Electrocautery, Diathermy, and Surgical Energy Devices

Are Surgical Teams at Risk During the COVID-19 Pandemic?

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Objective: The aim of the study was to provide a rapid synthesis of available data to identify the risk posed by utilizing surgical energy devices intraoperatively due to the generation of surgical smoke, an aerosol. Secondarily it aims to summarize methods to minimize potential risk to operating room staff.

Summary Background Data: Continuing operative practice during the coronavirus disease-19 (COVID-19) pandemic places the health of operating theatre staff at potential risk. SARS-CoV2 is transmitted through inhaled droplets and aerosol particles, thus posing an inhalation threat even at considerable distance. Surgical energy devices generate an aerosol of biological particular matter during use. The risk to healthcare staff through use of surgical energy devices is unknown.

Methods: This review was conducted utilizing a rapid review methodology to enable efficient generation and dissemination of information useful for concurrent clinical practice.

Results: There are conflicting stances on the use of energy devices and laparoscopy by different surgical governing bodies and societies. There is no definitive evidence that aerosol generated by energy devices may carry active SARS-CoV2 virus. However, investigations of other viruses have demonstrated aerosolization through energy devise use. Measures to reduce potential transmission include appropriate personal protective equipment, evacuation and filtration of surgical plume, limiting energy device use if appropriate, and adjusting endoscopic and laparoscopic practice (low CO_2 pressures, evacuation through ultrafiltration systems).

Conclusions: The risk of transmission of SARS-CoV2 through aerosolized surgical smoke associated with energy device use is not fully understood, however transmission is biologically plausible. Caution and appropriate measures to reduce risk to healthcare staff should be implemented when considering intraoperative use of energy devices.

Keywords: communicable diseases, COVID-19, emerging, surgery

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Electrocautery (diathermy), laser, ultrasonic scalpels, and other tissue- and vessel-sealing technologies are used across different surgical specialties. These devices are used for precise dissection, hemostasis and tissue mobilization. Each of them is associated with the production of a surgical plume.[1] Within the context of the coronavirus disease-19 (COVID-19) pandemic there are understandable concerns amongst the surgical community as to the risk of viral transmission within such surgical plumes.

To date, live SARS-CoV2 has been detected in lower respiratory tract samples, saliva, feces, bile, and blood specimens.[2,3] As such, during the perioperative process, precautions should be considered to minimize potential risk to the clinical team. Similar to the severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome outbreaks, there is a paucity of data on the potential of transmission of the virus intraoperatively. However, much like during these prior outbreaks, operating room practices must be adapted to maintain the safety of healthcare professionals.[4,5] Although different procedures may carry risks of viral exposure, patient care should not be compromised, and maintenance of surgical team safety is paramount. In response to this threat, surgical governing bodies and associations have therefore issued recommendations on the safe use of energy devices.

The American College of Surgeons have recommended the use of smoke extractors, minimizing the use of electrocautery where possible.[6,7] This advice is similar to the position adopted by the Royal Colleges of Surgeons in the UK, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the European Association for Endoscopic Surgery (EAES).[8–10] Their guidance suggests that energy devices should be used on the lowest reasonable setting, diathermy pencils should be used with smoke extractors where possible and filtration during laparoscopy.[10] Additionally, joint statements from the US and European professional gynecological societies have recommended that minimally invasive and vaginal surgeries are generally safe with adequate personal protective equipment (PPE), given the lack of evidence of SARS-CoV2 transmission in such procedures.[11,12] However, the Royal College of Obstetricians and Gynecologists suggests that gynecological procedures with bowel involvement be performed by laparotomy, as it is associated with a lower risk of generating contaminated aerosols.[11] This is in direct conflict with the Association of Laparoscopic Surgeons of Great Britain and Ireland who advocate for continued laparoscopic surgery, particularly in post pancreatitis cholecystectomy and obstructing hiatal hernia repair.[13] A statement by the Journal of Minimal Invasive Gynecology further endorses laparoscopy as the preferred surgical approach for gynecologic patients.[14] A significant challenge for practitioners is the changing nature of the guidance across organizations and time, despite little evidence underpinning the differing stances. A summary of stakeholder recommendations for operative practice during the COVID-19 pandemic is detailed in Supplementary Table 1, http://links.lww.com/SLA/C263.

The current recommendations attempt to take a pragmatic approach, as no current published research has sought to identify the presence of SARS-CoV2 particles within surgical smoke from any energy device intraoperatively. Conflicting guidance between

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organizations may lead to confusion and anxiety amongst healthcare staff. Here, we review the evidence that informs these guidelines in respect to utilization of energy devices, and critically appraise the quality of recommendations made.

