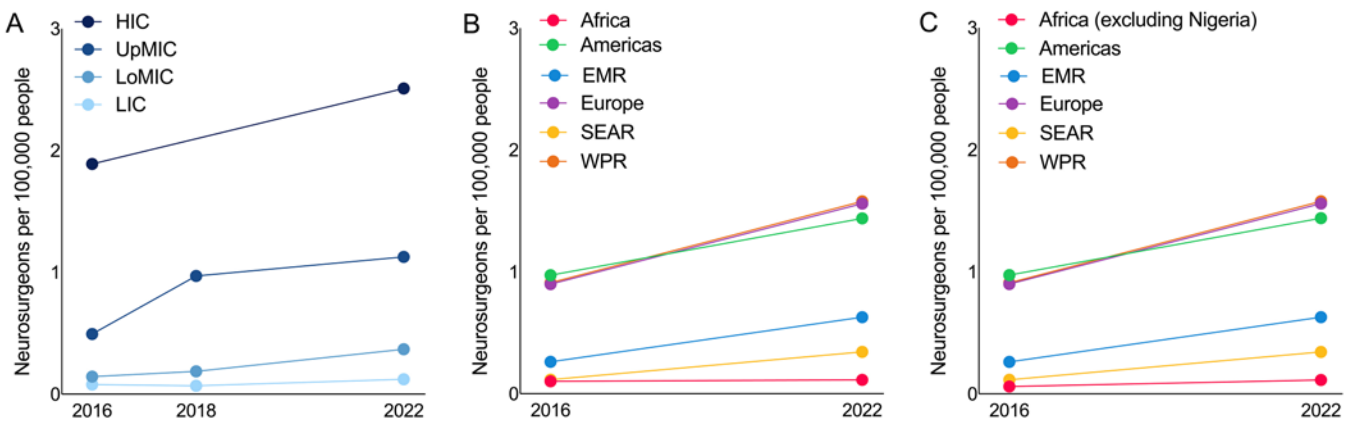


**FIG. 3.** Line graphs demonstrating the growth of the neurosurgery workforce since 2016. The largest absolute and relative growth has been in UpMICs. Data from 2016 and 2018 were obtained from previously published estimates.[5,6] Data are stratified by WB income level (**A**), WHO region (**B**), and WHO region excluding Nigeria (**C**), given the potential inaccuracy of prior estimates. SEAR = Southeast Asia region.

## Regional Subanalyses

### Africa

The WHO African region contains 47 countries and had the lowest workforce density and slowest workforce growth among all WHO regions. Nine countries had no neurosurgeons (19.1%), and these countries represented 2.8% of the region's total population. There was considerable variation throughout the region. There was growth in the total number of neurosurgeons in 24 (52.2%) of the 46 African countries for which trend analysis was available, and there was at least 100% growth in the total number of neurosurgeons in 19 (79.2%) of these 24 countries from 2016 to 2022. However, 15 countries in the African region had a decrease in their neurosurgery densities; 7 (46.7%) of these 15 countries were in West Africa. There was a significant discrepancy between 2016 estimates of the workforce in Nigeria (n = 505), the region's most populous country, and this study's estimate for the workforce in Nigeria (n = 138). Although growth in the region's workforce density was estimated to be 2.0% per year, the growth rate increased to 17.7% after excluding Nigeria.

### Americas

The WHO Americas region contains the subregions of the Caribbean (13 countries, 10 territories), Central America (6 countries), North America (3 countries, 2 territories), and South America (13 countries). North American countries had the highest pooled neurosurgeon density (1.82 neurosurgeons per 100,000 people), followed by South America (1.18 per 100,000), Central America (0.60 per 100,000), and the Caribbean (0.29 per 100,000). North American and Caribbean territories had 0.00 and 0.64 neurosurgeons per 100,000 people, respectively. Eleven of the countries and territories in the Caribbean had no neurosurgeons.

