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# The impact of COVID-19 pandemic on global neurosurgery collaborations

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## 1. Introduction

Low- and middle-income countries (LMICs) account for a major burden of neurological disease globally.[1,2] A workforce deficit of 23,300 neurosurgeons currently exists, limiting efforts to address the over five million essential unmet neurosurgical cases in LMICs.[1,3] In light of these deficits, several global neurosurgery collaborations (GNCs) have been established in recent years to mitigate the global deficiencies in neurosurgical access and care.[4–6] These collaborations inevitably involve institutions and organizations in high-income countries (HICs) collaborating with those in LMICs, due to the disparity in neurosurgery development between HICs and LMICs. Collaborative ventures have taken various forms, including service delivery through surgical missions, building workforce capacity through training partnerships, developing infrastructure and resources, data management, and improving research quality and capacity.[4–6] However, these collaborations are not immune to the global socio-political, economic, and health systems contexts within which they operate.

The pandemic caused by the coronavirus disease 2019 (COVID-19) has significantly affected how neurosurgical care is delivered globally.[7,8] During the initial stages of the pandemic, several studies worldwide showed a significant reduction in the number of neurosurgical cases, varying effects on research output, and limited opportunities for trainees to gain practical clinical experience.[9–13] The pandemic also impacted mental health, burnout, and stress for neurosurgeons and neurosurgical residents.[14–17] In LMICs already burdened with fragile health systems, adjusting priorities was necessary due to the shortage of resources and personnel.[18–22] In several instances, hospitals and academic programs pivoted to virtual learning and telemedicine, allowing continuity in training residents and delivering patient care.[23–27]

The COVID-19 pandemic also affected many GNCs, likely causing a paradigm shift that may have threatened the existence of some collaborations while strengthening others through adaptations and modifications of collaborative approaches.[16,28] Specifically, GNC activities were affected by restrictions on international travel, necessitating rescheduling, postponement, modification, and sometimes outright canceling of previously scheduled activities. As the pandemic eases and the world

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**Abbreviations list**

AAU Addis Ababa University
AFAN Association of Future African Neurosurgeons
Bergen-Haukeland: University of Bergen and University of Haukeland
CAANS Continental Association of African Neurosurgical Societies
CoA Children of Alabama Hospital
COVID-19 Coronavirus disease 2019
DGNN Duke Global Neurosurgery and Neurology
EANRC East African Neurosurgical Research Consortium
Egypt SNS Egyptian Society of Neurological Surgeons
FIENS Foundation for International Education in Neurological Surgery
GNC Global neurosurgery collaboration
GNF Global Neuro Foundation
IRB Institutional Review Board
KBNF Korle-Bu Neuroscience Foundation
LMICs Low- and middle-income countries
MUST: Mbarara University of Science and Technology
NANSIG Neurology and Neurosurgery Interest Group
NED Neurosurgery Education Development Foundation
NIHR National Institutes of Health Research
PGSSC Program in Global Surgery and Social Change
PI Principal Investigator
Rutgers GN Rutgers Global Neurosurgery
SANC Swedish African Neurosurgical Collaboration
UAB University of Alabama at Birmingham
US/USA: United States of America
UToronto University of Toronto
VUGN Vanderbilt University Global Neurosurgery
WeillCornell Weill Cornell Medicine
WFNS World Federation of Neurosurgical Societies

re-emerges from restrictions to travel and physical engagements, it is imperative to understand the pandemic's impact on various neurosurgical collaborations, the adaptations embraced by collaborations to sustain their activities, and how these could affect future global neurosurgery engagements. However, there is limited research on the effects of the pandemic on these collaborations. Thus, this study sought to systematically assess the impact of the COVID-19 pandemic on GNCs and its effect on future collaborative activities.

The study's objectives were to: 1) define how the COVID-19 pandemic has impacted GNCs, and 2) identify adaptive changes embraced by various GNCs to maintain their activities and the lessons learned. We hypothesized that the COVID-19 pandemic led to modified or reduced activities for GNCs, prompting them to implement adaptive changes and uncover lessons that could be applied to future challenges.

## 2. Methods

### 2.1. Study design and survey development

We conducted an online survey of named GNCs. The survey tool was developed and iteratively refined on Qualtrics Experience Management (XM) software (Provo Utah and Seattle Washington, USA) by Duke Global Neurosurgery and Neurology (DGNN). DGNN is a multinational and multidisciplinary group of neurosurgeons, global neurosurgery and global health researchers, neurologists, neuro-intensivists, neuro-physiotherapists, neuropsychologists, neurosurgery residents, and graduate and undergraduate students invested in neurosurgical capacity-building and research in LMICs. The survey tool consisted of 49 questions across seven collaborative domains, including research, service delivery, workforce and education, infrastructural development, data management, collaboration funding, and collaboration governance and policy (Supplemental File). The survey was distributed via emails and social media (Twitter, Facebook, and LinkedIn) using the survey web link (https://duke.qualtrics.com/jfe/form/SV_8GrjyuSMYirlufQ) and QR codes. Completed surveys were recorded on Qualtrics and exported to Google spreadsheets for analysis.

### 2.2. Study population

The study population comprised known leaders and principal actors in various GNCs. GNCs were defined as organizations that seek to advance the goal of ensuring equitable access to neurosurgery worldwide through various means, from research to capacity building efforts. These organizations are typically based in HICs with collaborations with LMIC partners. Collaborations between only HIC organizations were excluded from the study. The study population was identified through a combined purposive and snowball sampling technique, leveraging DGNN's robust network and previous research to identify collaborations. In addition, we utilized the list of organizations and individuals who presented at the global neurosurgery sessions of the XVII World Congress of Neurosurgery (WFNS Congress) in Bogota, Colombia to identify GNCs. Surveys were sent over a two-month period, from March 1 to April 30, 2022, with weekly reminders sent to participants. The participants did not receive direct compensation but are included in a collaborative authorship list.

