CHAPTER 7

The impact of the COVID-19 pandemic on neurosurgery worldwide

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ABSTRACT

The novel coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory distress syndrome coronavirus 2 (SARS-CoV-2), first appeared in December 2019 and was declared a pandemic by the World Health Organization on March 11, 2020 [1]. By September 9, 2020, 27.7 million cases and 0.9 million deaths were confirmed globally [2]. This disease placed an unprecedented strain on healthcare systems around the world [3], and had a substantial effect on clinical practice across all surgical specialties, with neurosurgery being no exception [5]. Many hospitals implemented no-visitor policies and COVID-19 testing for all inpatients in order to prevent spread and protect patients and healthcare workers [4]. To conserve beds, workforce, and valuable resources such as masks, gowns, and ventilators, surgeons had to restrict operations to emergency and essential interventions. Some neurosurgeons were redeployed to new intradepartmental roles, others lateralized to provide care for coronavirus patients. To limit in person interactions and contagion, there was a surge in telehealth and digital innovation for remote monitoring and management. Research laboratories were closed for prolonged periods. Medical education and residency training were also substantially altered, with cancellation of many in person events and a transformation to online meetings and educational sessions. In this chapter, we discuss the impact of COVID-19 on the global neurosurgery community with respect to clinical care, education, and research. While the pandemic has caused tremendous disruption in global neurosurgery already, there is hope that many of the lessons learned during this time have contributed to our resilience and preparedness for the future, be it a second wave of COVID-19, or a new unexpected challenge.

COVID-19 IMPACT ON CLINICAL NEUROSURGERY

The advent of COVID-19 is dramatically changing how the world practices medicine. An abundance of patients requiring hospitalization for acute respiratory management has strained the healthcare system, forcing all specialties, including neurosurgery, to combat an unprecedented shift in patient prioritization, operative risk management, workforce redistribution, and financial challenges.

Prioritization

At the pandemic's onset, hospitals around the globe mobilized strategic plans to reduce non-COVID related care in order to preserve resources for those with infection, and to flatten the curve by decreasing contagion within the hospital. The surge of COVID-related acute respiratory distress syndrome and consequent need for mechanical ventilation made hospital ventilator capacity a critical resource. Given that operative interventions account for the majority of ventilator use within the hospital, there were concerted efforts to reduce surgical volume. Consequently, the neurosurgical community strived to establish important principles and guidelines for prioritization of neurosurgical operations [5, 6]. These discussions incorporated ethics, biology, health systems, and lessons learned from previous epidemics like SARS [7]. The foundational question to be answered was if surgery could be deferred without significant neurological deterioration or disease progression [5]. As elective operative time was restricted, hospital committees became responsible for transparent decision-making processes regarding operative urgency, accounting for factors such as disease pathology, patient symptomatology, and the possibility of an equally effective alternative treatment. Under normal circumstances, physician rationale for treatment approach typically follows Kantian or deontological ethical theory, which favors the best possible treatment for the individual patient, regardless of the ramifications to others. However, utilitarianism or consequentialist ethical theory, which centers on treatment of many as opposed to individuals, often dictates medical practice in global health crises like the current pandemic [5, 8].

