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International Neurosurgery: The Role for Collaboration

Aqeeb Ur Rehman[1*]; Aleena Ahmed[2]; ZaofshaZaheer[2]; BakhtawarAhmed[3]; Brandon Lucke-Wold[4]
[1]Department of Neurosurgery, King Edward Medical University, Lahore
[2]Department of Neurology, King Edward Medical University, Lahore
[3]Department of Neurology, University of Florida, Gainesville, Florida
[4]Department of Neurosurgery, University of Florida, Gainesville, Florida

ABSTRACT
The global death toll from lack of access to basic surgical care is three times as much as for tuberculosis, HIV and malaria combined. Patients dying of curable neurosurgical conditions solely because of inadequacy or absence of neurosurgical infrastructure is an issue deserving immediate attention and action. Global neurosurgery is an important step forward in this regard, under which different models of collaboration between HICs and LMICs aim to increase both the number of neurosurgeons as well the quality of neurosurgical care available in these countries through arranging surgical camps, providing neurosurgical training and education, and restructuring the health system in these countries in order to create an environment conducive to the provision of the highest form of neurosurgical care. Despite the many challenges faced by LMICs in furthering neurosurgery programs such as poor resource allocation, brain drain, turbulent socioeconomic conditions, limited training facilities, and population explosion, data now being reported from LMICs the world over, exemplifies the immense positive impact that collaborations have had over the last few decades in improving neurosurgical capacity and infrastructure. So far, conventional methods of collaboration (i.e. neurosurgical missions to LMICs and training of neurosurgeons in HICs) have been effective in progressively bringing about the desired change in LMICs. However, these methods have been limited by a finite funding, pushing the global neurosurgical community to look for alternatives such as online curricula, task shifting and sharing, and long distance mentor-mentee relationships. In this review, we aim to provide an update on the current state of neurosurgical collaborations and identify the barriers in the way of collaborations and what alternative models of collaboration might be used to overcome them..

Keywords: *Neurosurgery; Global neurosurgery; Collaboration; Neurosurgical collaboration; Global surgery; Lower middle-income countries*

***Corresponding Author**
Aqeeb Ur Rehman
Department of Neurosurgery, King Edward Medical University, Lahore

INTRODUCTION
The advancements in neurosurgical care have not been able to find a way to lower middle-income countries (LMICs) and lower income countries (LICs). The equitable distribution of surgical expertise and surgical infrastructure continues to be a problem even today. Surgery, by default, has long been treated as the neglected stepchild of all medical sciences, with an estimated 2 billion of the world population without adequate surgical care available [1]. Neurosurgery's plight has been even worse still. The Global Neurosurgery Initiative (GNI) estimates that out of a total of 13.8 million neurosurgical cases that require surgical intervention, more than 5 million cases go unattended each year, all in low resourced settings in Africa and South-East Asia. Neurosurgical cases that require consultation but not necessarily surgical intervention are even higher, hinting at a gross disparity of neurosurgical expertise and resource distribution in the world [2].

However, all is not lost for neurosurgery in lower income countries. The concept of Global neurosurgery was conceived to offset this disparity in the 1960s as surgical camps organized in Africa under the umbrella of Foundation for International Education in Neurological Surgery (FIENS) which spearheaded the development of neurosurgical capacity in Africa where neurosurgery was practically nonexistent up until that time [3,4]. Global leaders were fast to acknowledge and respond to the gap in access to neurosurgical care in developing countries, leading to the birth of several organizations and various models of collaboration over the coming years. Collaboration in neurosurgery or

Global neurosurgery efforts, led and funded by neurosurgeons and neurosurgical societies in High Income Countries (HICs) have yielded significant improvements over the last few decades[5,6]. One notable success story resulting from these efforts has emerged in Ethiopia, where a 20 fold increase in neurosurgical capacity was witnessed over 14 years from 0.0022 to 0.045 neurosurgeons per 100,000 population [7]. Although the new figures themselves do not sufficiently cater to the needs of the immense populations in such settings, a much greater and oft neglected problem arises from the economic sustainability of such efforts. For instance, neurosurgical capacity in Ethiopia is now limited not by the neurosurgical workforce, but by a very finite availability of infrastructure [7]. Therefore, while neurosurgical collaborations work on the expansion of neurosurgery programs over the world, the attention to the problem of workforce must be balanced with an attention to the local challenges of infrastructure and possibility of brain drain in low resourced settings [8]. The sharing of expertise must be complemented with a sharing of endorsements and a long-term framework of local training in order to ensure the sustainability of such collaborations [9].

