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# Subarachnoid hemorrhage guidance in the era of the COVID-19 pandemic – An opinion to mitigate exposure and conserve personal protective equipment

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Aneurysmal subarachnoid hemorrhage (SAH) patients require frequent neurological examinations, neuroradiographic diagnostic testing and lengthy intensive care unit stay. Previously established SAH treatment protocols are impractical to impossible to adhere to in the current COVID-19 crisis due to the need for infection containment and shortage of critical care resources, including personal protective equipment (PPE). Centers need to adopt modified protocols to optimize SAH care and outcomes during this crisis. In this opinion piece, we assembled a multidisciplinary, multicenter team to develop and propose a modified guidance algorithm that optimizes SAH care and workflow in the era of the COVID-19 pandemic. This guidance is to be adapted to the available resources of a local institution and does not replace clinical judgment when faced with an individual patient.

**Keywords:** Subarachnoid hemorrhage—COVID-19—Critical care—Aneurysm—Vasospasm—Endovascular—Fever—PPE  
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## Introduction

Aneurysmal subarachnoid hemorrhage (SAH) patients require frequent neurological examinations, neuroradiographic diagnostic testing and lengthy intensive care unit stay. Previously established SAH treatment protocols are

impractical to impossible to adhere to in the current Coronavirus-Disease-2019 (COVID-19) crisis due to the need for infection containment and shortage of critical care resources, including personal protective equipment (PPE) and health care providers. As with acute stroke protocols, centers need to adopt modified protocols to optimize

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SAH care and outcomes during this crisis.<sup>1–4</sup> In this opinion piece, we assembled a multidisciplinary, multicenter team to develop and propose a modified guidance algorithm (Table 1) that optimizes SAH care and workflow in the era of the COVID-19 pandemic. This guidance is to be adapted to the available resources of a local institution and does not replace clinical judgment when faced with an individual patient.

### First contact in the field and Emergency Department

Every suspected SAH patient (evaluated in the field, direct presenting to the Emergency Department (ED) or in transfer) should be screened for possible COVID-19 symptoms and risk factors per local institutional guidelines. Symptoms and risk factors may include, but are not limited to: cough, fever, shortness of breath, new loss of taste or smell, nausea, vomiting, diarrhea, myalgia, and potential exposure to a COVID-19 positive person.

Any patient identified as meeting COVID-19 investigation criteria should be immediately placed under droplet plus contact precautions and into a negative pressure room if available. A surgical mask should be placed on the patient<sup>5</sup> unless the patient is intubated. Utilize telecommunication tools (phone +/- video) for neurological assessments if available. Follow local institutional guidelines for persons under investigation (PUI) for COVID-19, including nasopharyngeal swab testing or the recently available rapid severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) test.

If there is positive pulmonary symptomatology, consider non-contrast chest CT at the same time as head and neck CT/ CTA. CT chest can facilitate diagnosis of COVID-19<sup>6</sup> but may be nonspecific. Note, if a patient is clinically unstable, received in transfer from another hospital, or has already returned from radiology, chest CT should not be performed prior to aneurysm securing. Urgent stabilization and resuscitation including treatment of acute life-threatening hydrocephalus should follow established societal guidelines.<sup>7,8</sup>

Long intravenous tubing can be utilized through the patient's course to help maintain drips for patients in need of hemodynamic support or blood pressure lowering. The medication pump can be titrated outside the patient's room to protect nursing staff from exposure and to limit PPE use. However, these long intravenous tubings should be used judiciously. With increased use, shortages of these tubing have now been reported.<sup>9</sup> Long intravenous tubing is typically used with central lines, midlines or peripherally inserted central catheters. Peripheral intravenous (IV) lines may not work as well with long tubing due to flow rate challenges with longer tubing and smaller diameter of the peripheral IV.<sup>9</sup> Bar code scanning with the patient's medication and identification may not be possible when the pumps are located outside the

patient's room, and hence extra caution should be utilized to avoid medication error. Pumps in the hallway should not be used when there are two patients in one room. Tripping over long extension lines could expose patients and health care workers to fall risk.