During 2020, life threatening conditions deemed to be neurosurgical emergencies proceeded as usual across neurosurgical departments [9-11]. This included cerebral hemorrhages (epidural, subdural, subarachnoid, and intraparenchymal), acute hydrocephalus, spinal cord compression with neurological deficit, and cranial and spinal trauma emergencies. The timing of surgical management of other less urgent conditions varied. According to a recent US based survey of leaders of 40 large academic neurosurgical programs, 62% had cancelled all non-urgent cases, 80% of respondents still preferred operating within 1-2 weeks for newly diagnosed high grade gliomas, whereas for presumed low grade gliomas, half of respondents monitored patients with imaging and symptoms [12]. Groups from Italy (Lombardy) [8] and USA (New York and Detroit)[16] attempted to categorize common procedures and pathologies by urgency to facilitate clinical decisions. The Italian group classified oncological procedures in three categories: Class A++ comprised intracranial or spinal tumors that require emergency treatment (severe intracranial hypertension with declining level of consciousness, acute hydrocephalus, spinal cord compression with evolving quadri or paraparesis); Class A+ comprised tumors that need treatment within 1 week (intracranial tumors exerting mass effect with progressive neurological deficit, without declining level of consciousness); Class A comprised conditions needing treatment within a month (tumors with imaging suspicion of malignancy) [11]. An American group prioritized the relative urgency of 86 common neurosurgical scenarios from every subspecialty into six tiers and respective time frames, after a consensus that was achieved among 22 neurosurgeons (14 from the New York and 8 from the Detroit metropolitan areas) using the Delphi method [13]. As more time passed, the European Association of Neurosurgical Societies put forth a unified guideline for triaging, which offered a three-tiered triaging approach, but importantly noted that different countries and regions would be facing conditions that may differ greatly from one another and from day to day. Thus, they advocated for assessments using contemporary knowledge of the evolving local, regional and national conditions, which could result in significant differences in decision-making between regions [14].

As intended, hospital prioritization of COVID management and emergency cases translated to dramatic decreases in neurosurgical case volume. For instance, at the Toronto Western Hospital, neurosurgical cases decreased from 230 in January 2020 to 146 in March and 57 in April 2020; a reduction of 36% and 75% respectively. The subspecialties most affected were Functional and Spine with 80% and 73% reduction respectively, while Oncology and Vascular experienced fewer cancellations; 50% and 40% respectively. Triage schema for University of Toronto are presented in **Figure 1** [16]. Analogous case reduction was described in other large North American and European institutes [6-8]. While non-urgent case cancellation produced an intentional decrease in case volume, there were significant reductions in the number of patients seeking neurosurgical care in the emergency department, noted by University of Toronto as well as Mass General Hospital [11,12]. Furthermore, there have been significant global increases in delayed neurosurgical admissions during lockdowns and quarantine periods, as noted in Morocco [15]. Comparable declines occurred in in-person clinic visits across most neurosurgery departments [7,10]. This is suspected to result from fear of seeking care given risk of inoculation onsite at the hospital. In contrast, telephone consultations and video clinic visits gradually increased in number to cover patient care needs, discussed further below [7]. Overall, prioritization during the pandemic forced neurosurgeons to delay non-urgent and some urgent cases with hopes that it would help optimize care delivery for COVID patients and reduce the risk of contagion in the hospital. After the first wave of the virus passed, it has left a back-log of cases to address, but a newfound appreciation for the possibility and ease of telehealth, which will likely remain a core component of care going forward.