### 2.3. Ethical approval and informed consent

Ethical approval was obtained from the Duke Health Institutional Review Board (Duke Health IRB, Protocol ID: Pro00110241). Study participants also completed an online informed consent before responding to the survey.

### 2.4. Statistical analysis

A descriptive analysis was done to characterize the background of each survey participant and the collaborative teams in which they were involved. Specifically, we identified the distribution of individuals from different countries, their academic backgrounds, and other factors specific to their working environment.

We performed a qualitative, thematic analysis to assess participant feedback on their experience throughout the COVID-19 pandemic. We focused on lessons learned, adaptations made, and the overall impact of the pandemic on virtual education, service delivery, technology transfer, and research activities.

To assess the impact of the COVID-19 pandemic on research, service delivery, workforce, and education, we obtained data from participants on their year-by-year outputs between 2018 and 2021. These included elements such as the number of active projects, surgical camps, and personnel. Output values from individual collaborators were normalized to their sum over time (Equation 1), and values were compared across all collaborations.

$$norm\left(V_{output,year}\right) = \frac{V_{output,year}}{\sum_{k=2018}^{2021} V_{output,k}}$$

A one-way ANalysis Of VAriance (ANOVA) was performed to assess for significant variance across years. Post-hoc testing via independent *t*-tests was performed across all years if ANOVA reached significance. A *p*-value of 0·05 was chosen as significant. All analyses were performed in

python 3·8·13 using pandas 1·4·2, seaborn 0·11·2, matplotlib 3·5·1, numpy 1·22·3, and statsmodels 0·13·2.

## 3. Results

### 3.1. Respondent characteristics

131 individuals working with 30 named GNCs were targeted. 44 survey responses were started (response rate: 33·6 %), and 36 were recorded and exported for analysis (completion rate: 27·5 %). Table 1 summarizes the demographic details of the respondents. The respondents were from 14 countries, with most from the United States (US; 15, 41·7 %), Uganda (3, 8·3 %), and Nigeria (3, 8·3 %). The respondents worked in 28 different institutions; four respondents were from the University of Alabama at Birmingham (UAB; 11·1 %), while two (5·6 %) each were from Addis Ababa University (AAU), Duke University, Harvard University, Mbarara University of Science and Technology (MUST), and Vanderbilt University. Eight (22·2 %) respondents each were either full or associate professors in their home institutions, while 5 (13·9 %) were assistant professors. The respondents were associated with 23 named GNCs, with nine (25·0 %) each linked with the Foundation for International Education in Neurological Surgery (FIENS) and World Federation of Neurological Surgeons (WFNS), and six (16·7 %) each from the DGNN, and InterSurgeon. Seven respondents (19·4 %) each led their collaboration as the Director or functioned as a Collaborator in the collaboration, while four (11·1 %) led a part of the collaboration as Coordinator. The collaborations were affiliated with institutions in at least 21 distinct countries (Fig. 1), and the respondents were involved in various collaborating activities: 1) training and workforce capacity building (26, 72·2 %), 2) research and research capacity building (25, 69·4 %), 3) service delivery (19, 52·8 %%), 4) infrastructural development (12, 33·3 %), and 5) data and information management (12, 33·3 %) (Table 1).

### 3.2. Impact of COVID-19 on research collaborations

The pandemic had a variable impact on research processes and outputs (Table 2). The total number of reported active projects increased from 54 in 2018 to 63 in 2019, 92 in 2020, and 124 in 2021; manuscript publications decreased from 60 in 2018 to 41 in 2019 and subsequently increased to 83 in 2020 and 84 in 2021; published book chapters increased from one in 2018 to two in 2019, four in 2020 and five in 2021; conference attendance increased from 14 in 2018 to 25 in 2019, but decreased to 23 in 2020 before increasing to 44 in 2021; while conference presentations increased from 39 in 2018 to 43 in 2019, decreased to 21 in 2020 and then increased to 52 in 2021. When these counts were normalized, there was a statistically significant difference in the increase in the number of active research projects from 2019 to 2021 ($p = 0.014$), as shown in Fig. 2. Similarly, the increase in the number of attended conferences was statistically significant ($p = 0·034$, 0·046, 0·023), as was the increase in the number of conference presentations ($p = 0·01$). Collaborations were able to adapt to the changing research terrain through virtual conferencing, online research, and collaborator-implemented research. One respondent noted that all collaboration research activities were stopped in their institution. Some lessons learned about research during the pandemic included the need for technological adaptations such as virtual meetings and training and the need to increase collaborator engagement. Participants reported that the COVID-19 pandemic caused a need for project modification, exposed research knowledge, and practice gaps, and promoted increased collaborator roles. The reported future impact includes increased collaborator roles, project modification, and a rise in alternative research methods such as online methods. For collaborations that were unable to continue research activities, other alternative activities engaged included educational webinars, educational courses, and virtual training. These research adaptations, lessons, and pandemic impacts are summarized in Table 3.

