Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

The Utility of Remote Video Technology in Continuing Neurosurgical Care in the COVID-19 Era: Reflections from the Past Year

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■ OBJECTIVE: **In 2020, the coronavirus disease 2019 (COVID-19) pandemic exposed existing stressors in the neurosurgical care infrastructure in the United States. We aimed to detail innovative technologic solutions inspired by the pandemic-related restrictions that augmented neurosurgical education and care delivery.**

■ METHODS: **Several digital health and audiovisual innovations were implemented, including use of remote video technology to facilitate inpatient consultations and outpatient ambulatory virtual visits, optimize regional hospital neurosurgical coverage, expand interdisciplinary patient management conferences (i.e., tumor board), and further enhance the neurosurgical resident education program. Enterprise patient experience data were queried to evaluate patient satisfaction following the switch to virtual visits.**

■ RESULTS: **Between January 2020 and April 2021, use of virtual visits more than doubled in the Department of Neurosurgery. A survey of 10,772 patients following ambulatory visits showed that virtual visits were equal if not better in providing satisfactory patient care than in-person visits. After switching our interdisciplinary spine tumor board to a virtual meeting, we increased surgeon participation and attendance by 49.29%. Integration of remote audiovisual technology in resident didactics and clinical training improved our ability to provide comprehensive and personalized educational experiences our trainees.**

■ CONCLUSIONS: **Digital health technology has improved neurosurgical care and comprehensive training at our institution. Investment in the technologic infrastructure required for these remote audiovisual services during the COVID-19 pandemic will facilitate the expansion of neurosurgical care provision for patients across the United States in the future. Governing bodies within organized neurosurgery should advocate for the continued financial and licensing support of these service on a national fiscal and policy level.**

INTRODUCTION

Sometimes it takes a crisis to inspire innovation. The availability of televideo technology has experienced a worldwide boom in the last decade. While remote conferencing and meeting technologies existed before broad coronavirus disease 2019 (COVID-19) lockdown restrictions, wide-scale adoption was not seen until social distancing mandates forced a number of industries to adapt.[1] The benefits of using televideo technology have been realized across sectors, including improved collaborative ability, decreased infrastructural cost, and optimized workplace efficiency. All of these benefits will have lasting impact beyond pandemic-era precautions.

In the field of neurosurgery, the need for services is ever increasing in the United States; however, many centers have insufficient neurosurgical coverage.[2,3] Further, call coverage is a major contributor to burnout, stress, and diminished job satisfaction, even while neurosurgeons recognize the importance of providing the service. In academic programs, neurosurgery residents work long hours and may have trouble meeting the 80-hour work week regulations. In addition, individualized resident education, including didactics, supervised rounds, patient

Key words
- Care access
- COVID-19
- Digital health
- Pandemic
- Practice policy

Abbreviations and Acronyms
AANS: American Association of Neurological Surgeons
APP: Advanced practice provider
CNS: Congress of Neurological Surgeons
CG-CAHPS: Consumer Assessment of Healthcare Providers and Systems Clinician & Group Survey
COVID-19: Coronavirus disease 2019
EHR: Electronic health record

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visits, and direct mentorship, is limited by time constraints inherent to a busy inpatient clinical service. The COVID-19 pandemic has created further imbalance in this supply-and-demand relationship, as caregiver accessibility is limited and neurosurgical care demand continues to grow.

Pioneering efforts using mobile video platforms for inpatient telestroke services and telemedicine intensive care unit evaluation resulted in a tremendous expansion of neurology services in the United States in the last decade.[4-7] Development of mobile, high-resolution, video-conferencing devices has increased the utility and prevalence of these digital health systems and their usage by U.S. providers.[8,9]

In contrast, in neurosurgery, the practices of evaluating patients with nonstroke conditions as well as training residents in remote management have changed in only incremental ways over the last decade. Neurosurgeons have been reluctant to embrace use of digital health technology; however, the COVID-19 pandemic has inspired the rapid implementation of digital health infrastructure in many arenas. This was greatly facilitated by suspension of Health Insurance Portability and Accountability Act regulations, which allowed smartphone applications such as FaceTime (Apple Inc., Cupertino, California, USA) and Google Duo (Alphabet Inc., Mountain View, California, USA) to be used for this purpose and the emergency expansion of interstate licensing granted by all 50 state medical boards.[10,11] Critically important was the emergency institution of reimbursement for this care by the Centers for Medicare and Medicaid Services, with most other insurers following suit. In this article, we detail several innovative digital health programs recently introduced in the Department of Neurosurgery at the Cleveland Clinic Foundation. Programs include virtual inpatient consultations and rounding, outpatient ambulatory visits, interdisciplinary conferences, electronic image portability, and resident training and education. The description of each program details the challenges that needed to be addressed, obstacles that were overcome through early iterations, the current structure, and the benefits achieved.

MATERIALS AND METHODS

We compiled descriptive and quantitative data (when available) on a number of novel applications of digital neurosurgical endeavors adopted by our department during 2020. This included the use of remote video technology to facilitate inpatient consultations and outpatient ambulatory virtual visits, optimize our regional hospital neurosurgical coverage, expand our interdisciplinary patient management conferences (i.e., tumor board), and further enhance our neurosurgical resident education program. Using available enterprise-coordinated Consumer Assessment of Healthcare Providers and Systems Clinician & Group Survey (CG-CAHPS) patient satisfaction surveys, sent to patient 6 weeks following outpatient visits, we collected patient-reported scores assessing the experience of the virtual or in-person visit between April 2020 and March 2021 in the Department of Neurosurgery to further assess satisfaction following ambulatory visits. The χ^2 test was used to assess for significant differences in responses between visit types using a significance level of 0.05 for all tests.

