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Access to training in neurosurgery (Part 1): Global perspectives and contributing factors of barriers to access

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ABSTRACT

Introduction: Neurological disorders are one of the leading causes of death and disability adjusted life years (DALYs). Efforts have been made to increase the neurosurgical workforce in an attempt to address the global disease burden. Despite these efforts, there continues to be a shortage of neurosurgeons in both high-income countries (HICs) and low-and middle-income countries (LMICs).
Research question: The aim of the study was to identify the barriers to neurosurgical training in LMICs and HICs.
Materials and methods: We administered an electronic survey targeting medical students, neurosurgery residents, and recent neurosurgery graduates from 69 countries in both HICs and LMICs. Questions were framed to assess barriers to training.
Results: Of the 198 responses received (31.3% response rate), 72% identified as male, 27% female, and 0.5% as non-binary gender. 33 respondents were from HICs and 165 were from LMICs. 70.1% of respondents reported no availability of dissection labs in their home institutions. There was a significant difference in availability of subspecialty training between LMICs and HMICs ($p = 0.001$) but no significance was seen for competitiveness of programs ($p = 0.473$).
Discussion and conclusion: There are limitations to our study: it is not comprehensive of training programs globally, there is sampling bias, especially among LMICs, and the accuracy of responses is unclear. Nonetheless, our results highlight the need for a deliberate focus on designing and implementing both short and long term goals in tackling barriers to access to neurosurgical training, with a conscientious effort to involve interested stakeholders and governments to invest in the training and education of their neurosurgical workforce.

1. Introduction

Neurological disorders are one of the leading causes of death and disability worldwide (GBD, 2016 Neurology Collaborators, 2019). Each year, 22.6 million patients suffer from neurological disorders or injuries, 13.8 million of whom require surgical care. In order to address this need, an estimated 23,300 additional neurosurgeons are needed around the world to provide the essential surgical care (Dewan et al., 2018). Despite these reports, there continues to exist a wide gap in the provision of equitable access to neurosurgical care worldwide, with low- and middle-income countries (LMICs) bearing the brunt of the deficit, and large geographic treatment gaps particularly in Africa and Southeast Asia (Dewan et al., 2018). One of the critical key factors contributing to this wide gap is the lack of sufficient surgical workforce density. Many studies have supported the call to increase the neurosurgical workforce capacity, particularly in LMICs, and have called on the global neurosurgery community to assist in increasing the number of training programs, recruiting interested medical students and young physicians early into the field, and retaining existing trainees within their home countries (Dewan et al., 2018; Punchak et al., 2018).

Within high-income countries (HICs) in Europe and North America, neurosurgical training is usually standardized (Burkhardt et al., 2010a). The rigorous training requires medical school graduates and aspiring trainees to complete four or more years of medical school, followed by

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standard licensing, after which they commit to several years of residency training either via a direct route or after completion of a required general surgery training. This length of time varies depending on the specific program and country of training. Despite efforts to harmonize training in the European Union, there still exists significant variability in trainee access to educational materials and experiences such as hands-on surgical skills and simulation labs (Stienen et al., 2016a). In LMICs, there is even greater variability in training, with many countries lacking a uniform curriculum, varying training lengths, and different routes to training with differing certifications, or even no certification at all (Kato et al., 2020). This has led some to advocate for global standardized training in order to facilitate collaboration between training centers (Burkhardt et al., 2010a). Some of these efforts have met with success, such as in the multi-country training model of the College of Surgeons of East, Central, and Southern Africa (COSECSA). (Henderson et al., 2020).

As part of these efforts to increase and improve neurosurgical training, there must be a collaborative and conscientious effort to address the multitude of barriers students and trainees face in their pursuit to become neurosurgeons. Despite the increased momentum behind training neurosurgeons worldwide, there remain several barriers to accessing and completing accredited neurosurgical training programs, especially for medical school graduates in LMICs. Beyond the complete absence of any neurosurgical training in some countries, several barriers to easy accessibility to neurosurgical training have been reported in the literature for both HICs and LMICs that have training programs (Dias et al., 2013; Gnanakumar et al., 2020). Examples include lack of dissection and surgical skills labs, sustainable and cost-effective training modules or curricula, insufficient health research capacity to address local disease burden, and a paucity of mentors (Liang et al., 2016; Qayumi, 2010; Franzen et al., 2017; Lescano et al., 2019). These barriers; however, are significantly more pronounced in LMICs due to lack of standardized training, poor government investment in healthcare infrastructure, and more specifically, a lack of prioritization of surgical subspecialties. Studies from organizations such as the World Health Organization (WHO) have attributed this lack of investment in LMICs to a focus on communicable and non-communicable diseases such as heart disease over surgical disorders and injuries (Debas et al., 2015).

In this study, we assess the barriers to access to neurosurgical training for medical students seeking to enter training and for trainees in accessing resources to further their training, both in LMICs and HICs globally. Moreover, we explore the data to understand the similarities and differences in both settings, and seek sustainable long-term solutions for stakeholders to actively assist in breaking down these barriers.