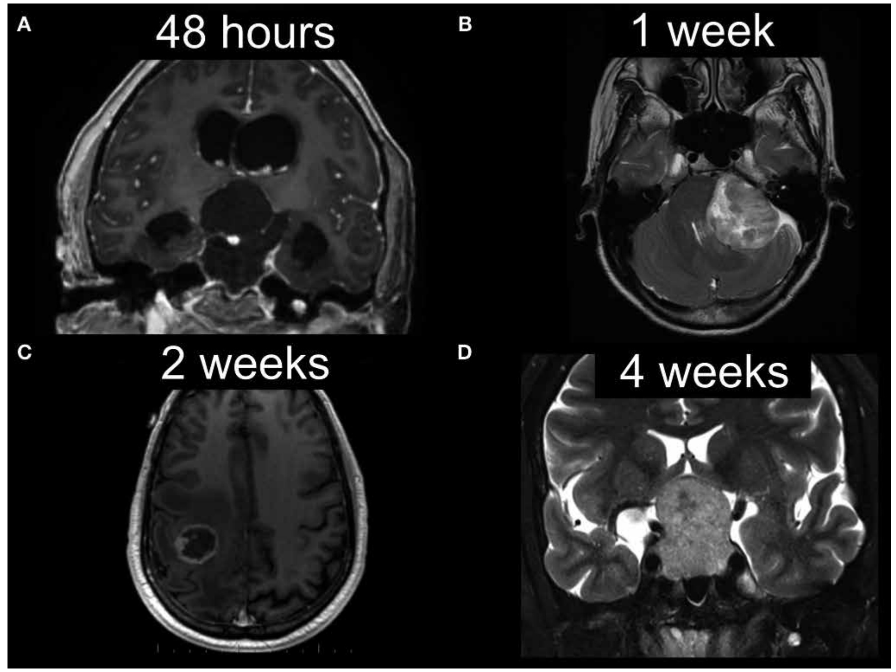

Figure 1: Covid-19 Neurosurgery Case Triage schema at the University of Toronto. Here, classified according to the prioritization scheme published by Thomas et al [13]. (A) Tier 2, Intra-axial tumor with neurological decline; treatment within 48 hours. (B) Tier 3, Cerebellopontine angle tumor with hydro and/or brainstem compression; treatment within 1 week. (C) Tier 4, Intra-axial tumor without shift; treatment within 2 weeks. (D) Tier 5, Transsphenoidal approach for skull base lesion with optic compression; treatment within 4 weeks.

Pre-operative measures and transformation of the OR

In addition to intentional decreasing of surgeries, the workflow and perioperative systems also had to transform to apply measures aiming to mitigate the perioperative spread of COVID-19 [16]. Once testing was more readily available, institutional policies began dictating that all patients undergoing surgery had to be tested for COVID-19 preoperatively. However, other institutions suggested that preoperative COVID-19 testing of asymptomatic patients should be examined according to the local epidemiology and availability of testing resources [17]. This was particularly important for low-income countries, however, given that at the time this chapter was written 17.9% of infected individuals were believed to be asymptomatic carriers [18], testing everyone if feasible could potentially decrease the spread.

The use of full personal protective equipment (PPE), such as N95 masks, gowns and gloves, by every health worker involved in neurosurgical operations was deemed mandatory at many institutions, due to the aerosol-generating potential of most neurosurgical operations (e.g. drilling; access to paranasal sinuses). Other groups have suggested that for low-risk patients (tested negative and asymptomatic with no recent travel history or contact with COVID positive patient), surgical masks and droplet precautions should suffice [16]. Having a risk-stratified PPE approach could safeguarding PPE reserve in the context of worldwide shortages and particularly for low-income countries. In some institutions or health systems there were "clean" and "contaminated" patient pathways. In Toronto, specific operating rooms were reserved for confirmed or suspicious COVID-19 patients, ideally with negative pressure ventilation. Additionally, different nursing teams were assigned outside the room for circulating and providing equipment as needed. They believed the number of OR personnel and movement of personnel in and out of the OR should be kept at minimum. Paper charts were kept outside the OR and monitors/machines were covered in plastic wrap. A rigorous decontamination after COVID-19 cases was also essential [16]. At Massachusetts General Hospital, all procedural consents became verbal as opposed to written to avoid cross contamination with pen and paper handling. In Switzerland, Morocco, and other nations, certain buildings were designated as "green zones" to allow for COVID-negative patient and provider care to resume [15]. For each of these approaches, rigorous traffic control and attention to infection status was required.

Intra-operative considerations in Neurosurgery

Modifications of operative practice also took place in order to moderate the effect of high-risk settings encountered in the neurosurgical OR. Local anesthesia or conscious sedation was increasingly preferred to general anesthesia, when feasible, in order to avoid endotracheal intubation and extubation to limit aerosolization. Awake fiberoptic intubation was avoided when possible. All non-essential staff were often asked to exit the room during intubation and extubation [19]. At some institutions, ORs were also closed to entry for 30 minutes after intubation and extubation to allow for aerosolized particles to clear.

Operations implicating the respiratory tract, due to the high viral load [20], carry significant risk of transmission. In neurosurgery, such procedures include endoscopic endonasal, transoral, and translabyrinthine approaches, as well as any craniotomy transgressing the frontal sinuses. Equally effective and safe alternative approaches (e.g. pterional instead of endoscopic endonasal; retrosigmoid instead of translabyrinthine) could be favored or the surgery could be deferred to a later time, when feasible.

