Infection prevention and surgery in the pandemic era

Helen Umpleby

Rebecca Houghton

Abstract

The COVID-19 pandemic has had a significant impact on surgical specialties. COVID-19 carries a significant risk to the surgical patient and the healthcare workers looking after them, with an increased incidence of pulmonary complications and mortality in patients who test positive perioperatively. Appropriate infection prevention and control measures are critical to ensure appropriate care is given and to reduce the risk of onward transmission. This article will discuss the measures that have been instigated and contributed to infection control in surgery, such as testing, patient isolation, personal protective equipment and ventilation. The COVID-19 pandemic has led to healthcare workers across many specialities working together to provide essential clinical care. This collaborative approach is critical to maintain excellent infection prevention and control practices required during this pandemic, which protect patients and preserve surgical services.

Keywords COVID-19; environmental cleaning; hand hygiene; infection prevention and control; surgery; ventilation

Introduction

Until now, surgical site infections (SSIs) and their prevention have been the main priority of infection prevention and control (IPC) in the context of surgery; the COVID-19 pandemic has changed that. COVID-19 disease is caused by Severe Acute Respiratory Syndrome Coronavirus 2 virus (SARS-CoV-2). It is a novel human coronavirus first isolated in Wuhan, China in December 2019. It has rapidly spread throughout the world and a global pandemic was declared by the World Health Organization (WHO) on 11 March 2020. SARS-CoV-2 causes a wide spectrum of disease ranging from mild disease consisting of fever, cough and anosmia to acute respiratory failure, requiring intubation and ventilation. Patients admitted to intensive care have a reported mortality of 30–40%.[1] The COVID-19 pandemic has overwhelmed hospitals worldwide, with theatres and recovery areas being converted into additional intensive care units, non-urgent operations being cancelled and large numbers of staff being redeployed to care for COVID-19 patients. Countrywide, and worldwide control of the pandemic has proved difficult, at least in part due to some shedding of the virus in the days before the onset of symptoms,[2] but also asymptomatic and paucisymptomatic people not realizing they are infected, transmitting the virus unknowingly. Advanced age and comorbidities such as cardiovascular disease, diabetes mellitus and underlying cancer significantly increase the risk of mortality. The Centers for Disease Control and Prevention (CDC) report people aged over 75 years are nine times more likely to be hospitalized and are 230 times more likely to die from COVID-19 when compared to the 18–29 year old group.[3] The over 75 year old age group account for approximately 25% of admissions to hospital in England, and therefore hospital-acquired COVID-19 carries significant morbidity and mortality for hospital inpatients.

The COVIDSurg Collaborative[4] performed an international multicentre cohort study across 235 centres. All patients undergoing a surgical procedure between 1st January and 31st March 2020 who tested positive for SARS-CoV-2 within the 7 days before or 30 days after surgery were included. The 30-day mortality was reported as 23.8% (268/1128); this study did not have a control arm. Another study from New York which also looked at perioperative mortality in patients; with confirmed COVID-19, had a control arm of COVID-19 negative patients; this group had a perioperative mortality of 1.4%.[5] This highlights the additional risk assessment required in all preoperative patients, not only in those who test positive for SARS-CoV-2, where surgery should be delayed if feasible, but also in those with a negative test who may be incubating the virus. Another multicentre prospective cohort study[6] by the COVIDSurg Collaborative carried out across 116 countries looked at postoperative mortality in patients undergoing any surgery in October 2020. The study demonstrated that mortality was higher in patients who underwent surgery within 6 weeks of their COVID-19 diagnosis. Patients operated on 7 weeks or more after testing positive for SARS-CoV-2 had a similar mortality to the control group who tested negative for SARS-CoV-2. In patients who had their surgery delayed by at least 7 weeks, mortality was higher in patients who were still symptomatic (6.0%, 95%CI 3.2–8.7), compared to patients whose symptoms had resolved (2.4%, 95%CI 1.4–3.4) and patients with asymptomatic infection (1.3%, 95% CI 0.6–2.0). The study concludes that, where possible, surgery should be postponed a minimum of 7 weeks following COVID-19 infection, and patients with persisting symptoms should have their surgery delayed further. A multidisciplinary consensus statement on behalf of the Association of Anaesthetists, Centre for Perioperative Care, Federation of Surgical Specialty Associations, Royal College of Anaesthetists and Royal College of Surgeons of England released in March 2021 affirms this by stating ‘Elective surgery should not be scheduled within 7 weeks of a diagnosis of SARS-CoV-2 infection unless the risks of deferring surgery outweigh the risk of postoperative morbidity or mortality associated with COVID-19’.[7]

Healthcare associated infection still occurs despite good IPC practice; patients who test negative on admission could be incubating the virus and test positive several days later, or acquire SARS-CoV-2 in the community after discharge. This risk is elevated at times of high community prevalence, especially when a highly infectious variant is circulating. The risks associated with COVID-19 perioperatively will need to be weighed up against the benefits of surgery for each individual.