As surgical collaborations continue to grow around the world, there is a need to update and synthesize our knowledge of collaborations in the past and use them to guide our future approach to the topic. Our paper summarizes the past and present of neurosurgical collaborations, what has changed with the advent of newer educational tools, what models may be of use in expanding the current programs and ensuring sustainability, what are the barriers to it and what should be the way forward.

Models of collaboration

Almeida et al. scrutinized the methods employed at the University of Toronto for dissemination of neurosurgical education to LMICs and proposed models of collaboration [10]. All of them have been detailed here with their merits and demerits, and a further few models have been proposed in addition to the existing models in order to cater to the issue of sustainability and brain drain.

1. Training programs in HICs

Training programs allow neurosurgeons from LMICs to visit well developed and well reputed neurosurgery programs in HICs and benefit not only from the patient load but also from the opportunity to work at well reputed programs and establish lifelong tele-collaborations with mentors of neurosurgery [10,11]. Also important is to note that these experiences allow for the advancement of a research collaboration between HICs and LMICs. Visiting neurosurgeons can participate in clinical and academic research activities in HICs, promoting evidence based approach towards surgery and developing a critical methodological approach towards neurosurgical questions on a case by case basis. The importance of research in training neurosurgeons can be further understood by a proportional rise in neurosurgery related research papers originating from countries directly benefiting from collaborative efforts [7]. However, training programs too are unfortunately not without controversy. Training neurosurgeons in HICs fail to acknowledge the technological differences between HICs and LMICs and thus accustom neurosurgeons to highly equipped settings that are almost always unavailable upon return to their home countries, raising concerns on the economic sustainability of such programs [12]. This can, however, be offset by expanding programs such as World Federation of Neurosurgical Societies (WFNS) to enable free transfer of ideas, expertise and technologies across neurosurgical societies from around the world [2] .

2. Neurosurgical missions

Traditionally, neurosurgical missions have meant a team of neurosurgeons from the developed world 'visiting' the developing countries in order to cater to the consultation and surgical needs of the population. However, these missions have now evolved to include education and training of neurosurgeons in LMICs as an integral part of building global neurosurgical capacity [13] . Collaborations are in fact considered to be more meaningful if they are directed at providing training as opposed to providing neurosurgical services alone [14] . This is also a more cost effective method [13] and allows to obtain greater output with a lesser input by creating a cascading effect whereby a few trained local neurosurgeons can go on to establish neurosurgical units and train many more neurosurgeons [15]. Moreover, neurosurgeons from HICs visiting third world countries are required to work in resource limited settings, thus providing them with a closer to reality picture of neurosurgery in the developing world and train local neurosurgeons accordingly. This model also exploits the underlying principle of "Exposure to inequities drives action". Exposing the HICs to LMICs will promote a culture of free transfer of technology and ensure sustainability in the long term.

3. Mentor mentee relationship

Mentor mentee relationships are a norm in medical practice. It is extremely common for such relationships to be established as a result of both of the above models and even remotely without them. It is, in fact, one of the most employed tools in the modern age of internet and allows the possibility of 'tele-collaborations', whereby well-trained mentor neurosurgeons from HICs can remotely assist in surgical procedures and management plans for rare case presentations via real time audiovisual tools [11,16]. This model, compounded by the preceding training of local neurosurgeons by one of the above models not only allows active monitoring of educational programs in the LMICs, but

may also be helpful in further promoting longitudinal collaboration between HICs and LMICs until the infant programs in the LMICs are capable enough to sustain themselves.