Decisions for definitive securing of the aneurysm via embolization or microsurgical clipping should be discussed in a multi-disciplinary approach based on the clinical and imaging findings. If the patient is felt to be a good endovascular candidate, cerebral angiography and/or aneurysm embolization should be planned with general anesthesia.

In patients in whom aneurysm securing is delayed for unavoidable reasons, empiric use of pro-thrombotic agents such as aminocaproic acid or tranexamic acid should be avoided due to the presumptive increased risk of disseminated intravascular coagulation or pro-thrombotic conditions in COVID-19 patients.<sup>10–13</sup>

### Aneurysm repair

Patients with good-grade SAH should be treated as per standard guidelines.<sup>7,8,14</sup> In the setting of the COVID-19 pandemic with severe shortages of ventilators and critical care beds,<sup>15</sup> thresholds for treating patients with high-grade SAH with diffuse cerebral edema or other comorbidities need to take into consideration the patient's likelihood of benefit and in accordance to proposed ethical frameworks for resource allocation during a pandemic.<sup>16</sup> This needs to be balanced by the fact that many high-grade patients can recover well even if presenting with high-grade SAH.<sup>17,18</sup>

Early aneurysm repair should be pursued as per local protocols to prevent aneurysmal re-rupture. In centers where there is a rapid turnaround time for SARS-CoV-2 testing (i.e. within few hours), it may be reasonable to wait for this test result as preparations are made to secure the aneurysm. A negative test may decrease PPE usage among all staff members. However, precautions should still be utilized in high-suspicion patients in the event of a false negative test.

### Consent and health care proxy

If the patient is not able to participate in the informed consent process, the legally authorized representative (LAR) should consent for the patient. Two physician emergency consent should be obtained if the LAR is not available in a timely manner.

If the patient is able to participate in the informed consent process, perform verbal procedural consent with a witness and avoid contact with inanimate objects such as pens and tablets which can be potential vehicles of viral transmission.<sup>19</sup> Alternatively, if a physical signature is preferred or required, pens should be disinfected before and after contact with the patient. To minimize patient contact and preserve PPEs, a single informed consent session should include all necessary consents such as consent