Prioritizing IPC in the planning of surgical services during the COVID-19 pandemic has been crucial to ensure patient and staff safety. It has involved the introduction of a broad range of

Helen Umpleby MBBS BA MRCP is a Specialist Registrar in Microbiology and Infectious Diseases at University Hospital Southampton, UK. Conflicts of interest: none declared.

Rebecca Houghton MBBS MRCP FRCPath DTM&H is a Consultant in Infectious Diseases and Microbiology at Hampshire Hospitals NHS Foundation Trust, UK. Conflicts of interest: none declared.

© 2021 Published by Elsevier Ltd.

interventions including preoperative screening, appropriate patient placement, personal protective equipment (PPE) and ventilation. Multiple layers of measures have been put in place and risk assessments made to ensure surgeries were and are carried out as safely as possible.

Testing for SARS-CoV-2

Testing for SARS-CoV-2 is primarily done by reverse transcriptase polymerase chain reaction (RT-PCR) on a nasopharyngeal swab. Deeper respiratory samples such as sputum or bronchoalveolar lavage can also be used. SARS-CoV-2 has an RNA genome; therefore, reverse transcriptase is required to generate a complementary strand of DNA, which is then used as the DNA template for PCR. Specific primers are added which bind to the DNA and determine the region of DNA to be copied. DNA targets can then be amplified through repeated cycles of heating and cooling resulting in exponential amplification of the target gene sequence. A typical PCR would undergo 30–40 cycles. Some platforms give a qualitative result (i.e. positive or negative), while others give a quantitative result by providing a cycle threshold (Ct) value. The Ct value tells you how many cycles of amplification were required to pass the positivity threshold, and therefore indicates whether there is a high or low amount of viral RNA present in the sample. A low Ct value (only a few cycles of amplification were required to exceed the threshold) is in keeping with a high concentration of virus or high viral load, where as a high Ct value indicates a low concentration of virus genetic material (low viral load). Ct values cannot be compared between different assays, due to the variation in sensitivity, gene targets, sample preparation and extraction techniques. A well-taken sample is essential to ensure the material present in the sample is reflective of the patient's viral burden.

Lateral flow assay devices (LFDs) are also used to test for SARS-CoV-2. These are antigen-based tests and identify a viral antigen or protein in the sample and are also performed on a nasopharyngeal swab. A report from PHE Porton Down and University of Oxford[8] of their validation of the Innova LFD demonstrates an overall sensitivity of 73–79% when used by a trained laboratory scientist or HCW, falling to 57.5% when performed by self-trained members of the public. They found a greater than 90% chance of positivity in a sample with a Ct value of less than 25.5. But no samples with a quantity of viral RNA equivalent to a Ct value of over 30 tested positive with this LFD. In summary, they pick up cases with high viral loads that are likely to be more infectious, but their sensitivity drops off markedly as viral load declines. Given their reduced sensitivity compared to RT-PCR, they should not be used in somebody who is high risk (i.e. symptomatic or a close contact of a known positive case). But they are easy to use, can be performed at home and provide a result in less than 30 minutes. Using them regularly (i.e. biweekly) helps to address the low sensitivity – for example, if an individual is infected but has a falsely negative test, on their subsequent test 3 days later their viral load may have risen high enough to pass the threshold of the test and become positive. The user needs to be aware that a negative test does not exclude SARS-CoV-2 infection and if symptoms develop they must isolate and seek a PCR-based test. Asymptomatic staff testing is typically done with LFDs.

Patient screening

Preoperative patients are already actively screened for meticillin-resistant *Staphylococcus aureus* (MRSA) and certain sub-groups for meticillin-sensitive *S. aureus* (MSSA) as supported by WHO and NICE. SARS-CoV-2 has become the first respiratory virus that we actively screen for. During the first wave of the COVID-19 pandemic, initially only symptomatic patients were tested by PCR using a nasopharyngeal swab or deeper respiratory sample. Then, on 27 April 2020 testing was opened up to all non-elective admissions and later to include elective admissions. Initially testing was very slow, with samples sent to centralized reference laboratories with turnaround times of up to 48 hours. Currently, most NHS hospitals have access to onsite or local testing laboratories or point-of-care testing with turnaround times from 50 minutes to several hours. Getting a prompt result is crucial to ensure appropriate placement of the patient to reduce the risk of onward transmission as symptoms cannot be relied on for safe patient placement. Infected individuals can be asymptomatic, viral transmission can occur prior to symptoms developing (pre-symptomatic) and certain patient populations can present atypically, for example the elderly may present with confusion alone. Patients undergoing elective procedures and surgery currently undergo a SARS-CoV-2 PCR within 72 hours of admission, are requested to self-isolate from that point and to practice good hand hygiene and appropriate social distancing in the 14 days prior to their operation. This, amongst other measures, helps to ensure surgery and the postoperative period is as safe as possible. The COVIDSurg international study[4] and a study from New York[5] report a significantly higher mortality in those testing positive for COVID-19 perioperatively (26.1% and 16.7%, respectively) compared to a mortality of 1.4% in COVID-19 negative patients. A patient's SARS-CoV-2 status must be considered when making the decision of whether to proceed with surgery due to the additional risks involved. This highlights the need for all acute hospitals to have access to rapid PCR testing, to aid safe patient placement and rapid surgical management decisions.

