Transnational Capacity Building Efforts in Global Neurosurgery: A Review and Analysis of Their Impact and Determinants of Success

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Key words
- Capacity
- Education
- Neurosurgery
- Olivieri classification
- Partnership
- Training
- Twinning

Abbreviations and Acronyms
AFR: African Region
AMR: Region of the America's
E1: Olivieri Engagement Class 1
E2: Olivieri Engagement Class 2
E3: Olivieri Engagement Class 3
EMR: Eastern Mediterranean Region
Etc.: Etcetera
EUR: European Region
HIC: High-Income Country
LMIC: Low- and Middle-Income Country
NA: Not Applicable
NGO: Non-Governmental Organization
NSG: Neurosurgery
SEAR: South-East Asia Region
T1: Olivieri Training Class 1
T2: Olivieri Training Class 2
T3: Olivieri Training Class 3
WHO: World Health Organization
WPR: Western Pacific Region

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BACKGROUND: **Neurosurgical capacity building efforts attempt to address the shortage of neurosurgeons and lack of neurosurgical capacity in low- and middle-income countries. This review sought to characterize neurosurgical capacity building efforts in low- and middle-income countries and the challenges they face, and identify factors that predict higher engagement, better training, and performance of high-impact activities.**

METHODS: **A scoping review using PubMed and Embase databases was performed and relevant articles were identified. Programs were classified into 6 categories and the activities they performed were classified as having a high-, medium-, or mild impact on capacity. Programs were also classified using the Olivieri engagement and training criteria.**

RESULTS: **Fifty-seven articles representing 42 unique efforts were included. The most important determinant of impact was a program's design and intent. Furthermore, 91% of training and twinning programs received high (class 2 or 3) engagement classifications compared to 17% of mission trips and training camps ($P < 0.001$); 91% of training and twinning programs received high training classifications compared to 64% of mission trips and training camps ($P = 0.015$); and 91% of training and twinning programs reported performing high-impact activities compared to 29% of mission trips and training camps ($P < 0.001$).**

CONCLUSIONS: **Training and twinning programs are more engaged, offer better training, and are more likely to perform high-impact activities compared to mission trips and training camps, suggesting that these types of programs offer the greatest chance of producing substantial and sustainable improvements to neurosurgical capacity.**

INTRODUCTION

Despite the high burden of surgically treatable diseases, providing surgical services in low- and middle-income countries (LMICs) was traditionally seen as a luxury rather than a necessary component of a comprehensive global health strategy.[1,2] Estimates from the Lancet Commission suggest that surgically treatable conditions account for roughly one third of the global burden of disease.[3] Despite this high global burden, only about 6% of all surgical procedures take place in LMICs. Currently, 22.6 million people globally have conditions that require a neurosurgical consultation and about 13.8 million of these cases will eventually require neurosurgical intervention.[4] The global distribution of neurosurgeons and neurosurgical case capacity differs drastically by region. While the United States, Canada, and Western Europe have enough neurosurgeons to meet their demand, Africa and Southeast Asia require an estimated 8400 and 11,000 additional neurosurgeons, respectively, to meet the demand for neurosurgical services.[4,5] This disparity is perhaps most