4. Online education of neurosurgeons

The rise of the internet has marked the advent of a new era for neurosurgical collaboration. Despite not being utilized up to its fullest potential yet, online education may be the future of neurosurgery for a number of reasons. For instance, it offsets the problems encountered due to a lack of funding for collaboration ventures without compromising the quality of education, as has been evidenced by extremely favorable results in other fields of medical sciences [17,18]. However, questions as to whether this method of education is a substitute for neurosurgery skill learning as happens in traditional neurosurgery training programs still remain unanswered owing to an unavailability of sufficient evidence in the field of neurosurgery. Assuming that such concerns are in fact well-founded in the absence of any evidence to suggest the contrary, online education can still be considered an excellent resource as an adjunct to traditional approaches [19], thus minimizing costs and broadening the exposure of neurosurgeons in LMICs.

5. Task shifting and task sharing (TS/S)

Owing to a persistent workforce deficit in LMICs despite a multifaceted approach to neurosurgical capacity building, there has been an increasing interest in the delegation of neurosurgical tasks to non-neurosurgeons such as general surgeons and neuro physicians in critical care settings [20]. While task shifting is actively being practiced in neurosurgery in LMICs [21,22], it has not been without controversy of giving undue autonomy to those not equipped for such procedures and the complications that may arise during the course of the procedure [20]. Task sharing hence is an alternative whereby both neurosurgeons and non-neurosurgeons share the responsibility and autonomy, with adequate training of the non-neurosurgical staff [23]. Adopting a model of TS/S would allow collaboration to expand out of the conventional arena of neurosurgeons and will permit local neurosurgeons to build extensive teams with non-neurosurgeons to carry out emergency procedures, with hitherto excellent outcomes [24].

History of collaboration in neurosurgery

One of the most outstanding examples of the benefits yielded by collaboration in the field of neurosurgery is provided by the Rhoton labs established by Dr. Albert L. Rhoton in 1975 at the University of Florida [15]. The Rhoton labs would go on to become the world's premier center for teaching microsurgery and microsurgical anatomy of the brain worldwide. But the tremendous impact that Rhoton labs had on shaping the field of neurosurgery goes beyond Dr. Rhoton's diligence in developing meticulously detailed and thorough training programs for aspiring neurosurgeons. Dr. Rhoton understood the significance of widespread dissemination of knowledge for the development of Neurosurgery. Therefore, each year, he would take on aspiring neurosurgeons as research fellows not only from the US but from all over the world, with many often not fluent in English, with the hope that his foreign trainees would go on to establish similar programs in their countries. Thus, over the next 40 years, 119 research fellows trained at his lab, with nearly a hundred of them from outside the US. The success of his initiative is evident by the fact that over the following years, as the lab grew and flourished, Dr. Rhoton and his team published over 500 papers, 2 supplements for Neurosurgery and the textbook "Rhoton's Cranial Anatomy and Surgical Approaches", which has been translated into several languages [15]. Dr. Rhoton's mentees are distributed all over the world, going on to establish similar programs in several countries like China, Turkey, Argentina, Spain, Portugal, Italy, Chile, Taiwan, and Russia [15,25–28]. Saying Dr. Rhoton's work has made not only a clinical but a structural impact worldwide would not be an overstatement [28].

In fact, the development of Neurosurgery as a distinct field in the United States is in itself a testimony to the importance of collaboration. The art of medicine is not just conveyed by textbooks and lectures, but in person through mentorship. Thus, Harvey Cushing, the Father of Neurosurgery, laid the foundations of neurosurgery as a distinct field by not only establishing and perfecting various neurosurgical techniques, but also training and mentoring many neurosurgeons over the span of his career, who went on to establish neurosurgery departments in various institutions all over the US [29]. This effectively laid the foundations on which the field would go on to flourish at a rapid pace in the coming years. Harvey Cushing also worked closely with Dr. Louise Eisenhardt, the pioneer neuropathologist, for years to establish and maintain a gross and microscopic brain collection. Dr. Eisenhardt went on to become the first woman president of the American Association of Neurological Surgeons [30]. The Spiller-Frazier operation is another reward of such collaboration between two prominent names in the field of medicine, William Gibson Spiller and Charles H. Frazier, the former known for his research, the latter, for his surgical skills. Building upon Spiller's observation that sensory root of trigeminal ganglion did not regenerate after its fibers were transected, Frazier showed that retro-resection of trigeminal ganglion was not only feasible but easier than resection of the whole ganglion, as was the common practice at that time. The Spiller-Frazier solution thus led to a safer intervention with lesser mortality rates for trigeminal neuralgia [31].

