Mitigation of COVID-19 transmission in endoscopic and surgical aerosol-generating procedures: a narrative review of early-pandemic literature

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Introduction

Coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), emerged in Wuhan, China, in December 2019. Coronavirus disease 2019 is a rapidly evolving and highly contagious disease that has caused numerous unprecedented challenges worldwide, particularly with respect to healthcare systems and the medical community.[1] Accordingly, groups at highest risk of infection include healthcare workers (HCWs); the World Health Organization reported that 22 073 HCWs worldwide had become infected with COVID-19 by 8 April 2020.[1] Although this number may have been influenced by underreporting, it emphasised the need to protect frontline workers in the COVID-19 pandemic.

Although SARS-CoV-2 RNA can be found in various bodily fluids,[2] the most probable modes of transmission involve respiratory droplets, fomites, and the faecal-oral route.[3] Considering that the size of SARS-CoV-2 viral particles ranges from 0.07 to 0.09 µm,[4] the potential for viral transmission via aerosols cannot be excluded.[5] Despite the recognition of specific perioperative and endoscopic procedures as aerosol-generating procedures (AGPs), there is lack of high-quality evidence regarding the potential for viral transmission to HCWs and effective methods to reduce this risk. Furthermore, a Delphi consensus panel confirmed ambiguity in terms of which procedures constitute AGPs.[6] Therefore, this review was conducted to summarise evidence up to July 2020 regarding the transmission of COVID-19 to HCWs via AGPs during surgery and endoscopy, along with recommended measures to minimise associated risks.

Literature search and evidence acquisition

A comprehensive literature search was performed using a combination of keywords (MeSH terms and free text words) including 'COVID-19'/ 'SARS-CoV*'/'SARS'/'MERS', 'aerosol', 'surgery', 'operation/procedure', 'endoscopy', and 'healthcare workers'. MEDLINE, Embase, the Cochrane Database of Systematic Reviews, and the Cochrane Central Register of Controlled Trials were searched up to 18 July 2020. Preprint servers, medRxiv, and bioRxiv were also searched for information up to that date. The search was limited to studies published during or after 2003, when the SARS outbreak began. Only articles published in English or published in another language but containing an English abstract were included. The search strategy is presented in the online supplementary Appendix. The search results were supplemented by guidelines from professional bodies.

Results

Perioperative considerations

Preoperative considerations

For all specialties, only urgent and essential procedures should be performed during the pandemic,[6] with

the smallest possible number of dedicated staff.[6,7] Planning and preparation of all equipment and kits should be conducted in advance to ensure maximal effectiveness with minimal resources.[8] Patients should be screened with a preoperative checklist that includes a COVID-19–specific review of respiratory symptoms, and appointments should be rescheduled when possible.[9] When preparing patients for emergency surgery, multiple triage protocols should be completed before admission and before entry into the operating theatre (OT); later triage protocols should include review of chest X-ray or chest computed tomography (CT) images[10,11] to screen for COVID-19. However, the use of CT to diagnose COVID-19 may be problematic because of the high number of HCWs needed to perform a single scan and the limited availability of personal protective equipment (PPE). Furthermore, air recirculation and thorough cleaning of the CT scan room after each patient may severely disrupt patient flow. The use of CT may also expose patients to radiation risk. Therefore, reverse transcription polymerase chain reaction (PCR) analysis of samples from the nasopharynx or oropharynx should remain the gold standard for diagnosis of COVID-19, as recommended by the WHO.[12,13] In patients with confirmed or suspected COVID-19, elective and non-emergency procedures should be postponed or cancelled because they carry considerable risks of pulmonary complications and postoperative mortality.[14] If emergency surgery operations must proceed, they should be performed in a dedicated negative-pressure OT where possible.[15]

