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Commentary

Infection prevention and control considerations regarding ventilation in acute hospitals

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SUMMARY

Infection prevention and control team members (IPCTM) are often intimidated by aspects of ventilation as they relate to healthcare, because they consider them technical and outside their area of comfort and expertise. However, engineers, estates departments and planners need IPCTM input to ensure appropriate design and use. The main areas of importance centre on the operating theatre, the provision of air-controlled ventilated isolation rooms, and how to respond to major outbreaks/pandemics. Concentrating on basic principles of infection prevention and control, developing relationships with key departments and individuals, and applying best practice to these and other areas as they arise, are of great value. Some background, information and suggestions are provided for IPCTM with a view to providing simple practical advice in these areas.

Background

Amongst the ways pathogens spread are through the aerosol and droplet routes. These are particularly important for respiratory infections, whether caused by viruses, e.g. influenza, bacteria, e.g. tuberculosis and fungi, e.g. aspergillus. Adequate physical separation and personal measures such as hand hygiene and respiratory etiquette are often adequate to minimise transmission for most general acute hospital patients. However, the acute hospital patient population is increasingly complex with some general medical and surgical patients on biological agents that affect the immune system. Furthermore, we are increasingly conscious of the risk of airborne transmission, not least highlighted by the recent COVID-19 pandemic, and a greater awareness of the environmental microbiome. A recent review by Stockwell and colleagues on the presence and impact of ventilation in hospitals found that bio aerosols were highest in in-patient facilities, and where there was natural ventilation, but were lowest in public areas, and where there were ventilation systems [1].

Settings and circumstances where the infection prevention and control team members (IPCTM) are involved and

Abbreviations: ACH, air changes per hour; ACV, air controlled ventilated; cfu, colony forming units; ED, emergency department; IPC, infection prevention and control; IPCTM, infection prevention and control team members; MIS, minimally invasive surgery; NIPPV, non-invasive positive pressure ventilation; PJA, prosthetic joint arthroplasty; SSI, surgical site infection; UDAF, unidirectional air flow.

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where they need to have an input are in the operating theatre complex, in the provision of isolation facilities and in responding to major outbreaks/pandemics. While it is not expected that individually or collectively the IPCTM have expertise in the engineering aspects of ventilation, the team must have some basic knowledge to ensure that such facilities are fit for purpose and that the monitoring of these is appropriate and carried out by competent persons. This can best be summarised by ensuring that the IPCTM know which questions to ask of whom and when. What follows is an outline of important issues on ventilation to address and consider in three areas; operating theatres, isolation facilities, and pandemic preparedness.

Operating theatre complex

While the IPCTM focus on ventilation here is to minimise surgical infection, it is important to realise that theatre ventilation also ensures the removal of potentially toxic gases and helps to ensure the comfort of both patients and staff.

Air filtration and frequent air changes such as 20—25 per hour, will reduce the numbers of bacteria carrying particles in a closed setting such as an operating theatre. However, linking those reduced bacterial counts with reduced infection, specifically surgical site infection (SSI) is complex. Vonci and colleagues have developed a model to evaluate the relationship between bacterial counts or colony forming units (cfu) and air changes for laminar and turbulent airflow ventilation, with the cfu being much lower for the former [2]. However, the impact of using unidirectional air flow (UDAF) for prosthetic joint arthroplasty (PJA) is controversial (see below) and a recent meta-analysis has not found any difference in SSI rates between both categories of ventilation for a variety of surgical procedures [3]. Practises and behaviours amongst healthcare staff and visitors while in the operating theatre will also affect the number of cfu. A study of 28 operating theatres with 250 air samples found that after controlling for confounding factors, the surgical stage (i.e. before incision and after surgical site closure), deep and organ space compared to superficial incisions, paediatric compared to adult surgery, the number of staff, and increases in the indoor temperature, all correlated with higher cfu [4]. Hence, while here we focus on ventilation aspects of operating theatres, the IPCTM need to address other issues that impact on cfu and potentially SSI rates.

Too often IPCTM become involved for the first time in issues relating to the operating theatre during a crisis when something goes wrong or when asked to commission a new or refurbished theatre against a tight timeframe. However, the IPCTM should be involved in advising on the design of new theatres, their upgrade, refurbishment and monitoring, and the IPCT role in this, is recognised in the UK [5].