2. Methods

This study was a collaborative effort by members of the Harvard Program in Global Surgery and Social Change, World Federation of Neurosurgical Societies Global Neurosurgery Committee, and the Ribat Neurospine Center, Ribat University Hospital of Sudan. The study was approved by the Harvard Medical School Institutional Review Board (IRB20-1372).

2.1. Survey design

Utilizing the EQUATOR checklist (Kelley et al., 2003), we developed a 12 to 23-question survey to assess the current neurosurgical training capacity and barriers to training around the world, with a particular focus on LMICs. Questionnaire length varied based on participant responses to initial questions. The survey was targeted at applicants to neurosurgical training, current trainees, and recent graduates from neurosurgical training programs within the past four years. All participants were asked questions regarding access and applying to neurosurgical training, while only current trainees and recent graduates were asked regarding resources and characteristics of training. The questionnaire was developed by one author (AA) and underwent review and revisions by the research team, which included members from the United States and Sudan, both neurosurgical trainees and medical students, until consensus was achieved.

Survey variables were designed to collect data on participant demographics, geographic location, training level, and barriers to access to training. Specific questions were constructed to assess the presence and size of training programs, length of training, cost of entry and training, workload, and caseload. Additionally, data was collected on participant perceptions of competitiveness, availability of mentorship, and research opportunities. The details of the survey questionnaire are included in the supplementary Appendix 1.

2.2. Identification of participants

We sought the perspective of applicants to neurosurgical training, current trainees, and recent graduates from neurosurgical training programs within the past four years. Efforts were made to include respondents who were representative of all WHO regions with a focus on LMICs. In order to achieve this, our recruitment efforts were focused on international groups that contained our target groups. We advertised our study with the Global Surgery Student Alliance, Young African Neurosurgeons, and the Neurosurgery Cocktail Facebook group, utilizing email, social media platforms such as Twitter and Facebook, and messaging apps such as Telegram and WhatsApp. Requests were also made for word-of-mouth advertisement and through personal contacts of the study authors.

2.3. Survey distribution

Participants consented to receive an invitation to the survey by signing up via a Google Forms (Google, Mountainview, CA) request. Study data were collected and managed using REDCap electronic data capture tools hosted at Harvard Medical School (Harris et al., 2009). REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing: 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources. The survey was administered in English. Responses were collected from September 7th to November 10th, 2020. In order to improve response rate, biweekly reminder emails were sent out during this period to all invited participants who had not yet responded to the survey, for a total of three reminders (Hoddinott and Bass, 1986). A total of 633 people were invited to participate in the survey with a goal response rate of approximately 33% (Nulty, 2008).

2.4. Data analysis

Results were exported from the REDCap system into Microsoft Excel© 2016, and analyzed using SPSS (SPSS Inc. Released, 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.). Mean, mode, and frequency distributions were determined for respective variables in each country. When more than one mode was found for a variable, clarification was obtained by searching the literature or contacting neurosurgical society representatives for the respective country. When an answer was not able to be found, consensus was obtained amongst the authors as to which answer to select, and was then consistently applied to all relevant answers for a variable. Data was then analyzed at both a global and country-specific level. Countries were also grouped into high-income (HIC) and low- and middle-income (LMIC) classifications using the World Bank income classification. (The World Bank) Nonparametric comparison of the means using the Mann-Whitney U test was performed, comparing the HIC to LMIC group.

3. Results

3.1. Respondent demographics

We received a total of 198 responses out of 633 people invited to complete the survey, giving a 31.3% response rate. Of 198 responses from 69 different countries, 33 (16.70%) were from HICs and 165 (83.30%) were from LMICs (Fig. 1). 143 respondents identified as male (72%), 54 as female (27%), and 1 as non-binary gender (0.5%). Aspiring neurosurgeons, current neurosurgery trainees and recent neurosurgery graduates comprised 37%, 36%, and 27% of respondents, respectively (Table 1). The mean year in training for the neurosurgery trainees was 3.6 ± 1.7. The mean age of respondents was 32.5 ± 8.4 years. 33 respondents, only one of whom was from a HIC, attended medical school in a country different from that of their country of origin; 15 respondents - 4 from HIC medical schools - then underwent neurosurgical training in a country different from where they attended medical school.

3.2. Global statistics

Measures of competitiveness for entering neurosurgical training and availability of mentorship were collected from all respondents. Globally, the mean competitiveness on a scale of 1–10 was ranked as 7.8 ± 2.5. The mean mentorship availability on a scale of 1–10 was ranked as 4.8 ± 2.6.

Data on research opportunities during training, availability of surgical skill or dissection labs, weekly work hours, and annual procedures were collected from participants who identified as neurosurgery trainees or recent graduates. 70.1% of survey respondents reported no availability of dissection and surgical skills labs in their home institutions. In regards to research, however, 76.9% of respondents reported that they did have research opportunities available to them. There was no apparent geographic distribution for the availability of dissection labs or research opportunities (Fig. 2). Of the countries represented, 45.6% were reported to have neurosurgical subspecialty training available. The majority of countries without subspecialty training were located in sub-Saharan Africa.