In addition to admission and pre-admission testing, regular testing of inpatients can help reduce healthcare associated cases of COVID-19. A letter from NHS England dated 24 June 2020[9] advised retesting patients 5–7 days after admission, with the aim of identifying those patients who are incubating an infection acquired in the community but test negative on admission. Our personal experience is that regular testing of asymptomatic patients across the hospital has been beneficial and has enabled earlier identification of hospital-acquired cases, as well as alerting the IPC team to potential outbreaks. This is supported by a study in a skilled nursing facility in the United States of America[2] where weekly PCR testing was implemented after the first COVID-19 case was diagnosed. Among the 76 residents that participated, 48 (63%) tested positive over the next 23 days, and of these, 56% were asymptomatic at the time of testing. Proactive screening identified numerous cases earlier than if reactive symptomatic testing had been performed. Another single centre study in the US[10] only identified two hospital-acquired cases from 9149 admissions, after instigating frequent testing of asymptomatic patients alongside a comprehensive IPC programme such as appropriate PPE, focusing on ventilation and no/minimal visitors.

© 2021 Published by Elsevier Ltd.

Earlier identification enables earlier isolation of newly positive patients and their contacts to reduce onward transmission and prevent outbreaks. This approach requires large capacity laboratory PCR testing, which not all acute hospitals have access to and so the local laboratory services must be considered when aiming to understand the impact on surgical service planning.

Staff screening

Staff testing comes in two forms - symptomatic testing and asymptomatic screening. Firstly, staff who have symptoms consistent with COVID-19 require a laboratory-based PCR test, a test with a high sensitivity is required to rule out infection if staff are to be allowed back to healthcare related duties. In a time when the NHS is already overstretched, a quick turnaround helps maintain a functional workforce, allowing staff members to return to work quickly and safely following a negative test. Secondly, regular surveillance testing of healthcare workers (HCWs) using LFDs was introduced in December 2020. Twice weekly testing using LFDs helps to overcome the lower sensitivity of LFDs as compared to PCR and maximizes the chance of detecting individuals most likely to transmit infection to others. Detecting those asymptomatic and pauci-symptomatic staff members who would not have otherwise been tested, is critical to protect patients and reduce staff to staff transmission.

In addition to SARS-CoV-2, other respiratory viruses such as respiratory syncytial virus (RSV) and influenza can cause significant disease and healthcare associated outbreaks. Due to the symptomatic overlap between the clinical presentations of these viruses and SARS-CoV-2, robust testing strategies for all three viruses will be needed in the winter months to ensure the appropriate management and placement of all patients admitted to hospital, this requires much planning, infrastructure and sufficient funds.

Access to large-capacity, laboratory-based PCR testing and rapid testing such as a point-of-care test (POCT) for both patients and staff plays a key role in infection control of SARS-CoV-2 and managing operational capacity effectively.

Isolation and cohorting

Isolation or (if no appropriate single isolation room is available) cohorting SARS-CoV-2 positive patients in an area or ward is another important step towards limiting transmission. Patients should ideally be placed in a side room, but there are typically only a small number of these in any acute NHS hospital. All hospitals in the UK saw large numbers of positive patients being admitted in the first and second waves, reaching a peak of 34,336 hospitalized patients with COVID-19 across England in January 2021. This required numerous wards to be converted into wards caring for COVID-19 patients. It is advised to have separate patient pathways depending on whether patients are assessed to be high, medium or low risk of COVID-19.[11] Table 1 lists some examples of individuals within these different care pathways, please refer to local guidance. Keeping patient pathways separate and having designated staff for each patient group also helps to prevent hospital transmission of SARS-CoV-2. Public Health England (PHE) COVID-19 IPC guidance[11] states that if the community prevalence is high, where possible, different teams of health and other care workers including domestic staff should look after individuals in isolation/cohort areas to those in low-risk pathway areas.

Contacts of known positive patients also require isolation much like they would in the community, those with the same contact date can be cohorted together if there are insufficient isolation facilities to place them in individual side rooms. HCWs must wear appropriate PPE, and the patients must undergo close monitoring for symptoms and regular testing.