Bacteria causing SSI enter the wound directly or indirectly via exposed sterile instruments. Hence, the infection prevention and control (IPC) priorities should focus on preventing both occurring, by helping to ensure optimal space and design, adequate ventilation in the operating theatre complex and optimal professional practice, such as theatre protocols, which are not discussed here. The main headings involved and the issues to address are highlighted in Box 1.

Box 1
Key issues for the infection prevention and control team members (IPCTM) to address relating to operating theatres.

- Develop and sustain ongoing relationships with estates, engineering, and other colleagues responsible for operating theatre maintenance.
- Ensuring that the IPCTM are involved in the planning of new or upgraded/refurbished operating theatres, including hybrid theatres or theatres constructed outside the operating theatre complex, e.g. in radiology departments.
- The move towards minimally invasive surgery outside of the acute hospital operating theatre complex has to be considered in the light of the potential ease of access for needed procedures on patients, and in optimising safety in terms of ventilation and other parameters; this is best achieved through multi-disciplinary risk assessment.
- Outside of the commissioning of conventional theatres, there is little role for routine air sampling.
- Uni-directional airflow theatres will probably continue to be required for joint arthroplasty in the UK and elsewhere but the IPCTM need to be aware of the arguments for and against their use.

New theatres and upgrades

Conventional operating theatres should have 25 air changes per hour (ACH) when built, for older theatres, over time this may fall to approximately 20 but ACH should remain close to this figure through regular maintenance. Newer theatres are expected to achieve 20 ACH for the duration of the life of the ventilation plant. Usually the pressure differentials between the actual operating theatre and the rest of the complex, e.g. corridors, anaesthetic or sluice rooms, will be such that air flows from the actual theatre to those other areas, through ensuring pressures are highest in that area of the operating theatre complex where there is the greatest risk, e.g. the exposed surgical site. However, if the preparation room is used to lay-up instruments, i.e. instruments are exposed in this room before use during surgery in the operating theatre, then the preparation room should have air of sufficient quality to ensure the dilution of any airborne contaminants. If the preparation room is used solely for storage, then the air pressure should be below that of the theatre. Other issues that IPCTM may be consulted about include where to locate scrub-rooms, general aspects of design such as storage facilities (these should not be in the actual theatre), and air sampling, as part of commissioning.

Air sampling

This is usually part of theatre commissioning and briefly, it should be carried out only when the building work is complete and the theatre has been thoroughly cleaned and with an active sampler. It should only take place when the operating theatre ventilation has been running for a sufficient time to ensure a steady state, and the operator undertaking the air sampling should ensure that they do not inadvertently add to the bacterial counts.

The IPCTM are often asked to conduct air sampling as part of the investigation of an outbreak or a cluster of SSIs. However, much else should be carried out first to exclude a

sequence of unexpected SSI before sampling, including considering a run of operations on high-risk patients, sub-optimal surgical antibiotic prophylaxis, inappropriate surgical practice with breaches in aseptic technique peri-operatively, and sub-standard contact precautions when assessing the surgical site post-operatively. Only when these issues have been investigated, should air sampling be considered, and only then after asking for confirmation of the efficacy of air filters and that there are appropriate air changes and differential air pressures between the operating theatre and the rest of the complex.

In UDAF theatres (usually used for (PJA) (Figure 1)), particle counting and the use of smoke air tests to check for the direction of airflow, and confirmation of the mechanical parameters via engineering and estate colleagues, suffice for commissioning. When and if air sampling is carried out while surgical procedures are being undertaken in a conventional theatre, the air counts will vary according to the number of staff present, the category of surgery, the stage of the surgical procedure and the ambient temperature [4]. In the UK, an acceptable bacterial/fungal air count in a conventional operating theatre has been set at 180/m^3 averaged over a five-minute period [6].

