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Lessons from the Pandemic: **Infection Prevention and Control and Building Design**

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1 Introduction

This review seeks to understand the lessons learned from the pandemic about the operation of hospitals and the implications of this for the design, layout and services that should be considered in the next phase of hospital building or in future major refurbishment.

The pandemic brought about an enormous amount of change in the way that hospitals operated. As the understanding of COVID-19 evolved and improved, the NHS responded by rapidly adapting and evolving treatments; the use of space; building services including mechanical ventilation systems; oxygen supply; the use of protective barriers; patient flows and pathways; and, use of technology. The NHS response also saw the rapid evolution of greater system cooperation, an emphasis on increasing site specialisation and the separation of pathways and sites. And we have witnessed the introduction of specific initiatives such as community diagnostic centres and elective surgery hubs to address the backlog of waiting times created by the pandemic. All this points to a rich source of learning that could and should inform the planning and design of hospitals being developed under the New Hospitals Programme.

The SARS-CoV-2 virus responsible for the pandemic was predominantly transmitted by respiratory particles with risks of transmission from staff to patients, patients to staff and between patients. Close contact (within 2 metres) for prolonged periods, exposure to crowded and/or poorly ventilated spaces were key factors in facilitating transmission. These conditions were difficult to avoid in many NHS facilities and caused challenges in implementing effective infection prevention and control measures. Although the mass vaccination programme has enabled the NHS to return service to a near normal footing, it is highly likely that similar pandemics will occur again within the next 10 to 20 years. It is therefore important that these lessons are learnt and NHS facilities are fit for purpose when this occurs.

The main questions we examined were:

- What changes in the clinical model and patient flows were necessary and what was learnt about the design and operation of services and buildings consequently? Were there secondary/unexpected impacts that need to be considered?
- What changes would you make if rebuilding or adapting buildings as a result of the pandemic e.g. ability to adapt in response to a surge in demand, availability of single rooms, ability to segregate flows?
- What are the pinch points that get in the way of productivity for planned work and how could changes in design, flows or other operational matters support a return to pre-pandemic levels of elective activity?

- What are the other key lessons for the design of facilities and service in manging infection prevention and control (IPC), particularly during a pandemic e.g. the significance of facilities for staff, support services, diagnostics, facilities/space for temporary structures, ability to plug-in services, or reconfigure space, entrances and separate flows, waiting areas, arrangement for visitors, etc.?

2 Approach

We interviewed a range of national and regional experts from NHS England, NHS Scotland, HSIB, several Royal Colleges and Professional Bodies such as the Institute of Healthcare Engineering and Estate Management and interviewed a range of clinical, managerial and estates professionals. Two focus groups for estates professionals were held via zoom.

Site visits were made to five hospitals representing a range of building types, age, layout and experience of the pandemic. There is no clear pattern in rates of nosocomial infection and key characteristics of the estate and so a pragmatic approach was taken to selecting them based on trying to achieve a mix of characteristics.

- Medium sized nucleus hospital
- Large teaching hospital with a mix of building types and ages
- Multisite trust
- Medium sized hospital with mix of buildings x 2

We met with CEOs, Chief Operating Officers, Chief Nurses, Directors of Infection Prevention and Control Leads, Clinical Directors, Estates Directors, Medical Directors, Consultants in Microbiology and Infectious Disease, Heads of Infection Control, Heads of Domestic Services, Heads of Patient Experience amongst others. These visits focussed on:

- Changes in patient pathways and patient movement caused by the pandemic
- How buildings were adapted and the adaptability of the buildings
- Constraints caused by building layout and design
- Engineering practices, medical gas oxygen supply, building ventilation systems and related challenges
- Issues relating to the layout and operation of imaging, theatres, recovery and critical care
- How staff facilities supported staff during their biggest professional challenge to date
- Some of the lessons associated with the operation of separate hot and cold sites more generally

We ran a seminar to explore the lessons of separating planning and emergency activity looking at the experience of three sites that operate models that do this. Two expert focus groups were convened by IHEEM and one with IPC leads. The approach to these was to use the framework followed by this report. Questions followed the structure used in this report.

We reviewed the findings and evidence from the Nuffield Trust small hospitals and COVID-19 report. Ten hospitals participated in this study and a minimum of four interviews was conducted for each hospital, including: lead/senior clinician in Emergency Medicine; lead/senior clinician in Acute Medicine; senior clinical manager at Divisional level or higher; senior non-clinical manager at Executive level.

A high level scan of the literature was also carried out but very little material has yet been published on this subject in the academic literature. We also reviewed the 40 business cases and planning documents submitted to the New Hospitals programme team to identify lessons that are already being incorporated in hospital design informed by the pandemic.

We spoke with members from the European Health Property Network (EuHPN) and extracted lessons from a series of seminars on adapting hospitals to respond to the pandemic and a separate report from this exercise including a review of the use of temporary accommodation can be found in the appendix.

The Infection Prevention Society have provided expert advice during site visits and on lines of enquiry.

3 Buildings and services

3.1 Ventilation and fresh air

Ventilation quickly emerged as a key issue for hospitals as it was identified relatively early as vital to the control of transmission. A detailed review of the issues associated with this is at Appendix 1. There was an awareness that future pandemics may have different challenges. Many of the sites relied on natural ventilation to ensure air changes and supply clean air. Indeed, there are only a small number of NHS hospitals that have a significant proportion of air change supplied mechanically.

