REVIEW

Minimizing SARS-CoV-2 exposure when performing surgical interventions during the COVID-19 pandemic

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ABSTRACT

Background Infection from the SARS-CoV-2 virus has led to the COVID-19 pandemic. Given the large number of patients affected, healthcare personnel and facility resources are stretched to the limit; however, the need for urgent and emergent neurosurgical care continues. This article describes best practices when performing neurosurgical procedures on patients with COVID-19 based on multi-institutional experiences.

Methods We assembled neurosurgical practitioners from 13 different health systems from across the USA, including those in hot spots, to describe their practices in managing neurosurgical emergencies within the COVID-19 environment.

Results Patients presenting with neurosurgical emergencies should be considered as persons under investigation (PUI) and thus maximal personal protective equipment (PPE) should be donned during interaction and transfer. Intubations and extubations should be done with only anesthesia staff donning maximal PPE in a negative pressure environment. Operating room (OR) staff should enter the room once the air has been cleared of particulate matter. Certain OR suites should be designated as covid ORs, thus allowing for all neurosurgical cases on covid/PUI patients to be performed in these rooms, which will require a terminal clean post procedure. Each COVID OR suite should be attached to an anteroom which is a negative pressure room with a HEPA filter, thus allowing for donning and doffing of PPE without risking contamination of clean areas.

Conclusion Based on a multi-institutional collaborative effort, we describe best practices when providing neurosurgical treatment for patients with COVID-19 in order to optimize clinical care and minimize the exposure of patients and staff.

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BACKGROUND

The coronavirus

The coronavirus species are a group of enveloped positive single-stranded RNA viruses belonging to the genus beta coronavirus.[1] Four of these viruses cause common cold symptoms while two previously known strains of zoonotic origin, severe acute respiratory syndrome (SARS-CoV) and Middle East respiratory syndrome coronavirus (MERS-CoV), can cause fatal respiratory illnesses.[1] The SARS-CoV-2 virus, also known as 2019-nCoV, is a new coronavirus species[1] that started the COVID-19 pandemic as a cluster of viral pneumonia in December 2019 in Wuhan, China, and which is currently spreading across the USA and the rest of the world.[1 2]

Transmission

There are two main routes of transmission for respiratory viruses: aerosolization with droplet transmission and direct contact modes of transmission, with the virus remaining viable for significant intervals of time between hours and days on most surfaces.[3] Aerosolized transmission[4 5] can be either droplet (SARS-CoV-2) or airborne (SARS), generally depending on the size of the expelled particle. Larger particles once expelled into the air tend to settle on surfaces or to the ground typically within 1 m of the source.[4] The SARS-CoV-2, like other corona viruses, can be transmitted via droplets within close proximity during coughing or sneezing, and thus the recommendation for individuals to remain 6 feet apart (www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html). The droplets can enter through the eyes, mouth, or nose of a nearby person. Person-to-person transmission via direct contact or contact with contaminated surfaces can also occur (https://www.cdc.gov/coronavirus/2019-ncov/infection-control/control-recommendations.html). Close range aerosol transmission[5] is most likely during high-risk aerosolization procedures such as endotracheal intubation, extubation, suctioning, chest compressions, and endonasal and transoral procedures. As per the WHO, airborne transmission—aerosolized particles that travel through the air over longer distances—has so far not been shown to be a transmission mode for this novel coronavirus (https://www.who.int/publications-detail/advice-on-the-use-of-masks-in-the-community-during-home-care-and-in-healthcare-settings-in-the-context-of-the-novel-coronavirus-(2019-ncov)-outbreak).

Covid-19 syndrome

Coronavirus disease 2019 (COVID-19) is a unique respiratory illness that can cause a range of symptoms varying from asymptomatic to respiratory distress to multiorgan failure with ensuing death. Anosmia may be a unique early symptom with the COVID-19 syndrome based on anecdotal reports from around the world. Based on the Chinese reports, 81% of patients have mild symptoms, while 14% have moderate symptoms and 5% have critical illness with the need for mechanical ventilation. Others present with flu-like symptoms and muscle aches, or gastrointestinal symptoms.[6] Elderly people and those with baseline cardiopulmonary disease appear to be at greatest risk for poor outcomes with COVID-19. At the time of this report, the US has the most infected documented cases in the world with a rising death toll.