Intraoperative considerations

Erbabacan et al[12] and Lie et al[15] recommended considering regional anaesthesia (when feasible) for patients with suspected or confirmed COVID-19 who are undergoing surgery; regional anaesthesia minimises viral transmission because it avoids airway manipulation, thus reducing aerosolisation.[12,15] Chen et al[16] recommended spinal anaesthesia as the preferred method for patients undergoing caesarean section. Furthermore, the use of PPE and other precautions should be considered when performing nerve blocks in upper limbs or the head and neck.[6] A cohort study by Zhong et al[17] revealed a 95.3% (95% confidence interval=63.7%-99.4%) reduction in anaesthetists' risk of contracting COVID-19 when wearing level 3 PPE, compared to level 1 PPE. When regional anaesthesia is performed on a patient with suspected or confirmed COVID-19, the patient should always wear a surgical or N95 mask. The indications and contraindications for regional anaesthesia must also be thoroughly considered because transition to general anaesthesia may lead to a higher risk of aerosol exposure for all professionals involved. When general anaesthesia is indicated, rapid sequence induction should be used to reduce the risk of coughing; full PPE is also essential.[16]

During surgeries, the use of forced air-warming systems should be avoided because such systems can contribute to aerosol generation. Alternative methods (eg, warming intravenous and irrigation fluids) should be considered.[12] Furthermore, Suresh[18] recommended that communication between the OT and the outside environment is conducted via telephone or other electronic means to reduce instances of door opening; movements of personnel in and out of the theatre should be restricted until case completion. Suresh[18] also recommended prohibiting the use of mobile phones in the OT, while requiring the use of landlines only.

Only essential personnel should be present in OTs, and all surgical personnel should wear appropriate PPE, including N95 masks or powered air-purifying respirators.[9] The use of face masks for source control has not been proven effective in OT settings,[19] but they are widely used in healthcare facilities to prevent infections via spills and sputum.

Postoperative considerations

Postoperatively, patients should recover in the same room and avoid entering large post-anaesthesia care units to reduce the risk of COVID-19 transmission.[20,21] After each procedure, Dexter et al[20] recommended disinfection of the OT and anaesthetic room using ultraviolet C (UV-C) light or fumigation. However, the effectiveness of UV-C action is unclear; therefore, this method should be used as a supplement to manual cleaning.[21] If UV-C light is unavailable, quaternary ammonium compounds should be sprayed on all surfaces using a top-down approach.[20] Additionally, the World Health Organization recommends the use of 75% alcohol and chlorine-based products at concentrations of 0.05% to 0.5%.[22]

Endoscopic considerations

Chan et al[23] revealed that oesophagogastroduodenoscopy (OGD) is an AGP. Coughing and retching, as well as suctioning of the upper respiratory tract, can lead to aerosol release. Viruses can also remain in aerosols for up to 3 hours after OGD.[7] The use of anaesthetic throat sprays for sedation, rather than a lidocaine swallow, can reduce retching and cough; this approach may reduce viral transmission via aerosols.[24] The design of endoscopic instruments, as well as the movement of instruments during OGD, can further enhance aerosol generation.[25] However, continuous use of a dental suction device in the oral cavity can significantly decrease aerosol generation and reduce the risk of disease transmission.[23] As an adjunct to full PPE, a barrier box may also be implemented to enclose the patient's head during OGD, thereby reducing

macroscopic droplet spread and aerosolisation.[26]

Regardless of SARS-CoV-2 shedding and infectivity in the gastrointestinal tract, there is no direct evidence, nor any reported cases, of viral transmission during colonoscopies.[7] Full PPE is recommended when performing endoscopies; the minimum equipment should include an N95 mask, a water-resistant gown, and two sets of gloves.[6,27] Furthermore, the use of a patient-worn perioperative N95/99 diaper is recommended as an additional precautionary measure to prevent aerosol transmission from expulsions of colorectal gas during colonoscopy.[28]