Cleaning

Understanding the structure of SARS-CoV-2 helps to better understand how to eradicate it from the environment. Viruses are small, obligate, intracellular particles, and must infect and take over a host cell to replicate. They consist of a viral genome of DNA or RNA (SARS-CoV-2 contains a single strand of RNA) and a protein coat (capsid) made up of protein molecules called capsomeres. The capsid with its enclosed viral genome is known as the nucleocapsid. The nucleocapsids of many viruses are surrounded by a flexible membrane known as an envelope. In SARS-CoV-2 the envelope is associated with three structural proteins: spike (S) protein, envelope (E) protein and membrane (M) protein. The S protein is instrumental to gaining entry to the host cell through binding to the human angiotensin converting enzyme 2 (ACE2) receptor. Figure 1 illustrates the schematic structure of a SARS-CoV-2 virion.

The envelope means that SARS-CoV-2 is relatively easy to remove through cleaning. Soaps and detergents are chemical proteins acting as surfactants — they emulsify the virus and reduce the surface tension, so it can be easily washed away. Alcohols denature proteins and dissolve lipids, leading to disintegration of the envelope. This means that the virus cannot then enter cells, which is necessary for replication. For viruses such as norovirus and rhinovirus which do not have an envelope, this is not the case, meaning alcohol is not a reliable means of inactivating these viruses.

Hand hygiene

Hand hygiene is a cornerstone of IPC, but compliance with hand hygiene is often lower than suggested targets. Good hand hygiene with alcohol-based hand rub or soap and water has been shown to eliminate microorganisms picked up from a patient, and is vitally important and a simple measure to help prevent hospital-acquired infections (HAIs) and spread of antimicrobial resistance.

The WHO ‘five moments for hand hygiene’ defines the key moments when HCW hands may become contaminated and hand hygiene should be performed.[12]

- before touching a patient
- before clean/aseptic procedures
- after body fluid exposure/risk
- after touching a patient
- after touching patients’ surroundings.

Handwashing for a minimum of 20 seconds has been a cornerstone of IPC practice throughout the pandemic. It has gained a considerable amount of attention and been widely promoted as part of the hands-face-space-fresh air campaign. This focus needs to continue even after COVID-19 prevalence

 © 2021 Published by Elsevier Ltd.

Examples of individuals in each care pathway		
High risk	**Medium risk**	**Low risk**
• Untriaged (symptoms unknown) • Positive test • Symptomatic/suspected COVID-19	• Asymptomatic but awaiting result of PCR test • Asymptomatic but known contact/ exposure	• Asymptomatic + no contact + negative PCR test • 14 days or more since COVID-19 diagnosis + no fever/cough for 48 hours

Table 1

falls, to ensure HCWs' hands are not a vector for transmitting other clinically significant microorganisms.

Environmental cleaning

Unlike spore-forming organisms such as *Clostridioides difficile* where ultraviolet light or hydrogen peroxide vapour are required to decontaminate healthcare environments, enveloped viruses like SARS-CoV-2 can be removed from surfaces with a thorough clean. A combined detergent/disinfectant solution at a dilution of 1000 parts per million available chlorine (ppm av.cl) or a general-purpose neutral detergent in a solution of warm water followed by a disinfectant solution of 1000 ppm av. cl. is advised. What is important is the increased frequency of cleaning especially of common touch points such as door handles which are typically re-contaminated after a couple of hours.

PHE COVID-19 IPC guidance[11] advises to increase cleaning of both the environment and equipment in care areas to at least twice daily — this includes frequently touched points and communal facilities such as shared toilets. One could hypothesize that increased cleaning would also reduce other microorganisms in the patient's environment. There are several studies that suggest cleaning is an important measure in the reduction of transmission of MRSA, vancomycin resistant enterococci (VRE) and multidrug-resistant (MDR) Gram-negative organisms including carbapenemase-producing Enterobacterales (CPE). One study[13] found enforced cleaning was associated not only with less surface contamination with VRE, but also a considerable reduction in VRE cross-transmission between patients. Another report[14] describes an MRSA outbreak among male patients on a surgical ward; it was only when time allocated for basic cleaning of the ward was doubled with emphasis on vacuum cleaning and regular cleaning of shared medical equipment that the outbreak resolved. Prior to the increase in cleaning, 69 patients had acquired the MRSA outbreak strain and it was found