SURGICAL SMOKE AND ULTRAFINE PARTICLES

The composition of surgical plume varies widely, with the nature and size of its components depending on the tissue dissected, and the energy method involved. Numerous investigations have shown that electrocautery (diathermy) creates the smallest particles, with a mean aerodynamic size of 0.07 μm, whereas the largest particles (0.35–6.5 μm) are generated by ultrasonic scalpels.[15–18] Laser tissue coagulation creates particles of about 0.31 μm in size.[15–18] Furthermore, the concentration or number of particles produced depends on the tissue dissected, with the highest emissions originating from cauterization of organ parenchyma and fat, and the lowest from muscle tissue. In fact, of 10 different tissue types tested, liver has been demonstrated to have the highest mass concentration of particles in surgical smoke.[19]

Particles with a diameter smaller than 10 μm are shown to be inhalable. Those with a diameter smaller than 2.5 μm are often referred to as ''lung-damaging dust'' as they are more likely to settle in the alveoli rather than the upper airways (Fig. 1). For reference, SARS-CoV2 is approximately 50 to 200 nm in diameter and has been shown to remain viable in aerosols.[20,21] This may play a role in the pathogenesis of the virus as it is known to gain host entry through angiotensin-converting enzyme 2 (ACE2) receptors, which are highly concentrated in alveolar pneumocytes, and present at lower densities in the mucosa of the upper airways.[22] Surgical masks, even if correctly worn, can only efficiently filter out particles greater than 5 μm in size, thus making filtration of ultrafine particles, including viral particulate, difficult.[23–25]

Whilst individual cases may vary, without adequate ventilation and PPE surgeons may typically be exposed to very high concentrations to these ultrafine particles during use of energy devices.[18] There are suggestions that a high initial viral dose may be associated with more significant disease burden,[26] however the quality, retrospective nature and systemic bias inherent within them makes it hard to prove a definitive causality. However, for surgical team safety, these should be considered until disproven.

COMPONENTS OF SURGICAL PLUMES

Surgical plumes are a byproduct of the use of energy devices intraoperatively. The contents of the plumes are derived from 2 separate products. Firstly, the heat produced results in rupture of cell membranes, releasing water vapor (making up 95% of the contents of surgical plumes).[27] The other 5% of surgical plumes are made up of combustion by-products (non-biological) and cellular debris in the form of particulate material.[27] This includes bacteria, viral particles and malignant cells.[27,28]

Lower temperature vapor from ultrasonic scalpels has a higher risk of carrying viable infectious particles as compared to higher temperature aerosols from electrocautery.[17] The composition of aerosols generated by ultrasonic energy devices are also less well studied in comparison to laser and electrocautery.[17]

Non-biological

In vitro investigations have identified more than 150 combustion byproducts, with hydrocarbons and nitriles present in greatest quantities and with benzene, hydrogen cyanide, and formaldehyde