Current shortage of personal protective equipment for covid-19

There is a nationwide shortage of personal protective equipment (PPE), and disruptions in global supply chains are aggravating this shortage. This protective equipment is needed most significantly by healthcare providers in close, repeated, or continuous contact with the infected patients. The WHO's interim guidance from February 27, 2020 advises a rational and appropriate use of PPE based on multiple factors such as the location of a patient, type of personnel involved, and type of procedures being performed. The document also highlights steps that can be taken to safely conserve PPE and improve their efficiency (https://apps.who.int/iris/handle/10665/331215).

Given the novelty of this disease and the current scarcity of reliable clinical data, it is essential and responsible for us to share our collective efforts and experiences in our responsibility to our patient population requiring neurosurgical care while protecting the healthcare population. The following document is a summary of lessons learned across multiple regions (13 healthcare systems and affiliated experts) of the USA in optimizing conditions for the safety of our patients and neurosurgical providers, and their support staff (box 1).

METHODS

The current document was formulated with a mission of serving patients requiring surgical intervention while minimizing SARS-CoV-2 exposure to non-infected patients and staff, understanding the significant shortages of personnel, facility, and PPE resources. We aim to describe a comprehensive approach to caring for a surgical patient during the COVID-19 pandemic including a strategy of decreasing elective surgical volume to create capacity for a surge in COVID-19 patients. The authors of this manuscript represent 13 different health systems including centers in hot spots of New York, Pennsylvania, Washington, and Michigan. They have shared their best practices being used at their centers, leading to a formulation of the best practices document. The process was conducted by creating an initial template for the manuscript led by the first author. This was iteratively revised by all authors. A thorough search of prior publications led to a very limited reference list. It was apparent that, while a lot is being rapidly published on COVID-19, the precise areas of critical interest for neurosurgical practice were severely limited. In light of the lack of data, we constructed the model where each author populated all the areas of the manuscript individually. These submissions were then collated and edited to optimize the subject matter by the first author and circulated for edits from the larger group to create a concise repository of best practices.

Given the tremendous challenges posed by the COVID-19 pandemic, there is a lack of data to support each of these recommendations and thus we present the best practices as options to adapt based on a health system's resources and goals. We are presenting a consortium of practices based on pre-print publications, studies of previous viral illnesses, and emerging experience from major centers during a worldwide pandemic.

Box 1 Principles of minimizing exposure during neurosurgical care of patients with covid-19

- Only surgical on-call teams should be present within hospital settings
- Demonstrate appropriate donning and doffing techniques
- Maximal PPE for all PUIs and COVID-positive patients
- Reuse N95 masks by placing a face mask over the respirator and store the N95 in a new brown bag
- Consider designating 3 ORs as COVID ORs and divide each OR specific to particular surgical type (Neuro-OTO, General-Trauma, and Cardiothoracic and Vascular)
- Anteroom needs to be used for donning and doffing as well as intubating/extubating patients
- Consider anesthesia team using long extensions to endotracheal tubes and portable ventilators to prevent need for circuit disconnection
- Minimize personnel for intubations and extubations

CATEGORIZATION OF EMERGENT AND URGENT NEUROSURGICAL PROCEDURES

While a comprehensive definition of non-elective procedures is lacking and depends on individual presentations, the following list includes procedures that are commonly understood as emergent or urgent:

1. Neurosurgical diagnoses
   A. Cranial mass-occupying lesions causing acute neurological deterioration
   B. Intracerebral hemorrhage presenting with impending herniation
   C. Symptomatic intracranial aneurysms that are not coilable or present with hematomas causing mass effect
   D. Cranial traumatic injuries
   E. Spinal cord compressions
   F. Myelopathy
   G. Spinal traumatic injuries
   H. Cauda equina syndrome

GENERAL PLANNING

It is critical that all planning and preparation for emergent neurosurgical care be performed in conjunction with the institution's central coordination committee.[7] Isolated planning without proper communication will lead to confusion and poor compliance. Additionally, this planning should be performed keeping in mind the institution's resources and best available scientific data. Unilateral expectations unsupported by best evidence may stress an institution's global response as adherence to extreme precautionary measures may not necessarily be safer and may deplete precious resources. It is also important to realize that new evidence may change practices in the future. The ultimate goal of general planning is to safeguard the operators and mitigate in-hospital transmission. The current environment demands creativity, up-to-date knowledge of emerging evidence, and a collaborative atmosphere. Thus, it is possible that multiple options could be equally safe and effective as long as sound scientific principles and emerging evidence are adopted.