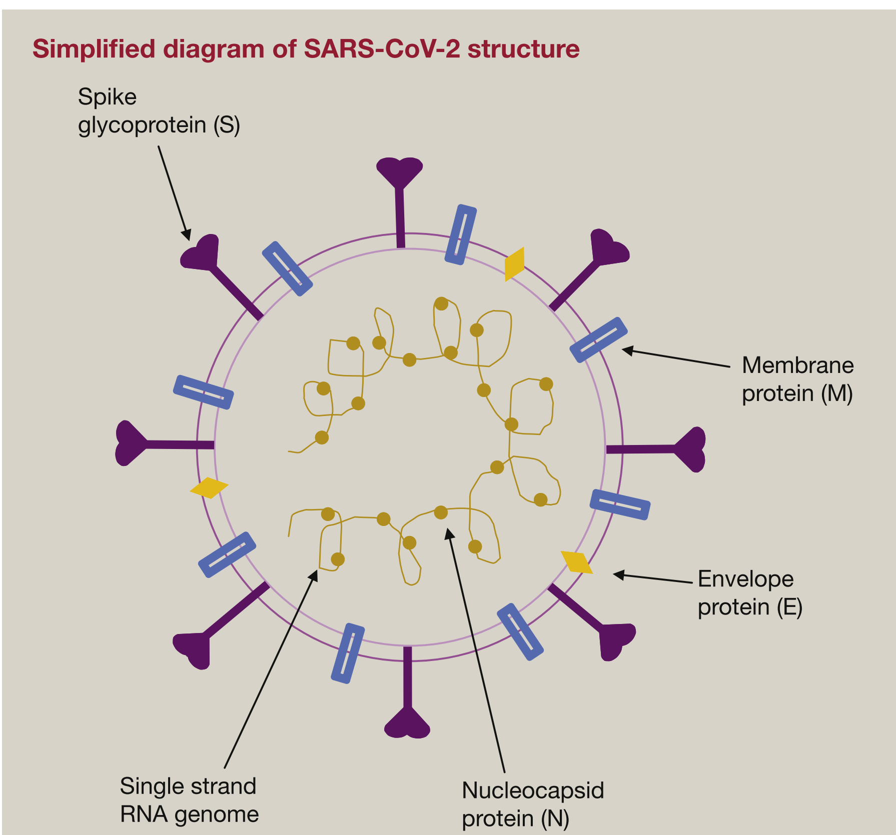

Figure 1

© 2021 Published by Elsevier Ltd.

to be widespread in the environment. After the cleaning intervention, the outbreak strain was eradicated from the ward environment and there were no further infections with this strain. A prospective single centre cohort study[15] which looked at MDR Gram-negative bacteria acquisition on an intensive care unit, found admission to a room previously occupied by a patient colonised with a MDR *Pseudomonas aeruginosa* or *Acinetobacter baumanii* was an independent risk factor for acquiring these organisms. The PHE Framework of action to contain CPE[16] stipulates the importance of effective cleaning to minimize the risk of transmission of MDR organisms. This is alongside other measures, including antimicrobial stewardship interventions to reduce the use of broad-spectrum antibiotics (crucial in preventing antimicrobial resistance) and performing a CPE risk assessment and screening and isolating high risk individuals — affirming the importance of taking a travel history especially any contact with healthcare.

These studies highlight the importance not only of standard infection control measures such as PPE and hand hygiene, but also how the environment can play a huge role in cross transmission of these microorganisms; and reducing the bioburden by regular and thorough cleaning may also decrease the incidence of HAI.

WHO IPC guidance[12] advises a terminal clean of the operating room after a known COVID-19 patient or if the patient's status is unknown (i.e. for patients on the medium and high risk pathways). A terminal clean involves the thorough cleaning and disinfection of all surfaces and re-useable equipment.

Personal protective equipment (PPE)

The Health and Safety Executive PPE at work regulations 1992 states; 'PPE is the equipment that will protect the user against health or safety risks at work'. It makes up one arm of the standard infection control precautions (SICP). SICPs are the basic IPC measures necessary to reduce the risk of transmission of infectious agents from both recognized and unrecognized sources of infection. The SICP PPE requirement depends on the risk of exposure to blood and/or other bodily fluids and includes gloves, apron or gown, mask and eye protection. In addition to SICPs are transmission-based precautions (TBPs) which are worn when a patient is suspected or known to have an infection. The TBPs depend on the route of transmission of the suspected or known pathogen and include contact, droplet and airborne precautions. Table 2 describes each TBP and depicts the appropriate PPE to be worn.

National IPC guidance for COVID-19 recommends that HCWs caring for patients with and without proven COVID-19 should use fluid-resistant surgical masks IIR (FRSMs) as respiratory protective equipment (RPE), unless aerosol-generating procedures (AGPs) are being undertaken, when a filtering face piece 3 (FFP3) respirator should be used. The most recent update in June 2021 adds that the FFP3 respirator is recommended if 'an unacceptable risk of transmission remains following rigorous application of the hierarchy of control'. The national guidance does not directly describe what PPE should be worn for surgery but this is implied to be in keeping with general guidance for the low-, medium- and high-risk pathways. Patients on the medium- and high-risk pathways should be anaesthetized and recovered in theatre, and with intubation and extubation being listed as AGPs FFP3 should be worn.