Relatively deep patient bays were difficult to ventilate by opening the windows as there were restrictions on their opening for patient safety reasons and the level of air change away from the windows was reported to be poor. Low-cost work arounds (temporary extractor fans) were used to overcome this but often at the expense of noise and issues with temperature control.

Sites with low ceilings unsurprisingly reported more difficulty in getting ventilation right as the space to site the appropriate sized ductwork was not sufficient.

A minimum of 6 air changes per hour is recommended for clinical areas (HTM 03/01) with higher air changes required for other areas such as isolation rooms where aerosol generating procedures are performed, and in critical care.[i] We heard evidence that this level of supplied ventilation is not achieved across all clinical areas.

Some NHS Trusts purchased expensive air purifiers. Our expert advisor had found that air purifiers did not always live up their claims and additional pieces of ad hoc equipment are noisy and bring heat into the room. Air purifiers vary in effectiveness and area covered is dependant on the quality of the fan and the quality of the filters that are used in the system. In terms of COVID-19 specific HEPA filters - H13 - are required to capture particles as small as respiratory viral particles, i.e. as small as 0.3 microns. The filtration unit needs to be placed away from windows, doors and supply and extract grilles and fans and filters require regular maintenance to ensure effective filtration, getting access for this can be an issue. This, and the risk of installing equipment that may quickly become out of date, will need to be considered in building this type of equipment permanently into the estate

Working in full 'Red Area' PPE (fluid-resistant gown, apron, FFP3 respirator masks, eye protection and long cuffed gloves) is challenging at the best of times and some sites struggled to regulate working environment temperatures in some areas. This is even more of an issue in the light of the recent high temperatures and the need for better temperature control was emphasised as an important issue to consider in future buildings. This, however, introduces tensions with other priorities, such as the drive towards low and zero-carbon designs.

3.2 Space

A particular challenge for many NHS Trusts was compliance with infection prevention and control (IPC) guidelines on social distancing. The ageing NHS estate embodies the planning and healthcare norms of its construction time. Trusts with older estates typically have less floor space than more modern structures. This inevitably impacts on the ability to repurpose areas and create different flows and patient moves. For example, the guidance on ward sizes today mandates twice as much floor space compared to the wards that were built following the best buy designs such Frimley Park, West Suffolk, Queen Elizabeth Kings Lynn, James Paget and Hinchingbrooke hospitals. Furthermore, hospitals built before the 1980s are characterised by a relatively smaller proportion of single rooms which are typically not ensuite. In addition to the problem of low ceilings, buildings we visited had issues with narrow corridors, open plan areas for treatment with limited distance between patient stations, beds very close together, small workstations, etc.

The review team heard and saw the perennial lack of storage space that typifies many NHS hospitals and the ED in particular. But it is also a major estate constraint that

hampers effective infection prevention control measures such as cleanliness, as often items are stored is ways that impedes cleaninig the areas effectively. We observed the increased need to store items such as beds, wheelchairs, PPE, as well as medical supplies, overspilling into and compromising the use of clinical and corridor spaces. This underscores the need to ensure that there is an appropriate provision of storage space in the new hospitals as this is something that is easily cut to reduce costs but ultimately can be counter-productive in terms of compromising infection prevention controls, patient and staff movement and convenience, and efficiency.

Economising on space in room sizes, corridor widths and the size of bathrooms etc. reduced the adaptability of space as well as creating a challenge for isolation, changing into PPE, etc.

3.3 Patient rooms

In terms of which estate configurations seemed to drive the highest rates of nosocomial infection and outbreaks, regional and national infection prevention leads emphasised the importance of the number of single rooms. The view of regional IPC leads based on their experience, was that, hospitals with low or zero nosocomial outbreaks were characterised by a high or 100% proportion of single rooms. Nevertheless, there are many other factors at play that makes such a definite statement difficult. They saw the benefit of single rooms, especially those with en-suite facilities, as creating a physical barrier limiting transmission, but also acting as a 'nudge' to ensure good IPC practice by healthcare professionals. Operational staff reported that single rooms also made it easier to maintain flow as patients can be placed and isolated before a definitive diagnosis is confirmed. Indeed, patient movement to maintain flow was highlighted to us as a possible source of additional transmission risks.

A high proportion of single rooms would likely reduce the risks of transmission associated with cohorting patients whilst awaiting confirmation of COVID status and transmission from pre-symptomatic patients. As the incubation of COVID-19 is symptomless, being able to place patients immediately into a single room would also reduce the risks of transmission during this period although as single rooms are not carefully controlled isolation rooms they will not provide full airborne isolation for patients.

Views about the desirability of single rooms and the optimal proportion varied considerably amongst those we spoke to and there were particular concerns about:

- Impact on nursing workload
- Increased space requirement and cleaning
- Observation (depending on the design)
- Isolation of patients and risk of patients falling or becoming isolated

A detailed evaluation of the literature and cost/benefit equation for single rooms is outside the scope of this report and is already being undertaken for by DHSC and this will address these questions in more detail.

A range of other lessons were identified by respondents.

If bed bays are going to be built or refurbished then feedback on the experience of current 6-bed bays will be relevant. In addition to difficulties in getting natural ventilation far enough into the room to get the requisite air changes they were also seen as being less flexible than small numbers of bays and harder to maintain social distancing and privacy. It appears to some respondents that bays without doors may have had higher rates of in-hospital transmission but there is no data to support this, although without careful planning putting doors on bays may also adversely affect air-flow. One solution being considered is 4-bed bays, each with two ensuite bathrooms and to provide maximum flexibility for segregation of flows and infection control with, as per the current guidance, each 4-bed bay having a door so that it can be segregated from the remainder of the ward.