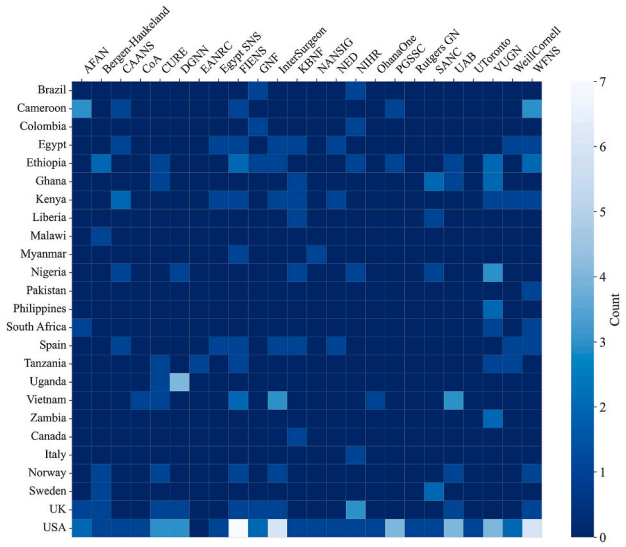


**Fig. 1.** A heatmap showing global neurosurgical collaborations along the horizontal axis, and their corresponding partner countries along the *y*-axis.

### 3.3. Impact of COVID-19 on service delivery

There was a decreasing trend in surgical camps and consultations pre-and-post the COVID-19 pandemic (Table 2). 13 camps totaling 485 consultations were organized in 2018 and 10 camps totaling 455 consultations were organized in 2019. However, no camps or consultations were reported in 2020 and 2021. In 2018, the reporting GNCs had 29

**Table 1**
Counts of respondent's countries, institutions, collaborations, academic positions, collaboration positions, and collaboration activities ($n = 36$).

| Respondent's Country | | Respondent's Institution | | GNC Affiliation | | Academic Position | | Collaboration Position | | Collaboration Activities | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| USA | 15 | UAB | 4 | FIENS | 9 | Assoc. Prof. | 8 | Collaborator | 7 | Training and workforce capacity building | 26 |
| Nigeria | 3 | AAU | 2 | WFNS | 9 | Prof. | 8 | Director | 7 | Research and research capacity building | 25 |
| Uganda | 3 | Duke | 2 | DGNN | 6 | Asst. Prof. | 5 | Coordinator | 4 | Service delivery | 19 |
| Cameroon | 2 | Vanderbilt | 2 | InterSurgeon | 6 | Lecturer | 4 | Chair | 3 | Infrastructural development | 12 |
| Ethiopia | 2 | Harvard | 2 | CURE | 5 | Senior Lecturer | 3 | Board member | 3 | Data and information management | 12 |
| Ghana | 2 | MUST | 2 | VUGN | 5 | Other | 8 | Secretary | 2 | | |
| Sweden | 2 | Other | 22 | PGSSC | 5 | | | Leader | 2 | | |
| Other | 7 | | | UAB | 5 | | | PI | 2 | | |
| | | | | Other | 30 | | | Other | 13 | | |

Acronyms: USA, United States of America; UAB, University of Alabama Birmingham; AAU, Adis Ababa University; MUST, Mbarara University of Science and Technology; FIENS, Foundation for International Education in Neurological Surgery; WFNS, World Federation of Neurosurgical Societies; DGNN, Duke Global Neurosurgery and Neurology; CURE, ***; VUGN, Vanderbilt University Global Neurosurgery division; PGSSC, Program in Global Surgery and Social Change; Asst., Assistant; Assoc., Associate; Prof., Professor; PI, Principal Investigator.

**Table 2**
Effect of COVID-19 on various global neurosurgery collaboration activities.

| Collaboration activity | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|
| Research | | | | |
| Active projects | 54 | 63 | 92 | 124 |
| Manuscript publications | 60 | 41 | 83 | 84 |
| Book chapters | 1 | 2 | 4 | 5 |
| Conference attendance | 14 | 25 | 23 | 44 |
| Conference presentations | 39 | 43 | 21 | 52 |
| Service delivery | | | | |
| Surgical camps | 13 | 10 | 0 | 0 |
| Surgical camp consultations | 485 | 455 | 0 | 0 |
| Procedures | 127 | 103 | 0 | 0 |
| Participating workforce | | | | |
| ● Neurosurgeons | 29 | 24 | 0 | 0 |
| ● Nurses | 25 | 31 | 0 | 0 |
| ● Anesthesiologists | 11 | 10 | 0 | 0 |
| ● Intensivists | 3 | 3 | 0 | 0 |
| ● Rehab personnel | 2 | 2 | 0 | 0 |
| ● Ancillary staff | 15 | 14 | 0 | 0 |
| Workforce and education | | | | |
| Educational activities | 161 | 164 | 153 | 193 |
| Participants | 80 | 111 | 155 | 312 |
| Didactic lectures | 76 | 108 | 143 | 242 |
| Resident training | 66 | 68 | 72 | 74 |
| Fellowship training | 10 | 33 | 60 | 80 |
| Short-term training | 34 | 34 | 10 | 18 |
| Seminars | 108 | 108 | 60 | 188 |
| Conferences | 105 | 107 | 130 | 362 |
| Ward rounds | 44 | 44 | 32 | 34 |
| Clinical learning | 38 | 38 | 24 | 80 |
| Technology and Infrastructure | | | | |
| Craniotome | 4 | 4 | 2 | 2 |
| Electric drills | 4 | 4 | 3 | 2 |
| Suction | 2 | 2 | 1 | 1 |
| Cranial surgery sets | 1 | 2 | 0 | 0 |
| Spinal surgery sets | 1 | 3 | 0 | 0 |
| Cranial implants | 2 | 1 | 0 | 0 |
| Spinal implants | 2 | 3 | 0 | 0 |
| Anesthesia equipment | 2 | 2 | 1 | 2 |
| Ultrasound scanners | 1 | 1 | 1 | 0 |
| Monitors | 2 | 1 | 1 | 1 |
| ICU ventilators | 1 | 1 | 0 | 0 |
| Repair and maintenance | 3 | 2 | 3 | 2 |