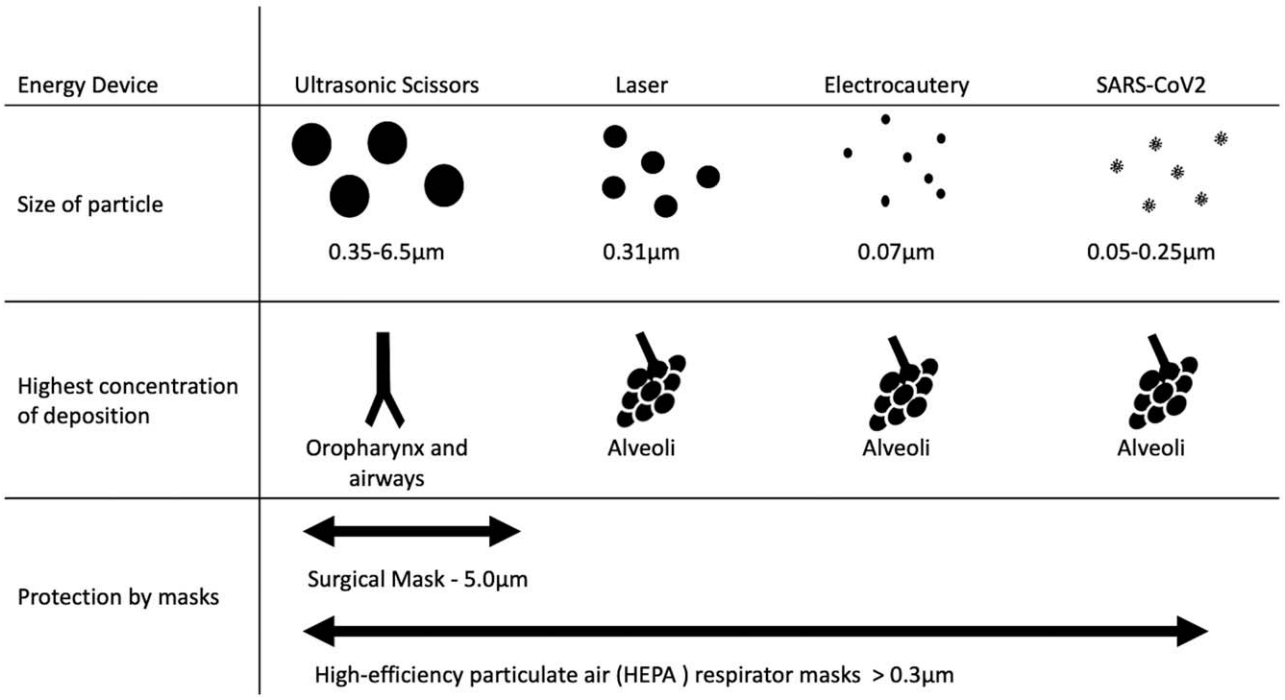

FIGURE 1. Surgical energy devices produce a spectrum of particles which are aerosolized. The size of the particles produced affects the site where they are most likely to deposit with smaller particles such as those produced during laser surgery and electrocautery more likely to settle in alveoli. The size and deposition of SARS-CoV2 is provided for reference. Surgical masks only confer protection against particles 5.0 μm or larger therefore high-efficiency particulate air respirator masks are the gold-standard for use intraoperative use of surgical energy devices in the COVID-19 pandemic.

being the most toxic.[28] In fact, several studies using animal models revealed that diathermy plumes induced a spectrum of histological changes in lung tissue consistent with pneumonia, emphysema, and bronchiolitis.[29,30] In addition to being associated with various pulmonary conditions, surgical smoke has been shown to have mutagenic potential, although a causal-effect relationship has yet to be established.[24]

The development of ambient ionization mass spectrometry techniques over the last decade, in particular the iKnife take advantage of this phenomenon by detecting cellular metabolite profiles and target compounds such as lipids for real time margin detection during oncological surgery.[31,32] The method of energy device can radically alter the composition of surgical plumes as a result of the heat tissues reach. In electrocautery, even different modes of cutting and coagulation produce different aerosolized products. For example, coagulation mode generates a higher concentration of triglycerides, but fewer phospholipids compared to cut mode.[33]

Biological

The number of studies demonstrating the presence of infectious particles in surgical plumes has grown considerably. However, conclusive evidence regarding the risk of infection via inhalation of the bioaerosol is lacking. To date, most investigations have focused on the viability of viruses in electrocautery and laser plumes.

As early as 1988, Garden et al[34] recovered intact bovine and human papillomavirus (HPV) deoxyribonucleic acid (DNA) from the vapor of laser-treated verrucae. In the years that followed, numerous other studies have validated these results. In 1994, Sood et al analyzed 49 samples of loop electrosurgical excision procedures-generated plume and found HPV DNA in 80% of samples.[35] The viability of these particles as infective agents was not studied. An observational study performed at the Mayo Clinic found that otolaryngologists who performed procedures with CO_2 lasers had an increased incidence of nasopharyngeal warts against age and sex matched controls, despite wearing surgical gloves and masks. Thus, HPV content within surgical plumes were the presumed etiology of these warts, given their occupational exposure to HPV.[36] In 2002, Garden et al investigated disease transmission through viral particles found in surgery smoke. After collecting bioaerosol from CO_2 laser-treated bovine tissue infected with HPV, they inoculated calves with the surgical plume. Through inoculation, the calves grew tumors that were shown to be histologically and biochemically due to the viral strains found in the plumes, thus demonstrating sustained pathogenicity.[37]

The presence of other viral particles has been detected in surgical bioaerosol. Viable oral poliovirus was identified in smoke produced by excimer laser systems.[38] Baggish et al found that HIV DNA was present in surgical plumes produced by CO_2 laser, and that it remained viable for 14 days.[39] In a more recent study, Kwak et al identified hepatitis B virus from surgical smoke emitted during laparoscopic abdominal surgery in 10 of the 11 obtained smoke samples.[40]

Additionally, viable bacteria have been isolated in surgical plumes. During laser resurfacing, a procedure widely used by plastic surgeons and dermatologists, Capizzi et al collected 13 smoke samples using High-efficiency particulate air (HEPA) filters in smoke evacuators. Five of these cultures grew coagulase-negative *Staphylococcus*. Of these 5 positive cultures, one also grew *Neisseria*, whereas another grew *Corynebacteria*.[41]