The issue of the provision of sinks in patient's rooms may require consideration based on our discussions. While hand washing is obviously a key part of IPC and the duplication of sinks for staff and patients might appear to be a sensible measure this was identified as carrying some other risks. Infrequently used sinks and plumbing can foster the growth of biofilms and hazardous organisms such as Klebsiella. The duplication of sinks is also expensive and uses space.

The availability of negative pressure rooms was a challenge in many cases although once case numbers became very high it was not such an issue. It may be desirable to have switchable pressure rooms (with the appropriate SOPs to ensure they are used correctly) but there was some debate about this in terms of cost and practicality. It is widely known that this is not often used or maintained correctly in the fast paced clinical areas. Reversable ventilation is an area which needs more research so it can be built into Health Technical Memoranda (HTMs). A positive pressure ventilated lobby rooms which can isolate most infections and provides protection also for the patient was seen as giving the most flexibility for patient management.

The space for changing into full or 'red area' PPE in isolation and single rooms was also an issue. With large numbers of infectious patients whole areas could be used for cohorting but even here sufficient space for changing was an issue. Related to this, and a recurring theme, is the need to ensure that there are appropriate levels of storage within rooms to reduce the need for staff to leave to look for basic supplies. However, it is important to understand that in normal times donning and doffing occurs outside the patient room.

Visibility is an issue and the use of whole length glass with appropriate screening controllable from outside and links for monitoring equipment to a central station is also important for IPC reasons – although there are risks of patient isolation. For staff in PPE in isolation rooms, especially in the ED, the ability to call for help and to get assistance via video is an important feature that could be incorporated into future hospital building design.

3.4 Emergency departments

The need to redesign the internal flows and operation of EDs and to ensure that there is a better match between capacity and demand was evident before the pandemic which has shone a light on the results of previous design, layout and process issues. The growth of different types of unit within emergency services designed to meet the clinical needs of particular patients fragmented capacity and increased the number of patient moves. From other work by our team and our interviews for this project there is a question about whether the service delivery model in use in many places is actually fit for purpose.

Emergency departments had major challenges in terms of space and the high level of traffic passing through them. All of the hospitals we spoke to had been operating their EDs at levels that were much greater than their design capacity and as a result modifications, additions and extensions had been built over the years. This created problems with:

- Internal flow
- Patient segregation – especially when patients are moved
- Observation areas with no natural light and poor ventilation
- Work areas with staff in very close proximity
- A lack of privacy

These factors clearly hampered the ability to maintain an optimal response to the pandemic.

EDs needed to stream patients into three categories to separate those with covid from those suspected of covid who also needed (amber) to be kept away from those that probably did not have covid (green). This presented a major challenge.[1] We heard about

[1] All organisations wrestled with the problem of triaging patients into the correct streams, especially during the first wave. Some hospitals relied on patients to self-select the correct stream, while others actively triaged. Two organisations used 'pods' or 'the sieve' in the car park as a triage area. This changed with the advent of rapid testing for COVID-19, with most hospitals switching to the isolation of all patients until the results of tests were available. As with emergency departments, pathways through the hospital evolved over the course of the two waves and were shaped by the availability and speed of local COVID-19 testing. Most organisations attempted to keep their admission pathways from the emergency department as close as possible to existing ones at the outset. Where side-rooms were available, these were used for patients presenting with a high suspicion of COVID-19 or a confirmed positive test on admission. Otherwise, patients were cohorted into Amber and Green streams, within AMU. In many organisations, however, the capacity of the AMU to manage this was soon outstripped. The usual solution was to stop AMUs from accepting direct referrals from GPs, direct all patients through the ED and then use three streams – 'Red', 'Amber' and 'Green' - to admit patients directly to inpatient wards, with the AMU reserved for the sickest patients. Two organisations were able to set up a parallel AMU, with one each for Amber and Green, the Amber patients being placed either in single rooms, or cohorted until test results were available. Cohorting such patients, however, while awaiting a definitive test result, was less than ideal, as there was potential for negative patients to be exposed to symptomatic/infectious patients and therefore this increased the risks and the transmission rates.

several different responses such as the: creation of parallel green and amber emergency departments; internal separation of green and amber streams within the existing department, or; assuming all patients were COVID-19 positive until proven otherwise which was the approach many took during the second wave. The creation of parallel departments, however, was only possible in organisations where other facilities were fortuitously available.

During our site visits, we observed a range of measures and building adaptations to emergency departments. Floor and space markers were put in place, and Perspex screens and barriers were erected both in reception and waiting room areas. These adaptations, however, were not uniform and are unattractive and ad hoc. An important response was the creation of a range of triage and streaming flows that sought to separate out flows within the department but the existing layout does not support this well.

Walled cubicles were better than open areas between patients, or where patients were only separated by a curtain, Although as noted above putting in doors has potentially adverse implications for ventilation.

Changes to EDs suggested by experience of the pandemic include:

- Ensure improved workspaces for staff
- More attention to flows within the department with wider corridors than have typically been provided
- Doors not curtains on treatment areas
- Better storage in rooms and for the department generally
- Create staff facilities for changing, breaks, etc.
- Oxygen supply – to all areas
- The provision of dedicated negative pressure resus rooms and isolation facilities with the required ventilation as per HTM003
- Hands free doors
- See also the section on patient rooms

3.5 Critical care

A number of lessons about the design and operation of critical care emerging from the pandemic were identified. These included:

- Further enhancement of some bed spaces to allow for additional equipment to be deployed

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Red/Green separation in the ED was a particular challenge especially for patients needing intubation and other forms of respiratory support. This was because they did not have time to manage the patients in a different emergency setting, and due to the risks attached to performing an aerosol generating procedure in the space where the ventilation was not always adequate.