The number of weekly hours varied widely across countries with 43.1% of respondents reporting working >80 h per week (Table 2). The number of annual procedures performed at training programs also varied widely, with the greatest number of respondents (34.5%) reporting more than 500 procedures performed (Table 3).

Table 1
Respondent demographics with number of respondents for each category listed and percentage of respondents in parentheses.

	Amount (Percentage)
Country-Income Group	
HIC	33 (16.7%)
LMIC	165 (83.3%)
Gender	
Male	143 (72%)
Female	54 (27%)
Non-binary	1 (0.5%)
Training Level	
Aspiring Neurosurgeon	70 (37%)
Neurosurgery Trainee	68 (36%)
Recent Neurosurgery Graduate	51 (27%)

3.3. Country statistics

Country specific data on the number of training programs, availability of subspecialty training, neurosurgery training length in years, number of trainees in a training program, gender demographics, average weekly work hours for trainees, average number of annual neurosurgical procedures performed at a training institution, availability of research opportunities, availability of dissection or surgical skills labs, competitiveness for entering neurosurgical training, and neurosurgical mentorship availability are reported in Table 4. The number of training programs in a country varied widely, from none to 120. Sub-Saharan Africa and South-East Asia had the fewest number of training programs per country (Fig. 2). Training length varied from 1 to 10 years, with the most common duration being 5 years. The size of training programs also varied widely, ranging from 2 to 70 trainees in a program. Men mostly outnumbered women in gender breakdown of trainees, with a mean percentage of 75% men to 25% women. Algeria and Spain were reported to have more women than men in their training programs, however.

3.4. Comparative analysis

In comparing LMICs to HICs, there was no significant difference found in ranked competitiveness for entering neurosurgical training, with a mean of 7.8 on a scale of 1–10 amongst both LMIC and HIC respondents

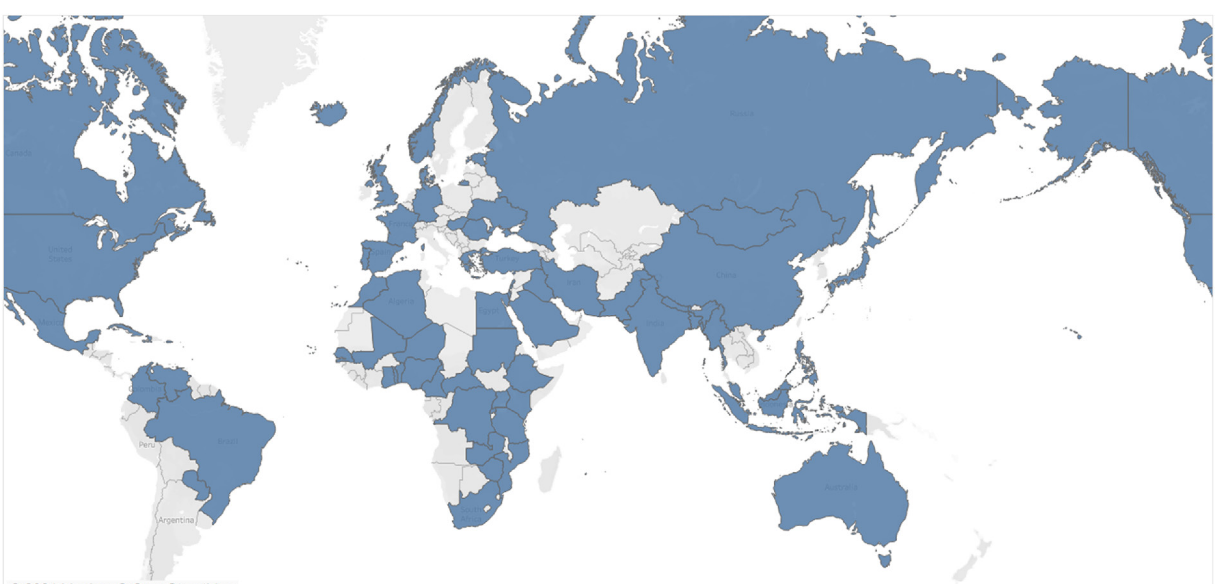

Fig. 1. Map view of country representation. Each blue-filled country had at least one respondent from that country. Number of respondents from each country is not shown here. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