Urgent endoscopies should be conducted by a clinical team dedicated to high-risk patients or, when possible, endoscopies.[7] The use of air or insufflation should be minimised during procedures.[6] Workflows and endoscopy units should be arranged to minimise cross-contamination.[7] Examples include a one-way passage system to transport used and contaminated equipment, separate doorways to enter and exit endoscopy rooms, separate gown-up and gown-down areas, and the use of different rooms for specific endoscopic procedures.[24]

Ideally, endoscopic procedures should be performed in negative-pressure rooms; if such rooms are unavailable, rooms with high-efficiency particulate air (HEPA) filters should be used.[24] Standard room disinfection with effective disinfectants should be conducted before and after each procedure[29]; non-disposable equipment should be disinfected with 3% hydrogen peroxide or 75% alcohol.[12] Endoscopes should be reprocessed using detergents and disinfectants, then subjected to leak assessment in accordance with manufacturer instructions and validated guidelines.[30]

Surgical considerations

Laparoscopy, robotic procedures, and open procedures

Despite the high theoretical risk of COVID-19 transmission associated with aerosols from surgically generated smoke, artificial pneumoperitoneum, ultrasonic scalpels, and electrocautery, there is insufficient evidence to suggest that laparoscopic surgery is contra-indicated.[6,31] Moreover, there is no formal evidence that minimally invasive procedures are AGPs, nor has there been confirmation regarding the potential for aerosol transmission via surgical smoke or insufflation. Laparoscopy has been classified as an AGP,[6] but consistent guidelines for minimally invasive surgery have not been established. At the time of this review, a prospective case-control study regarding surgical smoke contamination by SARS-CoV-2 was underway in Switzerland.[32]

The Association of Laparoscopic Surgeons of Great Britain and Ireland recommended the continued use of laparoscopy over open surgery; other experts have made similar recommendations.[6,33-35] However, some authors oppose this approach because of concerns regarding airborne transmission of COVID-19.[36] The Royal College of Obstetricians and Gynaecologists, in conjunction with the British Society for Gynaecological Endoscopy, recommended the use of laparoscopy alone for procedures with bowel involvement[37] because SARS-CoV-2 is present in stool.[2] A joint statement from the major Royal Colleges of Surgeons recommended the performance of minimally invasive surgery only when clinical benefits outweigh the risk of potential aerosolised viral transmission to surgical personnel.[38] When appropriate PPE is used (ie, fit-tested respirator or HEPA respirator, eye protection, and gowns),[39] laparoscopy does not carry an increased risk of viral transmission.[33]

Despite conflicting indications for minimally invasive surgeries, guidelines and experts agree on intraoperative precautions. During trocar insertion, the incision length should be minimised to ensure an adequate seal.[6] The use of surgical energy devices should be minimised[35]; when such devices are necessary, the lowest power setting should be used to reduce surgical smoke.[6,12] Where possible, the accumulation of blood should be avoided by wrapping the surgical field with gauze to reduce aerosolisation when blood comes in contact with the surgical energy device.[40] For procedures that involve the creation of an artificial pneumoperitoneum, a flow rate of 5-10 L/min is recommended[6]; a high degree of caution is needed during trocar insertion/removal and specimen retrieval.[33] The application of a smoke evacuation system or trocar-specific suction has also been recommended.[31] The use of AirSeal mode may help to control airflow during the creation of an artificial pneumoperitoneum.[31,34] The incorporation of valveless access ports minimises gas leakage during instrument exchange, thereby decreasing the risk of disease transmission.[31,33,36] However, the recirculation of carbon dioxide within the pneumoperitoneum carries a higher theoretical risk of viral aerosolisation during AirSeal mode; thus, the type of trocar used in AirSeal or smoke evacuation mode must be thoroughly considered. A lower pneumoperitoneum pressure (≤12 mmHg) should be used to reduce potential aerosolisation of SARS-CoV-2.[31] Special considerations, such as the use of a HEPA filter, are needed to minimise potential gas leakage during deflation after a laparoscopic procedure.[34] Additionally, trocars should also be removed only after desufflation.[37] The conversion of OTs to negative-pressure rooms should also be considered.[39] The above precautions should also be implemented during robotic procedures.[31]