Bioaerosols produced by lasers, ultrasonic scalpels and electrosurgical units have also been shown to contain blood components and intact cells. Some of these particulates remain viable and pose a risk of dissemination of malignancy. In fact, viable melanoma cells were identified with a tetrazolium (MTT) viability test in plume generated by electrocauterization of pellets of B16-F0 mouse melanoma cells.[42] This may account for the occurrence of port metastasis at sites remote to the removal of the cancer tissue. The proposed mechanism for this, the "chimney effect," states an association between the accumulation of metastatic cells via smoke intraoperatively, and the development of port-site metastases.[42] Whilst this requires further investigation, it demonstrates that intra-abdominal aerosol can be transmitted to and potentially through port incisions and actions to mitigate risk during laparoscopy are important to protect healthcare staff. Interestingly, plumes from ultrasonic scalpels have not been shown to disseminate viable airborne cancer cells.[43] Ambient mass spectrometry has also been successfully deployed to detect bacteria, and yeasts in diathermy plumes.[44–46] It is also able to discriminate HPV infected cervical samples from those without HPV.[47] It is therefore highly likely that if present in tissue or biofluids subjected to diathermy, remnants of the SARS-CoV2 are likely to be detectable.

LIMITING RISK

In the presence of unknown risk of transmission, it is important to mitigate potential risk for surgical staff as much as possible. Patients who are scheduled for surgery should be considered as potential vectors of SARS-CoV2 for the duration of their hospital stay. Taking into considering the median incubation time of the virus – 5.1 days,[48] they should be screened 24 hours before surgery using a combination of screening questions, clinical evaluation and oro-/nasopharyngeal reverse transcriptase polymerase chain reaction swabs.[49] It is important to consider that false positives are present in around 30% of cases and therefore if clinical suspicion remains after a negative test result the same precautions should be taken as confirmed cases.[49] Chest computed tomography may provide greater sensitivity but is typically negative in early disease and therefore is likely insufficient to use as a screening tool in isolation, particularly in the absence of symptoms.[49]

For operations on all suspected or positive SARS-CoV2 patients, the number of staff in the operating theatre should be kept to a minimum to limit exposure. This is especially important during operations requiring general anesthetic. In fact, endotracheal intubation, noninvasive ventilation, tracheostomy and manual ventilation before intubation have been shown to have a potential risk of transmission of pathogens causing acute respiratory infections (including SARS).[50] Additionally, when available, negative pressure operating rooms and/or anterooms are recommended, especially during intubation.[51] Anesthetizing and recovering the patient in the operating theatre, further limits the zones of contamination.[52] During intubation both intubator and assistant should be donned in full protective equipment (PPE) to protect against aerosols. The operating theatre should be emptied of nonessential staff for intubation before induction and only allowed to return 20 minutes after intubation to allow for clearance of aerosolized viral particles. SARS-CoV2 has been shown to survive on plastic and stainless steel for 72 hours and therefore all operating on infected patients should be performed in designated operating theatres with disinfection between cases.[21]

Evacuation and Filtration

Surgeons should not deviate from a high standard of care whilst operating and should continue to use energy devices when necessary to maintain patient safety. However, they should be used in conjunction with surgical smoke extraction devices. Whilst evidence about their effect on healthcare worker exposure is limited, their use in experimental conditions has shown significant filtration (>90%) of particles down to 0.02 μm in size, depending on the device used.[53,54] SARS-CoV2 can remain viable in aerosols for up to 3 hours, with a half-life of around 1.1 to 1.2 hours and therefore it

is important to optimize evacuation of airflow within the operating theatre.[21] To ensure the most effective use of smoke evacuation systems, the nozzle should be placed approximately 5 cm away from the tip of the energy device and have a capture velocity of 31 to 46 m/min.[1] Moving the tip to 15 cm away can increase the background particle exposure 8-fold.[54] Similarly, utilizing the highest available evacuator flow rates also improves efficiency of filtration.[54]

In endoscopic and minimally invasive surgeries, filtration may be an effective way to minimize propagation of viral particles by aerosol. HEPA and ultra-low particulate air (ULPA) filters are adequate options; as they have 99.97% efficiency for removing particles =0.3ïμm, and 99.9995% efficiency for removing particles $\geq$0.12 μm, respectively.[55] Powered air purifying respirators may be used during anesthesia (intubation, extubation), bronchoscopy, and tracheostomy.[10,14] Moreover, during any endoscopic procedure, personnel should ensure that the jet stream is not pointed toward them, to avoid the potential seeding of viable particles by the chimney effect.[42] If available, attachable filters should be placed on Luer-lock valves to ensure continuous filtration and ventilation of the pneumoperitoneum, at a rate that should not exceed that of the insufflator (which typically ranges from 4 to 6 L/min).[1] Note that only emergent endoscopies should be considered, due to the risk of aerosolization.[9]