A number of organizations in England have formed their own guidance and are providing airborne precautions to all HCWs caring for COVID-19 positive patients irrespective of whether AGPs are being carried out. Cambridge University Hospitals NHS Foundation Trust collated data from their HCW testing programme and during the first and second wave of the pandemic found a higher incidence of infection amongst HCWs caring for patients with COVID-19, compared to those who did not, and this did not correlate with community prevalence. They instigated a change in respiratory protective equipment from FRSM to FFP3 respirator for all staff on COVID-19 wards and examined the effect on staff infection rates. Following the change there were similar rates of infection on both COVID-19 and non COVID-19 wards, with no statistically significant difference between the two, indicating that FFP3 respirators do protect HCWs from acquiring COVID-19 at work.[17]

PPE shortages have been widespread, particularly in the early months of the pandemic; the PPE received through the NHS supply chain has not been consistent with varying types of masks received. This poses challenges with FFP3 masks where HCWs have been fit tested to a particular one. Some FFP3 masks have valves, although protective to the wearer, the HCWs' unfiltered exhaled breath may be directed towards the patient. This poses a potential risk if the HCW is infectious but asymptomatic, although this risk is mitigated to some extent through regular testing and vaccination. Commonly reported concerns raised by surgeons include condensation building up on the valve and the risk of contaminating the sterile area during surgery and increasing the risk of infection. Therefore, non-valved FFP3 masks are advised during theatre and for sterile procedures.

It is imperative that HCWs are adequately protected while caring for COVID-19 patients; however, this cannot be to the detriment of the standard of care a patient receives. One study[18] was conducted after concerns were raised regarding an increase in central line associated bloodstream infections in COVID-19 patients in the intensive care unit. Their audit revealed a reduction in hand hygiene compliance and concerns of substandard hand hygiene following the introduction of sessional long sleeved gowns in April 2020. They subsequently found a reduction in line infections following a change to short sleeved gowns and enhanced cleaning of their critical care unit. This highlights the importance of basic infection control practices and good hand hygiene when bare below the elbows and potential risk of cross contamination when wearing the same long gown between patients (sessional gowns). It is important to note that PHE guidance as of June 2021 now states that 'sessional or extended use of gowns must be minimized and only used in areas where cohorts of confirmed COVID-19 patients are managed and there is a lack of single rooms/isolation rooms. If sessional use is required, an individual patient risk assessment must be undertaken and reviewed daily. Gowns are not required when moving around a unit or department'. Although not directly related to surgery, many surgical patients spend a short time in intensive care or the high dependency unit following their operation and during the first and second waves many surgical staff were redeployed to other areas in the hospital including critical care.

 © 2021 Published by Elsevier Ltd.

The difference between the various TBPs

TBP	Description	Examples	PPE
Contact	Direct contact with patient or indirect with patient's environment	Resistant bacteria, e.g. MRSA, CPE, VRE SARS-CoV-2	Gloves Apron (or gown) +/− mask +/− visor
Droplet	Spread over short distances (<2 m) via droplets (>5 μm) from the respiratory tract through coughing, sneezing and talking directly onto a mucosal surface or conjunctiva of another individual	SARS-CoV-2 Influenza RSV	Gloves Apron (or gown) FRSM IIR mask Visor
Airborne	Microorganisms in airborne droplet nuclei (<5 μm) can remain suspended in the air for long time periods and can be dispersed widely by air currents	SARS-CoV-2 *Mycobacterium tuberculosis* Varicella	Gloves Gown FFP3 + visor or respirator hood

Table 2

Ventilation

Two types of ventilation can be installed and used in an operating room − conventional and laminar flow. Conventional airflow prevents contamination entering the operating room from outside and dilutes any contamination generated in the operating room. It is dependent on positive pressure to remove air from clean areas (theatre and preparation room) to less clean areas. It can change the air up to 25 times per hour and is associated with less than 180 colony forming units per metre cubed (cfu/m^3) of bacteria. Laminar flow or ultra clean ventilation was pioneered by Sir John Charnley, an orthopaedic surgeon in the 1960s. Air filters supply clean air via high efficiency particular air (HEPA) filters. This filtered air moves from the operative field to the periphery and is extracted by exhaust grills. As well as preventing contamination from outside coming into the operating room, it also rapidly and efficiently removes any contamination created in the operating room, for example from around the wound and contaminated surgical instruments. These systems can change air up to 300 times per hour and are associated with less than 10 cfu/m^3 of bacteria. There is evidence that laminar flow systems reduce the incidence of SSIs in orthopaedic procedures involving a prosthesis, and currently they are recommended by both NICE and the British Orthopaedic Association. However, in general surgery any benefit has yet to be proven.