Coccolini et al[41] reported the presence of SARS-CoV-2 in the peritoneal fluid of a patient with confirmed COVID-19 during laparoscopy for bowel

obstruction; in this fluid, the viral load was higher than loads observed in the patient's own respiratory cultures. Although viral isolation has not been achieved, and no further evidence of transmission has been reported, the potential for transmission via peritoneal fluid should be considered when choosing between laparoscopy and open surgery.[42]

Urology

There is potential for SARS-CoV-2 exposure via urine.[2] However, the only evidence regarding aerosol transmission of SARS-CoV-2 has been acquired in transurethral resection procedures, during which urine, blood, irrigation fluid, and surgical smoke are mixed.[43] Severe acute respiratory syndrome coronavirus 2 also directly attacks kidney tubules[2]; thus, viral aerosolisation during partial nephrectomy is possible and a high degree of caution is needed. Because SARS-CoV-2 is present in stool, caution is also needed during transrectal prostate biopsy and cystectomy with urinary diversion (involving the use of intestinal tissue).[2]

Cardiothoracic surgery

Although lung isolation is essential for surgical access in thoracic surgeries, the type of access used (eg, single-lumen, bronchial blocker, or double-lumen) requires careful consideration because of the high risk of aerosol generation.[44] Procedures during ventilation, such as bronchoscopy or correction of tube malposition, should be avoided or performed with particular caution to minimise aerosolisation; moreover, continuous positive airway pressure should be conducted with a HEPA filter to manage hypoxia during one-lung ventilation.[44] When establishing surgical access to the chest, ventilation should be interrupted before incision; single-lung ventilation should be resumed when lung integrity and adequate lung exclusion are confirmed.[45] Transoesophageal echocardiography is regarded as a potential AGP[46] and should only be performed when necessary.[47] Similar caution is needed for other potential AGPs such as sternotomy, thoracotomy, chest drain insertion, and the use of a blower-mister during off-pump coronary artery bypass surgery.[46]

Otolaryngology

Otolaryngology procedures carry a high risk of aerosol transmission. Paediatric otolaryngology procedures have a particularly high risk because the proportion of patients with asymptomatic COVID-19 is higher among children.[48] If COVID-19 tests are unavailable, all patients should be assumed to have COVID-19 until proven otherwise.[49] During surgery, pharyngeal packing should be avoided, and the mouth and nostrils should be covered with an adhesive dressing; additionally,

drills, saws, microdebriders, and electrocautery should not be used during surgical procedures involving the mastoid and rhinopharynx.[50] The risks of aerosolisation and bleeding should be carefully considered before choosing to perform intraoperative electric diathermy.[49] For PCR-negative and non-suspicious surgical cases, as well as routine examinations including anterior rhinoscopy and oropharyngeal inspection, basic PPE (surgical cap, N95 mask, goggles, gown, and gloves) is sufficient.[51] For PCR-positive and PCR-negative suspicious surgical cases, as well as higher-risk procedures (eg, throat swabs, endoscopy, treatment of nasal bleeding, or foreign body removal), a higher level of PPE (coveralls, boot covers, and face shield) is needed.[49] A powered air-purifying respirator should be used during invasive airway procedures, such as tracheotomies.[51] There may also be benefits associated with the implementation of a patient-worn enhanced protection face shield.[52]

Chen et al[53] reported increased odds of SARS-associated coronavirus patient–to–HCW transmission during tracheostomies (odds ratio=4.15, 95% confidence interval=1.50-11.50, P<0.01). Mortality is approximately 50% among ventilated patients with COVID-19; thus, tracheostomies should only be considered in patients with favourable prognosis or in patients who cannot be extubated within 2 to 3 weeks.[54] The choice between an open tracheostomy or percutaneous tracheostomy should be made by each medical team based on their own experience and ability to perform the procedure as rapidly and safely as possible.[55]