### EMR

The WHO EMR contains 21 countries and 1 independent state (West Bank and Gaza); 9 (41%) of these countries and states are currently in the midst of an armed conflict. The neurosurgeon densities in conflict and nonconflict areas in this region are 0.24 and 1.27 neurosurgeons per 100,000 people. Despite the lower workforce density in conflict compared with nonconflict areas, 8 (88.9%) of 9 of these countries and states in conflict have organized national neurosurgery societies, which represent potential collaboration partners for outside neurosurgeons and societies.

### Europe

The WHO European region consists of 54 countries, 3 territories, and 2 independent states. Split by UN geoscheme designation, the pooled workforce density was lowest in Northern Europe (0.96 neurosurgeons per 100,000 people) and increasingly higher in Eastern Europe (1.46 per 100,000), Southern Europe (1.78 per 100,000), and Western Europe (1.87 per 100,000).

### Southeast Asia

The WHO Southeast Asia region contains 11 countries, all of which are LMICs. The range of workforce densities is 0.00–0.77 neurosurgeons per 100,000 people, with a pooled density of 0.34 neurosurgeons per 100,000 people.

### WPR

The WHO WPR contains 25 countries, 7 territories, and 1 disputed state. The region is composed predominantly of isolated island nations with no roadway connections to other countries or regions (n = 23, 69.7%). Thirteen (56.5%) of these 23 isolated island nations were estimated to have no neurosurgeons, the most populous of which was the Solomon Islands. There was considerable variation within the region—this region had the highest pooled neurosurgeon density, but that was largely driven by a few countries with an especially high workforce. Three (9.1%) of the 33 countries, territories, and disputed states each had more than 3 neurosurgeons per 100,000 people (Taiwan, South Korea, and Japan); an additional 4 (12.1%) had more than 1 neurosurgeon per 100,000 people

(China, Brunei Darussalam, Guam, and Hong Kong); and 14 (42.4%) had no neurosurgeons.

## Discussion

This is the largest study designed to assess the global consultant neurosurgeon workforce and its trends over time, and is the first study to assess the variation in resources available to neurosurgeons. We estimate that there are approximately 73,000 trained neurosurgeons worldwide, and that there is a pooled density of 0.93 neurosurgeons per 100,000 people worldwide. There are wide disparities in the neurosurgery workforce and their access to resources in different WHO regions and WB income categories. We estimate that the neurosurgeon workforce has grown by 11.9% per year between 2016 and 2022, with the fastest growth in UpMICs and LoMICs.

### Data Evaluation

Better access to neurosurgery is associated with decreased mortality and improved neurological function across a variety of neurological pathologies.[13–15] In this study, we found that HICs tended to have the highest neurosurgeon workforce density, as previously described.[6] Initial estimates suggested that at least 1 neurosurgeon is needed per approximately 100,000 people.[16,17] While half of HICs met this target, the majority of UpMICs and LoMICs did not, and no LIC met this target. Notably, this estimate does not account for other relevant factors, including subspecialization, intensive care units, specialized nursing, and equipment.[17] More recent reports suggest a neurosurgeon ratio of approximately 1 neurosurgeon per 65,000 people is not adequate, especially in environments with aging populations and demand for subspecialized neurosurgeons.[17]

The largest relative growths were observed in UpMICs and LoMICs, where there have also been the largest recent increases in national health financing.[18] These middle-income countries are poised to rapidly expand their operative services given their current pace of development and ongoing neurosurgery needs, while HICs generally already have large workforces, and LICs may not have the public funding to support the accelerated expansion of neurosurgery. These growth rates suggest that more middle-income countries may meet the discretionary target of 1 neurosurgeon per 100,000 people in the coming years.

There were several regional trends identified in this study. The Southeast Asia region and WPR have demonstrated some of the most rapid growth, and future efforts in these regions may focus on solidifying their regional organization, ensuring adequate equipment, and continuing to develop training centers.[19] The WPR has the highest neurosurgeon density, largely due to high workforce densities in Japan and South Korea, which may be related to several educational, cultural, or workplace factors in these countries, and requires further exploration. Although the African region had the lowest workforce density, there were several countries within this region that saw exponential growth, suggesting the potential for rapid growth over the coming decade.[20,21] The workforce density growth was lowest in the African region, but this was likely influenced by overestimation from prior studies given that our estimates in this study were more closely aligned with figures in the Nigerian popular press.[22] The growth of the workforce in Africa is therefore likely to be considerably higher than 2.0% per year estimated here, as other estimates have also suggested.[23] Current efforts to grow the neurosurgery workforce in Africa should include strengthening regional centers of excellence and supporting countries with no or very few neurosurgeons, especially in West Africa. It is also imperative to ensure these new neurosurgeons are adequately resourced.