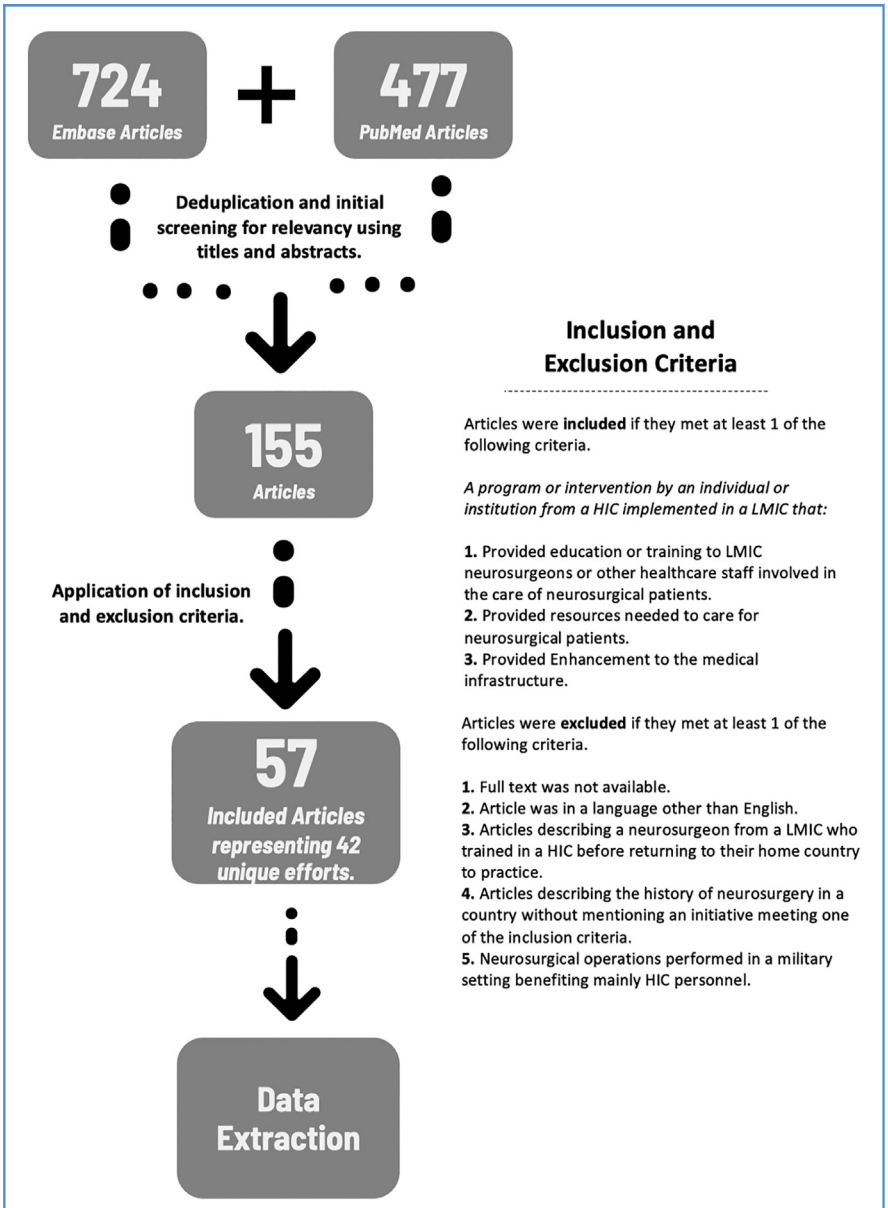

Figure 1. Article selection process. LMIC, low- and middle-income country; HIC, High-income country.

stark in Africa where there are only 1974 neurosurgeons for 1.2 billion people.[4,6]

The global neurosurgical community, individuals, and institutions aiming to ensure equitable access to neurosurgical care across the world, has made substantial efforts to increase capacity in LMICs. These efforts often involve partnerships between a high-income country (HIC) and an LMIC where the HIC sponsors capacity-building activities such as workshops, teaching operations, didactics, or research.[4,7,8] Historically, short-term mission trips have formed the cornerstone of these efforts; however, the main goal of mission trips was typically provision of care with capacity building being a secondary goal. As our understanding of capacity building evolved, there has been a shift away from short-term mission trips as the principal method for improving capacity and toward long-term, systems focused programs that target the entire neurosurgical care pathway.[9] In the past 15 years, "twinning" has emerged as a way to bring about more sustainable change by building long-term, collaborative relationships between HICs and LMICs. These programs take a health systems approach to improving capacity and emphasize improving the entire health care system including infrastructure improvements and training anesthesiologists, nurse anesthetists, critical care nurses, equipment repair technicians and nonmedical personnel.[9,10]

Given the increased interest in neurosurgical capacity building, there is a need for research that characterizes these efforts and their impact on capacity. Prior reviews have looked broadly at partnerships between HICs and LMICs and classified the degree of engagement and training provided by the HIC.[8,11] To our knowledge, no review thus far has focused on specifically characterizing neurosurgical capacity-building efforts or their relative impact on capacity. The aims of this review were to identify transnational neurosurgical capacity-building efforts, characterize who is engaged in these efforts and the types of activities they perform, identify factors related to the intervention that predict a high impact on neurosurgical capacity, and characterize the challenges faced by capacity building efforts.

METHODS

This review was conducted following Arksey and O'Malley's 5-stage framework for scoping reviews.[12] A team approach was used to ensure that the literature reviewed was relevant and comprehensive.

Identifying Relevant Studies

We conducted a search of 2 electronic databases, PubMed and Embase, on February 12, 2022. Search strategies were developed with a librarian (author D.H). Our search included keywords and database-specific terms related to global neurosurgery, neurosurgical partnerships, and LMICs (full search terms in **Appendix A**). Search results were imported into the citation management software Zotero, and deduplicated and exported to Rayyan.ai, a free online systematic review management software.

Article Selection and Data Extraction

Article selection was completed using a two-stage screening process. Authors Z.L.

Table 1. Definitions Used in Determining Program Type

Program Type Classification	Definition
Training program	Formal program designed to train additional neurosurgeons (e.g. establishing a new residency program), or formal program designed in order to train surgeons on a particular procedure or to treat a particular condition (e.g. establishing a neurotrauma fellowship).
Twinning program	Dyads between HIC and LMIC in which personnel from HIC repeatedly return to the same LMIC with the goal of developing collaboration around patient care, clinical research, workforce education, and surgical capacity building.
Mission trip	Short-term trips predominantly focused on performing operations or teaching a specific procedure.
Training camp	Short-term program that primarily uses didactics, simulation, and observation to transfer information/skills.
Research	Intervention primarily focused on developing capacity for neurosurgical research.
Other	Programs that did not fit into one of the above categories.

LMIC, low- and middle-income country; HIC, High-income country.

and T.N.T reviewed titles, abstracts, and full text for relevance and possible inclusion. A second screening stage was then performed using the inclusion and exclusion criteria shown in Figure 1. Any disagreements between the 2 screeners were resolved by author N.A.

For the purposes of this study, a global neurosurgery capacity-building effort was defined as a program or intervention by an individual or institution from a HIC that resulted in an improvement in the infrastructure, personnel or technical ability needed for an LMIC to independently manage neurosurgical conditions, or conduct research. HIC and LMIC status was based on designations assigned by the World Bank.[2]

After full text review of each article, variables of interest were extracted and entered into an MS Excel sheet. Variables included author names, journal of publication, World Health Organization (WHO) region of the HIC and LMIC partners, a list of activities performed, and a list of challenges faced. See Supplementary Table 1 for a full list of extracted variables. Efforts deemed by authors to be subcomponents of a group's broader work were grouped and counted as a singular effort.

In order to determine gender of the author, names were checked in the online database Genderize.io; this database was created by Caspar Strømgen in 2013 and has been used in prior publications in the field neurosurgery.[13,14] The predicted gender was assumed to be correct if the prediction confidence was above 0.8; for any prediction with a confidence score of below 0.8, a manual search was conducted looking at images from institutional websites, social media accounts, and news articles with masculine presenting people identified as male and feminine presenting people identified as female. Authors cited on multiple papers were counted toward the total number of authors each time they were cited.