The COVID-19 pandemic has heightened the importance of ventilation, not only in theatres but also in other clinical areas such as wards and critical care. Poor ventilation is associated with increased risk of hospital SARS-CoV-2 transmission. If a patient is suspected or has been diagnosed with an infection known to aerosolize such as Measles they should be placed in a negative-pressure isolation room with an anteroom. Air naturally moves from areas of higher pressure outside the room to the area of lower pressure in the patient's side room. The negative pressure prevents any airborne particles escaping to other areas of the hospital. If an AGP needs to be performed on a COVID-19 patient it should be done in a negative-pressure room if possible, with a minimum of 12 air changes per hour (ACH).[12]

As discussed previously, theatres have positive-pressure ventilation in relation to the surrounding environment which raises the question of safety if emergency surgery needs to be performed on patient high risk for COVID-19. Changing a positive-pressure ventilation operating room into a negative-pressure room would be complex and timely. Surgery should only be performed in a known positive patient if the benefits outweighed the risks due to the much higher risk of mortality and pulmonary complications in addition to the potential surgical and anaesthetic complications. However, for life and limb saving operations this must be done.

The clean air flow path in the operating room (which also applies to delivery rooms and endoscopy suites) passes from the air supply point, past the staff, then onto the patient and out via a low-level extract. The dilution ventilation provided by the air change rate and wearing airborne TBPs including an FFP3 respirator adds additional safeguarding for the HCWs, the risk of SARS-CoV-2 acquisition is very low.

Once a patient on the medium- or high-risk pathway has left the operating room, the waiting time to ensure any potentially aerosolized SARS-CoV-2 has been removed depends on both the time since the last AGP (likely extubation) and the ACH. At 25 ACH, it takes 11−17 minutes to remove 99% and 99.9% of contaminants, respectively.[19]

Summary

COVID-19 has had a huge impact on surgery and caused major disruptions to planned operations; recovery areas were needed for makeshift ICUs and anaesthetic, surgical and recovery HCWs were redeployed to areas in need. Not only were there not the available resources and staff to carry out routine operations but there were no beds for elective patients and the risk of acquiring COVID-19 perioperatively was too high. Acquiring SARS-CoV-2

 © 2021 Published by Elsevier Ltd.

prior to, or following surgery, has been shown to have a detrimental effect on surgical outcomes and hospital-acquired COVID-19, remains a real risk even with good IPC practice especially in times of high community prevalence. Hospital-acquired COVID-19 cases have been associated with prolonged length of stay and increased mortality.

NHS hospitals continue to strive to get back to full operating capacity as safely as possible. IPC is central to optimizing patient management, keeping patients and HCWs safe, and maintaining operational capacity. Patient and staff testing remains vital-rapid turnaround of PCR testing aids appropriate patient placement and large laboratory-based testing capacity enables regular in-patient asymptomatic testing, pre-admission testing of elective cases and potentially visitor testing as we look to how we can safely re-introduce patient visiting. Retaining the renewed emphasis on hand hygiene and the enhanced environmental cleaning aimed at the removal of SARS-CoV-2 virions may also reduce the bio-burden of bacteria in the immediate patient environment and in turn reduce HAIs such as SSIs but this is yet to be seen.

Throughout this pandemic we have seen extraordinary levels of resilience and dedication across the healthcare workforce of all specialties. This collaborative approach is the perfect requisite for good IPC practice. Infection prevention is not just down to the IPC team but is the responsibility of the entire workforce including, but not limited to doctors, nurses, laboratory staff and cleaners. There is not just one magic intervention but several layers of interventions are necessary to protect patients and staff and preserve essential surgical services. ◆

REFERENCES

1 Armstrong RA, Kane AD, Kursumovic E, et al. Mortality in patients admitted to intensive care with COVID-19: an updated systematic review and meta-analysis of observational studies. *Anaesthesia* 2020; **76:** 537–48.

2 Arons MM, Hatfield KM, Reddy SC, et al. Presymptomatic SARS-CoV-2 infections and transmission in a skilled nursing facility. *N Engl J Med* 2020; **382:** 2081–90.

3 Centers for Disease Control and Prevention. Risk for COVID-19 infection, hospitalisation and death by age group. Internet; Updated 19 July 2021. Available at: www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-age.html (accessed 1 August 2021).

4 COVIDSurg Collaborative. Mortality and pulmonary complications in patients undergoing surgery with perioperative SARS-CoV-2 infection: an international cohort study. *Lancet* 2020; **396:** 27–38.

5 Knisely A, Zhou ZN, Wu J, et al. Perioperative morbidity and mortality of patients with COVID-19 who undergo urgent and emergent surgical procedures. *Ann Surg* 2021; **273:** 34–40.

6 COVIDSurg Collaborative. Timing of surgery following SARS-CoV-2 infection: an international prospective cohort study. *Anaesthesia* 2021; **76:** 748–58.