A hypothetical and controversial risk in neurosurgery is the airborne transmission of COVID-19 following the use of aerosol-generating instruments such as, drills, monopolar cautery, lasers, and ultrasonic aspirators [17]. However, the infectious potential of aerosolized particles is based on the hypothesis that they include virions. Although, this is proven for the respiratory and digestive tracts [20], this is no longer believed to be the case for cerebrospinal fluid, central nervous system (CNS) tissue, or bone. As such, the recommendation to avoid or restrict the utilization of the aforementioned instruments was deemed unnecessary by many [17].

Redeployment

As the influx of COVID-19 patients rose at each institution, hospital personnel had to adapt to a new reality, and trainees and staff from both medical and surgical specialties worldwide had to be redeployed [9]. The reassignment of staff is a common, often temporary, response to expand coverage in a crisis. With COVID-19, not only was there potential for discomfort from working in a foreign role, but also susceptibility to and fear of infection. In such challenging times, strategic health systems approaches can facilitate timely access to safe and affordable care and provide reassurance that there is an element of control.

Task shifting and task sharing are workforce strategies that involve duty redistribution [21]. Task shifting is transference of clinical autonomy from highly qualified healthcare workers to those with shorter training and fewer qualifications. In contrast, task sharing uses tiered staffing models with collaborative teams of specialists and less qualified groups who share clinical responsibility and rely on iterative communication and training to preserve high quality outcome. Ideally, hospitals requiring redeployment of workers would use a task sharing approach that invokes a three-phase model of training, practice and maintenance (**Figure 2)** [22, 23]. A principle step in task reassignment is strategic identification of providers and redistributing in a manner that minimizes "things to be learned" in order to satisfy the "job to be done." Once assigned, individuals should have a dedicated preparation period and ideally a competency-based evaluation of readiness. Subsequently, the practice phase should involve team-based care with tiered oversight to ensure individuals know who and when to ask for guidance when appropriate. Many neurosurgery residents were redeployed to work in COVID intensive care units, and responsibilities ranged from assisting medical teams as a responding clinician, to facilitating procedures such as central lines and prone positioning. Others filled shifts in testing clinics, and some were redeployed to work on medicine triage floors or in the emergency ward. In institutions with a lower demand for workforce distribution, plans for redeployment were developed, but were not required. Still, many residents took on new roles within their teams. Many hospitals developed systems in which neurosurgical non-COVID-19 patients in the wards and intensive care unit (ICU) were managed with two available teams - one working in hospital and one working from home. Where redeployment plans were not enacted, hospitals have been encouraged to adequately train personnel in case of a second surge of COVID-19.

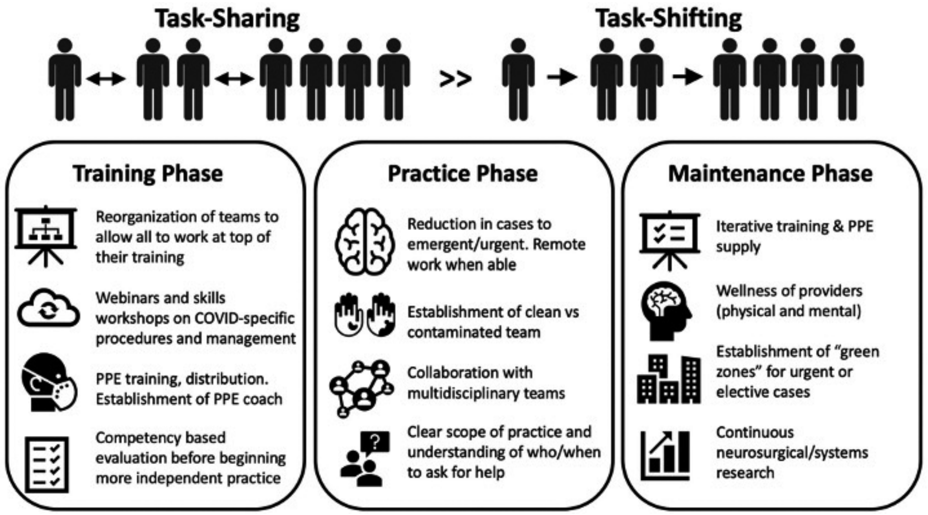

Figure 2: A strategic plan for task sharing during the COVID-19 pandemic. Previously published by Robertson et al, Journal of Neurosurgery [22].