RESULTS

Virtual Consultations and Inpatient Rounds

One of the first challenges of the COVID-19 pandemic was providing urgent and emergent neurosurgery consultation while limiting the exposure of neurosurgical personnel to possibly infected patients. In an attempt to quickly operationalize virtual patient evaluations and limit exposure to infected patients, initial steps involved the use of an already existing mobile televideo system utilized for management of patients in our neurological intensive care unit. The InTouch Health Vici system (Teladoc Health Inc., Purchase, New York, USA) was used for neurosurgical consultations throughout the hospital (Figure 1). The InTouch Health unit provides high-resolution audio and visual recording for patient evaluation and is equipped with a mounted screen to allow the provider to be visible to the patient. The communication platform can be accessed by either a web-based platform for computer users or a mobile application such as a smartphone or tablet, all of which require institutional subscription for provider access. The most sophisticated versions, not typically required for most consultations, have full three dimensional robotic capability with full electronic medical record integration. For inpatient rounding on established patients, if the robot was not available,

Figure 1. Inpatient technology. The InTouch Health mobile televideo unit could be mobilized from a central docking station to patient rooms around the hospital for remote patient examinations or video team rounds.

use of a cell phone application such as FaceTime or Google Duo sufficed to complete the daily examination and patient counseling.

For patients with a positive COVID-19 test, active symptoms, or other concern for underlying COVID-19 infection, the InTouch Health system was taken to the inpatient floor of interest. For consultations, the unit was then taken into the room by the assigned nurse or primary provider (i.e., intensivist), and the history and physical examination were then performed remotely by a neurosurgeon. During rounds, team exposure and crowding during rounding could be controlled by having the senior staff or other medically vulnerable care givers participate remotely using the robot or phone, with the resident or advanced practice provider (APP) in the room for the critical portions of the visit, including the examination and discussing the plan with the patient.

The video consultation and rounding system lent itself well to thorough interviewing and history gathering, and with facilitation of a licensed nurse or other medical provider, a complete neurological examination was easily obtained. This included cranial nerve examination, strength grading of the myotomes, sensation in the dermatomes, reflexes, and more specialized neurological examination techniques. No personal protective equipment needed to be used by the house officer or staff remotely observing the evaluation in these cases, thereby protecting what was initially an extremely limited resource in the early days of the pandemic, and there was no required exposure of extraneous personnel within aerosolizing distance. Finally, the remote audiovisual technology is supplemented by simultaneous remote access to the electronic health record (EHR), which includes patient images and laboratory test results, allowing for real-time assessment of clinical, laboratory, and radiographic data, further expediting decision making and care.

Use of the system was limited mainly by time constraints and ease of use. Acquisition of the docked video system with removal from the docking station in the intensive care unit, relocation of the system to the appropriate floor, positioning of the system (sometimes in a crowded patient care environment or elevator), and log-in time to the application with synchronization to the machine could add up to 20 minutes of setup time before neurosurgical evaluation. In the setting of need for emergent neurosurgical care, or even in the context of an already long and overburdened day, this amount of time investment for setup could be impractical. Another ongoing challenge was that the robot system has not been optimized to include any surrogate participation, which was particularly problematic during the height of the pandemic when family visitation was extremely limited. As neurosurgeons, delivering bad news is a frequent part of our work, made even harder if the patient is isolated. As remote technology expands in health care, wider availability of access to machines and applications by both providers and patients will likely minimize both the logistical time burden of and surrogate access to the inpatient virtual encounter.

Regional Hospital Neurosurgery Emergency Coverage

At our affiliated regional hospitals, teleneurosurgery was rapidly deployed primarily to cover the multitude of inpatient and emergency consultations with limited neurosurgical staff. Before the COVID-19 pandemic, owing to the rising demand of regional neurosurgical care, our affiliated staff found themselves spread thin as they provided enterprise-wide call responsibilities for two Level 2 trauma centers as well as for all neurosurgical services at 3 different regional hospitals. With limited staff at each hospital, frequent call burden for each hospital's separate staff created a perfect environment for dissatisfaction and burnout. As the hospital scaled back elective services at the beginning of the pandemic, our regional departments were forced to reevaluate and redistribute personnel for remaining urgent neurosurgical care.