Data Summarization and Analysis

Each unique intervention was classified using the engagement and training classification system described by Olivieri et al.[11] The Olivieri classification system assesses global neurosurgical partnerships on a 1–3 scale based on the degree of engagement and quality of training provided by the program. Engagement class 1 represents low engagement; these programs perform activities at least once per year, with minimal HIC presence throughout the year when activities are not taking place. Engagement classes 2 and 3 represent high engagement; these programs perform activities at least 2 times per year, have made a substantial financial and logistical investment, offer a formalized educational structure, and track outcomes through research. Training class 1 represents less effective training; these programs offer informal lectures and operative skills are observed or passed along informally. Training classes 2 and 3 represents high-quality training; these programs offer in-person teaching by HIC neurosurgeons, offer didactics >6 times per year with a more formal curriculum, and provide trainees with essential neurosurgical skills.[11]

Programs were classified into one of 6 categories: twinning program, training program, mission trip, training camp, research, and other. Definitions used in determining classification can be found in Table 1.

Activities performed by the capacity-building effort were classified into 17 broad categories based on common themes identified during the literature review; these 17 categories were subsequently classified into 3 tiers (high impact, medium impact, and mild impact) based on their likely effect on the LMIC's neurosurgical capacity as determined by author consensus. Challenges faced during planning and implementation were classified into 26 broad categories.

A one-way ANOVA (Analysis of variance) was conducted to determine if the average number of LMIC authors per paper differed between Olivieri engagement and training classifications. Univariate and bivariate analyses were performed to identify factors associated with high Olivieri engagement and training classes as well as factors associated with the performance of high-impact activities. Class 2 and class 3 engagement and training scores were combined for statistical analysis to improve sample size; programs in the "research" and "other" categories could not be classified using the Olivieri criteria and were excluded from statistical analysis. All statistical analysis was performed using the statistical package STATA (StataCorp LLC, College Station, Texas, USA).

RESULTS

Publication Information

Full texts of 155 articles were reviewed using the inclusion and exclusion criteria outlined in Figure 1. A total of 57 articles, representing 42 unique capacity building

Table 2. General Information on Articles and Capacity Building Effort Extracted During Review

Category	No. (%)
Total number of articles	57
Number of unique efforts	42
Journal	Frequency
World Neurosurgery	21 (37%)
Neurosurgical Focus	8 (14%)
Surgical Neurology	3 (5.3%)
Neurosurgery	3 (5.3%)
World Journal of Surgery	2 (3.5%)
Journal of Neurosurgery	2 (3.5%)
JNS Pediatrics	2 (3.5%)
Frontiers in Surgery	2 (3.5%)
Child Nervous System	2 (3.5%)
Other (n = 1)	12 (21%)
Intervention location (if available)	
Academic hospital	15 (40.5%)
Government hospital	10 (27%)
Missionary hospital	4 (10.8%)
Private hospital	4 (10.8%)
Other	4 (10.8%)
Reported funding sources	
Academic institution	7 (25%)
Nonprofit or NGO	7 (25%)
Private donations	5 (17.9%)
HIC government	5 (17.9%)
LMIC government	3 (10.7%)
Personal funds	1 (3.6%)
WHO region of LMIC partner	
African region	18 (42.9%)
Western Pacific region	7 (16.7%)
Region of the Americas	6 (14.3%)
European region	4 (9.5%)
South-East Asia region	4 (9.5%)
Eastern Mediterranean region	3 (7.1%)
Type of intervention	
Training program	17 (40.1%)
Mission trip	11 (26.2%)
Twinning program	6 (14.3%)
Training camp	6 (14.3%)

LMIC, low- and middle-income country; HIC, High-income country; NGO, Non-Governmental Organization; WHO, World Health Organization.

Continues

efforts, were ultimately selected for inclusion in our review. These 57 articles were published in 21 different journals; the most common being World Neurosurgery (37%), followed by Neurosurgical Focus (14%). The articles in our review consisted of a wide variety of study types including cross-sectional studies, field reports, outcome studies, and historical reports. The 57 articles were coauthored by 343 total authors. Of which, 59% of the authors were males from HICs, 24% were males from LMICs; females from HICs represented 12% of the authors, and females from LMICs were the least represented group comprising 5% of total authors (Figure 2). There was no statistically significant difference between average number of LMIC authors per paper for both Olivieri engagement and training classifications ($F = 1.37$; $P = 0.26$ and $F = 2.56$; $P = 0.09$, respectively).

Capacity Building Effort Characteristics

The 57 papers reviewed described 42 unique capacity building efforts across 24 different LMIC countries. HICs participating in these efforts were largely concentrated in the Americas and Europe; LMIC partners were concentrated in Africa, South America, and South-East Asia. The HICs with the greatest number of efforts were the United States of America, followed by Canada, and Germany. Four efforts were international efforts led by multiple HICs. The most common LMIC partner was Tanzania followed by Nigeria and Uganda; 8 efforts took place in multiple LMICs (Supplementary Table 2). The setting for these efforts was most commonly academic hospitals in LMICs followed by government hospitals. Of the efforts that reported a funding source, academic institutions (n = 7), and Non-Governmental Organizations/nonprofits (n = 7) were the 2 most common sources (Table 2).