7 El-Boghdadly K, Cook TM, Goodacre T, et al. SARS-CoV-2 infection, COVID-19 and timing of elective surgery: a multidisciplinary consensus statement on behalf of the association of Anaesthetists, the centre for peri-operative care, the federation of surgical specialty Associations, the royal College of Anaesthetists and the royal College of surgeons of England. *Anaesthesia* 2021; **76:** 940–6.

8 Joint PHE Porton Down & University of Oxford SARS-CoV-2 LFD test development and validation cell. Preliminary report from the Joint PHE Porton Down & University of Oxford SARS-CoV-2 test development and validation cell: rapid evaluation of Lateral Flow Viral Antigen detection devices (LFDs) for mass community testing. Internet; 8 November 2020. Available at: www.ox.ac.uk/sites/files/oxford/media_wysiwyg/UK%20evaluation_PHE%20Porton%20Down%20%20University%20of%20Oxford_final.pdf.

9 NHS England and NHS improvement. Healthcare associated COVID-19 infections – further action. Internet; 24 June 2020. London: NHS England and NHS Improvement. Available at: www.england.nhs.uk/coronavirus/wp-content/uploads/sites/52/2020/06/Healthcare-associated-COVID-19-infections–further-action-24-June-2020.pdf (accessed 1 August 2021).

10 Rhee C, Baker M, Vaidya V, et al. CDC prevention epicenters program. Incidence of nosocomial COVID-19 in patients hospitalized at a large US academic medical center. *JAMA Netw Open* 2020; **3**: e2020498.

11 Public Health England. COVID-19: infection prevention control guidance [update 1 June 2021]. 2020. London: Public Health England. Available from: www.gov.uk/government/publications/wuhan-novel-coronavirus-infection-prevention-and-control (accessed 1 August 2021).

12 World Health Organization. Infection prevention and control during health care when coronavirus disease (COVID-19) is suspected or confirmed [Updated 12 July 2021]. 2021. Geneva: World Health Organization. Available at: www.who.int/publications/i/item/WHO-2019-nCoV-IPC-2021.1 (accessed 1 August 2021).

13 Hayden MK, Bonten MJ, Blom DW, et al. Reduction in acquisition of vancomycin-resistant enterococcus after enforcement of routine environmental cleaning measures. *Clin Infect Dis* 2006; **42:** 1552–60.

14 Rampling A, Wiseman S, Davis L, et al. Evidence that hospital hygiene is important in the control of methicillin-resistant Staphylococcus aureus. *J Hosp Infect* 2001; **49:** 109–16.

15 Nseir S, Blazejewski C, Lubret R, et al. Risk of acquiring multidrug-resistant Gram-negative bacilli from prior room occupants in the intensive care unit. *Clin Microbiol Infect* 2011; **17:** 1201–8.

16 Public Health England. Actions to contain carbapenemase-producing Enterobacterales (CPE). 2020. London: Public Health England. Available at: www.gov.uk/government/publications/actions-to-contain-carbapenemase-producing-enterobacterales-cpe (accessed 18 August 2021).

17 Ferris M, Ferris R, Workman C, et al. FFP3 respirators protect healthcare workers against infection with SARS-CoV-2. Authorea, 2021. https://doi.org/10.22541/au.162454911.17263721. Preprint.

 © 2021 Published by Elsevier Ltd.

18 Meda M, Gentry V, Reidy P, et al. Unintended consequences of long-sleeved gowns in a critical care setting during the COVID-19 pandemic. *J Hosp Infect* 2020; **106:** 605–9.

19 Centers for Disease Control and Prevention. Guidelines for environmental infection control in health-care facilities [Updated July 2019]. 2003. Atlanta: U.S. Department of Health and Human Services Centers for Disease Control and Prevention. Available at: www.cdc.gov/infectioncontrol/pdf/guidelines/environmental-guidelines-P.pdf (accessed 1 August 2021).

Practice points

- Patients who test positive for SARS-CoV-2 perioperatively have an increased risk of mortality and pulmonary complications
- Surgery should be delayed for at least 7 weeks (if feasible) after testing positive for SARS-CoV-2
- Current practice advocates: Patients should be tested on or in the 72 hours prior to admission
- If laboratory PCR testing capacity allows, regular testing of in-patients could aid earlier identification of hospital-acquired cases
- Patients who test positive for SARS-CoV-2 should be isolated or cohorted
- Patients should be managed by low-, medium- and high-risk pathways
- Regular HCW SARS-CoV-2 testing is crucial to identify asymptomatic and pre-symptomatic members of staff
- PPE should be worn in keeping with local and/or national guidance. Valved FFP3 respirators should not be worn for surgery or any sterile procedure
- Increased frequency of environmental cleaning and hand hygiene may reduce the bacterial bioburden in patients' environment and on HCW hands. This may reduce the risk of HAI
- Risk to HCWs in theatre is low due to the clean air flow pathway. ventilation and wearing appropriate PPE

© 2021 Published by Elsevier Ltd.