It can be concluded from this discussion that collaborative models, though hard to establish effectively, result in tremendous efficiency. They owe their success to the generation of a diverse and inclusive environment that allows the

free flow of innovative ideas, while providing the mentorship and facilities to polish and develop those ideas. Thus, collaboration not only among neurosurgeons from diverse regions but diverse fields is essential to further improving the discipline.

Neurosurgical collaboration in the modern era

The advancements in science and technology have changed the landscape and challenged the relevance of traditional collaboration models. Collaboration among different fields of medical sciences via online curricula is now not only feasible but also extremely productive and hence is now done very frequently [32]. Social media has played a pivotal role in this regard by acting as a knowledge transfer bridge between developing and the developed countries. Various social media applications and websites have driven the spread of information and educational support, both nationally and internationally, especially to those in neurosurgical training [33].

Studies on the use of Twitter and Instagram in neurosurgery have consistently revealed that these social media platforms can act as a communication platform for connecting not only neurosurgeons, trainees and medical students across the globe, but also patients across borders, allowing for remote consultation and taking load off of the already struggling neurosurgery programs in LMICs [34,35]. Similarly, Brainbook, an initiative aimed at enhancing the general public's understanding of neurological diseases via global engagement and supporting neurosurgical research has been massively successful owing to its creative illustrations and jargon free information dissemination to the masses. The success of such ventures can be quantified by the Brainbook experience, where 101,418 impressions from across the world were achieved on a Brainbookneurotrauma case over a mere 72 hours [36]. Another web-based social network is Inter Surgeon which serves to connect surgeons from around the world and enhances global collaborations [37]. A welcome corollary of the increasing discourse surrounding neurosurgery on social media is that it may act as a source of inspiration for students both in HICs and LMICs, accustom them with neurosurgeons and their research works, and allow them an opportunity at networking, so as for them to have a fairer ground to compete for fellowships in a field as competitive as neurosurgery [38]. This is especially useful for women who are globally underrepresented in the field [39], and may benefit from a shared safe online space with neurosurgeons from around the world.

Neurosurgery without borders

As is evident from our detailed discussion on the topic, cross-border collaborations and partnerships in neurosurgery between LMICs and HICs have been crucial in the advancement or even establishment of neurosurgery departments in LMICs. However, the state of neurosurgery worldwide still leaves much to be desired. For instance, in contrast to a ratio of 1 neurosurgeon for 100,000 population in HICs, LMICs have a ratio of 1 neurosurgeon for a population of 6400,000 [40]. Neurosurgeons in LMICs are estimated to be responsible for a population 30 times greater than HICs but their neurosurgical capacity stands at just a fraction of HICs [40]. These figures point to a dire need for not only more training programs for young neurosurgeons and residents [41], but also ensuring sustainability in LMICs through replicability of training programs. Responding to this disparity in neurosurgical care, several projects aimed at promoting collaboration between LMICs and HICs have been initiated and are underway. Table 1 summarizes some of the ongoing neurosurgery collaboration ventures between HICs and LMICs.

Table 1. A brief summary of ongoing collaborative neurosurgery projects

Collaboration	HIC	LMIC	Project (s)
The Ptolemy Project	Canada (University of Toronto)	East African Countries	Ptolemy project contributes directly to building research capacity in Africa by providing electronic access to medical literature for early career neurosurgeons in East Africa
Global NeuroTrauma Fellowship Program (GNTF)	US (Barrow Neurological Institute) UK (University of Cambridge) Spain, Germany	Colombia (Meditech Foundation) Brazil, Venezuela, Pakistan, Cuba, Ecuador, Peru	GNTF is a 12-month fellowship program to provide training opportunities to aspiring neurosurgeons from developing countries