The rise in Telehealth for outpatient assessment and postoperative follow up

While digital or telehealth services existed prior to the pandemic, uptake and integration into regular clinical practice had been slow, predominantly due to learning curves, lower demand, and barriers in financial reimbursement [24]. However, the need to deliver care while reducing the use of PPE and risk of viral transmission with personal contact served as a catalyst for the exponential increase in telehealth. Benefits for the patients include less cost and time of commuting, and no need for missing work, while it can help neurosurgeons optimize their schedules [25]. A recent systematic review of 52 neurosurgical studies (25 prospective and 27 retrospective; 13 US, 39 other countries) with 45,801 patients demonstrated that 99.6% of visits were completed successfully [26]. Of the 0.4% of visits that required subsequent appointments, 81.5% were due to technology failure, and 18.5% required further face-to-face evaluation or treatment. Regarding reimbursement, 94.3% of telemedicine visits were billed using face-to-face procedural codes. Overall, both patients and providers have seemed to enjoy this transition. In a study of 596 neurosurgical patients who had telehealth visits at Michigan State University, patients reported high satisfaction with the experience, providing an average rating of 6.32 ± 1.27 out of 7 [27]. Furthermore, telehealth visits have the potential to be financially advantageous for patients. A study from Mayo Clinic on video telemedicine rather than face-to-face clinic visits for postoperative follow-up showed that patients saved an average of $888 per visit [28]. In-hospital telehealth options are also being explored. In Kuala Lumpur, Malaysia, virtual and physical ward rounds on neurocritical patients were conducted using smart glasses for an individual to

broadcast rounds to the team for 103 neurocritical care patients with high overall inter-rater reliability [29].

More importantly, the potential of digital health for system improvement greatly exceeds video phone calls, and COVID-19 emphasizes the need to invest in this arena. Wearables and digital phenotyping can facilitate both active and passive data collection for remote screening and monitoring of early symptoms to indicate when a patient may need to seek higher levels of care. This technology has already been tested in neurosurgical populations, such as monitoring for physical activity rates and pain control with post-operative spine patients [30]. As such technology becomes more prevalent in home monitoring for COVID symptoms, we as a neurosurgical community should continue exploring remote management of our patients as well, and advocate for appropriate reimbursement for these efforts that account for the value added to patient care.

Future directions – Lessons learned

At the present time, healthcare protocols and national quarantine regulations have enabled countries around the globe to flatten the curve and begin resuming clinical neurosurgery activity. The next steps of health policy will focus on dealing with the backlog of the cancelled neurosurgical cases while maintaining a level of responsiveness in case of a new COVID-19 surge. The strategy should first accomplish the return to "normal" neurosurgical practice with the overarching goal of reaching full capacity. Some possible solutions would be to extend everyday operative hours and running elective ORs during weekends. Resources should be appropriately allocated - additional OR and ICU nurses should be employed, and additional ICU beds should be created. These measures put a financial strain on health systems, especially in low-income countries, however they can help boost surgical capacity as well as create a well-prepared system for a future COVID-19 outbreak. Additionally, widespread application of telemedicine is essential to reduce viral exposure. The achieved improvements in digital health infrastructure and platforms can facilitate more timely and cost-effective outpatient care that enhances value, particularly for the patient. Even if we return to a COVID-free planet, these modes of practice will likely persist.

COVID-19 IMPACT ON NEUROSURGERY EDUCATION AND TRAINING

Similar to other medical and surgical specialties, the consequences of the COVID-19 pandemic on neurosurgery education and training cannot be understated. The experiences of the neurosurgery residents, registrars, and fellows during the acute phase of the pandemic have spurred multiple opinion pieces, letters to the editor, and survey studies conducted around the world [31-35]. Although the structure of the neurosurgery training programs varies significantly among different countries and regions, almost all neurosurgery departments have uniformly reported loss of training opportunities for young neurosurgeons. In a short span of time, adjustments had to be made in order to sustain neurosurgery education while ensuring trainee safety under challenging circumstances.