Most patients who are in need of emergent/urgent neurosurgical care may be lacking appropriate COVID-19 risk factor history or covid testing and thus should be considered as persons under investigation (PUI) or COVID-19 positive.[8] Taking this approach allows for creation of standardized protocols in managing such patients as well as enhances safety for all involved, given the necessity of maximal PPE when interacting with PUI/COVID-19 patients. Coordinated rehearsals of personnel responsibilities and processes for patients with covid needing neurosurgical care are essential, given that personnel within the OR suite should not move to clean areas. It is also ideal to have numerous posters/laminated sheets to outline the procedures for contacting personnel for PPE, personnel exposure, terminal clean, and hospital-based infection protection authority.[9]

Personnel

Across the USA there is a general trend to cancelling elective procedures to minimize the number of healthcare providers at risk of exposure within the hospital environment. Donning and doffing of maximal PPE should be demonstrated and hand hygiene during this process should be emphasized. Given the importance of proper PPE placement in preventing exposure to the SARS-Cov-2 virus, adherence should be monitored.

Members of the surgical, anesthesia, and neuromonitoring team should limit their movements within the OR and between rooms so as to not expose clean areas to SARS-CoV-2 particulate matter. This will require the placement of a team member outside the operative suite in case surgical equipment that is not present in the OR suite is necessary for continuing the operation. Donning and doffing should take place within the anteroom to prevent exposure of clean areas to infectious matter from the operating suite.

Operative suite

Given the multitude of OR suites within most hospital settings, it is ideal to concentrate all COVID and PUI cases within several COVID designated ORs. Such ORs should ideally be attached to an anteroom as a mechanism of preventing exposure of clean areas. In addition, the designated COVID-19 OR suites should be divided into rooms focusing on three surgical types: (1) neurosurgical, otolaryngology, and spinal procedures; (2) general surgery, transplant, and trauma; and (3) cardiothoracic and vascular surgery. Such division will allow for surgical specialty specific equipment to be housed within the dedicated covid OR, thus preventing movement of equipment from clean areas to covid designated areas and vice versa. Hybrid ORs deserve special consideration, and cross-specialty collaboration might be the only way to achieve economies of scale that allow focusing one or more hybrid ORs for patients with covid and others for non-COVID patients.

Given the positive pressure areas within the operative suite, it is essential to have a negative pressure area with HEPA filtration for doffing, donning, as well as intubation and extubation as both of these procedures will lead to significant aerosolization. Such an area is defined as the anteroom which needs to be attached to each COVID designated operative suite and serves an essential feature of preventing contamination of adjacent clean areas. Post procedure, the COVID OR should undergo a terminal clean of all exposed material from ceiling to floor including lighting.

INTRAOPERATIVE AND PERIPROCEDURAL NEUROSURGICAL CARE

Direct communication should take place between the transporting team to the OR personnel in the room to be certain that all individuals have appropriate PPE before transport. Transportation of non-intubated patients should be done with a face mask in place. Portable ventilators and extensions to endotracheal tubes are important ways to prevent the need for disconnecting the circuit. When a disconnection is necessary, clamping of the endotracheal tube is essential to prevent aerosolization.

Intubations and extubations are ideally performed within a negative pressure room and thus the anteroom is a suitable location.[10] Only the anesthesia team donning maximal PPE should be within the room when performing intubation and extubation in order to minimize exposure to other team members.[11,12] The surgical team should wait for a period of time post intubation/extubation, ideally corresponding to twice the predicted time of air turnover in the room, to reduce the aerosolization content within the COVID OR environment before entering with maximal PPE including a N95 respirator. Given the rise in patients with COVID-19 and thus the demand for ICU beds and ventilators, extubation post procedure should be emphasized thus freeing up a ventilator and ICU room. Post extubation, efforts should be made to transport the patient to a final destination rather than intermediary locations such as the post anesthesia care unit. This will minimize the number of areas and personnel exposed to patients withCOVID-19. However, it may be more efficient to have the ability to turn an OR suite into a negative pressure environment where the patient can be transported for extubation. This will allow the COVID OR suite to be more efficiently used for surgical procedures rather than extended periods of time for recovery until extubation. Some may advocate extubating only outside of the OR, in particular to perform extubation in the critical care unit; however, this does not fully incorporate the flow of patients in the hospital, especially in busy centers, and may add a significant number of ventilator days during a time when ventilators are a scarce resource.