Surgical Neurology International (SNI) Digital-Baghdad neurosurgery collaboration	United States	Iraq	SNI promotes online neurosurgical learning in an internet meeting format that allows neurosurgeons from US and Iraq to share their learning experiences
Swiss Neurosurgeons International	Switzerland	Myanmar	This program provides a fully sponsored fellowship at an academic hospital in Switzerland to Myanmar neurosurgeons and organizes workshops, lectures, and educational surgeries in Myanmar
Development of Neuroscience Center	US (Barrow Neurological Institute)	Tanzania	A neurosurgical center of clinical and training excellence has been established within Tanzania in order to train local neurosurgeons
Other notable neurosurgery collaborations	Australia, China	Papua New Guinea	Under this collaboration, Australian neurosurgeons visit PNG twice a year and do capacity building by teaching the skills to local surgeons and nurses

With internet based education on the rise, an online model of education has been adopted by the Surgical Neurology International (SNI) Digital- Baghdad neurosurgery educational series, a joint effort between the United States and Iraq to discuss, debate and scrutinize the unique and complicated experiences in neurosurgery together in an online meeting format and provide a symbiotic educational experience to people from different parts of the world [42]. A step ahead from SNI is the Ptolemy Project, an international collaboration program between the University of Toronto and the East African surgical community that represents roughly 400 surgeons who are responsible for a population of 200 million people [43]. As a part of this project, the East African surgeons have become research affiliates of the University of Toronto and have access to the full-text resources of the university. The Ptolemy Project also has a reading course "Surgery in Africa" designed especially for low resourced settings in Africa in order to train local leaders in surgical education. This model of training coupled with research collaboration and economic assistance combines the merits of all the collaboration models and bolsters an environment of inclusivity in a largely exclusive profession while also ensuring viability of these projects for LMICs. Collaborative electronic media initiatives like The Ptolemy Project have proven to be cost-effective and achievable strategies to aid the global neurosurgical community in developing health research capacity in their home countries [43,44].

Apart from lacking research capacity, neurosurgery residents and medical students from LMICs also lack access to specialized training fellowship programs and by extension, newer advances in the field of neurosurgery. To address this issue, The Global Neurotrauma Fellowship (GNTF) Program was initiated in 2015 by Barrow Neurological institute, USA [45]. It is a 12-month training program academically supported by Barrow Neurological Institute at Phoenix Children's Hospital and Meditech Foundation in Colombia with additional support from the University of Cambridge. Till now the fellowship program has trained fellows from Brazil, Venezuela, Cuba, Pakistan, Colombia, Ecuador, Peru, Germany, Spain, and the USA. This amalgamation of international graduates and exposure to both high and low-income environments creates a unique global training setup by bringing together competent minds from around the world [46].

Conventional methods of neurosurgical camps and workshops are also being employed in the modern world for countries determined to be seriously lacking in the neurosurgery skillset, especially in the context of African countries but also pertaining to other developing nations. Papua New Guinea (PNG) is one such developing Pacific nation where neurosurgical services are still close to none. Australian neurosurgeons, therefore, visit twice a year in order to extend the range of surgery and work on capacity building by teaching the skills to local surgeons and nurses [47]. Myanmar is another perfect example of an alliance between HICs and LMICs for the promotion of neurosurgery in the country. Swiss Neurosurgeons International have commenced a program that provides every Myanmar neurosurgeon with training and a fully sponsored fellowship at an academic hospital in Switzerland. Under this program, regular workshops, lectures, educational surgeries, and a series of contemporary neurosurgical technologies and procedures have been introduced to Myanmar [48]. Tanzania, a country in East Africa, has a total of 18 neurosurgeons for 70 million people and is now benefiting from similar programs hosted and funded by the Barrow Neurological Institute and Weill Cornell Brain and

Spine center [49,50]. Barrow has recently set up a neuroscience center within Tanzania for training future neurosurgeons for the country [49]. The Weill Cornell Neurosurgery-Tanzania collaboration uses hands-on training of Tanzanian neurosurgeons using locally available equipment and resources, organizes local educational conferences, periodic virtual calls and observer ships in the US [50], in an effort to promote the development of neurosurgical expertise and capacity in East Africa.