- Water supply to support dialysis should be considered. This will provide increased flexibility[2]
- Power outlets were sometimes insufficient
- Internal flows within departments may need attention
- As with most other areas storage is an issue both within areas and in the unit more generally
- Isolation rooms and the ability to divide the unit in a modular way to separate out different types of patients and to be able to provide -/+ pressure environments
- Flexible space within the department to allow for additional donning/doffing facilities – we heard one example of a toilet that could be converted to an airlock style lobby.

One very clear lesson is that while they have good facilities in terms of power outlets, gases and suction operating theatres and anaesthetic rooms are unsuitable environments for the provision of critical care. Many theatres across the NHS have no or limited natural light, can become hot, can be isolating for staff providing one to one care all making it challenging workspace for staff providing critical care. We heard very clearly that this type of escalation should not be planned for in new facilities, it was a work-around because other ward accommodation lacked the gases, power or adaptable space. In future hospitals builds potential expansion areas for critical care should be identified.

3.6 Work environments and ergonomics

We heard the pandemic had shown the importance of ergonomics in workplaces. IPC professionals and estates managers pointed out the importance of behavioural insights into practical design features that make it easy to do the right thing, such as locating sinks and dispensers in areas that promote handwashing and hand sanitation before entering clinical spaces. Where ward or work areas were standardised or similar this was mentioned as aiding efficiency and safety because throughout the pandemic staff were often asked to work in new locations and we were told that this can create anxiety if the environment is unfamiliar.

It was found that the location of PPE dispensers near sinks can help infection prevention control but that it can be counterproductive if the process of handwashing generates contaminated and often pathogenic droplets which can then splash onto the surrounding areas and any PPE located nearby. This underscores the importance of attention to detail in how building design encourages behaviours which reinforce good infection prevention control.[ii]

3.7 Oxygen

The treatment of patients with SARS CoV2 involved very high levels of oxygen therapy, much higher than that anticipated when it was thought that ventilator support would be a key mode of treatment. This was for two reasons – the expansion of the use of non-invasive ventilatory support (NIV) outside of intensive care and high dependency units

[2] There were shortages of fluids to support haemofiltration during the pandemic

and the adoption of high-flow nasal oxygen (HFNO), which requires up to 50L/oxygen/min, as a standard treatment. So only were there significantly more patients than is usually requiring ventilatory support, but the amount of oxygen required was unprecedented and put an extraordinary strain on the systems of every hospital. The supply of oxygen and medical gases to ward areas was a major influence on the location of where patients were cared for. Not every NHS trust has piped oxygen to all its inpatient beds. This had to be considered in determining the siting of patients requiring oxygen therapy. Thus, the placement of patients sometimes had to reflect oxygen availability rather than other clinical criteria.

The majority of hospitals in our study of small hospitals encountered problems with their oxygen supply and delivery, posing a major risk to patient safety, especially during the peak of the second wave. While no organisation actually exhausted their oxygen supply, all reported design flaws or other problems with their delivery systems, such as: high dependency areas located at the further point in the hospital from the oxygen tanks, with insufficient pressure to deliver ventilatory support; inconsistent flows across identical wards areas; some with very limited supply or inconsistent supply within the same ward; O-rings and valves freezing due to a combination of very high flows and cold temperatures. Future hospital design will need to reduce the risks in this area.

Estates directors we spoke to had to take rapid emergency action to expand the supply in the early stages of the pandemic. This argues for increased redundancy in both pipe capacity and the provision of oxygen storage (VIE Vacuum insulated evaporator). A number of estates directors commented that only having one VIE was a significant risk that they were taking steps to deal with.[3]

The ability to monitor oxygen flow and supply levels across the site was a key part of the response and future systems will need this capability

3.8 Cleaning and decontamination

Many Trusts developed rapid response teams to provide deep or enhanced cleans to infected areas. This involved cleaning surfaces with disinfectants. Mobile hydrogen peroxide vapour (HPV) devices were also used as part of decontamination and infection control regimes. HPV devices work by releasing HPV into the air and is effective at decontaminating surfaces. The surface needs to be physically cleaned prior to the vapour to remove the organic material, otherwise the vapour doesn't penetrate it. HPV devices are frequently deployed to deep clean clinical areas. As part of our site visits, we heard from one site that, because of bed pressures, they had not had the

[3] These only became apparent as the demand for oxygen increased. These problems had major knock-on effects. They drove the rearrangement of wards, sometimes repeatedly, and determined ward configurations by levels of supply, rather than infection control considerations or clinical adjacencies. In one hospital, the respiratory unit, which delivered CPAP and HFNO, was moved three times, resulting in considerable disruption and distress. In another, the problem of low pressure in high demand areas was solved only by the army working 24/7 to deliver additional oxygen canisters.

opportunity to do a thorough deep clean programme for 10 years. For ward areas, conducting an annual deep clean requires capacity in which to decant patients while the deep cleaning process is conducted. This underscores the importance of creating space and flexibility within a trust estate to facilitate infection prevention control best practice, such as regular deep cleaning and the provision of ring-fenced decant space.