Neurosurgical procedures specifically involving the airways can lead to significant aerosolization and exposure of surgeons and others within the operative suite. In addition, high-speed

Box 2 Procedure prioritization

A strategy to prioritize invasive procedures that are allowed to continue under conditions of pandemic surge. Level IIIb cases are the first to be cancelled or disallowed.

Level I – Delay in surgery >24 hours will result in adverse clinical outcome (urgent/emergency surgery)

Level II – Prolonged delay in surgery may result in adverse clinical outcome

- Level IIa – System stress: surgery will use limited hospital resources that are needed for patients with higher levels of acuity
- Level IIb – Patient stress: prolonged delay likely will place patient at clinical risk
  - i. Risk of disease progression within 1 month places patient at risk that is felt to outweigh risk of procedure in pandemic environment
  - ii. Risk of disease progression within 3 months places patient at risk that is felt to outweigh risk of procedure in pandemic environment

Level III – Prolonged delay in surgery will not result in adverse clinical outcome (truly elective surgery)

- Level IIIa – Elective surgery that does not use significant system resources
- Level IIIb – Elective surgery that does use significant system resources

Box 3 Prioritization of common cerebrovascular interventions

Level I – Urgent/emergency
- Ruptured intracranial aneurysm/arteriovenous malformation/arteriovenous fistula
- Symptomatic intracranial aneurysm (crescendo headache, cranial neuropathy, visual deterioration, etc)
- Acute ischemic stroke thrombectomy
- Carotid blowout/bleeding head and neck tumor with airway compromise
- Intracranial hemorrhage or mass with high risk for herniation
- Refractory, severe epistaxis
- Acute stroke meeting hemicraniectomy criteria
- Symptomatic vasospasm
- Cortical venous thrombosis with infarct or hemorrhage, high risk with medical treatment alone

Level II – Risk for adverse clinical outcome
- Level IIa – System stress
- Any Level IIb(i) procedure expected to require >5 days of ICU stay and/or >3 days of mechanical ventilation
- Level IIb – Patient stress
    - i. Risk of disease progression within 1 month
    - Acutely symptomatic carotid stenosis, low risk for reperfusion injury
    - Recurrent, severe epistaxis under temporary control
    - Delayed angiography of atypical, angiogram-negative subarachnoid hemorrhage
    - Intervention for idiopathic intracranial hypertension with vision loss
    - ii. Risk of disease progression within 3 months
    - Surveillance angiography for ruptured aneurysm treated by endovascular occlusion first
    - Intracranial mass lesion, minimally symptomatic or asymptomatic

Level III – Limited risk in adverse clinical outcome (truly elective surgery)
- Level IIIa – elective surgery that does not use significant system resources
- Surveillance angiography of unruptured aneurysms or after 1 year for ruptured aneurysm
- Level IIIb – elective surgery that does use significant system resources

bone drilling has been shown to increase production of contaminant aerosolized particulate matter, as reported by Workman *et al*,[13] and thus participants should be in full PPE. In the same manner, the use of electrocautery has also been shown to increase production of contaminated aerosolized particulate matter.[14] Thus, neurosurgical operative procedures involving endonasal approaches for tumor resection and pituitary surgeries as well as transoral approaches for spinal pathology should be avoided unless absolutely necessary. Such procedures should be some of the first cases delayed secondary to the substantial exposure of healthcare personnel to infectious particulate matter.

RESOURCE UTILIZATION IF PPE IS NOT AVAILABLE

With the continual rise of COVID-19 cases it is plausible that there will be scarcity of appropriate PPEs. Specifically, N95 masks are integral to preventing exposure to COVID-19 particulate matter and appear to be in short supply. Ideally, N95 masks should be changed from patient to patient. There are ongoing discussions regarding the reuse or sterilization of used N95 masks. The FDA has recently approved the use of hydrogen peroxide vapors to decontaminate N95 masks, as this disinfects without compromising the mechanical integrity of the mask (https://www.fda.gov/media/136386/download). Innovative mechanisms of sterilizing used N95 respirators have also included heat and ultraviolet light sources as well as hydrogen peroxide vapors. There is no evidence to support sterilization with ultraviolet light and heat without the possibility of reducing the effectiveness of the N95 respirator.