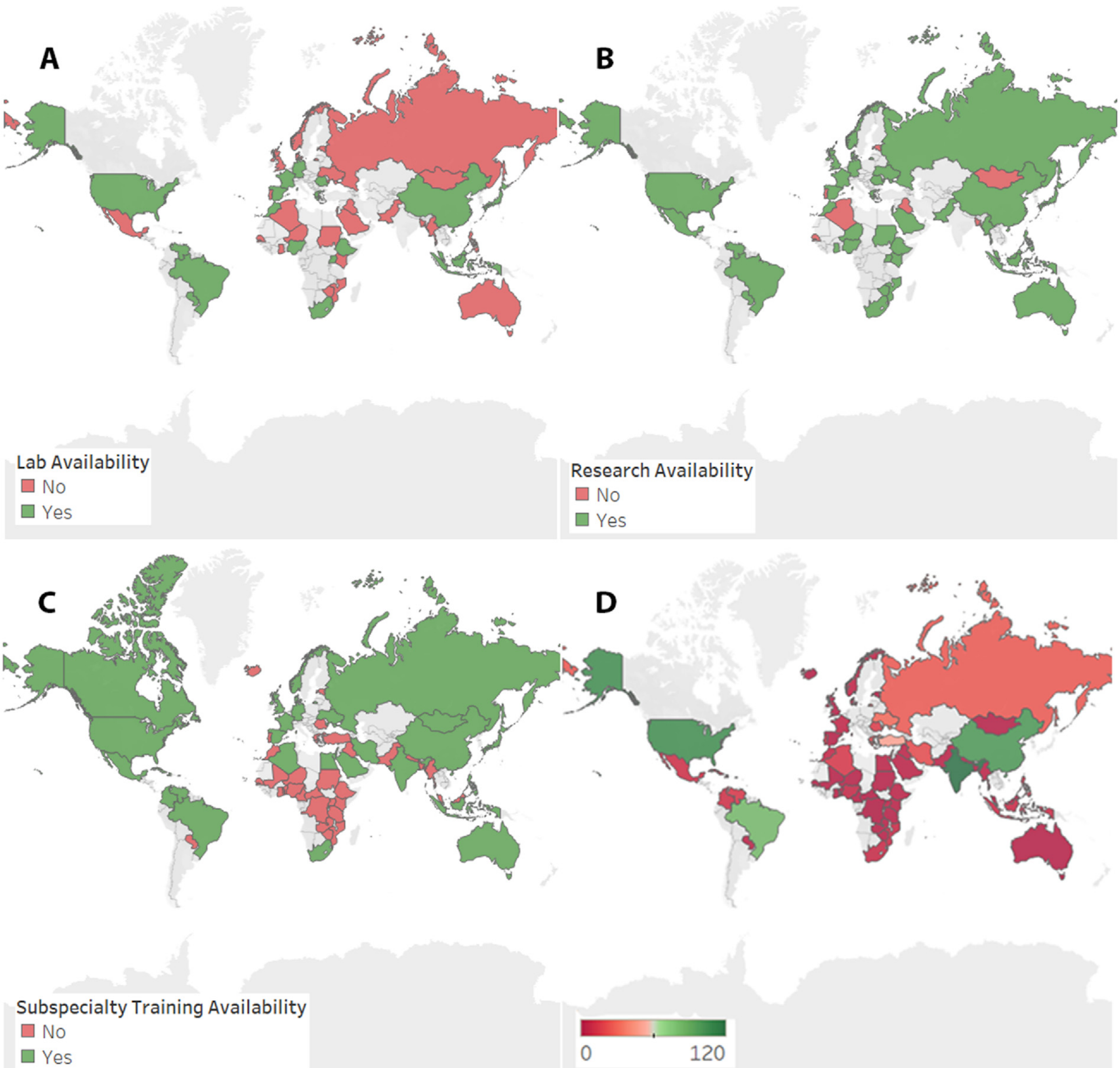

Fig. 2. Geographic heatmaps demonstrating countries for which respondents reported the availability of dissection and surgical skills labs (A), availability of research opportunities (B), and availability of subspecialty neurosurgical training (C). The number of training programs per country is demonstrated in panel D, ranging from 0 (dark red) to 120 (dark green). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Distribution of respondents who reported working the respective number of hours per week.

Weekly Work Hours	Percent of Respondents
0–10	0.9
10–20	3.4
20–30	0
30–40	2.6
40–50	11.2
50–60	14.7
60–70	12.1
70–80	12.1
>80	43.1

Table 3
Distribution of respondents who reported the respective number of annual procedures being performed at their training institution.

Number of Annual Procedures	Percent of Respondents
<50	2.7
50–100	6.2
100–200	16.8
200–300	15
300–400	13.3
400–500	4.4
>500	34.5
Unsure	7.1

($p = 0.473$). There was also no significant difference in ranked availability of mentorship, with LMIC respondents reporting a mean of 4.7 on a scale of 1–10 compared to 5.4 reported amongst HIC respondents ($p = 0.162$). In addition, no significant difference was found between LMIC and HIC respondents for annual number of procedures ($p = 0.122$), availability of research opportunities ($p = 0.692$), or availability of surgical skill or dissection labs ($p = 0.262$) (Table 5). A significant difference was found in weekly work hours ($p = 0.016$) and subspecialty training availability ($p = 0.001$) between LMICs and HMICs. HIC respondents reported on average fewer weekly work hours than LMIC respondents. Subspecialty training was reported to be available more often by HIC

Table 4
Country specific data on number of training programs, availability of subspecialty training, neurosurgery training length in years, number of trainees in a training program (size), gender demographics, average weekly work hours for trainees, average number of annual neurosurgical procedures performed at a training institution, availability of research opportunities, availability of dissection or surgical skills labs, competitiveness for entering neurosurgical training on a scale of 1–10, and neurosurgical mentorship availability on a scale of 1–10. Some countries have more than one training pathway; different lengths of training are separated by a comma. Program size varied by program within a country, so presented values denote a range where more than one value was reported. LIC = low-income country; LMIC = lower-middle income country; UMIC = upper-middle income country; HIC = high-income country; SD = standard deviation.