Ultraviolet (UV-C) light can be used as an adjunct ~~[and designed into buildings] -~~ to help with decontamination of an area post physical cleaning has been carried out Using UV-C light as part of a disinfection method known as Ultraviolet germicidal irradiation (UVGI) kills or inactivates microorganisms by destroying nucleic acids and disrupting their DNA. Rooms still needs to be cleaned prior to the use of UV-C, to remove organic matter, and only surface in direct contact with the UV will be decontaminated. However, we heard how UV-C could be used alongside cleaning to potentially cut down the turnaround cleaning times between rooms from about two to three hours to 15 minutes. Some hospitals were considering building this technology into some department rooms, inpatient wards and even lifts.

We also heard about the opportunity to use infection-resistant surfaces (such as sharklet). This is more relevant to bacterial risks and the evidence for the effectiveness of copper is limited[iii] and we could not find many good studies about the real-world deployment of these surfaces. Hospitals told us about the importance of ensuring that material and surface characteristics promote ease of cleaning and reduced degradation over time as this will limit the ability for organisms to stick to them. This can then be combined with enhanced cleaning regimes and sanitation points, to reduce fomite transmission through contaminated surfaces. This is particularly critical for frequently touched surfaces such as computers, door handles, lift buttons, work and countertops. The flow and layout of staff work activities and interaction with equipment also creates further transmission risks. In many hospitals, the number of ward-based workstations-on-wheels (WoWs) is limited by space, which means that several members of staff use the same (as opposed to separate) machines which increases the surface transmission risks. The use of moveable equipment poses challenges for to ensure it is appropriately cleaned between patients and areas, as is well documented. A number of experts that we spoke to brought this up as a source of potential staff transmission.

Bed decontamination and storage facilities are also required to allow quick turnaround between patients. At one hospital, we heard how they had the site space to create separate and dedicated decontamination facilities and area. They would remove the bed and bedside furniture to dedicated cleaning facilities, which would then be subject to a steam-based deep clean. Furniture was provided from pre-cleaned stock. What is more this innovative infection control best practice was combined and integrated with their innovative RFID tele-tracking system, which ensured that the movement and cleaning of equipment could be monitored and expedited as beds became available .

4 Movement through the hospital

4.1 Patient flows

After the initial surge, many hospitals sought to establish COVID-19 and non-COVID-19 pathways and areas, taking advantage of the rapid roll-out of testing capabilities across the NHS. There were many different approaches trialled across the NHS.[iv] There is not any definitive guidance on the most effective way of setting up pathways designed to minimise infectious disease transmission and facilitate ongoing service delivery. Such guidance would also need to consider ergonomic considerations such as the impact of complexity on guideline adherence.

Typically, three principal distinctions typically referred to as red, amber, green areas or pathways were developed. Red areas or pathways were assessed as having a high viral load and/or definitive gold standard (PCR) diagnosis of COVID-19 and represented the highest transmission risk. Amber areas or pathways were either suspected patients with COVID-19 and/or assessed areas of medium to low risk of transmission, reflecting a step down in the severity and infectiousness of the COVID-19 risk. Green areas or pathways were the lowest area of risk, sometimes referred to as clean zones or COVID-free areas. Green pathways was used to describe the non-COVID-19 services that were being restored following their suspension during the first wave of the pandemic, these included surgical pathways.[v] Where possible, green pathways also incorporated separate entrances and exits and sometimes completely different buildings and even separate sites.[vi]

Our interviews, examining the impact of COVID-19 on small hospitals, as well as our site visits, highlighted that the practical challenges of keeping potentially infected patients separated from those with other presentations, were major for all organisations. This became particularly so during and after the second peak, when normal activity and electives were reinstituted. Responses were very much dependent on the pre-existing size and configuration of the estate.

Key to the effective separation of red and green pathways was the provision of sufficient diagnostic and testing facilities that could handle large numbers of samples. Indeed, rapid and effective testing is critical to the effective management of any pandemic. Investment in large scale laboratory testing to support the effective segmentation of patients and isolation of staff was therefore pivotal. NHS England also sought to accelerate pathology transformation and consolidation through the establishment of major testing laboratories but at least one hospital we spoke to pointed out the advantages of on-site laboratory services in terms of being able to turn around tests very rapidly and thereby place patients more quickly into the right place.[vii] However in other instances the sheer volume of specimens required was not feasibly possible to turn around and therefore some organisations needed to outsource to other bigger laboratories, but found timeliness an issue and this impacted on operational decision making.

4.2 Entrances

Feedback from the EuHPN seminars picked up discussions with some of our NHS interviewees about rethinking entrances.

The possibility of separating flows implies that the building and the different units are accessible from multiple entrances. The access to multiple entrances is not obvious because it requires access to multiple elevators and staircases, as well as proper accessibility from outdoor spaces. It is a solution that might in the future conflict with another relevant trend in hospital design: the concentration of few public entrances due to security risks.

Some consideration was being given to multiple rooms with direct access from the outside. A&E and clinics dealing with infectious or immunocompromised patients might be planned and re-adapted to have multiple rooms that can be accessed directly from outside. In A&E departments, it has been crucial to separate triage and testing of Covid-19 patients as much as possible from other patient flows. This solution might considerably determine the layout of these units in future hospital projects.

5 Flexibility and resilience

5.1 Adapting services

One of the most important lessons from the pandemic was how the NHS estate supported rapid changes in clinical spaces, flows and staff working. Decanting space and surge capacity were obviously important and our interviewees thought that the lack of this was already an issue prior to the pandemic which had exposed just how significant a shortfall there is in this area.