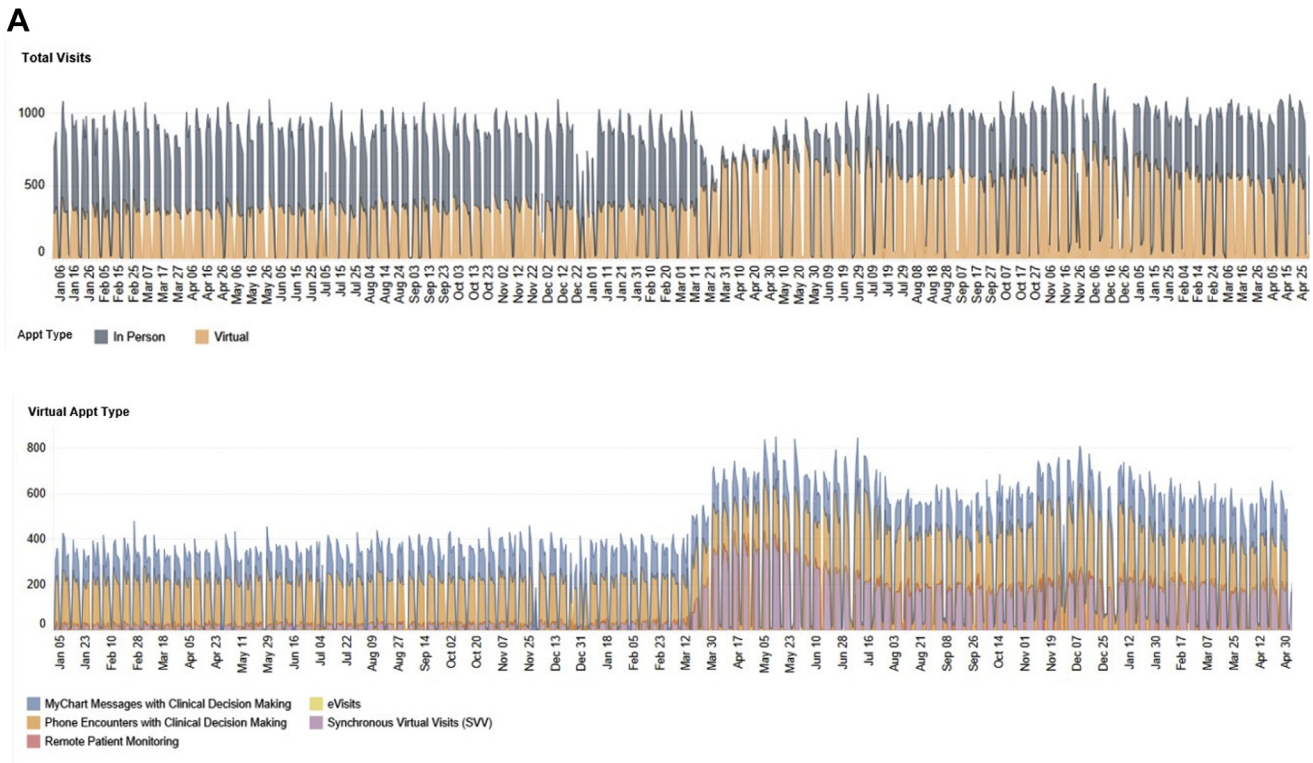
The first stage of this plan involved merging the regional hospital staff, who immediately provided call coverage for all hospitals simultaneously using digital health support with a team of APPs at each facility. On the weekend, virtual rounds (via FaceTime, Google Duo, or InTouch Inc.) would be made at each hospital seeing all critically ill patients, any patients with changes in their status, and any new consultations seen previously by the APP staff in-person. On an average day, a staff would complete 8–10 urgent or emergent consultations, see multiple postoperative patients, and respond to the wide spectrum of patient-related queries at all 3 hospitals. Second call, which was required because of trauma center designations and the rare but potential requirement to have emergent surgical needs at both hospitals simultaneously, was provided by board-eligible neurosurgical fellows who had little educational activity during the state-mandated moratorium on elective procedures. Initially, the program had to be approved by hospital administration and the neurosurgical staff themselves. Within the context of uncertainty surrounding the COVID-19 pandemic and necessary precautions, approval was expedited as a means to ensure the continuity of emergent neurosurgical services at all hospitals.

The success of the endeavor during the height of the pandemic led the regional neurosurgeons to elect to continue with this system on hospital reopening with slight modification. The transition required a size increase in the APP team to supply sufficient full-time equivalents to provide first call coverage all weekend and for 12 hours/day during the week. This total cost was ultimately less than the salary support needed to compensate 3 separate staff to cover all 3 hospitals. Evaluation of the program initially showed a reduction in satisfaction by the APP team, as they took on significantly more responsibility and had new scheduling concerns; however, this was short-lived as the staffing numbers were increased. Staff satisfaction was also dramatically improved with the reduction in weekend call requirements. Assessment by the emergency department, trauma team, and hospital leadership rated the quality and access to neurosurgical services as excellent. After 12 months, few, if any, patient safety issues or quality issues have been raised.

Virtual Outpatient Visits: Practice Value

From the onset of the precautionary lockdowns and even following the full-service reopening of the hospital system for routine care, our institution placed significant emphasis on shifting a majority of outpatient clinical visits from in-person to virtual appointments. With the relaxation of Health Insurance Portability and Accountability Act regulations to allow patient evaluation with consumer applications such as FaceTime, Google Duo, or Zoom (Zoom Video Communications, Inc., San Jose, California, USA) as well as certified virtual patient platforms such as AmWell

(American Well Corporation, Boston, Massachusetts, USA), our department has found the transition to virtual patient visits to be relatively seamless. The Cleveland Clinic has had significant experience with the development of digital health platforms over the last decade; however, utilization within the Department of Neurosurgery was limited until the COVID-19 pandemic. For reference, within the Center for Spine Health, use of virtual visits increased from 3% to 40% of overall visit volume between 2019 and 2020 (with only a 13% decrease in overall visit volume). Overall, the Department of Neurosurgery doubled its use of virtual



B

In Person Visits: Completed or future scheduled appointments outside of Imagining or Pathology/Lab departments that are not virtually

Synchronous Virtual Visits (SVV): Real-time audio and video (whenever possible) connections between caregivers and patients for the purpose of providing medical care.