neurosurgeons, 25 nurses, 11 anesthesiologists, three intensivists, two rehabilitation personnel, and 15 ancillary health professionals involved in service delivery through surgical camps. In 2019 there were 24 neurosurgeons, 31 nurses, 10 anesthesiologists, three intensivists, two rehabilitation personnel, and 14 ancillary health professionals involved in surgical camps. However, in 2020 and 2021, these collaborations reported 0 health professionals involved in surgical camps. Fig. 3 shows the normalized counts for these service delivery efforts and personnel.

Participants reported multiple service delivery adaptations in the COVID-19 pandemic, including relying on efficient knowledge and technology transfer and more virtual webinars. Collaborations learned strategies to be more efficient in projects and to reduce surgical site infections. Participants reported that experiences during the COVID-19 pandemic led to improved efficiency, reduced surgical site infection, creation of additional collaborations, increased investment in health, and reduced numbers of surgeries and admissions. GNCs engaged in webinars, clinical research, and in-person training as alternative service delivery activities during the COVID-19 pandemic. Participants reported that the COVID-19 pandemic may lead to smaller in-person teams, more focused and efficient in-person visits, and efficient virtual and distant learning for service delivery activities in the future (Table 3).

### 3.4. Impact of COVID-19 on workforce and education

There was an increasing trend in 1) education and training activities and 2) participation in workforce development and education pre-and-post pandemic. These data are summarized in Table 2. The normalized counts of these educational activities and outputs (Fig. 4) did not show any statistical significance. The platforms used for virtual education before COVID-19 included Zoom, Adobe Connect, and other unspecified platforms. Since COVID-19, the use of Zoom, Google Meet, and other platforms showed a significant increase in use. Education adaptations to the COVID-19 pandemic included using virtual platforms like Zoom, webinars and teleconferencing, online training modules, and web videos. Participants reported that during the COVID-19 pandemic, they learned that virtual education platforms are cheaper, easier to use, have greater potential and improve participation compared to traditional methods. Many needs were identified, including the need to increase local capacity building, a need for alternative, flexible, and adaptable education methods, and a need for further international education collaborations. Alternative education activities during the COVID-19 pandemic included webinars/online conferences, online courses, research, dissection courses, and virtual reality skills labs. Participants identified that in the future, there would be a continued need for virtual medical education, increased international educational partnerships, improved virtual educational content, and the creation of new educational activities and methods. These adaptations, lessons, and pandemic impacts are summarized in Table 3.

### 3.5. Impact on technology and infrastructure

The use of technology evolved during the COVID-19 pandemic, according to the survey responses. From 2018 to 2021, between four to five collaborations reported initiating technological transfers (Table 2 and Fig. 5). While the data provided were limited, overall, there was a decrease in the types of equipment sent comparing pre-COVID-19 years (2018–2019) to the pandemic period (2020 and 2021). This equipment included those related to cranial surgery (craniotomies, drill sets, cranioplasty implants, cranial surgical sets), spinal surgery (spinal surgery sets, spinal implants), anesthesia/critical care (monitors, ventilators), and general equipment repair. These efforts to transfer technology were impacted by delays in shipments reaching their destination. However, these collaborations noted that several adaptations emerged out of the pandemic. These included shifting to virtual meetings and seminars, using the opportunity to evaluate cases more comprehensively, emphasizing the need for the presence of a technology maintenance team, and empowering local hospitals to play a critical role in facilitating the clearing of equipment from customs. Collaborations learned lessons about the importance of building a robust data management and transfer infrastructure that can support local data collection and cross-institutional/international collaborations. Table 3 details these adaptations, lessons, and pandemic impacts.

## 4. Discussion

The impact of the COVID-19 pandemic on clinical and academic neurosurgery has been well reported; however, its impact on GNC activities is largely unknown. To our knowledge, this study is the first to assess the experiences of GNCs regarding the changes they experienced, adaptations they implemented, and lessons learned that are attributable to the pandemic. We found that for GNCs, the COVID-19 pandemic led to widespread changes in research, service delivery, workforce and education, and technology and infrastructural improvement efforts. These changes caused the various collaborations to adapt in different ways, applying the lessons learned in their collaborative activities.

Regarding neurosurgical research collaborations, we found that the number of active research projects increased prior to and during the COVID-19 pandemic. This same trend was seen in manuscript and book chapter publications. This suggests that collaborations were able to maintain or increase their active projects despite the pandemic. This could be due to the adaptations identified, including implementing online research methods and increasing collaborator-initiated research, which was more feasible during the COVID-19 pandemic. However,