Our international interviewees said that general key to success in the adaptation and transformation of existing hospitals is the high flexibility of spaces, layouts and technical supplies. In the specific context of the Covid-19 pandemic, larger rooms with a high standard of technical installations, such as operating theatres, pre- and post-operating rooms, have been transformed into ICU rooms for Covid-19 patients. Flexibility for future transformation is a demonstrated best practice principle for future-proof and pandemic-resilient hospitals, although it might implicate a higher capital investment in the short term.

We heard that while theatres were converted to critical care their layouts are not very conducive to this and that the ability to switch should not be a design requirement for theatres in future, it would be better to adapt other parts of the hospital and ensure that these had adequate gases and other utilities to support this.

International experience pointed to the value of sectionable units and demountable walls etc.. Units and departments could be planned to be divisible in sections, each with separate entrances. The possibility to dedicate part of one department to infectious patients is a design solution that could be prepared in future projects or existing buildings, when possible. It implies, for example, solutions for physical separation through sluices, separation of flows and entrances, separation of technical supplies as well as redundancy in certain functions or rooms. The strategic placement of utilities - sluice locations on wards and outpatients will need to be carefully chosen around planned dirty/clean flows and to allow later adaptation.

As noted above redundancy and high capacity in medical gas supply is a key enabler of a flexible response and important for providing resilience.

It was also discovered that to be able to accommodate dialysis the water supply was not adequate. Clearly this is not required in every part of the hospital but attention to the potential for needing to ramp up this services may be prudent.

5.2 Temporary hospitals and other accommodation

The experience of EuPHN members with field or temporary hospitals mirrored some of the issues with the Nightingale programme in the UK. A detailed summary of the options explored and the learning from these is at appendix X. One interesting strategy that may be more successful than the use of non-health buildings off-site is the use of 'plug-in' facilities on the hospital site using the utilities and other hospital facilities. This allows easier segregation on site, reduces the need to provide support services off-site and also does not require staff to travel to work in a distant and less familiar settings. However, temporary spaces such as these lack both good working and healing environment; low standards of accommodation and offer more limited security for staff, patients and supplies. They require a reasonable large and flat area close to a main corridor which was a challenge in some cases.[4]

The ability to erect temporary structures to create staff facilities, ED triage and extended waiting and a range of other functions was an important part of the response of a number of the hospitals we spoke to and visited.[5]

5.3 Hot and cold sites

Our international work[viii] confirmed a view we heard from interviewees in the NHS that the ability to operate a separate site for planned work had significant advantages in ensuring that elective work could continue. In addition to providing a much safer environment for planned care patients with lower risks of in-hospital covid transmission it also reduces the risk of the disruption of services by more routine emergency work.

[4] Sheba hospital in Tel Aviv used an underground car park for this purpose.

[5] Some trusts rapidly erected a range of permanent and temporary structures. Wolverhampton, for example, built a new 52 bed modular ward in nine weeks and also added an ITU 8 bedded extension, to increase capacity to cope with the predicted increases in demand. Such modular builds incorporated the latest guidance. Many hospitals also expanded their temporary mortuary spaces.

While there is some concern that separating out work on to different sites will increase duplication, lose time to staff travel, undermine team work and coordination between clinicians and reduce emergency resilience we heard that there are also significant potential advantages in terms of increased efficiency, better standardisation and smoother patient flow. Further research and investigation of how to manage the clinical, organ https://nervecentresoftware.com/nottingham-university-hospital-benefits-from-nervecentre/isational and cultural risks is needed.

As part of this work we looked at three models of separate planned care facilities and a short description of these is given in the appendix. These were working well and as in a number of other countries had allowed elective work to continue. Similarly, the Netherlands have been developing diagnostic and day treatment hubs with similar success in keeping non-covid work going.

6 Staff facilities

In our discussions it became clear how far the pandemic had revealed major problems and shortcomings in the facilities provided to staff across the sites. Operational workarounds were sought, but this impacted on staff wellbeing as they became more isolated at work.

All the experts we spoke to and site visits that we made highlighted: the lack of sufficient staff changing facilities; cramped handover rooms; multi-occupancy office space;; the geographical challenges of accessing designated rest areas that were significant distances from workspaces; the limited number of appropriate rest areas, and; the challenges that shared offices brought. It was also highlighted that there was insufficient space to have proper donning and doffing areas or appropriate collection of dirty PPE in ward areas requiring a further detailed look at the overall layouts of the wards adjacencies. More generally, changing areas and arrangements for uniform exchange were also a problem as this space has often been reused for other purposes over the years.

Future hospital design should consider how access to changing rooms, rest areas and office space impacts on the ability to deliver an optimal response to a future pandemic. Similarly it should also consider how staff are required to work or actually work in non-clinical areas and the way in which these interactions may increase the risk of nosocomial transmission. An important lesson of the pandemic is that these facilities cannot be regarded as an easy way to reduce the size of new buildings.

7 Other issues and ideas

7.1 Control systems and building management

We encountered two organisations using information systems to track capacity. One uses RFID tags on patients, equipment and some staff and the other uses an extension of their Nerve Centre system.[6] Equipping hospitals for the use of RFID tracking could be a cost-effective investment. Certainly, there are significant benefits in terms of forward planning, agility and the appropriate placement of patients of this sort of system oversight can support. These systems could also feed whole area control centres that might be a valuable tool in future.