Country	Country Income Group	Number of Training Programs	Subspecialty Training Availability	Training Length	Program Size	Male:Female Ratio	Weekly Work Hours	Number of Annual Procedures	Research Availability	Lab Availability	Competitiveness (Mean ± SD)	Mentorship availability (Mean ± SD)
Algeria	LMIC	13	Yes	5	3–9	1:3.5	50–60	200–300	No	No	2.7 ± 2.1	6.3 ± 1.2
Australia	HIC	1	Yes	6			70–80	200–300	Yes	No	10	6.5 ± 0.7
Bangladesh	LMIC	2	No	5			>80	50–100	No	No	10	9
Barbados	HIC	0	No									
Benin	LMIC	0	No									
Brazil	UMIC	82	Yes	5			70–80	>500	Yes	Yes	9.3 ± 0.6	5 ± 1
Cameroon	LMIC	1	No								7 ± 3.1	4.5 ± 3.7
Canada	HIC		Yes									
Cape Verde	LMIC	0	No									
Central African Republic	LIC	0	No									
China	UMIC	100	Yes	4, 7	40	1:0.18	40–50	>500	Yes	Yes	6 ± 1.4	6 ± 5.7
Colombia	UMIC	10	Yes								10	1
Cuba	UMIC	9	Yes								6	9
Denmark	HIC	4	Yes	5	4	1:0	30–40	100–200	Yes	No	9.5 ± 0.7	5
DR Congo	LIC	0	No								9.5 ± 0.7	2.3 ± 1.2
Egypt	LMIC	3	Yes								5 ± 5.7	7.5 ± 0.7
Estonia	HIC	1	No	5			50–60	300–400	No	No	4	7
Ethiopia	LIC	3	No	5	15	1:0.15	70–80	>500	Yes	Yes	9.3 ± 1.2	4.3 ± 3.2
France	HIC	5	Yes	5			0–10	>500	Yes	Yes	6.5 ± 5	7
Germany	HIC		Yes	7			40–50	50–100	Yes	Yes	4.5 ± 5	3 ± 2.8
Ghana	LMIC	2	No	4, 7, 8	5–6	1:0.22	60–70	100–200	Yes	No	7.4 ± 1.7	4 ± 1.9
Greece	HIC	18	No	9			60–70	100–200	Yes	Yes	1	3.5 ± 2.1
Haiti	LIC	1	Yes								10	2
Hungary	HIC											
Iceland	HIC	0	No									
India	LMIC	120	Yes								9.7 ± 0.6	4.3 ± 2.9
Indonesia	UMIC	8	Yes	5, 6	9–50	1:0.12	>80	100–200	Yes	Yes	7.7 ± 2	6.5 ± 2.5
Iran	UMIC	20	Yes								8	10
Iraq	UMIC	3	No	5	15		10–20	>500	No	No	2.1	1.4
Israel	HIC	10	Yes	6	11	1:0.37	>80		Yes	No	9	6
Japan	HIC		Yes	5			50–60		Yes	Yes		
Kenya	LMIC	2	No	6	4	1:0	>80	200–300	Yes	No	7.4 ± 3.4	3.8 ± 1.9
Lebanon	UMIC	5	Yes									
Malaysia	UMIC	1	No	4			>80	100–200	Yes	Yes	9.3 ± 1	4.5 ± 2.6
Mali	LIC	1	No									
Malta	HIC	0	No									
Mauritius	HIC	0	No									
Mexico	UMIC	10	Yes	6			10–20	200–300	Yes	No	8	5.5 ± 2.1
Mongolia	LMIC	1	Yes	1			60–70	300–400	No	No	3.3 ± 2.1	4.7 ± 2.5
Montserrat	HIC	0	No									
Morocco	LMIC	5	No	5	27	1:0.35	70–80	400–500	Yes	Yes	8.5 ± 2.1	5 ± 4.2
Mozambique	LIC	7	No	5	6	1:0.2	60–70	>500	Yes	No	5	5
Myanmar	LMIC	3	No	8	70	1:0.37	>80	200–300	Yes	No	5	1
Nepal	LMIC	2	No									
Niger	LIC	1	No	5	11	1:0.22	50–60	50–100	Yes	No	6	8
Nigeria	LMIC	6	No	4, 6, 7, 10	6–17	1:0.06	>80	300–400	Yes	Yes	9 ± 1.3	3.8 ± 1.7
Norway	HIC	4	Yes	6	9	1:0.5	50–60	200–300	Yes	No	8	4
Pakistan	LMIC	2	No	3, 5	2–16	1:0.22	>80	>500	Yes	No	7.1 ± 2.3	3.6 ± 2.2