Attribution: Epic department

SVV Types:
- **On Demand**
  - **Urgent Care:** "Walk-in" or without a prior appointment real-time audio and video (whenever possible) connections between Cleveland Clinic caregivers and patients for the purpose of providing medical care
- **Scheduled**
  - **Virtual Visit:** By appointment, real-time audio and video (whenever possible) connections using "ECO" software between caregivers and patients for the purpose of providing medical care
  - **Phone Visit:** Real-time audio encounters between Cleveland Clinic caregivers and patients for the purpose of providing medical care where significant clinical decision making was required
  - **MyChart Virtual Visit:** By appointment, real-time audio and video (whenever possible) using "MyChart" software connections between caregivers and patients for the purpose of providing medical care
  - **Face Time Duo Visit:** By appointment, real-time audio and video (whenever possible) connections on a variety of software platforms that were approved as a temporary measure in response to Covid-19 to ensure caregivers could continue to provide needed medical care in the face of pandemic

Other Virtual Visit Types:
Provider Criteria: Limited to activity completed by providers with NPIs
Attribution: Unless otherwise stated Institute and Department/Center attribution is tiered. First is by the completing provider's primary clinical assignment, if the provider is not mapped then the Epic department mapping for outpatient visit reporting is used

eVisits: "Walk-in" or without a prior appointment asynchronous encounters for COVID-19 originating from a MyChart "eVisit" completed through MyChart between Cleveland Clinic caregivers and patients for the purpose of providing medical care. Attributed by encounter provider's primary assignment. Department/center reporting is not available

eConsults: Asynchronous provider to provider consults for the purpose of assisting in the evaluation of a patient for medical care. Attributed to Institutes by order type

Remote Patient Monitoring: Monitoring of patients outside of conventional clinical settings. Current reported methods
- **Cardiac Monitoring**
- **Pacemaker Monitoring**
- **Eye Fundus Interpretation**

Phone Encounters with Clinical Decision Making: Real-time audio encounters between Cleveland Clinic caregivers and patients for the purpose of providing medical care. Where clinical decision making is defined as the encounter having an updated medication, lab, diagnosis or note

MyChart Messages with Clinical Decision Making: Patient initiated MyChart messages where a provider with an NPI responds; attributed by encounter provider's primary assignment

Source: Epic
Frequency: Daily

Figure 2. (**A**) Outpatient virtual visit utilization. Following lockdowns imposed by the state, the Department of Neurosurgery more than doubled its use of virtual visits (top panel), with a significant increase in synchronous audiovisual virtual visits in particular (bottom panel). (**B**) Descriptions of the types of virtual visits provided by staff at the Cleveland Clinic.

visits following March 2020 compared with the previous year, with virtual visits accounting for a majority of outpatient visits overall between March 2020 and May 2020 and at least half of all outpatient visits since June 2020 (Figure 2).

Patient satisfaction improved with virtual visitation (Table 1). A total of 10,772 total visits were assessed (5541 in-person office visits and 5171 virtual appointments). Patients were more likely to answer "satisfied" or higher on a Likert scale from 1 to 5 in the virtual setting when considering the availability of appointments (69.7% vs. 63.3%, $P < 0.0001$), degree to which they felt cared for by the provider (87.9% vs. 85.8%, $P = 0.001$), and the likelihood of recommending services to others (88.4% vs. 86.7%, $P = 0.007$). When considering ease of scheduling, inclusion in decision making, and understanding the explanation the provider gave, there was no significant difference in satisfaction between the virtual and in-person samples.

Our status as a quaternary-level referral center increases the likelihood that patients who seek care at our institution live outside our conventional geographic catchment area. Decreased travel time and cost as well as simpler logistical planning improved satisfaction, decreased tardiness, and improved coordination with other provider visits that may have been scheduled on the same day. Patients could participate from their own home or an acute care facility, and interested parties such as family or friends could join the visit despite at many times strict in-person visitor limitations. When the visit started, the EHR was already open, allowing for ease of access to the electronic patient-provider interface. For example, sharing virtual resources or reviewing patient radiographic studies was simple using screen-share functions, and prescriptions could be written or orders placed with only a few simple steps. A large portion of the outpatient visit is composed of history taking, counseling and answering questions, refilling prescriptions, planning, and setting expectations—all essential components of relationship building with patients. These tenets of the physician-patient relationship are easily met and strengthened in the virtual visit (Table 1). Finally, limiting the number of people who needed to come out of their home environment to the institution was advantageous in infection control for both patients and staff.

Conducting outpatient virtual visits was initially thought to be limited mainly by the inability to perform an in-person physical examination; however, with time and some imagination, we found that the critical components of the neurological examination were accessible through the virtual platform. For example, the use of lifting common household objects and observing simple tasks done by the patient could be used to assess motor function and symmetry. Including a family member in the examination who could provide direct tactile stimulation allowed for directed sensation grading or if they could operate the mobile camera, a more thorough inspection of a wound or drainage. Enough information could be elicited to make reliable clinical decisions. Further, if any uncertainty remained, the patient could be directed to present in person to the clinic or the emergency department for further evaluation. On multiple occasions, concerned postoperative patients presented to the emergency department for evaluation of a concerning postoperative issue (e.g., wound drainage or pain) and could connect with us via video call and an evaluation could be done virtually. This would allow us to provide immediate recommendations and care planning, recommend the patient come into the office for an in-person visit, or confirm the need for presentation immediately to the emergency department. This limited unnecessary emergency resource utilization, cost, and exposure to COVID-19 for our patients.