**Table 1.** Subarachnoid hemorrhage traditional protocol vs COVID-19 pandemic guidance.

| Locations workflow                                         | Traditional protocol                                                                                                                                                                 | COVID-19 pandemic                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>First contact in the field and Emergency Department</b> | <ol style="list-style-type: none"> <li>1. Secure airway, breathing, circulation (ABCs)</li> <li>2. Control hypertension per institution protocol</li> <li>3. STAT imaging</li> </ol> | <ol style="list-style-type: none"> <li>1. COVID-19 risk screen, if yes =&gt; Place under COVID-19 precautions</li> <li>2. Secure ABC. If COVID-19 PUI =&gt; full PPE for airborne precautions. If COVID-19 PUI with suspected impending respiratory failure =&gt; Intubate early under controlled situation in negative pressure room, if available.</li> <li>3. Control hypertension per institution protocol</li> <li>4. STAT CT/CTA head and neck; consider concomitant chest CT</li> <li>5. Patient wears surgical mask if not intubated</li> </ol>                                                                                                                                                                                       |
| <b>Airway</b>                                              | Airway and respiratory support per standard of care                                                                                                                                  | Evaluate patient's airway, respiratory status. If high oxygen requirement, tachypneic, orthopneic, unable to protect airway, consider COVID-19 precautions and early controlled intubation in negative pressure room and following COVID-19 airway workflow per local institutional protocol. Avoid BP fluctuation during intubation, particularly sudden hypertension.                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Initial imaging</b>                                     | Emergent CT/CTA head.                                                                                                                                                                | <ol style="list-style-type: none"> <li>1. If COVID-19 PUI =&gt; to CT/CTA head with precautions per institutional policy.</li> <li>2. Consider also obtain chest CT for COVID-19 evaluation (note: sensitivity and specificity may be limited)</li> <li>3. Decontamination of CT scan suite per institutional policy.</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>EVD</b>                                                 | Emergent bedside EVD placement as needed.                                                                                                                                            | <p>If COVID-19 PUI =&gt; Emergent bedside EVD placement with droplet precautions, in negative pressure room if available, with full PPE.</p> <p>Minimize number of people in the room.</p> <p>If need conscious sedation for EVD placement and concern for respiratory insufficiency =&gt; intubate early under controlled conditions.</p> <p>Consider lumbar drainage as alternative in patients with communicating hydrocephalus with no contraindications (i.e. intraparenchymal hemorrhage, low cerebellar tonsils)*</p>                                                                                                                                                                                                                  |
| <b>Consent and HCP</b>                                     | If patient is unable to participate in informed consent process, identify LAR for surrogate consent.                                                                                 | If patient is able to participate in informed consent process, obtain verbal consent with witness or adhere to local protocol. Include consent for other potential relevant procedures at the same time (anesthesia, external ventricular drain, access line). If the patient is unable to participate in informed consent process, identify LAR for surrogate consent. Visitors likely are not permitted in the ER/ICU and therefore LAR need to be contacted via phone/videoconference. Use 2-physician emergency consent only if LAR cannot be reached and the procedure is considered indicated for life-threatening reasons                                                                                                              |
| <b>Aneurysm treatment – pre-op angio suite/OR</b>          | CTA review and aneurysm treatment planning with neurointerventionist, neurosurgeon, neurointensivist or per local protocol.                                                          | <p>CTA review and aneurysm treatment planning with neurointerventionist, neurosurgeon, neurointensivist or per local protocol.</p> <p>Designated angio suite or operating room for COVID-19 if multiple rooms available.</p> <p>COVID-19 room preparation including clearing all unnecessary equipment, preparing medications and necessary equipment in advance, cover supply closets before patient entrance, utilization and covering of lead shields for radiation and COVID-19 protection.</p> <p>In patients where there is unavoidable delay of aneurysm securing procedure, avoid empiric use of pro-thrombotic agents such as aminocaproic acid or tranexamic acid given presumptive increased DIC/ thrombotic risk in COVID-19.</p> |

(Continued)

Table 1 (Continued)