(*continued on next page*)

Table 4 (*continued*)

Country	Country Income Group	Number of Training Programs	Subspecialty Training Availability	Training Length	Program Size	Male:Female Ratio	Weekly Work Hours	Number of Annual Procedures	Research Availability	Lab Availability	Competitiveness (Mean ± SD)	Mentorship availability (Mean ± SD)
Paraguay	UMIC	3	No	5			50–60	300–400	Yes	Yes	6	3
Philippines	LMIC	10	Yes	5, 6	3–12	1:0.5	>80	>500	Yes	No	9.4 ± 1.2	5.3 ± 2.6
Portugal	HIC	11	No	6	7	1:0.75	60–70	>500	No	No	8	8
Romania	HIC	15	No	6			50–60	<50	Yes	Yes	6.3 ± 1.5	3 ± 1.7
Russia	UMIC	25	Yes	2, 5			30–40	100–200	Yes	No	6.8 ± 2.4	3.6 ± 1.7
Rwanda	LIC	1	Yes									
Saudi Arabia	HIC	3	Yes	6	39		60–70	50–100	Yes	No	7	4
Senegal	LMIC	1	No	1, 5	42	1:0.27	60–70	100–200	No	No	3 ± 2.8	2.5 ± 2.1
South Africa	UMIC	7	Yes	5			50–60	300–400	Yes	Yes	9 ± 1.4	5.5 ± 0.7
Spain	HIC	1	Yes	5	5	1:1.5	40–50	200–300	Yes	Yes	10	4
Sudan	LIC	1	No	6	25–36	1:0.64	>80	300–400	Yes	No	8.2 ± 1.6	4.2 ± 2.1
Tanzania	LMIC	1	No									
Togo	LIC	0	No									
Turkey	UMIC	50	No								3	9
Uganda	LIC	2	No	4, 7	3–13	1:0.14	10–20	>500	Yes	Yes	9 ± 2	4 ± 4.2
UK	HIC	1	Yes	8			40–50	200–300	Yes	No	9.3 ± 1.2	5.7 ± 2.1
Ukraine	LMIC	30	Yes	6	5	1:0.67	50–60	>500	Yes	No	8.7 ± 2.3	3 ± 1.7
USA	HIC	105	Yes	7	3–11	1:0.2	>80	>500	Yes	Yes	9.6 ± 0.5	6.9 ± 2
Venezuela	UMIC	13	Yes	5			>80	>500	Yes	Yes	9	1
Zambia	LMIC	1	No									
Zimbabwe	LMIC	1	No	5			40–50		Yes	No	9	9

respondents than LMIC respondents.

4. Discussion

Neurosurgical training continues to be a competitive and difficult undertaking around the world. The long training duration, immense library of knowledge, and technical expertise necessary to become a neurosurgeon already stand as barriers to increasing the neurosurgical workforce. These standards of excellence cannot be diminished, but there exist a multitude of other addressable barriers that limit the equitable training of neurosurgeons. Our study provides a snapshot of the unmet needs in neurosurgical training around the world and can inform efforts to improve equitable access to training in order to address the global neurosurgical workforce shortage.

4.1. Availability of neurosurgical training

Although our study is not a comprehensive accounting of all neurosurgical training programs around the world, we found an unsurprising lack of neurosurgical training programs in LMICs and smaller island nations, including Iceland. Sub-Saharan Africa and South-East Asia had the fewest number of training programs per country. Due to this dearth of training opportunities, many survey respondents, most from LMICs, reported travelling to other countries both for medical school education and neurosurgical training. We did not assess the various reasons for this finding in our study; however, even if training programs are present in LMICs, training positions in HICs are still highly sought after, contributing to brain drain (Scheitler et al., 2020).

In addition, we found that 54.4% of countries represented in our study did not have neurosurgical subspecialty training available. LMICs were less likely than HICs to have subspecialty training available ($p = 0.001$), with the largest deficit in sub-Saharan Africa. This finding is consistent with a recent study where 40% of respondents from LMICs reported lack of adequate subspecialty exposure (Deora et al., 2020). The field of neurosurgery has witnessed an increase in subspecialization due to advanced technology, need for more expertise, and advances in minimally invasive procedures. In LMICs, the low workforce density and lack of necessary equipment can make it difficult to have subspecialty practices; however, studies have shown that the majority of the unmet neurosurgical needs in these countries are head injuries (Dewan et al., 2018). Subsequently, the scale up of the neurosurgical workforce and the skill-set they should possess should match the disease burden. These countries may want to develop two tracks for training - a shorter and more limited training focused on neurotrauma and general neurosurgical skills to manage the most urgent and common conditions, and a longer and more specialized training in the care of more complex conditions, scaled up to match the capabilities and the capacities of the neurosurgical system of the country.

This finding underscores the importance of strategic investment in neurosurgical health system development by local governments, supplemented by country-led north-south (between HICs and LMICs) and south-south (between LMICs) collaborations for specialized training of the neurosurgical workforce (Fuller et al., 2015). One confounding factor in these findings is that advanced neurosurgical training in LMICs can often focus on technical skills such as endoscopic training rather than the traditional Western subspecialty categories. These advanced training opportunities may not have been captured by our survey. They also encompass a training dynamic that must be thoroughly understood when developing training partnerships.