The most common intervention type was training programs (n = 17) followed by mission trips (n = 11), then twinning programs (n = 6), and training camps (n = 6) (Table 2).[15-18] Only one effort met our definition of a research program (Supplementary Table 2), a research incubator program for LMIC medical students and physicians interested in neurosurgery.[19] One effort, the creation of InterSurgeon, an online platform

Table 2. Continued

Category	No. (%)
Research program	1 (2.4%)
Other	1 (2.4%)
Capacity measure	
Trained neurosurgeons	41 of 42 efforts
Technology improvements	21 of 42 efforts
Trained other staff	19 of 42 efforts
Infrastructure improvements	10 of 41 efforts

LMIC, low- and middle-income country; HIC, High-income country; NGO, Non-Governmental Organization; WHO, World Health Organization.

facilitating partnerships and telecollaboration between HICs and LMICs, did not fall into any of our established categories and was classified as "other".[20]

Assessing Engagement Levels, Quality of Training, and Capacity Improvements

The vast majority of programs (97.6%) provided direct education and training to surgeons including neurosurgeons, neurosurgery residents, and general surgeons. Of which, 45% provided training to nonsurgical staff including anesthesiologists, radiologists, pathologists, neurologists, ICU physicians, nurses, EEG technicians, engineers, radiology technicians, and/or equipment repair technicians. Furthermore, 25% of efforts resulted in infrastructure improvements, and 45% resulted in technological improvements (Table 2). The most commonly donated equipment included surgical instruments (n = 11), operating microscopes (n = 7), drills (n = 4), and neuroendoscopes (n = 3).

When classified using the Olivieri engagement and training classifications, the majority of training and twinning programs (96%) were classified into engagement class 2 or class 3 (E2, E3), representing high levels of engagement by the HIC partner whereas the majority of mission trips and training camps (82%) received class 1 engagement classifications (E1).[17,18,21] Regarding training classification, most training and twinning programs (96%) were classified into training class 2 or class 3 (T2, T3), representing high-quality training. 64% of mission trips and training camps received class 2 training classifications and 36% received class 1 training classifications (T1); no training camp or mission trip received a class 3 training classification.[16,17,21]

Training programs and twinning programs performed the greatest number of high-impact activities per program (2.05 and 1.67, respectively), compared to 0.45 per program for mission trips and 0.167 per program for training camps. In addition, a larger percentage of the total activities performed by training programs and twinning programs were classified as high impact (49% and 34%, respectively) compared to 15% for mission trips and 5% for training camps (Table 3).

Bivariate analysis (Table 4) showed that efforts classified as E2/E3 were more likely to be training or twinning programs ($P < 0.001$), to have trained nurses and other staff ($P = 0.041$), and to result in infrastructure improvements ($P = 0.003$). Efforts classified as T2/T3 were also more likely to be training or twinning programs ($P = 0.015$) and more likely to have trained nurses and other staff ($P = 0.027$). The calculated correlation coefficient between engagement and training classes was 0.51 ($P = 0.0008$), indicating a positive correlation between higher levels of training and higher engagement.

Both E2/E3 ($P < 0.001$) and T2/T3 ($P = 0.048$) programs performed more high-impact activities when compared to E1 and T1 programs, respectively. Both engagement and training class are associated with an increased number of high-impact activities, only engagement class was associated with whether or not high-impact activities were performed. There was no correlation between WHO region of the LMIC and engagement class, training class, and performance of high-impact activities (Table 3).

Challenges Faced

Table 5 summarizes the challenges reported by capacity-building programs stratified by program type. Overall, the 5 most commonly reported challenges were: 1) a lack of equipment or outdated equipment, 2) funding challenges, 3) a lack of nurses or inexperienced nurses, 4) language barrier, and 5) poor local infrastructure. Interestingly, no twinning programs reported challenges with funding. When looking at these challenges more broadly, the most common challenges fell into the equipment/infrastructure category followed by personnel shortages and local factors (such as hesitancy from LMIC partners and lack of support from the local government).

DISCUSSION

What Should Future Capacity-Building Efforts Look Like?

Twinning and Training Programs are the Most Effective Ways to Improve Capacity. In our study, twinning programs were 2–3 times more likely to train nurses or non-neurosurgery physicians than training programs and mission trips. In addition, 5 out of the 6 twinning programs reported training nonphysician hospital staff compared to 3 out of 17 training programs and 2 out of 11 mission trips. A lack of nurses, anesthesiologists, equipment breakdown, and a lack of equipment are among the top reported challenges faced by capacity-building programs (Table 5), and the collaborative approach taken by twinning programs is an effective way to address these challenges. Since its inception, the Duke-Uganda partnership has donated over $8 million in equipment and trained nurses, biomedical engineers, and anesthesiologists. In the first 2 years of the program, they saw a 313% increase in capacity measured by the number of cases performed independently by Ugandan surgeons.[10] Twinning programs and the systems-based approach they employ have been incredibly successful in

Table 3. Activities Conducted by Neurosurgery Capacity Building Efforts by Olivieri Engagement Classification, Olivieri Training Classification, and Program Type. Activities Were Also Classified Based on Their Likely Impact on Neurosurgical Capacity. Program Types with n = 1 (Research and Other) Were Excluded