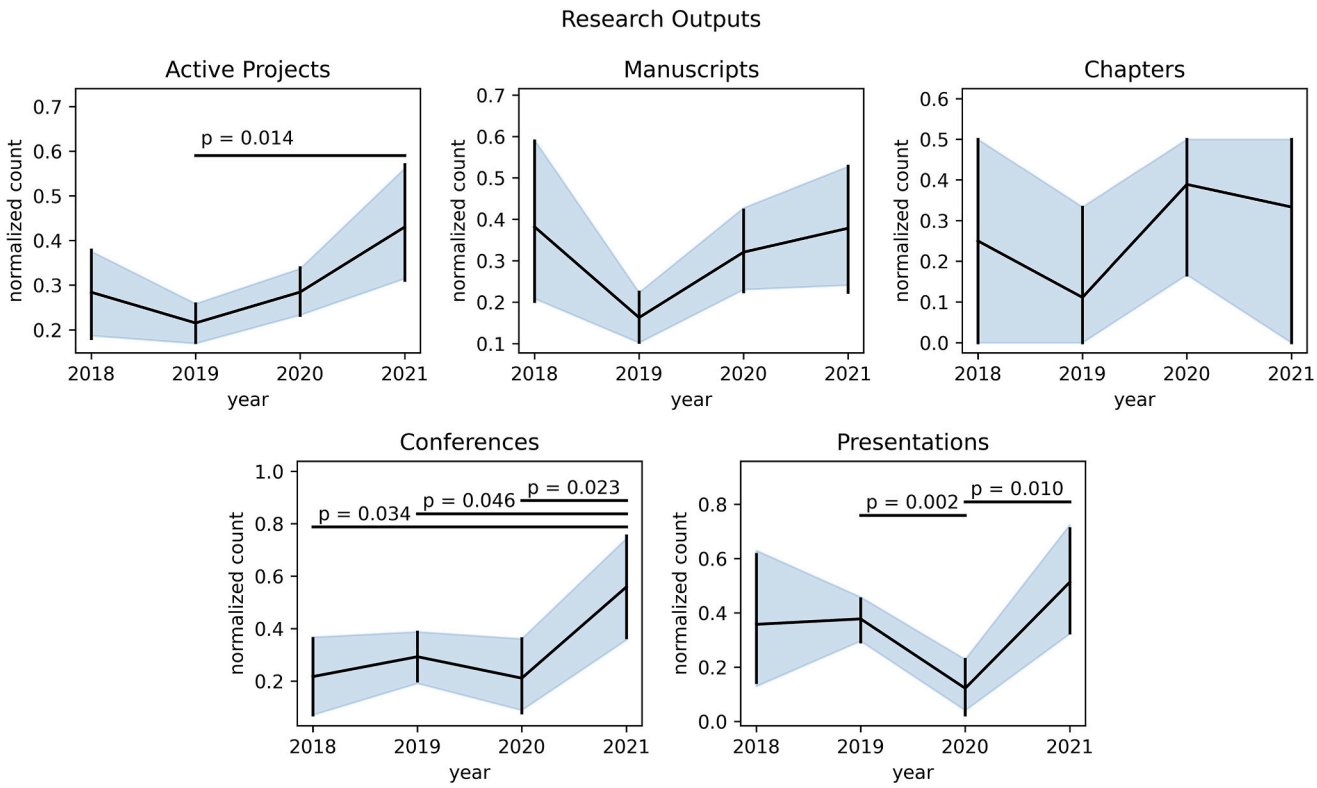


**Fig. 2.** Normalized counts of various research outputs shown over time, with significant differences noted (as given by ANOVA and post-hoc *t*-test).

**Table 3**
Adaptations, lessons, and current and future impact of COVID-19 on global neurosurgery collaborations.

| Collaboration activity | Adaptations | Lessons | Current impact | Future impact | Other activities |
|---|---|---|---|---|---|
| **Research** | Virtual conferencing<br>Online/Remote research<br>Collaborator-implemented research | Learned to work virtually<br>Improved collaborative skills improved<br>Gained skills in literature reviews<br>Improved financial management<br>Improvements to technology<br>Reduced reliance on other resources for research<br>Use of social media and technology to connect | Accelerated research conversations<br>Increased productivity<br>Increased literature-based work<br>Improved patient adherence in clinical trials<br>Decreased meeting frequency<br>Increased technology use<br>Improved project management<br>Increased South–South collaboration | Move future meetings online<br>Increased choice in collaboration<br>Increased use of alternative research methods<br>Increased international leadership in projects<br>Increased sharing on social media<br>Increased technology transfer | Virtual webinars and courses<br>Medical education<br>Grant writing<br>Supply shipping<br>Policy development<br>Advocacy<br>Use of augmented reality |
| **Service delivery** | Efficient knowledge and technological transfer<br>Reduced surgical wait time<br>More virtual webinars | Learned to be more efficient in projects<br>Reduced surgical site infections | Improved efficiency<br>Reduced surgical site infections<br>More collaborations<br>Increased investment in health-related expenditure<br>Number of surgeries and admissions reduced | More efficient virtual and distance learning<br>Smaller in-person teams<br>More focused, efficient in-person visits | Online webinars<br>Clinical research<br>In-person training |
| **Education/ Workforce** | Webinars and Teleconferencing<br>Zoom<br>Online training modules<br>Web videos | Virtual education platforms are cheaper, easier, important, have great potential, and improve participation<br>Collaborators have great enthusiasm to learn<br>Need to increase local capacity building<br>Consistency and timing<br>Need for more international collaborations | Continue virtual methods using Zoom, Webinars<br>Increase participations<br>Include more activities | Virtual CME<br>Increase international partnerships<br>Create and improve online educational content<br>Include more activities and educational methods | Webinars/Online conferences<br>Online courses, e.g. Coursera etc.<br>Research<br>Dissection course<br>Virtual reality skills lab |
| **Technology** | Virtual meetings<br>Local hospital facilitate customs clearance<br>Direct shipment to local facility | Early planning and shipment<br>Mission still vital and critical<br>Need for tech maintenance team<br>Need for improved internet infrastructure | Shipment delay<br>Better case discussion and plan implementation | Improved planning<br>More publications | Seminars |