| Locations workflow                                            | Traditional protocol                                                                                                                                                                                                     | COVID-19 pandemic                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Aneurysm treatment – intra-op angio suite/OR</b>           | Hemodynamic support                                                                                                                                                                                                      | In COVID-19 patient or PUI, careful attention to intra-procedure fluid balance, maintain euvolemia, avoid hypervolemia.<br>Avoid blood loss.<br>Full PPE for COVID-19 or suspect patients per institutional protocol<br>Consider PAPR during craniotomy to minimize inhalational and transconjunctival exposure.                                                                                                                                                                                                                      |
| <b>Aneurysm treatment – immediate post-op angio suite/OR</b>  | Access site checks per institution protocol<br>Multiple teams examine patient post-procedure (i.e. nursing, neurocritical care, neuro-interventional, neurosurgery)<br>Family communication in person if family on site. | OR team in full PPE brings patient to ICU and performs access site/craniotomy site check and initial neurological exam in the ICU before exiting room and doffing PPE. Receiving team stays outside of the room.<br>Combine vital sign, neuro exam, access site checks with one provider in PPE.<br>Be proactive with family communication given visitation rights restricted in COVID-19. In high-grade patients or those at risk for pulmonary deterioration, early discussion of goals of care.                                    |
| <b>Post aneurysm treatment ICU care:</b>                      |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Care location</b>                                          | NICU or other specialized critical care locations able to care for SAH patients.                                                                                                                                         | High-grade (WFNS $\geq 3$ ) SAH or intubated, not COVID PUI: NICU<br>COVID-19+ or PUI (all grades): COVID unit per institutional protocol<br>Low-grade SAH (WFNS $< 3$ ), no EVD: step-down unit with frequent neurological exam capability                                                                                                                                                                                                                                                                                           |
| Neurological monitoring:                                      | Q2h neuro exam                                                                                                                                                                                                           | Utilize tele-communication technology for clinical neuro exam monitoring.<br>Enter room q4h instead of q2h<br>If COVID-19 + with ARDS:<br>-Follow institutional/SCCM guideline for COVID-19 ARDS management. Run strictly normovolemic. Prone early. Intubate early under controlled situation. Avoid non-invasive positive pressure ventilation or high-flow oxygen.<br>-Neuro exam may not be available due to sedation/paralysis<br>Avoid hypotension which may increase risk for DCI/brain injury in SAH.                         |
| Laboratory/investigational tests                              | Echocardiography per institutional protocol<br>Laboratory studies per local SAH treatment protocol and/or national guideline.<br>CT, CXR as needed                                                                       | Limit focused bedside clinical point-of-care ultrasound use if critical assessment of cardiac function and hemodynamic status needed.<br>Lung ultrasound instead of CXR if clinically applicable.<br>Minimize blood draws to every other day                                                                                                                                                                                                                                                                                          |
| DCI prophylaxis:                                              | Nimodipine 60 mg q4h. If hypotension occurs -> nimodipine 30 mg q2h.<br>Maintain euvolemia: monitor in/out balance q4h                                                                                                   | Nimodipine 60 mg q4h. If hypotension occurs -> nimodipine 30 mg q2h.<br>If COVID-19 patient with ARDS => judicious fluid use to maintain euvolemia, avoid hypervolemia. Hypovolemia should only be considered in refractory hypoxia cases, as hypovolemia may worsen DCI.                                                                                                                                                                                                                                                             |
| Vasospasm monitoring/symptomatic DCI treatment considerations | Daily TCDs<br>Neuro exam<br>Euvolemia, permissive hypertension with secure aneurysm<br>Possible advanced monitoring techniques                                                                                           | -In low-grade (WFNS $< 3$ ) patients: Spread out or defer routine TCDs. Monitor neurological exams. No CTA/angio at day 7 unless otherwise clinically indicated.<br>-In moderate-grade (WFNS = 3) patients: spread out or defer routine TCDs, monitor neurological exam, no day 7 CTA or angio unless clinical deterioration occurs.<br>-in high-grade (WFNS 4-5) patients: spread out routine TCDs. Neuro exam is not sensitive screen for DCI and this group of patients are at high risk for vasospasm. Perform CTA or angio post- |

**Table 1 (Continued)**

| Locations workflow                  | Traditional protocol                                     | COVID-19 pandemic                                                                                                                                                                                                                                                     |
|-------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ICP and CSF output monitoring       | per institutional protocol (e.g. cEEG, modal monitoring) | bleed day 6–8. If suggestive of vasospasm – discuss whether, when, and how often to undergo endovascular evaluation/therapy. COVID-19 patients with symptomatic hypoxic/ respiratory failure requiring intubation may not tolerate medical therapy for DCI/vasospasm. |
| Thromboprophylaxis and coagulopathy | EVD wean per institution protocol                        | EVD wean early if patient can tolerate                                                                                                                                                                                                                                |
| Post-acute Care                     | DVT Prophylaxis per institution protocol                 | CrCl > 30 ml/min, low molecular weight heparin                                                                                                                                                                                                                        |
|                                     | Coordinate with case management                          | CrCl < 30 ml/min, heparin (see Table 2 for doses)                                                                                                                                                                                                                     |
|                                     |                                                          | Test for COVID-19 in patients who have not been tested if going to post-acute care facility, or in patients with high suspicion.                                                                                                                                      |

See accompanying text.

PAPR: Powered air-purifying respirator, PUI: Person under investigation, L:AR: Legally authorized representative, DCI: Delayed cerebral ischemia, ARDS: Acute respiratory distress syndrome, SCCM: Society of Critical Care Medicine, TCD: Transcranial doppler, EVD: External ventricular drain, ICP: intracranial pressure, CSF: cerebrospinal fluid, WFNS: World Federation Neurosurgery, OR: Operating Room

for general anesthesia, aneurysm securing, external ventricular drain (EVD) placement, central line and/or arterial line if appropriate.