Virtual Outpatient Visits: Educational Value

One of the strengths of virtual visits has been its utility in providing an optimal learning environment for neurosurgical trainees. Using a group chat model of conferencing, the video visit allows residents and other trainees to interact with a patient with the attending physician present, observing more naturally in the virtual setting than would be feasible in the in-person setting. Our use of virtual visits has allowed a rare opportunity for our trainees to obtain specific and direct feedback on communication skills,

Table 1. Outpatient Visit Satisfaction

Visits		Number
Office		5541
Virtual		5171
Question	**Satisfied or Higher (%)**	***P* Value**
Ability to get appointment when wanted		
Office	3507 (63.3)	<0.0001*
Virtual	3604 (69.7)	
Ease of scheduling		
Office	3912 (70.6)	0.367
Virtual	3604 (69.7)	
Degree to which you felt the provider cared about you		
Office	4754 (85.8)	0.001*
Virtual	4545 (87.9)	
Explanations the provider gave you about your problem or condition		
Office	4682 (84.5)	0.307
Virtual	4406 (85.2)	
Care provider's effort to include you in decisions about your treatment		
Office	4699 (84.8)	0.080
Virtual	4447 (86)	
Likelihood of recommending care provider to others		
Office	4804 (86.7)	0.007*
Virtual	4571 (88.4)	

Virtual visits matched or improved upon standards set by the typical in-person visit. Surveys were sent following all visits to Cleveland Clinic Department of Neurosurgery, including Cerebrovascular, Neuro-oncology, Spine, Epilepsy, and Center for Neurological Restoration, 6 weeks following appointments between April 2020 and March 2021. Responses were collected in a Likert scale format from 1 to 5, with 1 representing "very unlikely/very unsatisfied" and 5 representing "very likely/very satisfied." Percentages presented represent patients with responses of "satisfied" or greater (scores 3–5) on the Likert scale.

*Statistically significant.

physical examination techniques, and history-taking abilities. The ability for attending physicians to be present in the virtual chat rooms allows for these interactions to take place in a time-efficient manner that is usually lost on a normal busy in-person clinic day. This is especially valuable as increasing inpatient clinical demands pull residents away from outpatient experiences, and increasing outpatient clinic volumes limit the amount of teaching trainees can receive during a normal clinic-day.

Imaging Exchange and Portability

Growing digital clinical services required a bolstering of our electronic imaging infrastructure and the ability to easily transfer images from outside centers or facilities for review during virtual visits. Neurosurgery is heavily dependent on diagnostic imaging findings for treatment planning,[12] and many neurosurgeons prefer to review the hard images as opposed to only reading imaging reports from radiology. With patients no longer coming to in-person clinic appointments with imaging in hand, development of a patient-accessible system was necessary to allow for efficient image sharing from outside institutions with our clinical staff. Our institution had previously implemented a secure online patient portal, through Ambra Health (New York, New York, USA), that allows patients to easily upload Digital Imaging and Communications in Medicine images directly from a CD-ROM via a website. This then directly imports into our EHR and imaging library. This process negates the need for a physical disc to be mailed or delivered by courier to our facility and shortens a 1-week process to <48 hours. In some cases, with provider facilitation, staff can request upload of images into the EHR within a few minutes of entry into the portal. Similar infrastructure has been implemented for digital media and clinical photos collected from patients, such as wound photos, which can be directly e-mailed to a secure central server for upload and documentation in the electronic patient chart.

Our health system also participates in a national image exchange program, in which our picture archiving and communications system allows for electronic image exchange with complementary servers at >200 health systems in the United States. This allows for seamless transfer of high data—volume images across systems within minutes and without the need to burn the images to a physical disc or the need for transport services for hard copies from hospital to hospital. In October 2020, our Neurological Institute partnered with our central transfer center to coordinate and facilitate electronic image export at the initiation of an inpatient transfer request. This allows images to be available to our on-call staff in many cases at the time of the initial transfer request and discussion. Our surgeons can then more accurately triage remote patients, counsel the consulting physicians, and prepare for care once patients arrive at our hospital, sometimes from great distance and in many cases in critical condition.

Virtual Interdisciplinary Treatment Conferences

The transition of our interdisciplinary patient management conferences was one of the more intuitive applications of video-conferencing technology. Our Department of Neurosurgery participates in at least 5 unique weekly patient management conferences, including the brain tumor board, spine tumor board, pituitary tumor board, and head and neck tumor board and the epilepsy patient management conference. These conferences are integral to comprehensive patient care and greatly improve the efficiency of our practice and optimization of patient care.

The benefits of the transition to a virtual platform are best exemplified by our spine tumor board. As one of our newer interdisciplinary meetings, we struggled with coordination of schedules and location, as our Center for Spine Health is located in a separate building on campus, multiple blocks away from offices of the collaborating staff from radiology, radiation oncology, and medical oncology. In contrast, our cranial and neuro-oncology staff share office space with these colleagues within the Brain Tumor Institute, which makes it easier to coordinate schedules in a way that would accommodate attendance and participation in the conference while also balancing busy clinic or inpatient schedules, surgical cases and start times, and other clinical duties. Inconsistent attendance limited the discussion of patient cases and further coordination among services. While significant accommodation had been made before the COVID-19 pandemic to provide a virtual platform for the spine tumor board, it was not until pandemic lockdowns forced the shift to the virtual platform as well as the major market introduction of the Zoom application that virtual attendance became a reality. The reduction of elective cases early in 2020 likely facilitated improved spine surgeon participation in the conference; however, even with the restart of elective procedures, improved attendance was sustained and engagement maintained through remote technology. For surgeons, there is no longer a need to travel to a different building for the conference before or during operating room cases; a surgeon can simply participate in discussion from their office or while waiting for anesthesia induction and preparation before start of a case. Supporting staff joining the meeting virtually (scheduling, nursing, and case managers) can also follow along and facilitate further enhanced care coordination simultaneously. With increased attendance, we have noted an improved robustness in the discussion and significantly increased ease in coordinated and integrated care among our collaborating services (**Figure 3**).