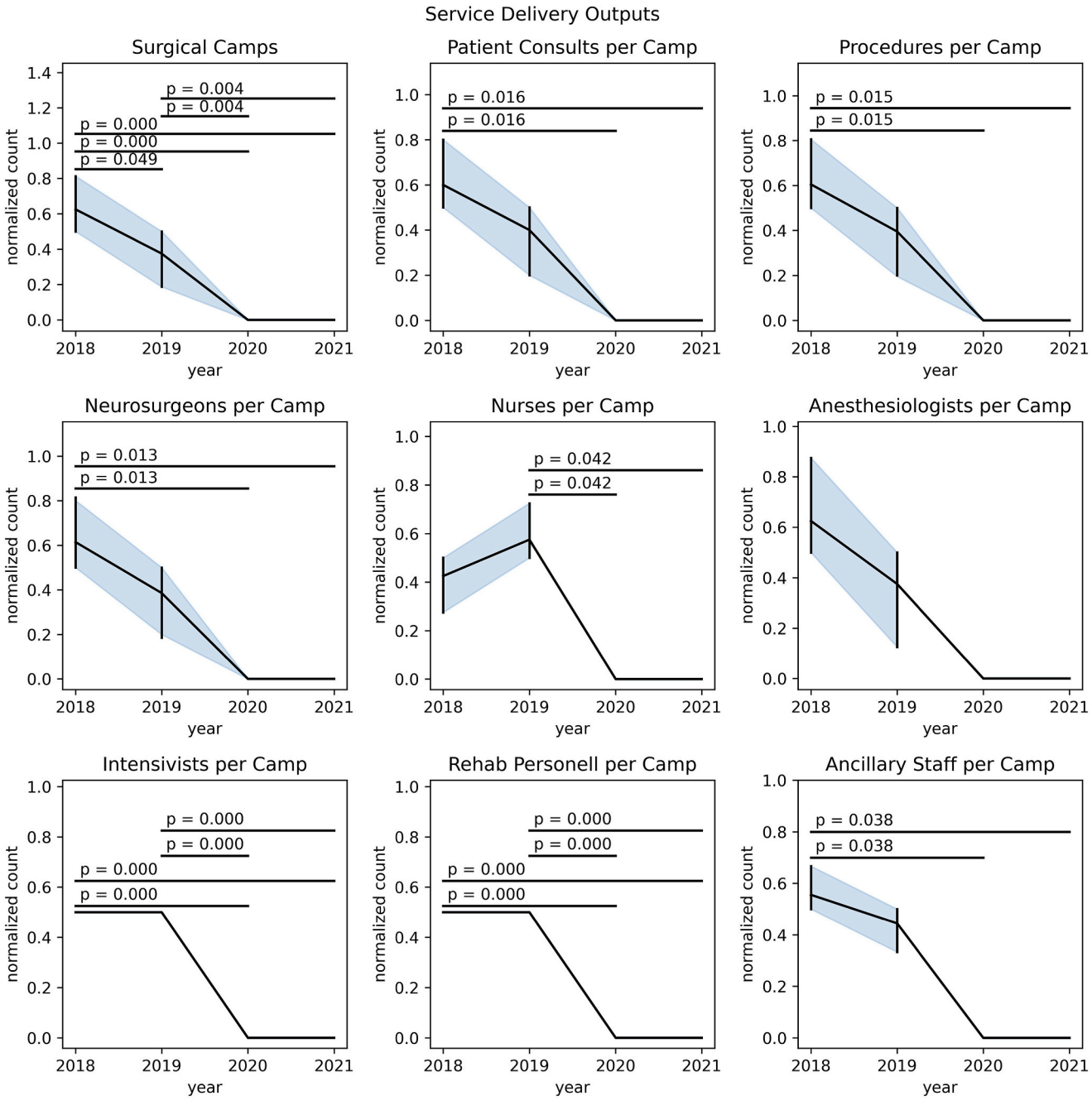


**Fig. 3.** Normalized counts of various service delivery outputs shown over time, with significant differences noted (as given by ANOVA and post-hoc *t*-test).

yearly research output in global neurosurgery has overall been increasing over the last decade[29]; thus, these findings could reflect the broader trend of increasing research productivity in global neurosurgery. This is consistent with findings of increased neurosurgical research outputs during the COVID-19 pandemic seen in another study.[9] In the same period, conference attendance by GNCs initially decreased during 2020 but began increasing again in 2021. Many conferences were canceled at the beginning of the pandemic, but the use of virtual conference platforms in 2021 likely supported the increase in conference attendance beyond 2019 levels. Our results suggest that, overall, research collaborations were able to successfully adapt to the challenges faced due to the COVID-19 pandemic, but they do highlight the importance of adaptation through virtual platforms and increased collaborator engagement.