In addition, the patient should designate a health care proxy with a staff witness in the event that patient loses the ability to provide informed consent later in their hospital course.<sup>19</sup>

### Airway preparation

When a patient with suspected or confirmed COVID-19 is at risk for impending respiratory failure (i.e. orthopnea or respiratory distress lying flat, high oxygen requirement, rapid neurological decline), consider early and controlled intubation in a negative pressure room in the ER/ICU/OR with staff wearing full PPE including N95 mask, gown, double gloves, face shield or per local institutional COVID-19 intubation policy. An aerosol box can be utilized to protect the intubating proceduralist from droplet and aerosol spread.<sup>20,21</sup> Most angiography suites are positive pressure rooms; hence, this would not be the room of choice for any non-emergent aerosolizing procedure. Following intubation and while the clinical team is still in full PPE, consider completing all other potentially necessary procedures such as placement of an oro-or naso-gastric tube in high-grade patients thought likely to need enteral access, and/or central venous line and/or arterial line access for close hemodynamic monitoring and control.

### Cerebrospinal fluid diversion

Cerebrospinal fluid diversion should proceed according to otherwise established guidelines and institutional practices.<sup>7,8</sup> Any neurosurgical procedure that requires a burr hole including an EVD placement should consider the logistics of minimizing the risk of virus aerosolization during drilling. Prior research has shown in animal models that bony microspicules can serve as a vector of virus transmission, including through the cornea, although the applicability to SARS-CoV-2 is unknown.<sup>22</sup> Although it is expected that aerosolization through a twist-drill is reduced compared with a high-speed drill, the procedure should be performed using full PPE in COVID-19 confirmed or suspected patients including the use of a face-shield and an N95 respirator. Additionally, depending on the clinical urgency and the hospital logistics, consider performing this procedure in a negative-pressure room. Due to these considerations, as well as the hypercoagulable state associated with COVID-19 which may require early venous thromboembolism prophylaxis, lumbar CSF drainage may be an option in patients with communicating hydrocephalus who do not have contraindications such as an intraparenchymal hemorrhage or low-lying cerebellar tonsils.

## Endovascular aneurysm securing room preparation before patient arrival

Similar to thrombectomy room preparations,<sup>19</sup> when treating a COVID-19 confirmed or suspected patient, all unnecessary objects or items in the angiography suite / operating room (i.e. lead aprons that won't be utilized) should be removed to minimize need for cleaning post-procedure. Countertop items should be covered with plastic or removed. Medications and the procedural table should be prepared in the room before patient arrival (i.e. for an angiography suite, cover detector, pedals with plastic, bags etc.) to minimize the time of the patient in the room and to protect room equipment. The cabinets and supply closet should be covered before the patient arrives.<sup>19</sup>

Gloves, a face shield that covers the eyes, N-95 mask or powered, air-purifying respirator (PAPR) and protective gear should be utilized in COVID-19 PUI or positive patients. In an angiography suite, hanging lead shields and standing lead shields should be used as another layer of protection.

Proceduralists' pager and phone should be placed inside plastic bags at a pre-planned area in the control room and communication maintained in the event the proceduralist is called. Devices should be placed in plastic bags that can be cleaned from the outside.

## Aneurysm securing intra-procedure

Staff should be kept to a minimum during the procedure (i.e. 1 nurse, 1 technologist/scrub RN, 1 physician, 1 anesthesiologist) to minimize exposure, conserve PPE and to allow 6 feet of distancing. All persons in the control room should wear a surgical mask particularly if there is an opening between the procedure room and the control room. Place a sign on the room or tape the doors to avert room entry without protective gear.

Maintain euolemia during the aneurysm procedure but take care to avoid hypervolemia/over-resuscitation given the risk of pulmonary complications in COVID-19 patients may be worsened by excessive fluid intake. Intraprocedural blood loss and need for transfusion should be minimized due to the current national shortage of blood products.