As we have expanded our membership, we have found places for involvement outside our institution as well. Cases from the surrounding region or even internationally presented by physicians looking for a second opinion or more nuanced recommendations for patients not affiliated with our institution have been presented at our brain and spine tumor boards in a few instances. Though we have not made arrangements for formal inclusion of guest presenters, we recognize the promise this program imparts in expanding our ability as a highly specialized neurosurgical center to deliver high-quality neurosurgical care around the world.

Resident and Departmental Education

In the days following a statewide mandated canceling of elective surgeries in Ohio, our neurosurgical service slowed to almost a standstill as resident and faculty in-hospital activities were limited to only those deemed emergent or essential. Daily in-person educational conferences, a departmental point of pride for faculty and residents, were canceled, and residents were left without structured sessions that formed the backbone of the resident-led education program. Capitalizing on available remote conferencing technology and the open schedules of many of the

department faculty, 6 days following the hospital shutdown our department shifted to daily 1- to 2-hour grand rounds—style virtual lectures that focused on a range of neurosurgical topics (**Figure 4A**). These included time for resident and faculty discussion and debate, and continuing medical education credit was granted to faculty who attended as presenters or in the audience.[13] These lectures continued daily for almost 2 months until an institution-wide reopening for normal hospital services was approved (**Figure 4B**). The conferences still continue daily, but have been shortened to 30 minutes before first round surgical cases, and they now resemble a virtual version of our previous resident-driven morning conference program. We have found that the virtual platform allows residents to participate in lectures more efficiently while balancing early morning patient care responsibility. Furthermore, it allows faculty to join in with much more ease to supplement resident education with their practical experience. Faculty attendance was more cumbersome and limited before moving to the virtual system. Even further, department interdisciplinary conferences (e.g., morbidity and mortality conferences, tumor boards, spine surgical indications conferences, cerebrovascular case conferences) have adopted virtual platforms, as detailed previously, increasing the accessibility of these learning opportunities to residents. In the context of a busy clinical day including rounding, documentation, consultations, operative cases, and sign-out rounds, virtual access to educational conferences allows residents to supplement their education more efficiently and completely than in the past.

DISCUSSION

There is a paucity of literature demonstrating the effective use of modern digital health strategies in neurosurgical care in the inpatient and outpatient setting outside of the realm of acute endovascular stroke intervention.[5] A new study of ambulatory neurosurgery consultation services over the last year has shown positive provider and patient experiences similar to our own.[14] For our institution, provider and patient experience have both been positive, with virtual clinics allowing for more efficient, yet equally medically valuable visits with patients. Our analysis of satisfaction surveys allowed for review of a large sample of patients (N = 10,772). While significant differences were noted in the satisfaction among patients attending in-person and virtual visits, it is important to note that the raw difference in percentages was no more than 7% for any category. With our data, we can conclude at the very least that virtual visitation matched and, in some cases, may have slightly exceeded in-person visitation to further support validated use of the technology for ambulatory neurosurgical care.