Bronchoscopes allow visualisation of the introducer needle as it enters the trachea, and their risk of aerosolisation should be minimised by sealing with an in-line suction sheath.[56] Alternatively, operators may choose ultrasound-guided puncture, which is associated with a lower risk of aerosolisation.[57] Compared to laryngotracheal topical anaesthesia, deep neuromuscular blockade is recommended because it prevents coughing and aerosol spread.[58] The ventilator circuit should remain closed throughout the procedure and be opened only when the ventilator is switched on during periods of apnoea.[59] After the procedure, the tracheostomy should not be adjusted until the absence of COVID-19 has been confirmed.[55]

Neurosurgery

The use of high-speed drills for short or long intervals during endonasal surgery is strongly associated with aerosolisation,[60] and the use of such drills should be avoided during endoscopic trans-sphenoidal surgeries.[6] Microdebriders and other non-powered instruments (eg, septum rongeurs and Kerrison rongeurs) can be used because they carry a lower risk of aerosolisation.[61] Furthermore,

to maximise safety during endoscopic skull base surgery, a three-dimensional ventilated upper airway endoscopic procedure mask can be used to create a sealed barrier between surgical instruments and the nasal cavity.[62]

Orthopaedic surgery

Bone sawing and shaving are regarded as AGPs.[6] Therefore, the use of tools such as diathermy machines, oscillating saws, broaches, and pulsed lavage systems should be avoided; additionally, percutaneous surgeries are preferred over open surgeries.[63] During arthroscopic procedures, a separate drainage cannula with attached suction should be used inside the joint to minimise the risk of COVID-19 transmission.[64] When evaluating intraoperative surgical margins of skeletal tumours (eg, sarcomas), imprint cytology is recommended over frozen sections.[65]

Maxillofacial surgery

Many dental and maxillofacial procedures generate droplets and aerosols, thereby exposing dentists and patients to a risk of COVID-19 transmission. With respect to maxillofacial surgical procedures, a preoperative oral rinse with 0.12% chlorhexidine or 0.05% cetylpyridinium chloride is recommended to reduce the levels of microbes in oral aerosols; moreover, a rubber dam and high-volume suction should be used to ensure maximum protection.[6] Notably, the use of any drill in the oral cavity is regarded as an AGP and precautions are needed.[6] The use of local irrigation during mandibular plate screw drilling can substantially reduce aerosol generation.[66] Drills with built-in irrigation systems should only be activated when their tips are fully submerged in a surgical field filled with saline; this approach can reduce aerosol generation.[67]

Ophthalmology

Coronavirus disease 2019 may initially manifest as conjunctivitis; protective shields should be installed on slit lamps, and disinfection should be conducted between consultations.[68] Aerosol-generating procedures (eg, non-contact tonometry) should be avoided; instead, an iCare tonometer or Goldmann applanation tonometer should be used to assess intraocular pressure. Nasal endoscopy should not be performed immediately before or after endoscopic dacryocystorhinostomy.[68] In order to minimise droplet transmission, patients' nose and mouth should be covered by a surgical drape or surgical mask in all procedures performed by oculofacial plastic and orbital surgeons.[69] Currently, there is a lack of evidence regarding whether phacoemulsification and vitrectomy constitute AGPs. However, both involve the use of high-speed instruments[70] and

therefore should be considered as potential AGPs.