GNCs faced greater difficulty in continuing their service delivery activities during the COVID-19 pandemic. Surgical camps were the main service delivery activity reported; our results indicate that surgical camps stopped in 2020 and 2021. While the number of surgical camps, procedures, patient consultations, and specialists involved generally decreased before the COVID-19 pandemic, pandemic-related travel restrictions and limited resources likely played a greater role in the discontinuation of surgical camps in 2020 and 2021. These findings from GNCs align with findings in the field of neurosurgery; many neurosurgical practices saw their clinic visits, operative procedures, and inpatient consultation volumes decrease during the pandemic.[8,9,12,18,20–22,30] While the service delivery activities of GNCs will likely resume as travel restrictions and resource limitations ease, lessons learned during the pandemic can help ensure successful activities in the future. Improvements in the efficiency of collaboration activities and financing of service delivery activities were all seen as

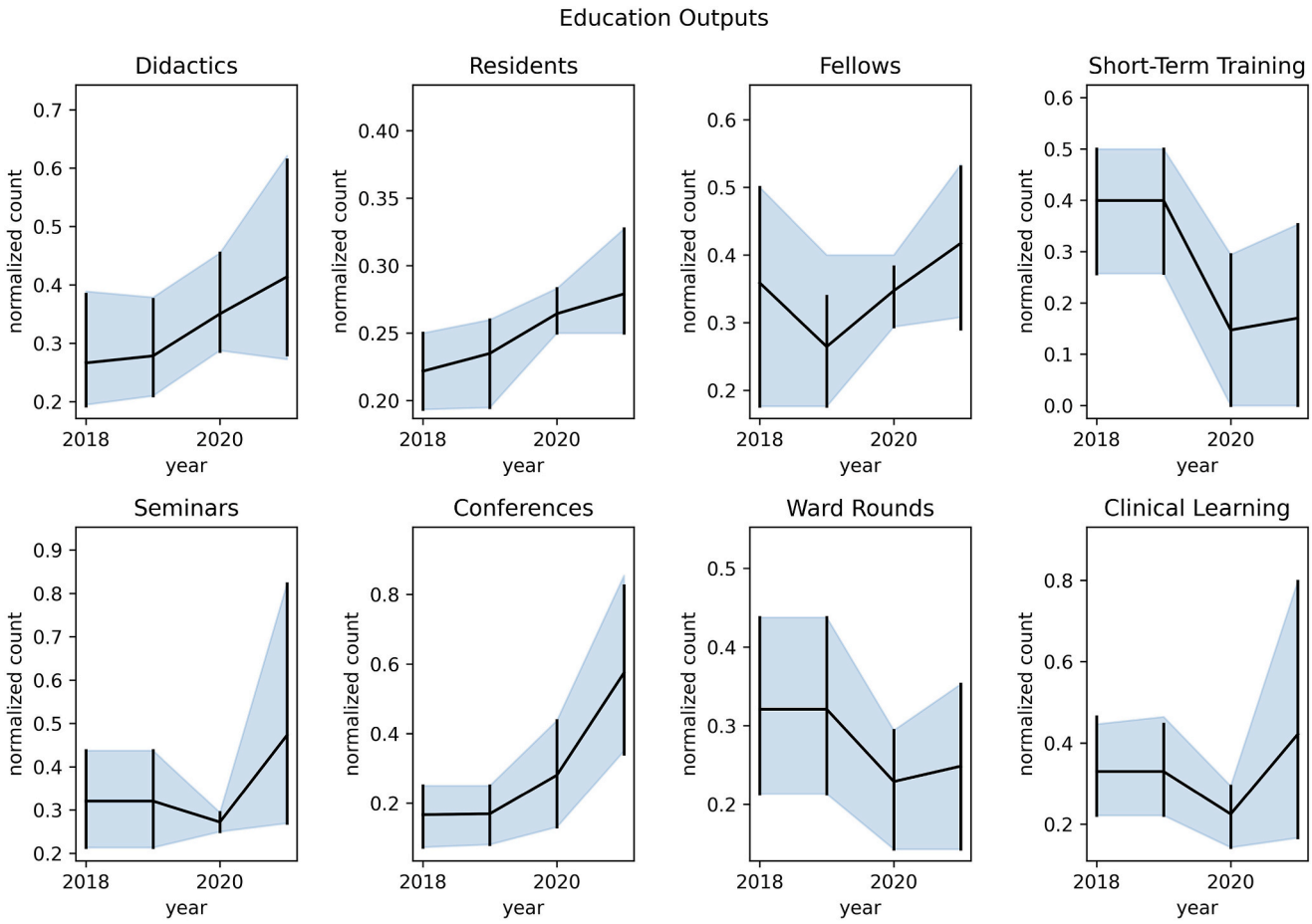


**Fig. 4.** Normalized counts of various educational outputs shown over time. Note that no significant differences were found among these data.

important for collaborations involved in service delivery. Alternative service activities that can be completed remotely may also increase the success of future efforts. The use of telehealth for neurosurgical care helped some neurosurgical practices return to their pre-pandemic capacity,[30] suggesting that virtual delivery of service activities could also be beneficial for GNCs.

In GNCs, workforce and education outputs increased even during the COVID-19 pandemic. The number of educational activities and participants involved in educational activities increased from 2018 to 2021, suggesting that many collaborations were able to sustain or expand their involvement in education. The switch to virtual platforms likely played a key role in the ability to continue education activities. Many live platforms, including Zoom, were used, but other strategies like training modules and videos were used as well. The increase in virtual platform use is consistent with the switch to virtual platforms for the provision of neurosurgical education during the pandemic more broadly.[19,20,23,26] This allowed residency training to continue despite decreases in clinical exposure for trainees and provided a new way for practicing neurosurgeons to continue their education. Our study found that many global neurosurgery collaborators preferred virtual platforms for education because they were cheaper, easier to use, and they improved participation. However, the COVID-19 pandemic highlighted the need for more adaptable education methods that can be successful amidst future challenges, as well as the need for increased collaboration and international partnerships.

GNCs involved in technology and infrastructure faced challenges in continuing their activities during the COVID-19 pandemic. They saw a decrease in the type of equipment transferred during the pandemic, and they experienced delays in technology reaching their intended destinations. From these challenges, collaborations learned the importance of utilizing virtual meetings for planning and seminars, evaluating changes in technology needs, and building capacity at the level of the local hospital.