Medical gases - The experience of the problems with medical gases demonstrates the need to understand and monitor oxygen levels and flow rates across the hospital site as well as understand the resilience of the distribution sets ups. Indeed, many clinical teams set up oxygen use groups to monitor and ensure that oxygen use was appropriately optimised. To support this regular monitoring of air quality has also proved to be important although it is not clear that this can be easily automated.

7.2 The future of office space

We heard how high rates of staff-to-staff transmission had occurred in open plan environments such as break rooms and multi-disciplinary offices and hospitals now need to understand how to balance the benefits of open plan arrangements, such as improved collaboration, creativity and culture with these risks.

Many estates directors we spoke to were considering the future use of office space on their sites. Very radical reductions (50% and above) were being considered for 'back office' functions including estates management, HR, finance and other administration using a hybrid of working from home and organized 'in-office' days. The approaches varied and it would be useful for work to be done to compare the thinking behind this. While the experience of this appeared to have been broadly positive in the hospitals we spoke to some research on the longer term impact of this on the effectiveness of services, their link to other parts of the hospital, the impact on employees and the broad cost/benefit equation would seem to be called for.

7.3 Waiting areas

With a very significant shift to digital outpatients and reduction in follow ups that the pandemic and the need to recover has accelerated it is likely that there will be a change in the nature of outpatients and that those patients that do attend are likely to have longer appointments on average (the proportion of new patients will increase as a result of these changes) and they will be more likely to have investigations or procedures or be

[6] https://nervecentresoftware.com/nottingham-university-hospital-benefits-from-nervecentre/

seeing multidisciplinary teams. This will change the number of people waiting and the nature and size of the space required.

The ability to change and segregate the ED waiting area might be considered although in a pandemic the option to use other areas of outpatient are available.

7.4 Guidance

Our discussions identified a number of areas where guidance needs to be updates or in some cases where it would be useful to produce it.

Relevant Health Building Notes (HBNs) which are out of date or inadequate

- Building resilience (cf. HBN 00-07 2014 "Resilience planning for the healthcare estate, published 1 May 2007, last updated 30 April 2014)
- Infection Prevention Control standards (cf. HBN 00-09 2013 'Infection control in the built environment', published 26 March 2014)
- HBN for adult isolation facilities (cf HBN 04-01 Supplement 1 Isolation facilities for infectious patients in acute settings". published December 2009), Last updated 2013.
- HBNs for patient waiting areas (cf. HBN 00-03 2013 'Clinical and clinical support spaces', published 20 March 2013)
- HBNs for staff changing facilities (cf. HB 00-02 2016 'Sanitary Spaces', published 20 March 2013, last updated 25 May 2016)
- HBNs for circulation space (cf. HBN 004 116 2013 'Designing stairways lifts and corridors in healthcare buildings', published 18 June 2007, last updated 16 April 2013)

Areas for where new HBNs or modification to existing HBNs could be useful:

- HBNs for entry or exit areas and red and green pathways
- HBNs for staff canteens
- HBNs for staff rest rooms
- HBNs for staff offices
- HBNs for outpatient spaces
- HBNs for ceiling height and interstitial space

Health Technical Memoranda (HTM) which are out of date or inadequate

- Medical gas resilience (cf. HTM 02-01 'NHS estates guidance for medical gas pipeline systems', published 1 May 2006)

- Pathology laboratory design (cf. HTM 67 'Design of laboratories for health sector buildings', published 1 January 2005)

8 Conclusions

There are a number of changes to the way that hospitals, wards and departments and the overall estate that are required where there is very good evidence that can be drawn from experience during the pandemic.

Many of these changes are relatively straightforward. There are others where the focus on minimising capital costs may be an obstacle to a long term and a broadly defined life cycle cost approach to investment planning needs to be adopted to avoid future problems.

The COVID-19 pandemic has underscored how important infrastructure and the built environment are for infection prevention and control. This experience also shows that the science of infectious diseases is likely to be in a state of constant flux, especially with respect to the emergence of a future infectious pathogens and their associated contagion and contamination characteristics. How future NHS buildings provide for a flexible response, therefore, will be a key component of reducing overall transmission in hospital environments in the future.

There are a number of themes that emerge across the different areas we looked at.

Guidance - there are a number of areas where guidance needs to be revised in the light of lessons learned e.g. on ventilation. There are also some design questions about the layout and operation of departments and wards that need to be reviewed more generally where the pandemic has highlighted pre-existing problems e.g. Emergency Departments.

Cutting corners to reduce the initial capital costs, whether this is in terms of flexibility and resilience, space – many hospitals paid a price for previous decisions to reduce the space available for staff, circulation, storage, beds, etc. redundancy and spare capacity – e.g. in oxygen supply. A particular issue is the approach to the HBN derogation process to ensure that IPC is not constantly compromised by cost considerations.

Single rooms - ensuring a high proportion of single en-suite rooms to facilitate isolation and encourage IPC best practice. More research is required to identify the most cost

effective design to reduce staffing requirements and to understand if the target should be 100% and this is underway

Staff – it is clear that insufficient attention has been given to facilities for staff or staff experience in working in some departments and areas.

Managing buildings – the use of building management and the ability to monitor how the hospital is operating was an important theme in ensuring an effective response.

Overall, ensuring resilience and flexibility will be vital and the failure to pay sufficient attention to this in the past has created problems which can be avoided in future. Future pandemics may involve other respiratory diseases with different transmission routes and so, while learning the lessons from the current pandemic it will also be important to think about the next.