While describing the workforce within the WHO region framework is helpful to establish trends over time, it is important to consider the significance of local variations. For instance, there is a wide variation in the workforce density in the Americas region—North American countries had a three- and six-fold higher density than Central American and Caribbean countries, respectively. Subregions like the Caribbean islands face the added challenge of island-based geography, which hampers rapid triage and treatment for urgent pathologies.[24]

We identified several correlates of growth in the neurosurgeon workforce. While many of these factors are nonmodifiable (population size, development aid, GDP), the presence of a national neurosurgery society is something that nearby regional societies could help promote in countries that do not have one. There is likely a bidirectional relationship between growth of the workforce and the creation of neurosurgery societies, but theoretically, organizing neurosurgeons within a society should help them support training, organize academic meetings, and raise the profile of the specialty.

We observed a trend toward decreased availability of equipment and resources in countries with decreasing income levels. Efforts to expand neurosurgical capacity in LMICs should focus on supporting the growing workforce with technology that makes surgery safer and improves outcomes. Neurosurgeons' access to spine instrumentation may vary by country based on the division of labor and training paradigms between neurosurgeons and orthopedic surgeons.[25,26]

Many of these resources are needed to treat neurosurgical pathologies beyond neurotrauma. In particular, only 5% of neurosurgeons in LICs are estimated to have access to angiography, but the global incidence of stroke, particularly in LICs, has rapidly increased.[27,28] Biplane angiography suites are also an effective method to treat other neurovascular pathologies ranging from aneurysms to arteriovenous fistulas, and they also provide a way to efficiently diagnose and treat common nonneurosurgical pathologies such as gastrointestinal bleeding. International groups such as Mission Thrombectomy 2020+ provide a vehicle to obtain funding, improve access to specialty neurosurgery care, and track changes in access over time.[29] Brain and spine tumors are often urgent pathologies that require neurosurgical evaluation.[30] Surgery for brain tumors is made safer by the growing armamentarium of microscopes, endoscopes, and intraoperative neuronavigation.[31] Functional neurosurgery, including epilepsy and movement disorders, is a major focus area for the next decade, especially given its high unmet burden and its inclusion as a WHO priority within its "Intersectoral Global Action Plan for Epilepsy and Other Neurological Disorders 2022–2031."[32,33] While not included in our survey, epilepsy surgery offers a means to reduce seizure frequency and the need for seizure medications.[34,35]

### Solutions to Workforce and Resource Disparities

Solutions to the future challenges in global neurosurgery depend on collaboration and implementation. While this study identifies several regions with low neurosurgery capacity and highlights the inequities in access to equipment, collaborative efforts between ministries of health, regional and national neurosurgery societies, and neurosurgery departments are needed to develop local solutions to increase the neurosurgery workforce. Collaboration between neurologists and neurosurgeons is necessary to develop regional centers of excellence with gold-standard diagnostics and treatment options for neurovascular pathology, neurooncology, and epilepsy. Stroke and TBI have a high and increasing incidence in LMICs and require efficient triage systems and rapid interventions, which necessitates collaboration between ministries of health, municipal planners, hospital administrators, emergency transport companies, and physicians.[28,36] In regions that contain island nations, collaboration between larger regional centers and more rural islands to establish systems for efficient triage and transfer should be implemented. Strategies to expand the workforce should also consider patient impact in different contexts. For instance, neurosurgeons and trainees in LICs may benefit from education on public policy to better advocate for more resources and funding for neurosurgery services.