Uni-directional air flow theatres

Since the 1980s and the original UK Medical Research Council trials, the use of ultraclean ventilation, or perhaps better referred to as UDAF theatres, have been the norm when PJA is undertaken. However, recent reviews and recommendations have suggested that there may not be benefits from cleaner air arising from UDAF compared to that provided by conventional theatres [3,7,8]. These claims have been rebutted by others on the basis of flaws in the systematic review and other factors such as the inadequate size of the unit providing UDAF with exposed instruments being outside that area and becoming contaminated, possibly explaining why UDAF does not appear to be effective [9,10]. Currently, there

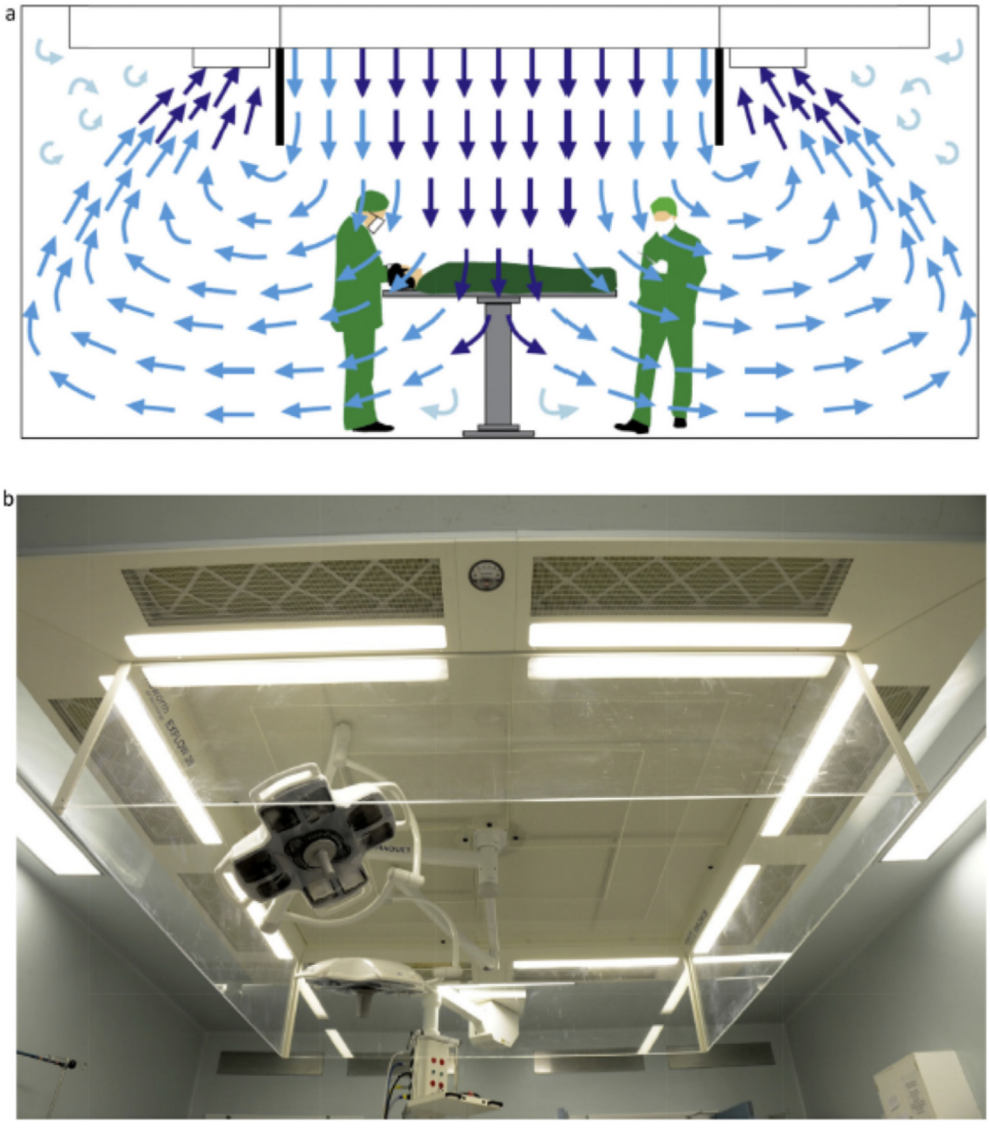

Figure 1. Unidirectional airflow theatre used for joint arthroplasty. (a) Schematic outline (b) Example with partial walls (*Surgeon* 2015: 13: 52—58).

appears to be no move in the UK, nor in France or Germany [9,11], not to use UDAF theatres for PJA. However, IPCTM may be asked for their views when and if new theatres are being constructed or refurbished. Some may argue against UDAF because of these recent publications and the high building and energy costs. Nonetheless, professional organisations, such as those involving orthopaedic surgeons, will probably continue to insist on their use until more evidence against their efficacy becomes available.