Discuss with the primary team regarding additional blood tests the proceduralist can draw off the arterial sheath for COVID-19 and SAH workup (i.e. ABG, CBC, Comprehensive metabolic profile, LFTs, BNP, CK in young patients, Troponin, Ferritin, CRP, Sedimentation Rate, D-dimer, fibrinogen, cardiac biomarkers, and additional coagulation studies).<sup>23</sup>

If available, performing cone-beam CT in the angiography suite or hybrid room at the end of the procedure may help avoid another trip to CT post-procedure to evaluate for developing hydrocephalus or interval hemorrhage.

## Aneurysm securing by open craniotomy

When microsurgical clipping is determined to be the best modality for aneurysm treatment, there are many

considerations among patients who are SARS-CoV-2 confirmed, suspected, or unknown. Due to the risk of virus aerosolization during bony work, as described above, operating rooms should be set up to minimize the risk of contamination of equipment and staff members. As high-speed drills have a risk of aerosolization, surgeons and staff members may want to consider the use of a PAPR during the actual craniotomy to minimize the risk of both inhalational and transconjunctival exposure. If PAPR is not available, then an N95 mask and full face-shield or protective goggles may be used.<sup>24</sup> Given the logistical limitations to wearing full PPE while utilizing the operating microscope, as well as the fact that arachnoid dissection and aneurysm clipping may be a lower risk portion of the procedure, it would be reasonable for surgeons to continue to use the N95 mask and may consider forgoing eyewear. The eye piece of the operating microscope should be disinfected and fully covered prior to the surgeon coming into contact with equipment without eyewear. Given the high-viral load that is associated in the upper airway and sinuses, a clinoidectomy may be a high-risk portion of the procedure, particularly if the clinoid is pneumatized. To minimize aerosolization, consider preferentially using non-powered tools such as curettes.<sup>25</sup>

## Neurological exam, vital sign and access site checks post-aneurysm securing therapy

Post-procedure neurological exams and access site checks should be performed by one identified provider and minimized to conserve PPE.

When the patient is handed off to the receiving team, the gowned provider can check the patient's neurological exam, vital signs, and/or access/EVD/craniotomy sites prior to doffing their PPE. This can count as the 15- or 30-min check post-procedure, depending on the time performed.

When available, telecommunication/video should be utilized to evaluate the patient remotely. Otherwise, consider another neurological exam, vital sign and/or access site check 30 min after hand-off, and then every hour for two consecutive hours. Thereafter, these combined checks can be performed every 4 h.

The frequency of combined neurological, vital sign, and/or access site checks should be adjusted depending on the patient's clinical status (less if they are intubated and sedated), the patient's hemodynamic stability, and concern for access site bleeding.

## Post-aneurysm securing

Telephone or video communication with the family to update them post-procedure is important, as visitation rights may be restricted. In high-grade SAH patients thought likely to have a poor prognosis, consider early goals of care discussions with the family.

During rounding, stable SAH patients on contact and/or droplet precautions should be seen at the end of rounds to avoid unintentional viral spread to patients not on precautions.

### Neurocritical care and subsequent step-down course

A non-intubated, good-grade SAH patient may be treated on a step-down unit with appropriate nursing expertise in the event of a severe shortage of critical care beds. In stable, good-grade SAH patients, nursing and neurological exam checks may be reduced to every two or every four hours. In patients who are at high risk for neurological deterioration and requiring frequent (hourly or more frequent) neurological examinations, it may be feasible for the nurse in full PPE to stay inside the room with scheduled breaks to minimize PPE use and repeated PPE donning and doffing.

Repatriation of SAH patients to centers with neurosurgical or neurocritical care expertise can also be considered in systems of care with shortages in critical care beds. This model has been demonstrated to work well in maintaining access for thrombectomy patients.<sup>26</sup>

To minimize patient/staff exposure and preserve PPEs, consider deferring and minimizing tests that are unlikely to change clinical management. For example, daily transcranial Doppler in an asymptomatic patient is unlikely to change management<sup>27</sup> and there is little evidence that routine TCD in SAH patients leads to better outcomes.<sup>28</sup> Alternatively, a modified transcranial doppler protocol with a focus on an artery of concern could be considered for a related clinical concern.