Reuse of N95s may be enhanced by wearing a surgical facemask over the N95, thus preventing its gross contamination. In addition, a replacement of the N95 mask could be the reusable elastomeric half-mask respirator (EHMR), which has the same ability to filter infected particulate matter and allows for a tight fit over the face. In addition, the face piece can be disinfected with alcohol or bleach and the cartridges can be replaced to allow for reuse. Pompeii *et al*[15] recently reported that healthcare personnel can be rapidly fit tested and trained to use the EHMR. The utilization of other types of masks with the same functionality as the N95 has been discussed, including the use of anesthesia face masks attached to HEPA filter and straps. See the Occupational Safety and Health Administration (OSHA) video on the application of N95 and EHMRs at https://www.osha.gov/video/respiratory_protection/resptypes.html.

IMPROVING INPATIENT CAPACITY BY MINIMIZING SCHEDULED CASES

During a heavy influx of patients affected with COVID-19, hospital bed availability and critical care resources may become severely limited. A typical approach has been to create capacity by limiting routine clinical work. However, other clinical needs continue and cannot be ignored as the delay in management of emergent or urgent patient care can increase morbidity and mortality. Disrupted supply chains leading to limited PPEs, medical devices, and critical care resources and limitations in inpatient capacity make it necessary to identify patients whose care may be delayed without harm versus those whose health will be compromised by delay in care.

Procedure prioritization

A successful strategy for determining which invasive procedures should be allowed to proceed must take into consideration the medical urgency or risk to the patient, the resources required before, during and after the procedure, and the resources available within the local health system. One very reasonable approach was adopted by the TriHealth hospital system in Cincinnati, Ohio (M Delworth, MD; D Kirkpatrick, MD) and is offered here for consideration. The tiers of care take each of the factors listed previously into consideration so that lower priority (higher level number) cases are the first to be cancelled in a 'bottom up' approach (box 2).

While this stratification of case priority is clearly logical, interpretation requires a nuanced understanding of the clinical conditions being considered. For example, a cerebrovascular or endovascular specialist may see cases of obviously high urgency, such as stroke or subarachnoid hemorrhage, and cases clearly considered elective, such as embolization of a low-grade dural fistula causing tinnitus. However, many other cases are in the grey zone—for example, large unruptured aneurysms with significant yearly risk of rupture, carotid endarterectomy or stent for symptomatic disease, which should be done sooner rather than later as benefit wanes the longer one waits.

Consideration should also be given to what kind of delay is reasonable in some situations when it comes to prioritizing patients on a future schedule on a way back towards normalcy.

Many disease states may allow for several months of delay without any evidence of expectation of harm to the patient in excess of the periprocedural risk in itself.

Clinical and resource criteria

Assignment of cases at priority levels II and III should consider the risk of progression or recurrence of disease, the likely rate of that progression, and the potential adverse effect on the patient's outcome should progression or recurrence occur. It must also take into consideration the resources required to perform the procedure and to manage the patient before and after the procedure. One condition may have only a moderate concern for progression or recurrence, but its management may require few critical resources and only a brief stay in hospital, if any. Another may have a higher concern for progression or recurrence but require a lengthy stay in the ICU, possibly on a ventilator, and use of critical resources for many days. In this scenario, the first procedure may be allowed to move forward but the second may not. Guidance for appropriate prioritization of common neurovascular procedures based on these criteria is given in box 3.

CONCLUSIONS

Infection from the SARS-CoV-2 virus has led to the COVID-19 pandemic. Given the large number of patients affected, healthcare personnel and facility resources are stretched to the limit; however, the need for urgent and emergent surgical and interventional care will continue. We describe best practice options when providing neurosurgical treatment of patients with COVID-19 in order to optimize clinical care and minimize the exposure of patients and staff. The described best practices may apply to a variety of operative and interventional procedures given that the goal of preventing SARS-CoV-2 exposure is of the utmost importance in all disciplines.

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