Minimally invasive surgery

The last two decades have seen major changes in healthcare including in surgery (e.g. laparoscopic *versus* open procedures such as for appendectomy), medicine (cardiac stents *versus* cardiac bypass surgery), radiology (e.g. CT-guided draining of abdominal abscesses), and the performing of some operative procedures outside acute hospitals to facilitate patient access to care. These have lessened the dependence on open and more invasive surgical procedures with a move to minimally invasive surgery (MIS), leading to the emergence of radiology or hybrid theatres in which many of these procedures are carried out. While minor surgical procedures involving superficial incisions (such as the removal of skin lesions) can be carried out in a naturally ventilated room, it is recommended that ventilation facilities close to those of a conventional operating theatre should apply for new or refurbished facilities involving MIS [12]. Infection prevention and control team members are now often being asked for advice on what procedures can be carried out under what ventilation conditions, with the move to outpatient, day care and community delivered care. There are no simple or dogmatic answers to these queries, and most require a risk assessment. However, factors to consider when advising on what level of ventilation and facilities are required for a specific procedure include, how deep is the incision and its size, the complexity of the procedure including whether there is a prosthesis involved, and the vulnerability of the patient, e.g. an organ transplant recipient undergoing a procedure. A balance has to be struck between not delaying much needed MIS, the availability of current local facilities, but not compromising patient safety by facilitating surgical interventions under sub-optimal conditions.

Isolation facilities and the ventilation of clinical care areas

Most clinical areas of acute hospital facilities in the UK are naturally ventilated and that is probably acceptable for the majority of patients. The transmission of infection via air, however, is a concern in the context of especially vulnerable patients such as severely neutropenic patients who are at risk of systemic and pulmonary aspergillosis.

For most general ward areas outside the operating theatre and specialist clinical care areas, such as the intensive care unit, hitherto the main considerations have been patient comfort and energy costs, even if there has been an increasing recognition that many bacteria can be disseminated by the aerial route and not just by contact [13]. In the UK, there are more multi-bed facilities for patients in hospital, compared to in the USA, but even there where ambient temperatures can fluctuate more, and hence ventilation is required for comfort purposes, not all hospitals can comply with the suggested standards [13,14]. Natural ventilation can be maximised through open doors, large windows and high ceilings, where comfort allows this, before turning to assisted technology in the form of hybrid ventilation or the construction of specified ventilation controlled rooms, i.e. negative/positive or neutral pressure rooms [15].

Single rooms are currently used to isolate many patients, such as those with methicillin-resistant *Staphylococcus aureus* (MRSA) where contact precautions are the priority, but these rooms may not strictly constitute isolation rooms if they are not ventilated and not of an adequate size with an anteroom.

Droplet and airborne transmission

Most respiratory-type infections are thought to be transmitted by droplets, i.e. larger particles $>5\mu m$ and it is believed these are usually not transmitted further than 1m from the person coughing or sneezing. However, particles $<5\mu m$ (i.e. aerosols) will remain in the air for longer and can travel further from the source patient. Hence, these aerosols are believed to result in airborne transmission such as occurs with tuberculosis and measles. [16] For patients with infections spread by droplets, e.g. influenza, droplet precautions are required. This can include isolation in a single room; air-controlled ventilated (ACV) rooms are not essential as a room with natural ventilation is usually considered adequate. In contrast, patients with measles and tuberculosis, who transmit infection via aerosols, should be isolated where at all possible in an ACV room and staff entering that room should wear an N95 respirator or equivalent. Even so, entrance to and exit from rooms in those circumstances by staff and others, should be kept to a minimum.

Various efforts have been made to try to anticipate or calculate the risk arising from pathogens spread by the air. Using radio-active carbon dioxide and mathematical modelling, Knibbs and colleagues evaluated the potential impact of different conditions on influenza, tuberculosis and rhinovirus acquisition in three categories of facilities, i.e. a pulmonary function laboratory (negative pressure with air handling unit), two separate outpatient consulting rooms (mechanically ventilated) and an emergency department (ED) isolation room (outdoor air drawn in with exhaust fan) [17]. The risk of infection in the pulmonary function laboratory and ED room was 0.1—3.6% but in the outpatient rooms, the risk of influenza was calculated to be 3.6—20.7%, depending on the duration of exposure. They also calculated that remaining in a room for 15 minutes with five-six air changes per hour, and where there is an infectious patient with tuberculosis, results in a potential acquisition rate of 2% [17]. In a survey carried out in the last ten years, four of five reference centres did not have negative pressure rooms for the care of patients with tuberculosis and there was concern over sub-optimal infection prevention and control measures [18]. Hence, the appropriate ventilation and duration of exposure affects the risk of infection acquisition by patients and staff, and in some centres, adequate ventilation is not available.