While not universal, the DGNN's experience can provide some insight into how GNCs have responded to the challenges of the COVID-19 pandemic. Previously, DGNN had focused on improving neurosurgical capacity through technology transfer, twinning, and training, with activities involving research, service delivery, workforce and education, and technology and infrastructure. However, the restriction of international travel during the COVID-19 pandemic led to many challenges for collaboration. The pandemic necessitated a decrease in onsite research activities, causing online research activities to increase as a method of adaptation. In 2020 and 2021, surgical camps had to be postponed due to safety concerns and travel restrictions, and due to resource limitations, they have not yet been resumed. Without in-person education programs during surgical camps, the DGNN adapted by increasing virtual education programs. Additionally, equipment transfers and donations decreased during the pandemic. However, DGNN was still able to send a shipment of materials to Uganda which was used by our collaborating Ugandan neurosurgeons to conduct their own surgical camp in 2021. While the challenges caused by the COVID-19 pandemic threatened the success of DGNN's collaborative efforts, a number of adaptations allowed continuation and even improvement of the collaboration's activities.

### 4.1. Study limitations

While we can learn from the data collected and analyzed in this study, there are still several limitations that must be considered. First among those is the low number of survey responses compared to our

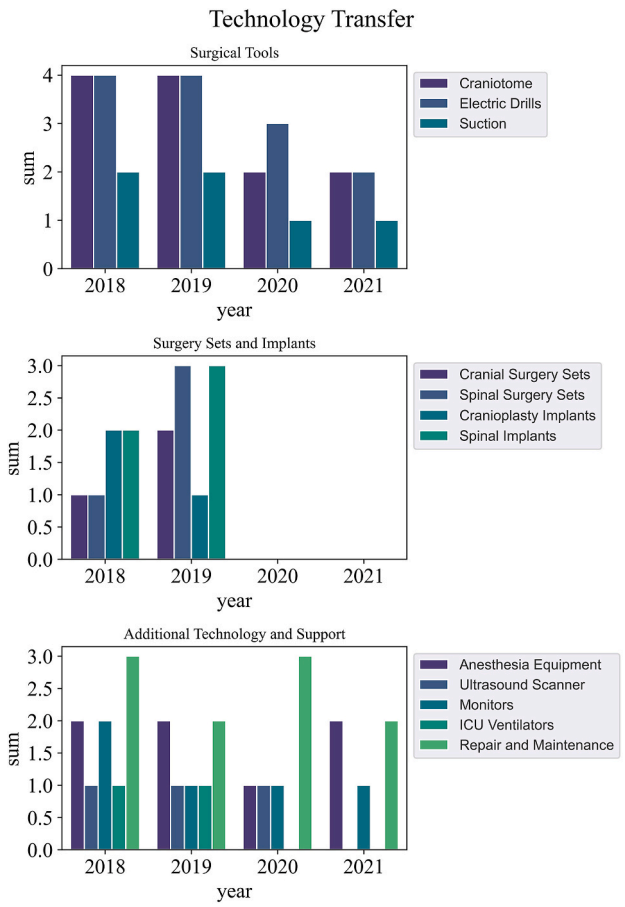


**Fig. 5.** Quantification of technology transfer performed by global neurosurgical collaborations from 2018 to 2021.

projected number of global neurosurgical collaborations. Only 36 survey responses from 23 global neurosurgical collaborations were recorded and analyzed. Yet it is clear from the literature and from our previous work that there are many more organizations involved in global neurosurgical collaborations.[31] This introduces a limitation with respect to our study power, something that can be seen in the non-significance of several trends and relationships in our statistical analysis. It also indicates potential bias in our study respondents, i.e., those with ready access to the internet and social and mainstream media had a higher probability of seeing and responding to our survey.

It is also clear that respondents sometimes interpreted and answered questions differently. In one case, several respondents answered with a yes/no rather than a number for the number of workshops and teaching rounds. These responses were treated as blanks and further reduced our number of complete responses and, therefore, our statistical power.

The survey was intentionally kept short to increase the number of responses. One aspect of this involved only collecting data for 2018–2021. While this did reduce survey length, it led to sparse data. It also reduced the data available to establish baseline outputs and values before the COVID-19 pandemic. To promote survey completion by all participants, responses were not required for every single question. However, this led to several sections with only one or two responses, potentially due to a lack of ready access to that information, or hesitation to share specific types of information. This was especially true for the finance/funding section, which was excluded from our analysis because of the low completion rate, as it potentially contained sensitive information for various collaborations.

## 5. Conclusions

GNCs faced many challenges during the COVID-19 pandemic, and many had to adapt to continue their work. Research collaborations were able to continue with adaptations including virtual meetings and conferences, along with a shift to collaborator-led studies. However, service delivery activities such as surgical camps stopped during the pandemic. For most collaborations involved in education and the workforce, there was overall growth in educational activities, with the use of virtual platforms playing a key role in the ability to adapt during the pandemic. Challenges with the provision of technology during the COVID-19 pandemic taught collaboration lessons on the importance of needs assessment and capacity building to ensure sustainable activities. In global neurosurgery, challenges faced during the COVID-19 pandemic led to reduced or altered activities in all focus areas. Adaptations by these collaborations led to new strategies for effective work as well as lessons learned that can be applied beyond the COVID-19 pandemic.

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## CRediT authorship contribution statement

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## Declaration of competing interest

The authors have no financial or other competing interests to disclose, and the work is not under consideration for publication by any other journal or in any other form.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wnsx.2023.100244.

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