It is also important to consider the safety on those outside the operating theatre. In both the SARS and Middle East respiratory syndrome outbreaks, operating theatres were temporarily converted into negative pressure environment, which has been shown to reduce dissemination outside of the operating theatre.[5,51] Air from within the operating theatre is drawn out of the theatre with fresh air supplied through a vent creating a negative pressure gradient drawing aerosolized particles out of the operating theatre. Negative pressure operating theatres can be created temporarily to accommodate operating during the COVID-19 pandemic.[5,51] It is important that ventilation outflows are correctly configured to avoid contaminating adjacent compartments as ventilation and air conditioning systems have been shown to spread SARS-CoV2 and SARS coronaviruses.[56,57]

Laparoscopy

There remains a paucity of evidence regarding the magnitude of transmission of infection to operating personnel during laparoscopy. Due to the nature of the procedure – use of CO_2 insufflation, energy devices and high-speed surgical equipment – a significant amount of bioaerosol is generated and disseminated within the operating theatre.[58] Guidelines have been published to minimize the production of surgical plume and ensure safety of the staff.[7–13] These recommendations are based on extrapolated data from studies that have demonstrated the presence of viable infectious and malignant cells within surgical plume emitted during laparoscopy.[39,40,42]

Precautions suggested by SAGES, the Royal Colleges, and the American College of Surgeons include using lower intra-abdominal CO_2 pressures, and minimizing energy device utilization when clinically appropriate (Supplementary Table 1, http://links.lww.com/SLA/C263).[7–11] Additionally, sudden release of pneumoperitoneum into the operating room before closure, trocar removal and specimen extraction should be avoided. Instead, the abdominal cavity should be actively desufflated via the least dependent port, through an ultrafiltration system. Ultrafiltration systems should be changed between patients to avoid risk of transmission between patients. Furthermore, port venting should be avoided when possible, unless presenting a safety risk to the patient. Utilization of balloon-tip trocars provide an atraumatic, airtight seal reducing leak of intra-abdominal aerosol.[59] If changing which port through which insufflation is provided, the port should be closed before disconnecting the tubing, and the new port should be closed until the insufflator tubing is connected. Hand-assisted surgery can lead to significant CO_2 leak and aerosolization and should be avoided.[10]

Personal and Protective Equipment

Generation of surgical smoke PPE should be used whilst operating including fit-tested respirator masks and eye protection. HEPA respirator masks such as the FFP respirators provide 11.5 to 15.9 times better protection than surgical masks against viral and bacterial particles.[60] FFP3 masks filter 99% of all particles $\geq$0.3 μm in size.[61] N95 masks, which are more commonly used in the United States, can filter out particles $\geq$0.3 μm in size, with 95% efficiency.[14,61] As such, in case of prolonged periods of electrocautery, laser tissue coagulation, or ultrasonic scalpel use, HEPA filter respirators are preferable to surgical masks (Fig. 1).[18] There is no definitive evidence to suggest that eye protection or face shields are beneficial in protecting against aerosols according to a Cochrane review in April 2020.[62] As a potential entry point to the respiratory tract by tear rinsing through the lacrimal and nasolacrimal ducts,[63] eye protection seems sensible until it is proven to provide no additional protection to healthcare workers. Careful planning and communication before, during, and after the procedure with the team, which should now be limited to only essential staff, will also be vital. Incorporating some of the above into a COVID-19 specific surgical checklist based on the World Health Organization checklist may also be useful.

Donning and doffing of PPE should be learnt before operating days with sufficient opportunity to practice. Double gloving, strict adherence to government guidance and spoken instructions using a ''buddy'' system have all demonstrated to reduce risk of contamination.[62] Whilst video training has been useful in allowing rapid dissemination of donning and doffing procedures during the current pandemic, face-to-face training should take place where possible as this is suggested to improve adherence to best practices.[62]

CONCLUSIONS

Whilst no SARS-CoV2 specific data is present currently there is a theoretical risk associated with energy device use intraoperatively. Optimally, studies should be initiated to investigate both the presence and pathogenicity of SARS-CoV2. However, in the presence of a global pandemic and the ongoing burden of both elective and emergent surgical disease recommendations which seek to optimize safety for operating room staff through utilization of correct PPE, aerosol evacuation and filtration, and limiting risk during laparoscopy are the most appropriate way to continue to operate safely at present.

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