		Olivieri Engagement Classification			Olivieri Training Classification			Program Type			
	Activity	Class 1 (n, %)	Class 2 (n, %)	Class 3 (n, %)	Class 1 (n, %)	Class 2 (n, %)	Class 3 (n, %)	Training program (n, %)	Mission trip (n, %)	Twinning (n, %)	Training camp (n, %)
High impact	Total (overall)	45	15	98	25	96	32	72	32	39	19
	Establishing residency or fellowship program	0 (0%)	1 (7%)	9 (9%)	0 (0%)	5 (5%)	5 (16%)	11 (15%)	0 (0%)	1 (3%)	0 (0%)
	Establishment of NSG unit/department	0 (0%)	1 (7%)	6 (6%)	1 (4%)	4 (4%)	2 (6%)	8 (11%)	0 (0%)	0 (0%)	0 (0%)
	Training non NSG-physicians*	1 (2%)	0	9 (9%)	0 (0%)	7 (7%)	1 (3%)	4 (6%)	1 (3%)	3 (10%)	0 (0%)
	Trained general surgeons/non-physicians to perform NSG	0 (0%)	2 (13%)	3 (3%)	1 (4%)	3 (3%)	1 (3%)	3 (4%)	0 (0%)	1 (3%)	0 (0%)
	Training nurses	3 (7%)	1 (7%)	10 (10%)	2 (8%)	9 (9%)	3 (9%)	4 (6%)	4 (13%)	3 (10%)	0 (0%)
	Increasing research capacity	2 (4%)	0 (0%)	7 (7%)	1 (4%)	5 (5%)	3 (9%)	5 (7%)	0 (0%)	2 (7%)	1 (5%)
	Total (High impact)	6 (13%)	5 (33%)	44 (45%)	5 (20%)	33 (34%)	15 (47%)	35 (49%)	5 (16%)	10 (34%)	1 (5%)
Medium impact	Teaching Operations†	9 (20%)	4 (27%)	12 (12%)	3 (12%)	19 (20%)	3 (9%)	10 (14%)	10 (31%)	5 (17%)	0 (0%)
	Exchange Program‡	3 (7%)	1 (7%)	5 (5%)	2 (8%)	6 (6%)	1 (3%)	3 (4%)	1 (3%)	2 (7%)	3 (16%)
	Didactic Sessions§	14 (31%)	3 (20%)	11 (11%)	6 (24%)	16 (17%)	5 (16%)	9 (13%)	9 (28%)	3 (10%)	6 (32%)
	Trained other hospital staff	1 (2%)	0 (0%)	8 (8%)	0 (0%)	8 (8%)	1 (3%)	3 (4%)	2 (6%)	5 (17%)	0 (0%)
	Simulation‖	6 (13%)	0 (0%)	4 (4%)	4 (16%)	5 (5%)	1 (3%)	3 (4%)	0 (0%)	1 (3%)	6 (32%)
	Career development/professional mentorship	0	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)
	Virtual consult/real time guidance	2 (4%)	0 (0%)	4 (4%)	1 (4%)	2 (2%)	3 (9%)	2 (3%)	1 (3%)	1 (3%)	1 (5%)
	Advocacy	0	0 (0%)	2 (2%)	0	1 (1%)	1 (3%)	2 (3%)	0 (0%)	0 (0%)	0 (0%)
	Total (Medium impact)	35 (78%)	8 (53%)	47 (48%)	16 (64%)	57 (59%)	15 (47%)	33 (46%)	23 (72%)	17 (58%)	16 (84%)
Mild Impact	OR observation (shadowing)	2 (4%)	0 (0%)	0 (0%)	1 (4%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (11%)
	Non-teaching Operations¶	2 (4%)	2 (13%)	7 (7%)	3 (12%)	5 (5%)	2 (6%)	4 (6%)	4 (13%)	2 (7%)	0 (0%)
	Total (Mild Impact)	4 (9%)	2 (13%)	7 (7%)	4 (16%)	6 (6%)	2 (6%)	4 (6%)	4 (13%)	2 (7%)	2 (11%)

LMIC, low- and middle-income country; HIC, High-income country; NSG, Neurosurgery.
*Anesthesiology, neurology, pathology, ICU, and oncology.
†Operations joint operations with HIC/LMIC surgeons with hands on training for LMIC surgeons.
‡Visit, of any length of time, by LMIC staff to HIC hospital for the purpose of training.
§Conferences, lectures, case discussions, ‖ techs, equipment maintenance, and admin.
‖Cadaver dissections, skills training, and workshop.
¶Operations performed by only HIC surgeon.

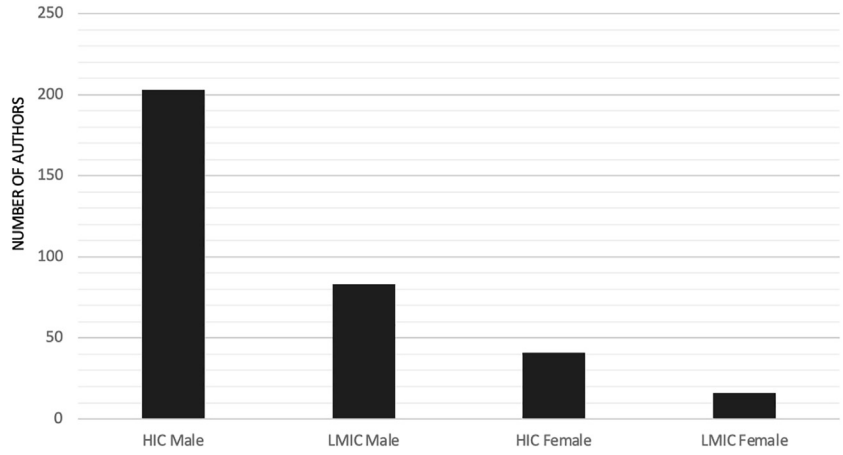

Figure 2. Distribution of authors by gender and high-income country/low- and middle-income country status. LMIC, low- and middle-income country; HIC, High-income country.

improving capacity and increased use of this model is likely to make a large positive impact on capacity and access.[9,10]

In addition to twinning programs, training programs are another option for increasing neurosurgical capacity. Of our 4 program classes, training programs perform the greatest number of high-impact activities per program (2.05 high-impact activities per program), which is 4.5 times more than mission trips and 12 times more than training camps (Table 3). Many training programs involve the establishment of a neurosurgery residency or fellowship program, directly increasing the number of neurosurgeons available to perform procedures.[18] These types of training programs require a substantial up-front investment of both capital and time; however, the continued investment required to maintain such a program may decrease as newly trained LMIC neurosurgeons eventually supplant HIC neurosurgeons. A 2016 partnership between the United States and Haiti established Haiti's first formal neurosurgery residency program capable of adding 1 new neurosurgery resident per year, resulting in a 4-fold increase in neurosurgical case volume in subsequent years.[18]