Platforms that encourage collaborative case discussion can organically foster international relationships that could grow neurosurgical capacity locally.[37,38] Further dialogue between public health officials and neurosurgeons will continue to push forward the aims of the organized global neurosurgery movement.[37,39,40]

Low-cost technological advancements can improve the capacity for advanced neurosurgery in LMICs. These advancements include tools that aid in microneurosurgery, including low-cost magnification and neuronavigation systems.[41,42] Private-public partnerships can accelerate access to advanced tools needed to perform neurosurgery while providing a framework for economic sustainability. Several examples of private-public partnerships have been described, including the development of intraoperative MRI at the University of Malaya.[43]

Interested individual participants and organizations have roles to contribute in growing the neurosurgeon workforce: well-resourced individual neurosurgeons and departments can partner with colleagues in poorly resourced regions in "twinning" programs;[8] they can also perform regional rotations to fill the case needs of different populations within a country;[44] national and regional societies can aid countries with an insufficient workforce through funding and educational opportunities;[8,45] ministries of health can prioritize neurosurgical pathologies; and academic global neurosurgeons can continue to advocate for neurosurgery at the strategic global health venues.[40,46]

### Setting Targets for 2030

The authors posit the need for a central, organized effort to estimate the neurosurgeon workforce and resources available to neurosurgeons in 2030. This could be accomplished with a collaborative, multilateral effort through the global neurosurgery committees of national and international neurosurgery societies. This effort should start with national and regional need analyses that help set goals for the equipment and workforce needed in HICs, UpMICs, LoMICs, and LICs. The de-identified data from this study and future efforts should be centrally stored with a multinational society to form a baseline for the next estimations.[5]

### Limitations of the Study

This study has several pertinent limitations. The quality of data is variable—survey responses were obtained from national neurosurgery society leaders in some countries and consultants unaffiliated with organized neurosurgery in others. The former may be more likely to overestimate their workforce and equipment, while the latter are on the "front lines" and may have a more accurate sense of the availability of equipment, at least in their context. There may be selection bias due to finding participants bibliographically. Quantification of the growth in the neurosurgery workforce was dependent on the accuracy of prior estimates of the workforce, which may have been inaccurate in several instances, including Nigeria among others.

This study provides data on the current shortcomings in the neurosurgeon workforce and resourcing, but local solutions that emphasize contextual understanding and buy-in from local stakeholders are needed. This study focuses on the supply of neurosurgeons, but the demand in different locations remains unknown. This study also does not provide data on the availability of subspecialized neurosurgeons.

## Conclusions

Worldwide, there are an estimated 72,967 neurosurgeons, representing a pooled global density of 0.93 neurosurgeons per 100,000 people. Despite the average global neurosurgeon workforce approaching target levels, there remain stark disparities in workforce size by income level and region. The consultant neurosurgeon density was higher in HICs, and highest in the WPR. Growth in the neurosurgery workforce was observed in all WB income-level brackets and WHO regions and was highest for LoMICs and UpMICs. Several disparities were observed in the availability of resources to provide advanced neurosurgery care based on a country's WB income level. There remain 29 countries, 14 territories, and 1 independent state with no neurosurgeons.

## Appendix

### WFNS Global Neurosurgery Committee

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## Disclosures

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

## Author Contributions

Conception and design: Gupta, Gal, Athni, Calderon, Callison, Dada, Lie, Qian, Reddy, Park. Acquisition of data: Gupta, Gal, Athni, Calderon, Callison, Dada, Lie, Qian, Reddy, Rolle, Baticulon, Chaurasia, Dos Santos Rubio, Esquenazi, Golby, Park. Analysis and interpretation of data: Gupta, Gal, Athni, Calderon, Callison, Dada, Lie, Qian, Reddy, Golby, Park. Drafting the article: Gupta, Pirzad. Critically revising the article: Gupta, Gal, Athni, Calderon, Callison, Dada, Lie, Qian, Rolle, Baticulon, Chaurasia, Dos Santos Rubio, Esquenazi, Golby, Park. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Gupta. Statistical analysis: Gupta, Gal. Administrative/technical/material support: Pirzad, Park. Study supervision: Golby, Park.

## Supplemental Information

### Online-Only Content

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

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### Companion Papers

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