4.2. Operative volume

Sufficient surgical volume and experience is also critical for neurosurgical training. The COVID-19 pandemic demonstrated the importance of this as many institutions were forced to cancel elective surgeries and restructure training (Aljuboori et al., 2021; Wittayanakorn et al., 2020).

Table 5
Comparison between LMICs & HICs. Competitiveness and mentorship availability were graded on a scale of 1–10 with increasing values denoting increasing competitiveness and mentorship availability. Weekly work hours was an ordinal variable with the following values: 1 = 0–10, 2 = 10–20, 3 = 20–30, 4 = 30–40, 5 = 40–50, 6 = 50–60, 7 = 60–70, 8 = 70–80, 9=>80. Number of annual procedures was an ordinal variable with the following values: 1=<50, 2 = 50–100, 3 = 100–200, 4 = 200–300, 5 = 300–400, 6 = 400–500, 7=>500. Research availability, dissection lab availability, and subspecialty training availability were all categorical variables with 1 = yes and 2 = no.

Variable	Income Group	Mean (SD)	Mean Rank	Sum of Ranks	Mann-Whitney U	p-value
Competitiveness	LMIC	7.8 (2.4)	92.8	14568	2165	0.473
	HIC	7.8 (3.0)	100.3	3010		
Mentorship Availability	LMIC	4.7 (2.6)	91.2	14408	1847	0.162
	HIC	5.4 (2.2)	106.5	2983		
Weekly Work Hours	LMIC	7.5 (1.9)	61.8	5931	645	**0.016**
	HIC	6.5 (2)	42.8	855		
Number of Annual Procedures	LMIC	5.3 (1.9)	59	5659.5	628.5	0.122
	HIC	4.4 (2.3)	46	781.5		
Research Availability	LMIC	1.3 (0.5)	59.4	5763	930	0.692
	HIC	1.2 (0.4)	57	1140		
Dissection Lab Availability	LMIC	1.8 (0.5)	60.3	5846.5	846.5	0.262
	HIC	1.7 (0.6)	52.8	1056.5		
Subspecialty Training Availability	LMIC	1.8 (0.7)	104	16946.5	1798.5	**0.001**
	HIC	1.3 (0.5)	71.5	2359.5		

In our study, there was no difference between HICs and LMICs in regards to the annual number of procedures their institutions performed, with only 34.5% of respondents reporting more than 500 procedures annually. Previous research has suggested 250–300 cases per year per trainee for proper training (Reulen and Marz, 1998), suggesting that approximately $^2/_3$ of respondents were in programs that could not support more than two total trainees. Based on these recommendations accreditation protocols often require training centers to have a minimum of 200 cases per year; however, approximately ¼ of our respondents reported less than 200 cases per year being performed at their institutions. This can be a significant barrier to increasing training as neurosurgical capacity as case volume must first be increased; this requires investment in not just neurosurgeons and operative equipment but multiple other facets such as radiology, anesthesiology, and critical care (WFNS Foundation, 2020). It is important to note that the COVID-19 pandemic may have affected these numbers depending on which years the respondents were basing their data.

4.3. Work hours

There is significant controversy regarding the effect of work-hour restrictions on neurosurgical training and patient care (Norby et al., 2014). We found wide variability across countries in regards to trainee weekly work hours, with 43.1% of respondents working more than >80 h per week. A small cohort (6.9%) of respondents reported working less than 40 h a week, and 0.9% reported only 0–10 h; most contracts for service or training positions have a minimum 40–48 h work week, and so the explanation for these lower work hours is unclear. There was a significant difference in weekly work hours between LMICs and HMICs ($p = 0.016$), with LMIC trainees working on average more hours than their HIC counterparts. This may be due in part to the work hour restrictions of 80 and 48 h per week in the United States and Europe respectively. (Accreditation Council for Graduate Medical Education; Stienen et al., 2016b) With few support staff in hospitals across LMICs, trainees may spend the majority of their time on administrative and logistical responsibilities instead of their core neurosurgery training. Thus, the increased work hours do not necessarily translate to more educationally beneficial experiences. It will be important for future studies to assess more specific parameters such as case logs, number of cases performed independently, and hours spent in the neurosurgery clinic and operating room.

4.4. Access to mentorship

Mentors are critical to the personal and professional development of neurosurgery trainees, teaching both technical and non-technical skills (Akhigbe et al., 2017). Historically, surgical training has been based on apprenticeship (Halsted, 1904), but this model has diminished in use as neurosurgery has grown, making mentorship relations even more crucial for the development of trainees. Our study found that mentorship availability in neurosurgery was ranked as just average, with a mean score of 4.8 ± 2.6 out of 10 reported by respondents. This deficit in mentorship can be detrimental for overall workforce training as well as equitable representation of marginalized minorities within neurosurgery, as demonstrated by lack of female mentorship being a major obstacle to women choosing spine surgery as their specialty, as studies have shown that early mentorship is a key indicator that influences women to choose a surgical specialty (Falavigna et al., 2021; Hemal et al., 2021). Interestingly, we found no difference in reported availability of mentors in LMICs compared to HICs. Nonetheless, although there are efforts to improve mentorship availability in HICs, in many LMICs, small neurosurgical workforces can preclude these efforts. International partnerships can help ameliorate this deficit (Research EoH, 2014); however, differences in cultural and hierarchical structures can make these relationships difficult (Warner, 2002).