A summary of all the evidence and mitigation measures for AGPs in various surgical specialties can be found in the Table.[2,6,8,43-46,48,50,51,53,56,60-65,67,68,70]

Discussion

At the time of writing, there has been considerable controversy regarding the potential for airborne or aerosol transmission of SARS-CoV-2. In laboratory settings, SARS-CoV-2 was reportedly able to remain viable in aerosols for up to 3 hours, with only a 29% reduction in infectious titre.[71] A comparison of community and hospital settings showed that HCWs have a significantly higher risk of contracting COVID-19, relative to the general population.[72] Although the aerosol transmission of SARS-CoV-2 in community settings remains controversial, the potential for viral transmission via AGPs has been recognised.[73] It is clear that the disruption of surface tension in the lining of the respiratory tract is required for airborne viral particles to form; this supports a mechanism associated with aerosol transmission via microdroplets.[5] However, there is a lack of evidence regarding potential aerosol generation from surgical and endoscopic procedures, as well as a lack of expert consensus.[6] Furthermore, conflicting recommendations from different professional bodies have enhanced the uncertainty and anxiety among perioperative and endoscopic personnel.[74] This comprehensive review has explored expert opinions regarding potential AGPs, both before and after surgical procedures and endoscopic procedures, as well as measures to mitigate the risk of COVID-19 transmission to HCWs.

The findings in this review support the following key recommendations. Before surgery, an experienced operating surgeon should be assigned; thorough and accurate triage should be conducted. Additionally, patients should undergo COVID-19 screening on the basis of respiratory samples and chest CT or X-ray images. Non-emergency procedures should be postponed or cancelled. Where possible, regional or spinal anaesthesia should be used to minimise the risk of aerosol generation. However, when general anaesthesia is necessary, it should be performed with appropriate PPE. Intra-operatively, sites of possible cross-contamination should be considered, and the minimum number of personnel should be present. After surgery, transfers to large post-anaesthesia care units should be avoided; thorough disinfection of the OT (using UV-C light or other appropriate disinfectants) is highly recommended.

Oesophagogastroduodenoscopy has been identified as an AGP.[23] Endoscopy remains a high-risk procedure because of the insufflation and viral shedding of SARS-CoV-2 in stool and urine,[2] as well as the potential for induction of coughing. Thus,

TABLE. Summary of evidence and mitigation measures for aerosol-generating procedures in various surgical specialties

Specialty	Evidence	Mitigation
Urology	• Potential for viral shedding in urine and stool[2] • SARS-CoV-2 directly attacks kidney tubules[2] • Transurethral procedures and partial nephrectomy procedures can potentially generate aerosols[43]	• High degree of caution needed for laparoscopic and open procedures, particularly nephrectomy procedures • Caution needed when performing transrectal prostate biopsy or cystectomy with urinary diversion (involving the use of intestinal tissue)[2]
Cardiothoracic surgery	• Lung isolation, OLV, bronchoscopy, transoesophageal echocardiography, sternotomy, thoracotomy, chest drain insertions, and the use of a blower-mister during off-pump coronary artery bypass surgery are potential AGPs[44,46]	• Use of tubing and HEPA filters should be carefully considered during lung isolation and OLV[44] • Ventilation should be interrupted before incision when establishing surgical access to the chest; it should only be resumed if lung integrity and adequate lung exclusion are confirmed[45]
Otolaryngology	• Paediatric procedures and tracheotomies carry high risks of aerosol generation[48,53] • Risk of aerosolisation during laryngotracheal topical anaesthesia[8]	• High degree of caution needed when performing tracheostomies • Tracheostomies should be guided by ultrasound, rather than bronchoscope[56] • Mouth and nostrils should be covered with an adhesive dressing during surgery[50] • During flexible fibreoptic laryngoscopy, a patient-worn enhanced protection face shield should be implemented[51]
Neurosurgery	• High-speed drills cause substantial aerosolisation[60]	• Microdebriders and other non-powered instruments should be used, rather than drills[60,61] • A 3D ventilated upper airway endoscopic procedure mask should be used to create a sealed barrier between surgical instruments and the nasal cavity during endoscopic skull base surgery[62]
Orthopaedic surgery	• Bone sawing and shaving are AGPs[6] • Frozen sections are associated with increased aerosol generation compared to imprint cytology during intraoperative evaluation of surgical margin[65]	• Aerosol-generating tools (eg, diathermy machines, oscillating saws, broaches, and pulsed lavage systems) should be avoided[63] • A separate drainage cannula with suction should be used during arthroscopic procedures[64] • Imprint cytology should be used when evaluating intraoperative surgical margins of skeletal tumours[65]
Maxillofacial surgery	• Many maxillofacial procedures generate droplets and aerosols • Use of drills in the oral cavity is considered an AGP[6]	• Preoperative oral rinse with 0.12% chlorhexidine or 0.05% cetylpyridinium should be performed • A rubber dam and high-volume suction should be used during procedures[6] • Drills with built-in irrigation systems should be activated when tips are fully submerged in saline[67]
Ophthalmology	• COVID-19 may initially manifest as conjunctivitis[68] • Non-contact tonometry is an AGP and should be avoided[68] • Phacoemulsification and vitrectomy are potential AGPs[70]	• Protective shields should be installed on slit lamps, and disinfection should be performed between consultations[68] • iCare tonometer or Goldmann applanation tonometer should be used to assess intraocular pressure[68]