Breakthroughs due to collaboration

Collaboration in neurosurgery has birthed several success stories around the world. For example, as a result of the work of Dr. Roger Härtl in Tanzania under the patronage of Weill Cornell Brain and Spine Center, the number of neurosurgeons in Tanzania has soberly increased from 2 to 8, and residents from 0 to 5. There has been a subsequent increase in the number of research papers and surgical procedures for basic life threatening conditions such as hydrocephalus, brain tumor, and cervical spine injury [50,51]. A mobile neuroendoscopy training program, started by the Neurosurgery Education and Development Foundation in Tanzania in 2006 has been a major step forward in the optimization of patient care in East Africa through neurosurgical collaboration [51]. Local neurosurgeons and nurses were trained to perform endoscopic third ventriculostomy using a mobile neuroendoscopic unit, which was designed keeping in view the specific requirements of the region in that it could be transported to far-flung areas of sub-Saharan Africa [52].

Collaborative efforts have also borne fruit in the form of a pediatric brain disorder program in Ukraine, the Ukraine Pediatric fellowship program (UPFP), by the Department of Neurosurgery at the Sick Kids Hospital in Toronto [53]. With six Ukrainian hospitals now collaborating with UPFP, it has overseen the training of 20 physicians at Sick Kids Hospital in Canada over a period of a mere 5 years. Also active in Ukraine is Dr. Benjamin Warf where, in collaboration with CURE International, he has founded and led a pediatric neurosurgery training program focusing on hydrocephalus and spina bifida with global implications [54–56]. With the support of Duke Global Neurosurgery and Neurology, the Uganda program beginning in 2009 has enrolled and trained 5 neurosurgeons and 6 residents from Uganda. These efforts also saw the graduation of the first woman neurosurgeon in Uganda [9].

Dr. Jawahar Dar from India established the first neurosurgery department in Kenya as early as 1974, followed by the establishment of a second department in 2007 by Dr. Florentius Koech, a locally trained neurosurgeon who had pursued his neurosurgery fellowship in Australia [57]. Dr. Koech has been able to organize projects and workshops in Kenya with participation of neurosurgeons from HICs owing to a strong network from his time in Australia (58).

Tapping the hidden potential in LMICs is no short of a breakthrough when it comes to cross-border neurosurgical collaboration. Allowing promising neurosurgeons from LMICs to experience firsthand state of the art neurosurgical care in HICs, become familiar with the novel research and technological advancements in the field, and connect with the giants bringing about these advancements, inculcates in them a deep-rooted desire to both set into motion and sustain similar practices in their home country on their return, to whatever extent is allowed by the resource strained health system of LMICs. Figure 1 summarizes the countries that are known to benefit from neurosurgical collaboration in various capacities and at varying magnitudes, driven primarily by the US, UK, and Canada.