4.5. Dissection labs

A significant number of our respondents (70.1%) reported no availability of dissection and surgical skills labs in their home institutions, with no difference between HICs and LMICs. This is consistent with the findings of another recent global study that found only 17.8% of trainees had access to cadaveric training courses, and represents a significant barrier to neurosurgical training (Gnanakumar et al., 2020). With the increase in the utilization of simulation in surgical pre-operative planning and intraoperative lesion location, it has become imperative for training programs to develop surgical skills labs in order to equip trainees with the necessary tools to effectively hone their surgical skills and anatomical knowledge (Stienen et al., 2016c). While efforts have been made by many programs and organizations in HICs to incorporate a dissection curriculum (Harrop et al., 2013; Liu et al., 2015), the results are not similar in LMICs. While this finding might be due to lack of institutional funding and resource availability, LMICs institutions such as the All India Institute of Medical Sciences (AIIMS) have been able to develop simulation labs that have shown promising results using limited resources (Suri et al., 2014, 2016).

4.6. Research

Although research opportunities were reported to be much more accessible than dissection labs, nearly a quarter of survey participants reported not having access to research opportunities. This provides an opportunity for improvement, as locally led quality research output has been linked to successes in overcoming global health challenges (Dye et al., 2013). Although our study found no difference in the availability of research opportunities between HICs and LMICs, research capacity, output, and representation has been limited in LMICs, as they represent only 4.5% of neurosurgery research output globally despite comprising 46% of the global population (Servadei et al., 2019). These disparities between HICs and LMICs are perhaps due to a lack of investment in building local research capacity. While there is availability of research opportunities, there are still several challenges - limited experience, lack of infrastructure, and minimal funding. In addition, in those cases where HIC actors have developed research collaborations to help build research capacity, partnership and authorship in articles may not be equitable (Uthman et al., 2013). Thus, research capacity building efforts must focus on education and equitable partnerships between researchers from HICs and LMICs (Nthumba et al., 2021).

4.7. Women in neurosurgery

Our survey respondents' gender demographics closely resembled the reported gender breakdown of training programs, with a mean percentage of 75% men and 25% women. This may simply be a reflection of the percentage of female respondents; however, this finding was similar to another recent study that found approximately 80% of trainees globally to be male without a significant difference between HICs and LMICs (Gnanakumar et al., 2020). This is a promising finding for equity, as the number of practicing neurosurgeons in the United States who are women was only 3% in 2008 (Burkhardt et al., 2010b). Variations will exist between countries and even different training centers within a country, but the overall trend is promising. This trend will likely only continue as more women in neurosurgery will lead to greater mentorship for female medical students and increase the likelihood that they will enter neurosurgical training (Hemal et al., 2021).

4.8. Limitations

Our study provides a snapshot of neurosurgical training around the world, with 69 different countries represented and 83% of responses from LMICs. There are multiple limitations to the study, however. Although we have a broad distribution and representation of countries around the world, the overall size of the study is small and it is not a complete picture. In addition, the number of respondents from each individual country was small, limiting the representativeness of the responses. Sampling bias exists as countries with no or limited neurosurgical training opportunities, especially among LMICs, were likely not captured. The barriers may be greater in these countries but are still likely similar to those we found in our sample population. In addition, we did not clarify with survey respondents whether they had applied for a training program unsuccessfully or were unable to pursue training for any reason. This contributes further to sampling bias, as we likely did not capture those applicants most affected by barriers.

It is unclear if participants were providing data from their country or from their own individual experience. In addition, as this is a survey study, the individual responses are the views of the respondents and the veracity of the reported findings is unclear. Although we attempted to clarify some contradicting responses, it is difficult to independently verify the responses. Furthermore, there was variability amongst respondents in their understanding of questions and their answers, such as the United Kingdom reported as having one training program due to the single national system for applying to residency, which limits the interpretability of the results.

5. Conclusion

Our study highlights the need for a deliberate focus on designing and implementing both short and long term strategic goals in tackling barriers to access to neurosurgical training. The appropriate provision of resources can provide aspiring and current trainees the tools needed to successfully matriculate into and complete a training program. In order to bridge the gap in the provision of equitable neurosurgical care across the globe, institutions and stakeholders need to develop collaborative efforts and invest in appropriate infrastructure to address these barriers to neurosurgical training and education.

Declaration of competing interest

We declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

There was no conflict of interest associated with this manuscript. As a corresponding author, I confirm that The manuscript has been read and approved for submission by all contributing authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2022.100900.

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