Abbreviations: 3D = three-dimensional; AGP = aerosol-generating procedure; COVID-19 = coronavirus disease 2019; HEPA = high-efficiency particulate air; OLV = one-lung ventilation; SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2

there is a need to use appropriate PPE and potentially rearrange the endoscopy unit workflow.

Surgical specialties should consider revising their routine practices to minimise the use of any AGP. Although surgical smoke from laparoscopy has been shown to contain viruses (eg, human papillomavirus and hepatitis B),[31] there is no direct evidence regarding the generation of SARS-CoV-2 aerosols from surgical smoke. Thus, there is inadequate evidence against laparoscopic or open procedures. Accordingly, judgements should be made with a focus on the patient's interests, while acknowledging the theoretical risk of aerosol transmission. The most important consideration involves determining when to avoid surgical procedures because high mortality rates have been observed among surgical patients with COVID-19.[14] Nonetheless, when surgery is necessary, air filters and PPE should be used with caution, regardless of the intervention.

The correct usage of PPE is prudent; appropriate donning and doffing procedures substantially influence the risk of COVID-19 transmission.[75] In this review, we found evidence that the use of N95 respirators, gloves, and gowns could significantly reduce the number of infections among frontline HCWs during the COVID-19 pandemic. In support of our findings, a 2019 Cochrane review recommended double gloving to further reduce the risk of disease transmission in clinical practice.[75] Although the use of PPE is essential, it is also important to maintain

good hand hygiene.[76] Furthermore, innovative ideas for modified tools (eg, dental suction devices and the 'Intubox') have allowed HCWs to provide safer care.

Although we comprehensively reviewed potential perioperative AGPs and the main approaches to mitigate the risk of aerosol transmission, some studies demonstrated low-quality evidence. Because the pandemic is rapidly evolving and the acquisition of high-quality evidence is difficult, some of the clinical adaptations and recommendations in this review were made on the basis of expert opinions and theories that may not be supported by clinical trials. Therefore, clinical studies focused on AGPs are urgently needed to justify specific risk-reduction measures. Nonetheless, despite the lack of practical evidence, caution is needed when performing any potential AGP.

Conclusion

We have summarised the evidence and mitigation measures for AGPs during surgery and endoscopy. Although there is limited high-quality evidence to confirm assertions that specific procedures constitute AGPs, HCWs should assume that these procedures are AGPs. Healthcare workers must wear appropriate PPE and maintain both awareness and caution when performing such procedures. Furthermore, trials are necessary to confirm the potential for COVID-19 transmission via AGPs (both surgical and endoscopic) to mitigate potential risks and protect HCWs from disease.

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Conflicts of interest

As the Editor-in-Chief and an editor of the journal respectively, MCS Wong and JYC Teoh were not involved in the peer review process. Other authors have disclosed no conflicts of interest.

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