Diagnostic testing for SARS-CoV-2 status should be obtained as soon as possible in all symptomatic or high-risk patients. In the event a patient develops classical symptoms of COVID-19 following initial negative screen for SARS-CoV-2 virus, repeat SARS-CoV-2 testing should be considered as initial testing may be falsely negative and interval nosocomial transmission is possible.

SAH patients should maintain intravascular euvolemia per national treatment recommendations and guidelines. In COVID-19 suspected and/or confirmed patients with symptomatic pneumonia, avoid intravascular hypervolemia given the risk of respiratory deterioration and hypoxia with fluid resuscitation in ARDS.<sup>29</sup>

As per ICU best practices, repeated ICU-phlebotomy should be minimized to reduce risk for anemia of chronic investigation and need for blood transfusion. In stable, good-grade SAH patients, consider reducing daily phlebotomy practice to every-other day or less. Frequently monitored laboratory studies in SAH patients include complete blood count and basic metabolic panel. Additional laboratory investigations to consider for COVID-19 suspected or confirmed patients include liver function tests (LFTs), total creatine kinase (CK), cardiac troponin to screen for

myocardial injury, and biomarkers associated with severe COVID-19 infection and poor outcome such as ferritin, C-reactive protein (CRP), d-dimer, and fibrinogen.<sup>23</sup>

Early weaning of the external ventricular drain should be considered in all patients regardless of SARS-CoV-2 status to minimize the risk of catheter-associated infection. As patients with COVID-19 may have persistent pyrexia, sampling of cerebrospinal fluid should consider the clinical probability of a catheter-associated ventriculitis and should not be performed based on temperature alone. To date, there is report of one patient with meningitis and SARS-CoV-2 detected in cerebrospinal fluid.<sup>30</sup>

Tracheostomy may be necessary in patients with prolonged endotracheal intubation for neurologic and/or pulmonary reasons. Performing tracheostomy in a COVID-19 confirmed or suspected patient poses high risk to the surgical team and health care providers. The Hong Kong SARS experience reported this could be done without transmission to the surgeon and staff.<sup>31</sup> Recommendations include adequate pre-oxygenation (100% oxygen for 5 minutes), complete paralysis to ensure there is no coughing or movement, ventilation only with cuff inflation, stopping ventilation prior to entering the airway, avoiding suctioning, and minimizing cautery.<sup>32</sup>

### Coagulopathy and thromboprophylaxis

Thromboprophylaxis should be initiated as soon as the aneurysm is secured and there is no evidence of a bleeding diathesis or requirement for an urgent EVD (Table 2). The rates of thromboembolic complications may be high in severe COVID-19 patients, with DVT reported in 25%<sup>33</sup> and PE in 21%,<sup>34</sup> despite already being on thromboprophylaxis. Case series to date suggest that coagulopathy and elevated serum d-dimer levels are associated with higher risk for multi-organ failure and mortality in COVID-19,<sup>13</sup> and low molecular heparin use may reduce mortality.<sup>12</sup> Patients with D-Dimer elevation to greater than 6 times normal value or elevated sepsis induced coagulopathy (SIC) scores > 4 may derive a mortality benefit from thromboprophylaxis.<sup>13</sup> Additionally, patients who weigh greater than 100kg may benefit from higher doses of thromboprophylaxis.<sup>35</sup> At this time, there is limited evidence to support routine use of full dose anticoagulation in patients with severe COVID-19. For patients with creatinine clearance less than 30 ml/min, subcutaneous heparin should be used for thromboprophylaxis instead of low-molecular weight heparin. Prior to starting an anticoagulant in a patient with EVD or post craniotomy either for venous thromboembolism chemoprophylaxis or systemic anticoagulation, it is important to ensure there is consensus among the treating neurointensivist, neurosurgeon, and/or neurointerventionist and adherence to local institutional protocol.