Twinning programs and training programs performed significantly more high-impact activities and were associated with higher engagement and higher quality training when compared to mission trips and training camps (Table 4). Provided that the sponsoring institution has the time and capital, future capacity-building efforts should ideally focus on establishing new twinning relationships or training programs in order to have the greatest impact on capacity.[16,18]

The Role of Mission Trips and Training Camps. In our study, mission trips and training camps were associated with a lower engagement class and were less likely to perform high-impact activities when compared to twinning and training programs. However, these types of programs play an important role in improving capacity by allowing institutions to become involved with global neurosurgery with relatively low time and financial investment, and can serve as the starting point for a higher engagement partnership. One potential way to increase the effectiveness of these programs is to incorporate aspects of twinning programs such as training allied neurosurgical staff, including nurses. Currently, to the best of our knowledge, no mission trips or training camps have been conducted that focus primarily on training neurosurgical nurses; such programs could represent an exciting and impactful option for future initiatives.

Tracking Increases in Capacity. There is currently no universal standard with which to measure neurosurgical capacity or changes in capacity, complicating efforts to evaluate the impact of these initiatives. Measures such as the number of neurosurgeons, number of neurosurgical procedures performed, and the "neuro-personnel, infrastructure, procedures, equipment and supplies (NeuroPIPES)" have been used as surrogates for neurosurgical capacity.[8,22] In our study, we attempted to quantify the number of neurosurgeons and other staff trained; however, only 11 papers made any mention of the number of neurosurgeons trained and only 5 mentioned the number of nurses and other staff trained. To facilitate the evaluation of an initiative's impact on neurosurgical capacity, it is important for initiatives to incorporate methods of tracking important measures of capacity into their program design and to conduct follow-up studies in order to assess impact.

Our study attempted to analyze the utility of Olivieri engagement and training scores as a measure for effective capacity building initiatives. We showed that higher engagement classifications were associated with twinning and training programs, consistent with existing literature stating that initiatives focused on long-term partnerships produce a larger impact on capacity.[9] In addition, both engagement and training classes were associated with an increased number of high-impact activities performed. These findings further support the utility of Olivieri scores in determining positive impact on capacity (Table 4).

Developing LMIC Researchers. Of the papers we reviewed, authors from LMICs represented only 29% of the total authors. In addition, we did not see a statistically significant increase in the number of LMIC authors per paper with increasing Olivieri engagement and training classes potentially indicating that developing research infrastructure is not currently a priority for capacity-building initiatives. Training academic neurosurgeons from LMICs and improving research infrastructure is crucial for the development of sustainable neurosurgical systems. In our review, we identified only 1 initiative dedicated to increasing research capacity, a research incubator program providing participants with the fundamental skills needed to conduct neurosurgery

Table 4. Univariate and Bivariate Analysis Comparing Various Program Characteristics and Their Association with Olivieri Training and Engagement Classifications and Participation in High-Impact Activities

	Engagement Classification				Training Classification			Performed High-Impact Activities		
	Total (n =)	Class 1	Class 2 and 3		Class 1	Class 2 and 3		No	Yes	
Total	***40***	***15(37.5%)***	**25 (65.5%)**	***P*-Value**	**8 (20%)**	**32 (80%)**	***P*-Value**	**14 (35%)**	**26 (65%)**	***P*-Value**
HIC WHO Region, n (%)										
Americas	26 (65%)	12 (80%)	14 (56%)	0.38	6 (75%)	20 (62%)	0.42	10 (71%)	16 (62%)	0.85
Europe	7 (17.5%)	1 (7%)	6 (24%)		0 (0%)	7 (22%)		2 (14%)	5 (19%)	
Western Pacific	6 (15%)	2 (13%)	4 (16%)		2 (25%)	4 (12%)		2 (14%)	4 (15%)	
Various	1 (2.5%)	0 (0%)	1 (4%)		0 (0%)	1 (3%)		0 (0%)	1 (4%)	
LMIC WHO region, (%)										
Africa	16 (40%)	7 (47%)	9 (36%)	0.78	5 (62%)	11 (34%)	0.56	4 (29%)	12 (46%)	0.13
Americas	6 (15%)	2 (13%)	4 (16%)		1 (12%)	5 (16%)		2 (14%)	4 (15%)	
SE Asia	4 (10%)	2 (13%)	2 (8%)		1 (12%)	3 (9%)		1 (7%)	3 (12%)	
Europe	4 (10%)	2 (13%)	2 (8%)		1 (12%)	3 (9%)		4 (29%)	0 (0%)	
Eastern Mediterranean	3 (7.5%)	1 (7%)	2 (8%)		0 (0%)	3 (9%)		1 (7%)	2 (8%)	
Western Pacific	7 (17.5%)	1 (7%)	6 (24%)		0 (0%)	7 (22%)		2 (14%)	5 (19%)	
Type of program, n (%)										
Mission trip	11 (27.5%)	8 (53%)	3 (12%)	<0.001*	2 (25%)	9 (28%)	0.015*	7 (50%)	4 (15%)	<0.001*
Training camp	6 (15%)	6 (40%)	0 (0%)		4 (50%)	2 (6%)		5 (36%)	1 (4%)	
Twinning	6 (15%)	0 (0%)	6 (24%)		0 (0%)	6 (19%)		0 (0%)	6 (23%)	
Training program	17 (42.5%)	1 (7%)	16 (64%)		2 (25%)	15 (47%)		2 (14%)	15 (58%)	
Location, n (%)										
Academic hospital	24 (60%)	9 (60%)	15 (60%)	1	4 (50%)	20 (62%)	0.52	7 (50%)	17 (65%)	0.34
Non-academic hospital	16 (40%)	6 (40%)	10 (40%)		4 (50%)	12 (38%)		7 (50%)	9 (35%)	
Trained surgeons, n (%)										
No	1 (2.5%)	1 (7%)	0 (0%)	0.19	1 (12%)	0 (0%)	0.043*	0 (0%)	1 (4%)	0.46
Yes	39 (97.5%)	14 (93%)	25 (100%)		7 (88%)	32 (100%)		14 (100%)	25 (96%)	
Trained other staff, n (%)										
No	21 (52.5%)	11 (73%)	10 (40%)	0.041*	7 (88%)	14 (44%)	0.027*	11 (79%)	10 (38%)	0.015*
Yes	19 (47.5%)	4 (27%)	15 (60%)		1 (12%)	18 (56%)		3 (21%)	16 (62%)	
Technology improvements										