Loss of training opportunities

The foremost concern was the significant decrease in the operative experiences of neurosurgery trainees. This was primarily due to the cancellation or postponement of elective procedures in most, if not all, neurosurgical centers, as described above. Several other factors contributed to the steep decline in surgeon logs. For instance, in Singapore and the UK, a senior surgeon was assigned to perform procedures that would have ordinarily been given to a junior trainee [36, 37]. Doing so reduced the number of people inside the operating room to limit virus exposure risk, but also minimized operating time and presumably lowered the risk of perioperative complications during a period when hospital resources such as ICU beds and mechanical ventilators were being conserved for COVID-19 services. Thus, it was more challenging for trainees to gain autonomy and practice skills that were at or above their level.

There had also been a reported decline in neurosurgery consults. In the case of neurotrauma, this had been attributed to restricted mobility from mandated lockdowns and quarantines. In developing countries, limited transportation had hampered the ability of patients to reach medical care. Patients had also delayed seeking medical opinion, even for urgent neurosurgical conditions such as aneurysmal subarachnoid hemorrhage. The closure of outpatient clinics and reduction of staff during ward rounds and other patient care activities also meant that opportunities to sharpen clinical skills essential for decision-making had likewise been markedly reduced.

More often than not, trainees had to be withdrawn from their elective and research rotations. Neurosurgery trainees have also been redeployed to areas of need during the peak of the pandemic in their respective countries. Among 192 neurosurgery trainees in Italy, 30% were directly involved in the clinical management of COVID-19 patients [31]. Between 17–54% of trainees in Indonesia, Malaysia, Philippines, Singapore, and Thailand reported working in COVID wards or ICUs, and acute respiratory infection clinics [33].

Because of lack of hands-on experience during this period, a significant proportion of trainees around the world were worried that the pandemic would have a negative impact on their training overall: about one-third of trainees surveyed in North America [34], and as high as 74% of those in Southeast Asia [33]. In a highly technical specialty such as neurosurgery, it is essential that this concern is addressed, and measures are taken to ensure that training programs continue to produce highly skilled and competent neurosurgeons.

Adaptations under fire

In centers where trainees are unable to meet requirements in cases numbers set by their respective neurosurgery boards or councils, the length of the training may have to be extended to compensate for the surgical volume loss. Other strategies included increasing the exposure of the trainees to private cases performed by consultants, and increasing the surgical capacity of designated non-COVID hospitals, and subsequently diverting elective neurosurgical procedures to these centers.

To maintain and develop surgical skills among trainees, neurosurgery departments have developed pandemic curricula, usually consisting of online didactics with practical, hands-on exercises on microsurgery and micronanastomosis using table-top microscopes, or when available, in dedicated simulation laboratories. Plans to develop realistic surgical simulators accelerated (e.g., https://upsurgeon.com), including the utilization of virtual and augmented reality [38][39].Face-to-face departmental teaching activities such as grand rounds, morbidity and mortality conferences, and subspecialty meetings were easily transitioned to the online environment using various meeting software and applications. In fact, many groups have reported an improvement in attendance during these interdisciplinary discussions, likely because of the decrease in clinical workload and ease of joining these activities, even at home. Trainees had to rapidly acquire communication and evaluation skills required for telemedicine, traditionally not taught in most training programs. Although less than ideal for getting a comprehensive clinical evaluation of patients, this replaced the learning experience from outpatient consults and follow ups, for both trainees and medical students aspiring to get into neurosurgery.

While the pandemic introduced an abrupt barrier and negative effect on the ability to train neurosurgeons, especially in LMICs, the increased use of social media and virtual platforms is markedly improving the interactions between institutions for shared learning between neurosurgeons at an international scale. Neurosurgical societies and organizations worldwide regularly conducted online webinars on myriad topics, often focusing on clinical evaluation of neurosurgical diseases and pearls and pitfalls of neurosurgical approaches. Although the advantages of these online learning experiences are many, these must be weighed against "Zoom fatigue," wherein long hours spent in front of a screen may lead to decreased attention span and ultimately, loss of interest in these educational activities.