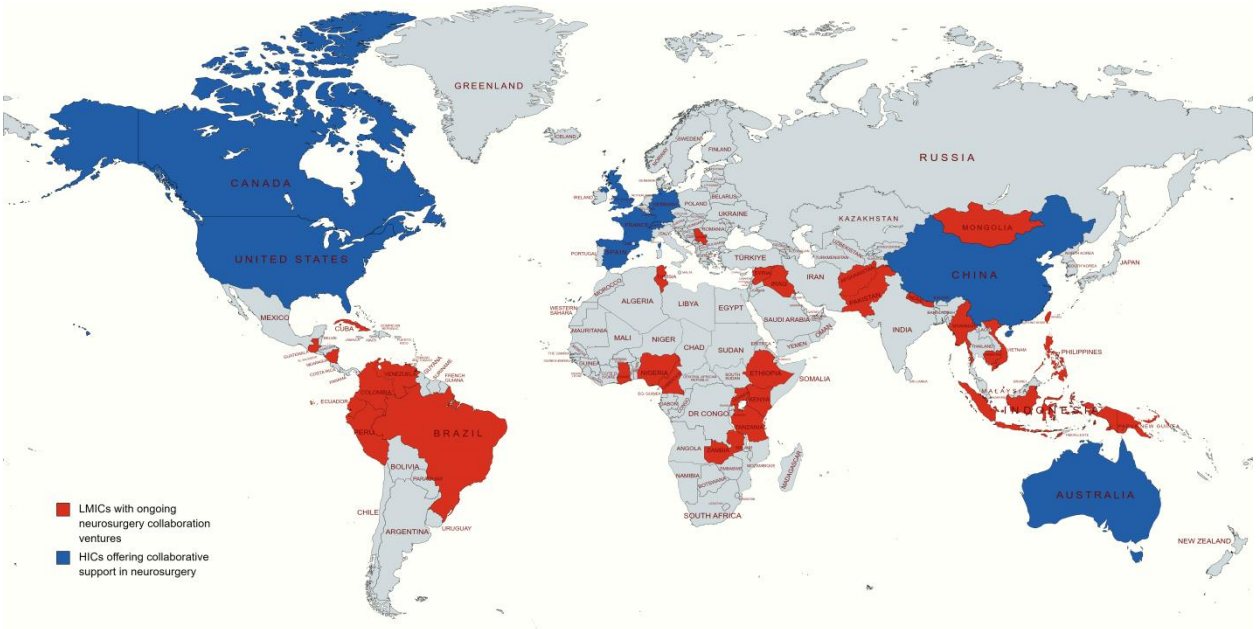

Figure 1. Geographical distribution of collaboration in neurosurgery

Despite the various breakthroughs as a direct result of collaboration, as Dr. Rhoton would say, there is no finishing line. There is still much work to be done to ensure equality and/or equity in neurosurgical care across the world. Traditional collaboration, however, is unfortunately becoming harder given the barriers explained in the subsequent section.

Barriers to collaboration

1. Financial constraints

Financial constraints impose a limit on both the number and magnitude of collaborative projects, implying that the efficacy of such undertakings will always be less than if they were to be reproduced in a model with ample funding. Government funding for these projects is often non-existent, leaving the involved surgeons to bear the cost themselves or depend upon donations. This decreases the likelihood of longitudinal collaborations that are more effective in producing sustainable programs in LMICs [10].

2. Brain drain

The surgical training model of neurosurgical collaboration between HICs and LMICs is associated with significant brain drain i.e. the promise of political stability, improved quality of life, better opportunities in research and career advancement, greater job satisfaction and abundant resources are often enough incentives for visiting doctors from resource-strained areas to choose to settle in HICs. While this collaboration model can further add to the deficit of neurosurgeons in the source countries, it should be viewed as an opportunity to improve healthcare as a whole in these source countries to combat brain drain [59–61].

3. Barriers to participation in Global Surgery Academic Collaborations

Three major themes pertaining to barriers to participation in global surgery academic collaborations have been identified as individual, community, and system barriers. Individual barriers encompass loss of income, family commitments, perceived risk to their well-being when traveling to politically unstable LMICs, and the choice of junior faculty to prioritize advancing their own career over involvement in such projects. Community barriers like lack of colleague support and early exposure to global surgery and system barriers like lack of time, institutional support, and funding also hinder participation. Another common theme is a greater sense of responsibility towards patients from their own country who require their attention and surgical care, which limits both the desire and the time to help out patients in foreign countries [62].

Outcome assessment of existing efforts

There is currently no standard metric to assess the outcomes of ongoing and past collaborative efforts between different countries in the field of neurosurgery. This makes it incredibly hard to call for greater resource allocation to further these collaborative efforts when impact of the previous collaborations cannot be accurately gauged [63,64].

The way forward

The advancement of neurosurgery in LMICs demonstrates the incredible impact that international neurosurgical collaborations have had in neurosurgical capacity and acumen building, especially in Africa. However, the challenges in providing ‘neurosurgical care for all’ persist owing to a poor infrastructure and lack of equipment, limited funding, brain drain, and population overload. Future collaborative efforts must focus on cost effective, self-replicative, and most importantly, sustainable models of collaboration along with the ongoing traditional collaborations.

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Conflicts of interest

The authors report no relationships that could be construed as a conflict of interest.

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Author contributions

Aqeeb Ur Rehman: Conceptualization, Methodology, Data curation, Resources, Writing-Original draft, Writing-Review and editing

Aleena Ahmed: Data curation, Writing-Original draft, Software

ZaofshaZaheer: Data curation, Writing-Original draft, Writing-Review and editing

Bakhtawar Ahmad: Data curation, Writing-Original draft
Brandon Lucke-Wold: Conceptualization, Resources, Supervision, Validation

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