The recent COVID-19 pandemic has led to much discussion about how SARS-CoV-2 is transmitted and in particular, the role and nature of both aerosol and droplet spread. Initially, it was believed that transmission of SARS-CoV-2 was thought to be mainly through the contact and droplet routes, but now many argue that there is convincing evidence that airborne

transmission may explain (in some circumstances) the wide dissemination of SARS-CoV-s [19,20]. Furthermore, Tank and colleagues have argued that the distinction between droplets and aerosols and what happens to microbe-carrying particles in the air, may be more complex than hitherto thought [21]. Other factors may come in to play other than the size of particles, including the direction of air movement that may facilitate the wider dispersion of droplets than previously though [21]. Hence, it is likely that ongoing and future research will provide greater insights and may suggest a continuum between droplet and aerosol transmission that is complex and impacted by a number of parameters, and not just the size of particles.

Ventilation and pandemic preparedness

During normal times, there are often predictable requirements for ACV facilities, such as those for transmissible tuberculosis (e.g. productive cough in a smear positive patient) and hospitals try to ensure that they have sufficient rooms to accommodate the relevant patients. However, during major epidemics or pandemics, such as influenza, SARS, or COVID-19, there is a requirement for enhanced facilities.

During the SARS outbreak in Hong Kong, there were insufficient ACV rooms, inadequate space between beds on wards, and non-invasive positive pressure ventilation (NIPPV) resulting in exhaled air from affected patients been blown towards other patients or staff, leading to nosocomial acquisition [22]. Since then all beds on general wards should be at least 1m apart and more than 1,400 isolation beds with double-door and negative pressure were provided in public hospitals [22]. Therefore enough space between beds, care in the use of NIPPV and sufficient isolation facilities, may have helped Hong Kong manage the recent COVID-19 outbreak.

During a pandemic, additional isolation facilities (especially air-controlled ventilation facilities), are urgently required, but will be challenging to provide at short notice. In the absence of adequate existing facilities, there are alternatives to a new build. Miller and colleagues have suggested that to deal with surge capacity in a facility with controlled air delivery, reducing the supply of airflow and arranging that all return and exhaust air be directed to be released through roof-stacks with no mixing or recirculation, can provide for the equivalent of a negative pressure isolation ward [23]. Where a clinical area has natural ventilation, the installation of window-mounted exhaust fans, with both doors and windows kept shut, can result in 12 air changes per hour as demonstrated by computational fluid dynamics, and such a facility could potentially be arranged at short notice [24]. Even maximising fresh air through open doors and windows has a role, and is a simple measure. Furthermore, openable windows have been shown to have a possible beneficial effect on ICU-acquired respiratory infections, possibly by dilution and by ensuring a greater diversity of microorganisms in the air [25].

During the recent COVID-19 epidemic, a combination of contact, droplet and airborne precautions, including masks for all HCW (N95 respirators if there is a risk of aerosol spread), and social distancing where possible, have helped minimise nosocomial transmission. Recent advice has suggested that many measures initially advocated, e.g. air humidification and additional air duct cleaning, are not required, but simple measures such as opening windows and flushing toilets when the lids are closed rather than when open, can greatly assist [26].

Conclusions

Infection prevention and control team members should familiarise themselves with ventilation aspects relating to patient care areas in their healthcare facility, especially the operating theatre complex and patient isolation facilities. Therefore, it is advisable to develop ongoing relationships with hospital engineering and estates staff as well as colleagues in the operating theatre, in advance of major refurbishment or new builds, or the arrival of a major outbreak/pandemic. This will also facilitate early consultation with IPCTM as part of new theatre design, construction and commissioning of new in-patient facilities, and in managing outbreaks/pandemics. Infection prevention and control team members are not expected to have detailed technical or engineering expertise but to apply their knowledge, training and experience to ensure the best design and use of such key facilities and services. Therefore, they should be familiar with important and relevant national documents, such as UK Health Building Notes or equivalent elsewhere, know key individuals in their organisation to contact, and share experience and expertise with members of other IPCTM, such as during the COVID-19 pandemic.

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