Other concerns of trainees

Lack of adequate personal protective equipment was a concern for many trainees, especially in areas hardest hit by the pandemic early on [31, 33]. This was crucial, not just for trainees redeployed to COVID-19 units of their hospitals, but also for those who had to perform emergency neurosurgical procedures on confirmed COVID-19 patients. Testing was likewise an issue, especially at the start when RT-PCR was not readily available in most centers and the turnaround time for tests took several days. Because of these issues, many trainees were understandably worried about their personal safety, and that of their families. In a global survey of neurosurgery trainees, 90% said that the pandemic had affected their mental health [32].

A delay in career advancement is looming for many neurosurgical trainees around the world. In the US, the Accreditation Council for Graduate Medical Education (ACGME) published multiple policies to address questions regarding how the pandemic impacted training. Ultimately, the determination of whether or not a resident or fellow can graduate as previously scheduled is the responsibility of the program director with case review by the Clinical Competency Committee [40]. The American Board of Neurological Surgery has postponed both primary and oral examinations. Similarly, in the Philippines, the Philippine Board of Neurological Surgery has decided not to allow final-year residents to sit their exams. Because of travel, work, and visa restrictions, many trainees—especially in low- and middle-income countries—are concerned about international fellowship positions or observership slots that they have previously applied for, or have already secured.

COVID-19'S IMPACT ON NEUROSURGERY RESEARCH

The COVID-19 pandemic has differentially impacted scientists and researchers around the world [41]. When cases began to rise in different countries, it became necessary for academic and research institutions to reduce activity in their physical laboratories to a minimum. By conducting only essential experiments and operations, the risk of COVID-19 transmission among laboratory personnel was mitigated and the need for PPE in these less critical areas similarly reduced. As a direct consequence of the pandemic, health researchers anticipated a decline in patient recruitment for ongoing trials, difficulty in procuring needed equipment and supplies, and subsequent delays in project completion and publication [42]. Studies that had the potential to have an impact on the prevention, diagnosis, and treatment of COVID-19 were prioritized. Others were postponed indefinitely, potentially delaying scientific productivity [38, 43]. Ultimately, those rooted in basic sciences (*e.g.*, biochemistry, biology, chemistry, and chemical engineering) had a greater reduction in research time compared with their colleagues whose work were less dependent on physical laboratories and experiments (*e.g.*, mathematics, statistics, computer science, and economics). In contrast, the reduction in clinical volume provided additional time for research that was able to be conducted remotely, such as outcomes, computational, and health science research. Furthermore, it has sparked an unprecedented rate of transnational collaboration on research. The short and long term implications of this are discussed herein.

In a global survey conducted in March 2020, out of 187 neurosurgeons, 27% reported cessation of research [44]. Women and those with young children were disproportionately affected—likely because of increased responsibilities at home—and the decline in publications authored by women has been documented [45]. Declines in research were more pronounced in low-income countries and those

that had a greater COVID-19 caseload; 36% of respondents said that their research activities had decreased. In India, the researches of academic neurosurgeons were more affected than that of neurosurgeons with non-teaching positions [46]. For many neurosurgical trainees, time away from clinical responsibilities translated to more time for research; they used this period to finish pending manuscripts or revise previously rejected submissions. Out of 192 trainees in Italy, 56% said that their production of scientific manuscripts had increased [31]. In North America, 65% of residents devoted more time to clinical research [34]. These figures are in contrast to Southeast Asia, where 33–60% of residents in Indonesia, Malaysia, Philippines, and Singapore had a decrease in their research activities [33]. Neurosurgery residents in Thailand were least affected, with 54% saying that their research work proceeded on schedule. Furthermore, 20–47% of trainees in the region reported that they would miss a research presentation at a neurosurgical conference due to travel restrictions and cancellation of international meetings. Consequently, during the spring of 2020, academic journals faced a massive surge in COVID-related manuscripts submitted to and published in scientific journals across major disciplines [47, 48]. For instance, from February to June 2020, the *Journal of Neurosurgery* recorded a 55% increase in manuscript submissions compared with the same time period in 2019 [49]. For *Journal of Neurosurgery: Spine* and *Journal of Neurosurgery: Pediatrics*, the increases were 77% and 78%, respectively.