LMIC, low- and middle-income country; HIC, High-income country; IQR, Interquartile range; WHO, World Health Organization; OR. Operation room.
*$P < 0.05$.

Continues

Table 4. Continued

Total	Total (n =)	Engagement Classification: Class 1	Engagement Classification: Class 2 and 3	Engagement Classification: P-Value	Training Classification: Class 1	Training Classification: Class 2 and 3	Training Classification: P-Value	Performed High-Impact Activities: No	Performed High-Impact Activities: Yes	Performed High-Impact Activities: P-Value
Total	***40***	***15(37.5%)***	**25 (65.5%)**		**8 (20%)**	**32 (80%)**		**14 (35%)**	**26 (65%)**	
No	19 (47.5%)	10 (67%)	9 (36%)	0.06	4 (50%)	15 (47%)	0.87	10 (71%)	9 (35%)	0.026*
Yes	21 (52.5%)	5 (33%)	16 (64%)		4 (50%)	17 (53%)		4 (29%)	17 (65%)	
Infrastructure improvements										
No	28 (70%)	15 (100%)	13 (57%)	0.003*	7 (88%)	21 (70%)	0.32	13 (93%)	15 (62%)	0.04*
Yes	10 (25%)	0 (0%)	10 (43%)		1 (12%)	9 (30%)		1 (7%)	9 (38%)	
# High-impact activities, median (IQR)	1 (0–3)	0 (0–1)	2 (1–3)	<0.001*	0.5 (0–1)	1.5 (0–3)	0.048*	0 (0–0)	2 (1–3)	<0.001*
# Medium-impact activities, median (IQR)	2 (2–3)	2 (2–3)	2 (1–3)	0.72	2 (1.5–3)	2 (2–3)	0.69	2 (2–3)	2 (0–3)	0.49
# Low-impact activities, median (IQR)	0 (0–1)	0 (0–1)	0 (0–1)	0.55	0 (0–1)	0 (0–1)	0.74	0 (0–0)	0 (0–1)	0.28
Engagement classification, n (%)										
Class 1	15 (37.5%)	NA	NA	NA	6 (75%)	9 (28%)	0.014*	10 (71%)	5 (19%)	<0.001*
Classes 2 and 3	25 (62.5%)	NA	NA		2 (25%)	23 (72%)		4 (29%)	21 (81%)	
Training classification, n (%)										
Class 1	8 (20%)	6 (40%)	2 (8%)	0.014*	NA	NA	NA	4 (29%)	4 (29%)	0.32
Classes 2 and 3	32 (80%)	9 (60%)	23 (92%)		NA	NA		10 (71%)	22 (85%)	
High-impact activities performed, (n %)										
None	14 (35%)	10 (67%)	4 (16%)	0.001*	4 (50%)	10 (31%)	0.32	NA	NA	NA
≥1	26 (65%)	5 (33%)	21 (84%)		4 (50%)	22 (69%)		NA	NA	

LMIC, low- and middle-income country; HIC, High-income country; IQR, Interquartile range; WHO, World Health Organization; OR, Operation room.
*$P < 0.05$.

research.[19] Such programs can help set the foundation for robust research programs in LMICs and should be replicated. In addition, all initiatives should seek to incorporate their LMIC partners in any research projects done as part of the initiative.

Limitations. Our findings should be interpreted in light of several important limitations. The results do not necessarily represent actual transnational capacity building efforts, but rather what has been published about such efforts. Undoubtedly there are many productive partnerships that have not been characterized in peer-review publications, and therefore, are not represented in this manuscript. In addition, we did not include partnerships exclusively between LMICs that did not include HIC involvement. One major limitation of our study was an inherent selection bias stemming from including only English-language articles. This likely contributed to the large number interventions conducted by the United States and Canada in our study and a failure to capture efforts by countries who do not routinely publish in the English literature. In addition, our designation for high-, medium-, and mild-impact activities was based on author consensus and has not been independently verified as an accurate measure of impact on capacity. Similarly, the Olivieri scoring system is based on the expertise of the authors and has not been independently validated. We also would like to acknowledge that mission trips and training camps typically have a different focus than training and twinning programs whose main goal is improving capacity and thus, any comparison between these categories based on capacity-building will be inherently biased. In addition, variation between papers in how data was presented complicated data collection and classification. Finally, gendrize.io utilizes an online database from Europe and the United States to predict gender, and although there was a high probability of a correct prediction, we cannot preclude that some names, especially those uncommon in Europe and the United States, were incorrectly allocated.[13,14] Even in the light of these limitations, we believe that these findings represent an important step in better understanding the landscape of

Table 5. Challenges Faced by Capacity Building Efforts Stratified by Program Type