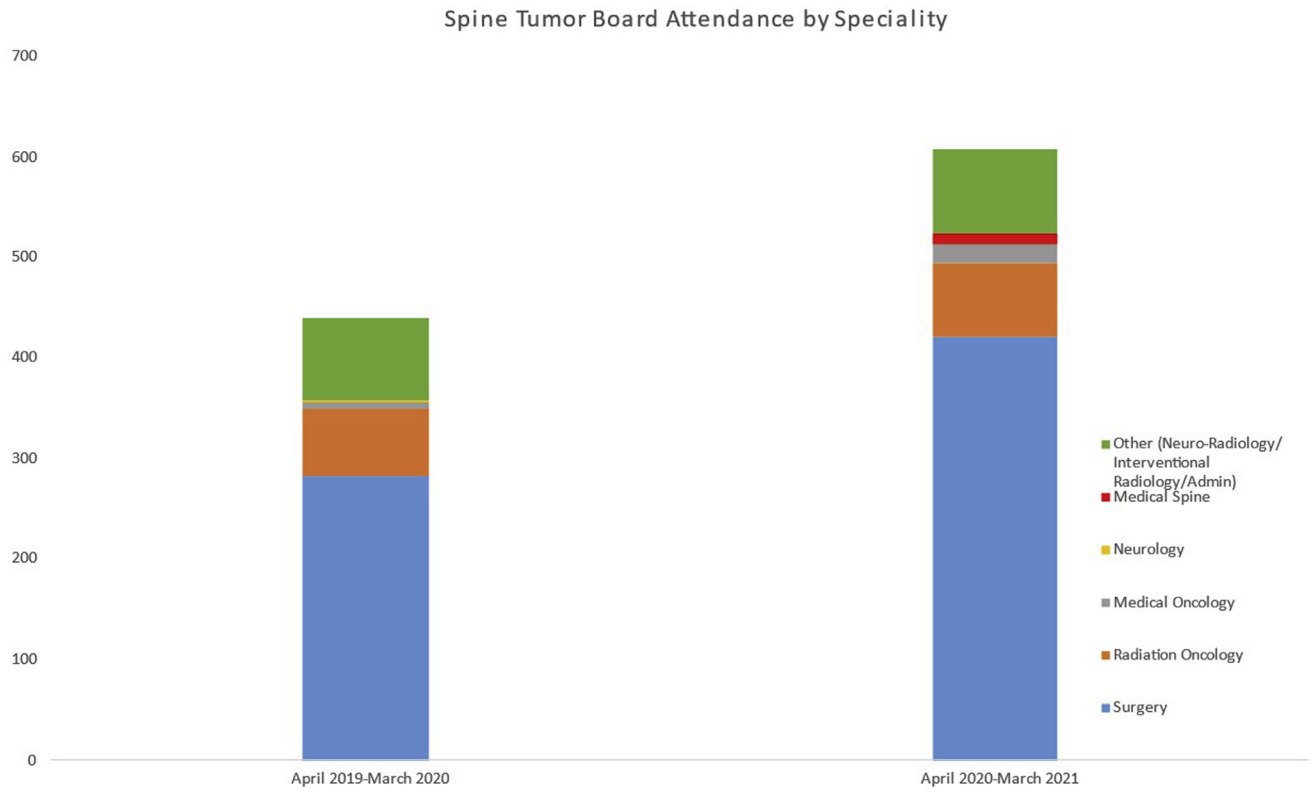


Figure 3. Improvement in interdisciplinary case collaboration. Overall attendance to the spine tumor board conference increased by 38.27% following the conversion to the virtual platform, with the most dramatic increases in surgeon attendance (49.29%) starting in April 2020. The virtual platform also encouraged more participation from diverse specialties overall.

The basic neurological examination/evaluation is particularly well suited for video evaluation, as the standard examination elicits visible clinical findings that are identifiable on video and require limited physical contact.[4] In March 2020, the American Academy of Neurology published emergency consensus guidelines detailing the use of video evaluation and digital health platforms for outpatient evaluation that detail components of a thorough neurological examination.[15] Furthermore, video evaluation has been shown to be equally as effective as in-person evaluation in a number of neurological pathologies, including Parkinson disease, multiple sclerosis, and essential tremor.[16-18] In the setting of our inpatient consultations or hospital transfers, including a licensed provider (e.g., a nurse or consulting physician) on-site for facilitation of the remote examination permitted a complete neurological examination that facilitated unencumbered recommendations to be given by the provider. Finally, neurosurgical care, while heavily reliant on the neurological examination, is equally dependent on the context of the clinical history and, most importantly, imaging findings to guide clinical decision making.[12,19] The majority of the time, information provided in a virtual visit or consultation is more than adequate to proceed with safe surgical decision making, especially as immediate and shared access to the EHR in a virtual context allows for simultaneous review of relevant imaging and laboratory work while collecting the clinical history during the visit. For our institution, adoption of digital health technology in multiple realms of patient care has served as a practical supplement and substitute to classical neurosurgical services. Our adoption of these remote technologies has allowed us to leverage our workforce and expand our traditional services to include a broader patient population in a cost-effective manner.

Our experience over the last year using digital neurosurgical resources has allowed us to expand the delivery of neurosurgical care and augment resident education. Evidence exists to suggest that the regionalization of neurosurgical care and the development of centers of excellence—single centers in which highly subspecialized neurosurgical care is provided in high volume—decreases the rate of adverse events while improving patient safety and outcomes.[20-22] These new technologic modalities, as described, present an opportunity to extend specialty neurosurgical evaluation and intervention to areas of the United States that previously had poor access and as such broadly improve the quality of that care when delivered. Remote technologies allow for the expansion of care networks. This counteracts the impact of workforce shortages, resource-poor environments, and geographic and distance base limitations, as it has in fields such as acute stroke care.[4,7,8,23]

As we have demonstrated, the possibilities for use of this technology in patient care include, but are not limited to, direct neurosurgical consultation for evaluation, inpatient rounds, and formalized inclusion of patient cases in multidisciplinary treatment panels. New opportunity to expand digital neurosurgery

April 2020

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
29	30	31	1 ZOOM Lecture - AVMs - Dr. Mark Bain	2 ZOOM lecture- Tethered Cord/Myelomeningocele - Dr. Violette Recinos	3 Zoom Spine Conference- Dr. Dominic Pelle	4
5	6 Zoom Lecture - Dorsolateral and Lateral Approaches to Ventral Spine surgery - Dr. Ed Benzel	7 Zoom Lecture - General Spine Oncology - Dr. Ajit Krishnaney	8 Zoom Lecture - Aneurysms: Clipping/Endovascular Coiling - Dr. Mark Bain	9 Zoom Lecture - Fusion and Motion Preservation Strategies - Dr. Ed Benzel	10 Zoom Spine Conference - Dr. Jason Savage	11
12	13 Zoom Lecture - Doing What's Right: Leadership, Knowledge, Wisdom - Dr. Ed Benzel	14 Zoom Lecture - Avoiding Complications in Spine Surgery _ Dr. Ajit Krishnaney	15 Zoom Lecture - Cerebral Bypass - Dr. Peter Rasmussen	16 Zoom Lecture - On Writing a Neurosurgical Paper - Dr. Ed Benzel	17 Zoom Spine Conference: Dr. Jason Savage	18
19	20 Zoom Conference: Socioeconomic Topics- Dr. Deborah Benzil	21 Zoom Lecture - Transphenoidal Approaches for Sellar Pathology - Dr. Pablo Recinos	22 Zoom lecture - Case Discussion of Spine Tumors - Dr. Ajit Krishnaney	23 Zoom Lecture: The Devil is in the Details: Getting What's Deserved for Each Patient	24 Zoom Spine Conference: Dr. Jason Savage	25
26	27 Zoom Lecture: Becoming an Academician - Ed Benzel	28 Zoom Lecture - Interesting Cases, Trauma and Vascular - Dr. Nina Moore	29 Zoom Lecture - High yield Rhoton Anatomy - Dr. Varun Kshettry Resident Case management conference	30 1. Zoom Lecture - High yield Anatomy part 2 - Dr. Varun Kshettry 2. Zoom Lecture - Radiographic Progression after Radiosurgery in Brain Metastasis - Dr. Alireza Mohammadi	1 Zoom Spine Conference: Dr. Jason Savage	2