Neurosurgical departments implemented several adaptations to maintain their research activities. Whenever possible, researchers were advised to work on the parts of their projects that could be accomplished at home, such as writing grant applications, literature review, remote data extraction, and data analysis [50]. Academic work that did not require patient contact were encouraged. These included conducting systematic reviews and meta-analyses, writing book chapters, and developing simulation models. Journal clubs were converted to virtual meetings [51]. Often, residents on their research rotation served as backup for those who rendered inpatient care and performed essential neurosurgical operations [52]. When faculty had concomitant research and clinical roles, they were only allowed to perform their research duties if they had no symptoms [53].

Other recommendations included streamlining related projects, dividing researchers into cohorts, limiting people working in the same room, and frequently decontaminating shared resources such as microscopes [50]. Over time, as scientists became more aware of the mechanics of viral transmission, it became necessary to renovate physical facilities to ensure adequate ventilation and social distance between personnel, a complete turnaround from the coworking spaces that were encouraged prior to the pandemic.

To accelerate the gathering of data and generation of recommendations in COVID-related studies, many institutions revised their protocols to expedite research processes, particularly those concerning ethics review by institutional research boards. Collaborative work among departments, organizations, and institutions were encouraged, facilitated by online networks. This was best exemplified by the COVIDSurg study [54, 55]. By rapidly recruiting international collaborators, the investigators were able to analyze the 30-day mortality and pulmonary complication rates of over 1100 patients with COVID-19 from 24 countries, concluding that the threshold for surgery in this group of patients must be raised, especially among the elderly.

To cope with the surge in manuscript submissions, major journals have had to make adaptations in their editorial and peer-review processes [48, 49]. In journals with limited human and technical resources, authors have had to contend with longer turnaround times. While there was a great need to disseminate evidence rapidly, there remained a strong responsibility to critically examine submissions for methodological flaws or scientific misconduct, especially those that had a potential impact on treatment algorithms and public health policies. In JAMA, readers were allowed to leave online comments on COVID-related content to obtain immediate feedback instead of relying on traditional letters to the editor [48]. Social media networks such as Twitter were also instrumental in swift dissemination of study findings and getting real-time peer review from the greater scientific community. More significantly, the majority of scientific journals published their COVID-related articles open access. Among the neurosurgery journals, the *Journal of Neurosurgery* released a special issue that tackled COVID-19 and its impact on all aspects of neurosurgery, while *Neurosurgery*, *World Neurosurgery*, *Acta Neurochurgica* and *British Journal of Neurosurgery* have all expedited the publication of experiences of neurosurgeons, trainees, and neurosurgical departments from around the world, as they grappled and coped with the COVID-19 situation in their respective countries. These articles highlighted strengths and best practices to continue providing essential neurosurgical care in both high-income and developing countries. *Neurosurgical Focus* put out a call for papers on preparedness and guidelines for neurosurgical practice during a pandemic, and the special issue is expected to be published in December 2020.

CONCLUSION

The COVID-19 pandemic rapidly swept the globe in 2020 and placed an unprecedented strain on healthcare systems around the world. At the time this chapter is being written, the full impact of the pandemic on global neurosurgery research remains unknown. However, we do know that it has both caused negative and positive change. COVID adaptations decreased case volume and interrupted training in the short term, but also guided neurosurgeons to reflect on protocols for case prioritization, workforce redistribution, pre and intra-operative safety, telemedicine and more. Regarding research, it interrupted many in-person basic science experiments, but also introduced new mays of carrying out global partnerships for big data collection, such as COVIDSurg. Journals have seen surges

in manuscript submissions during this time, and reformatted their processes to allow for more rapid publication. Education has transformed into more broad access of shared information with online webinars and live operation teaching sessions. Overall, the timespan of the virus as an acute threat for humanity is unclear, but we as a neurosurgical community should continue analyzing the positive changes which have manifested in 2020 as we prepare together for a second wave, another pandemic, or simply negotiating our "new normal."

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