		Program Type				
	Challenges Faced	Training Program	Mission Trip	Twinning	Training Camp	Total
Personnel shortage	Lack of nurses or inexperienced nurses	3	2	3	0	8
	Lack of anesthesiology/neuro-anesthesiology	2	3	2	0	7
	Lack of other non-anesthesiology physicians (ICU, neurologist, oncologist, pathologist)	2	2	2	0	6
	Lack of radiologist/imaging equipment	2	2	0	1	5
	Lack of post-op follow-up options	2	2	1	0	5
	Total (personnel shortage)	11	11	8	1	31
Equipment and infrastructure	Lack of equipment/outdated equipment	7	5	3	2	17
	Equipment breakdown	1	1	1	0	3
	Over-reliance on donated equipment	2	0	2	1	5
	Internet connection/audio/video latency problems	2	0	0	1	3
	Inadequate hospital infrastructure (not enough ORs, beds, no ICU, no EMR, no pharmacies, inadequate lab testing)	1	3	1	1	6
	Poor local infrastructure (roads in poor condition, town power supply, communication network, and ambulance service)	4	2	2	0	8
	Lack of research infrastructure	1	0	0	0	1
	Total (equipment and infrastructure)	18	11	9	5	43
Local factors	Cultural differences	1	1	0	0	2
	Language barrier	2	4	2	0	8
	Challenging climate	1	0	0	0	1
	Hesitancy from locals (stigma against certain diseases, reliance on traditional medicine, and distrust of local medical system)	4	3	1	0	8
	Lack of local government support	3	1	1	0	5
	Political instability	1	2	0	0	3
	Time difference	2	0	0	1	3
	Safety of visiting staff	0	0	1	0	1
	Total (local factors)	14	11	5	1	31
Legal and financial	Funding	4	1	0	4	9
	Logistics (tracking inventory, transporting equipment)	0	1	0	0	1
	Lack of educational material	1	1	0	0	2
	COVID Restrictions	0	1	0	0	1
	Administrative/legal barriers (lots of paperwork, legal challenges of having foreign physicians practicing)	2	0	0	2	4
	Total (legal and financial)	7	4	0	6	17

OR, Operation room; ICU, Intensive care unit; EMR, Electronic medical records.

neurosurgical capacity-building efforts and highlight the importance of being deliberate and thoughtful when engaging in this space.

CONCLUSION

Our review provides a detailed overview of current neurosurgery capacity-building initiatives, the activities they performed, and the challenges they faced. To the best of our knowledge, our review represents the first attempt to identify qualities of capacity-building initiatives associated with high levels of engagement and training, and performance of high-impact activities. We found that twinning and training programs are more likely to have higher levels of engagement, to offer higher quality training, and to perform high-impact activities when compared to mission trips and training camps, and are the most effective ways to improve capacity. Future neurosurgery capacity-building efforts should strive to form long-term, collaborative partnerships to produce substantial and sustainable improvements to capacity.

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Available online: ***www.sciencedirect.com***

APPENDIX A

Our PubMed and search consisted of 3 separate concepts:

1."Neurosurgery"[mesh] OR "neurosurg*"[tw]

2."Education"[mesh] OR "Capacity Building"[mesh] OR "Training Program*"[tw] OR "Workshop*"[tw] OR "Capacity Building"[tw] OR "Global Surgery"[tw] OR "Global Neurosurgery"[tw]

3.Low- and middle-income country (LMIC) filter consisting of ~600 different terms including multiple versions of LMIC country names as well as phrases indicating LMIC status (developing economy, lower income populations, etc.).

Our Embase search consisted of 3 separate concepts:

1.'neurosurgery'/exp OR ('neurologic surgery*' OR 'neurological surgery*' OR 'neurosurgical operation*' OR 'neurosurgical procedure*'):ab,ti,kw

2.'capacity building'/exp OR 'global surgery'/exp OR 'workshop'/exp OR 'global neurosurgery'/exp OR ('Training Program*' OR 'Workshop*' OR 'Capacity Building'):ab,ti,kw

3.The same LMIC filter used in the PubMed search.

APPENDIX B

Supplementary Table 1. Variables of Interest Extracted During Literature Review

Variable	Notes
Paper title	
Full name of all authors	
HIC/LMIC status of each author	As determined by the author information section. Authors with at least 1 LMIC institutional affiliation and no HIC institutional affiliation were classified as LMIC. Authors with at least 1 HIC institutional affiliation were classified as HIC.
Name of publishing journal	
Name of HIC partner	
Name of LMIC partner	
WHO region of HIC and LMIC	
Funding source	If available
Setting of intervention	Classified as into 4 general categories: Academic hospital, government hospital, private hospital, and missionary hospital.
A list of all activities performed during the intervention.	
A list of all conditions treated, and procedures performed.	
Surgeons trained	Yes/no followed by number if available
Infrastructure improvements	Yes/no followed by description
List of challenges faced	

LMIC, Low- and middle-income country; HIC, High-Income Country.

APPENDIX C

Supplementary Table 2. List of All LMIC Countries Represented in Study

LMIC Partner Countries	
LMIC Countries with single HIC Partner	**LMIC Countries with multiple HIC Partners (no. of Partners)**
Bolivia	Haiti (2)
Cambodia	Iraq (2)
Ethiopia	Kenya (2)
Georgia	Myanmar (2)
Malawi	Uganda (2)
Malaysia	Ukraine (2)
Mongolia	Vietnam (2)
Nepal	Tanzania (5)
Nicaragua	Multiple LMIC countries (8)
Nigeria	
Pakistan	
Papa New Guinea	
Peru	
Slovenia	
Taiwan	

LMIC, Low- and middle-income country; HIC, High-Income Country.