**Table 2.** Anticoagulation in COVID-19 patients with SAH.<sup>a</sup>

|                                                   |                                                                                                                                             | LMWH suggested doses<br>Cr CL $\geq$ 30 mL/min | Heparin for CrCL<br>$\leq$ 30 mL/min  |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|---------------------------------------|
| Low risk<br>standard dose                         | SAH<br>COVID-19 PUI or confirmed                                                                                                            | Enoxaparin 40 mg/kg daily                      | Heparin 5000 U BID                    |
| Intermediate risk<br>consider high intensity dose | Weight > 100 kg<br>SIC > 4<br>D-Dimer > 6-fold normal                                                                                       | Enoxaparin 40 mg/kg BID                        | No bolus<br>and low APTT Goal         |
| Confirmed or high risk<br>full anticoagulation    | Confirmed DVT or PE<br>Established indication for<br>anticoagulation High clinical<br>concern and unable<br>to perform confirmatory testing | 1 mg/kg enoxaparin BID                         | Bolus and standard<br>APTT Goal 55–90 |

<sup>a</sup>Please see accompanying manuscript, obtain consensus with neurointensivist, neurosurgeon, and/or neurointerventionalist or per local protocol. CrCL: Creatinine clearance; SAH: subarachnoid hemorrhage. DVT: deep venous thrombosis. PE: pulmonary embolism. LMWH: low molecular weight heparin. SIC: sepsis induced coagulopathy.

### Delayed cerebral ischemia (DCI)

In COVID-19 confirmed or suspected patients with hypoxia and/or respiratory failure, early discussion and pre-planning of potential treatment approaches for possible cerebral vasospasm is recommended. SAH patients with concomitant symptomatic hypoxia and/or respiratory failure due to COVID-19 may not tolerate medical therapy for DCI such as intravascular volume resuscitation or induced hypertension therapy. Use of vasopressor agents alone for blood pressure augmentation without volume resuscitation may be warranted. Patients with cardiac involvement of COVID-19 may need inotropic support and yet may not tolerate the pro-arrhythmogenic effects of inotropes. Vasospasm treatment strategies may need to be individualized based on each patient's clinical condition. In a patient who develops new focal neurological deficit attributable to cerebral vasospasm whose symptoms are refractory to or unable to tolerate medical therapy, consider early intra-arterial therapy under controlled conditions and with adequate PPE.

Given the reported increased risk for acute kidney injury (AKI) in 5-25% of COVID-19 patients,<sup>36, 37</sup> routine use of surveillance CTA/CTP for vasospasm screening should be minimized as the contrast load may increase risk for AKI and CTA is not a therapeutic procedure.

### Psychological intervention

An evaluation of a patient's mental health is essential to alleviate the psychosocial impact of the COVID-19 pandemic for a patient in isolation with a new diagnosis of SAH.<sup>38</sup> This can be done via telemedicine with a social worker, psychologist, or psychiatrist.

Health care workers on the frontline of care for COVID-19 patients are also vulnerable to the psychological burden of this pandemic and should be attended to.<sup>39</sup>

A periodic multi-disciplinary team debrief to learn from each patient and perform quality improvement is important.

### Post-acute care

In patients who will be transitioning to a post-acute care facility, consider routine SARS-CoV-2 screening prior to transfer to minimize risk for asymptomatic viral transmission to the receiving facility.<sup>40</sup> Coordination with case management, the post-acute care facility and the primary team is important.

### Conclusion

The COVID-19 pandemic has wreaked havoc on health-care systems worldwide. Clinical protocols for SAH care must be adjusted to incorporate infection containment, adequate provider staffing, PPE and critical care resources conversation while optimizing patient safety and care. We provide potential recommendations for SAH clinical protocol adjustments in this new COVID-19 era. Recommendations are subject to change with new data and scientific advances.

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### Declaration of interest

none

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