Figure 4. Virtual resident education. A full month of grand round–style lectures hosted by the Department of Neurosurgery during April 2020 to maintain a structured resident education system. Most lectures were hosted by department faculty, and attendance included both trainees and staff across the department.

services exists in the development of new technology.[11] For example, the addition of wearable or remote monitoring devices (e.g., smartwatches, smartphones, surgical implants) to neurosurgical care to provide home data could add a layer of personalization to care plans that has not previously existed.[24] Further, store-and-forward monitoring using digital databases, in which patients proactively collect and report data in a continuous fashion, could allow providers access to insight not seen in the typical episodic patient-provider interaction (e.g., in seizure frequency recording in the treatment of medically refractory epilepsy).[11,25] Telesurgery and use of robotic technology to perform neurosurgical procedures remains a frontier in innovation that would revolutionize the ability to provide distance-based neurosurgical care in the future. However, the field remains in its infancy, although it shows some promise in the realm of endovascular stroke intervention.[11,26]

Neurosurgical education has also experienced a true evolution in the last year.[27,28] Beyond the changes made at our institution,[13] nearly all neurosurgery-related national conferences adopted a virtual platform for the 2020 annual meetings, and many will be extending virtual options in addition to the standard in-person forums for 2021. New online resource forums, such as the Neurosurgical Atlas (Neurosurgical Atlas, Inc.; https://www.neurosurgicalatlas.com/) have expanded significantly, and the Congress of Neurological Surgeons (CNS) and the American Association of Neurological Surgeons (AANS) have introduced new virtual visiting professorships, lecture series, and online resources to replace previously in-person continuing medical education. This transition has allowed for an exponential increase in the availability of such neurosurgical education resources, as attendees may have been previously limited from access owing to time constraints or travel cost.[27] Our institutional interdisciplinary meetings have been enhanced by the digital platform, with improved attendance and participation among surgeons. This easy transition can serve as a simple solution to decrease the logistical and fiscal burden for future academic meetings, medicolegal proceedings, and other events in which neurosurgeons must make large sacrifices to appear and provide their expertise. At our institution, daily conferences have now transitioned to a virtual platform and have enhanced access to these resources for residents and staff throughout a busy clinical work week. Our ability to integrate residents into our virtual clinics has provided a new layer of observed clinical experience that allows for feedback and education not previously available to our program in its history.

Current COVID-19-related regulatory changes allowing for the expansion of reimbursement and interstate licensure were enacted in early 2020 and permitted a rapid expansion of digital neurosurgical coverage throughout the United States.[10,14,19] At this time, except for a few states and territories, there appears to be no plan to provide waivers of the regulatory burden past the period of the public health emergency. This may stifle the unexpected progress made over the last year using virtual technologies to improve neurosurgical care delivery at specialized centers in the United States. As policies lapse or expire, much of the capital investment made into digital infrastructure during the pandemic may become useless or too burdensome to use for neurosurgeons transitioning back to typical practice in the United States. As the country prepares to enter a postpandemic era, organized neurosurgery societies in the United States should develop formal guidelines on digital neurosurgical care, advocate for the expansion of interstate medical licensure and support the current Interstate Medical Licensure Compact now adopted by 34 states, encourage the sharing of medical information and imaging across institutions, and continue to work with the Centers for Medicare and Medicaid Services to continue reimbursement for digital neurosurgical services. Further, these bodies should continue to support neurosurgical innovation in digital health, including investing in broadband infrastructure in the United States and development of remote monitoring devices for neurosurgical disease.

Our experience using remote health technology previously and over the last year at the Cleveland Clinic has allowed us to develop an infrastructure to balance ongoing pandemic-related health care stressors while also building a platform to expand our delivery of neurosurgical services to patients in need across the United States. Our discussion is focused on neurosurgical practice in the United States, a resource-rich environment in which we are privileged to practice and, as such, may lack insight into infrastructural gaps, policy nuances, and cultural differences that may affect care in other countries, particularly low- and middle-income countries around the world. Nevertheless, the lessons learned in the past year reflect a new model for neurosurgical care delivery that can be leveraged to expand delivery of essential neurosurgical services worldwide.

CONCLUSIONS

Remote video technology and the implementation of neurosurgical digital health has proven to be a useful adjunct for the provision of neurosurgical care and continuation of resident education at our institution during the COVID-19 pandemic. Leveraging the technologic infrastructure required for these services during the pandemic, we can facilitate the expansion of neurosurgical care provision for patients across the United States. As we progress, governing bodies within organized neurosurgery in the United States should advocate for the continued financial and licensing support of these service on a national fiscal and policy level.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Akshay Sharma: Methodology, Investigation, Writing — original draft. **Robert D. Winkelman:** Investigation, Writing — review & editing. **Richard P. Schlenk:** Methodology, Investigation, Writing — review & editing. **Peter A. Rasmussen:** Methodology, Writing — review & editing. **Lilyana Angelov:** Methodology, Investigation, Writing — original draft. **Deborah L. Benzil:** Methodology, Investigation, Writing — original draft.

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