Annexe

Separating planned and unplanned work

The experience of dealing with COVID-19 and previous problems of protecting elective capacity in winter has led to increased interest in the development of a split between planned and unplanned work. This may also be attractive when considering reconfiguration options where it is necessary to maintain more than one site due to limits on capital or other constraints.

We held a workshop with Hampshire Hospitals and had input from three sites with well-developed models that separate planned from unplanned work:

- SW London Orthopaedic Centre (SWELOC)
- Chase Farm – part of the Royal Free Group of hospitals
- Northumbria

Some of the detail of the models is explained below and each have their own important features. There are however, some important general lessons:

- Careful selection can reduce perioperative problems significantly. The criteria can be more permissive and less rigid than is often assumed and as confidence grows the numbers of patients excluded seems to fall.
- For many patients remote medical cover is workable with nurse practitioners and well developed escalation processes. The availability of rapid response from the ambulance service can be an issue. The rate of transfers is very low in services that are well designed and risks are well managed.
- The approach benefits from the standardisation of equipment and approach across sites – this can be an issue where surgeons come from different trusts to use the centre, but it is possible to overcome this.
- The models can provide excellent opportunities for the training of surgeons and anaesthetists .
- Patients' willingness to travel does not seem to be a significant issue
- These models allow surgery to keep functioning during a winter surge.

Dividing the bed pool could be seen as reducing flexibility and duplicating costs. The discipline imposed on emergency services of not being able to spill over into elective beds combined with the economies from smoothing the flow of work and large scale standardisation of those procedures that may offset these issues.

South West London Elective Orthopaedic Centre (SWLEOC)

The model was established in 2004 focusing on orthopaedics in response to long orthopaedic waiting lists. It is a partnership between 4 acute hospital trusts – Epson and St Helier, St George's, Kingston and Croydon. This is embodied in a legal document which sets out profit sharing and relationships with partners. The policies and clinical governance in use are those of the host site - Epson and St Helier.

Outpatients are provided at SWELOC and the member trusts. Once a decision is made to operate the patient who is then put on appropriate pathway at SWLEOC. The patient understands from the outset that the operation will take place in SWLEOC.

The risk level of the patient is determined by the home trust. Pre-screening is very strong to quantify risk (Livebox is used for electronic pre-assessment) and there are pre-assessment nurses. The intensivists run a pre-assessment clinic for higher risk patients and develop an anaesthetic and peri-operative plan. There is no blanket exclusion based on ASA criteria. Emergency surgery takes place at the general hospitals.

There is a complex timetable for using the 6 theatres which work over 6 days/week. The facilities are used by 52 orthopaedic surgeons, staffed by partner trusts with a small number of surgeons employed by the centre to fill gaps. There are over 5000 elective operations per annum with an expectation of 4 joints per operating list. There are 7 SWLEOC anaesthetists supplemented by visiting staff from the member trusts.

Day cases are generally done locally, particularly where there are good day surgery facilities as this is more convenient for patients, relatives and staff.

Intensivists manage the wards working with advanced nurse practitioners and there is one intensivist on call 24/7. Most peri-operative problems are caused by underlying conditions. There is a PACU, but patients can be transferred to St Georges if very unwell. Only around 2 cases required treat and transfer per year.

There is a surgeon of the day drawn from the 6-7 surgeons who will be on site during operating hours to provide day time cover. Adverse events requiring the return of the surgeon who operated can be accommodated even where they are not able to but these types of events are rare – about 1/year

Patient information is shared across the sites (Bluespeir https://www.bluespier.com) and so scans are not repeated in SWLEOC. Information is transferred electronically for incorporation into the notes in the base hospitals.

Waiting lists are not pooled due to the administrative complexity involved in this.

The service is nurse-driven rather than relying on junior doctors. Nurse practitioners cannulate, take blood, etc. and discharge patients. Nursing and physio roles are integrated, and all staff are responsible for patient mobilisation. Patients are out of bed within 4 hours post operatively. Commonly people go home after 1 day. Average length of stay is 2.4 days

Training: orthopaedic trainees work with their own consultant and are not employed by SWLEOC. There are some research fellows who can backfill gaps in timetable for higher anaesthetic trainees, anaesthetic trainees come and spend days in the centre to develop particular skills.

Travel has not seemed to have been an issue for patients

Standardisation of equipment across sites - surgeons have to work with limited range of implants (4 or 5) determined by the surgeons collectively

Northumbria NHS FT

The trust is multi-site acute and community trust with an emergency centre Northumbria Specialist Emergency Care Hospital (NSEC) and other sub-acute hospitals at Wansbeck , Hexham and North Tyneside (referred to as base sites). Travel times between the emergency centre and these sites is 15-30 minutes. LOS in NSEC is 48-72 hours and then patients are discharged or transferred back to base hospital.

NSEC is central main emergency department with 6 theatres (including Obs) and110 beds (excluding Maternity, ITU and paediatrics). There are 21 theatres across the base sites

There are local diagnostics in each local/base acute sites which all undertake day surgery. Inpatient elective care mostly takes place at North Tyneside (there is a small amount at Hexham). Patients are selected on the basis that they do not need ITU support or are high risk based on a risk stratification/case selection process. Using ASC3 as the treatment ceiling for local treatment has been found to be too rigid and a review of cases was used to revise the criteria. Pre-screening is very effective and the data shows that numbers of patients needing post-operative blood transfusions / ITU are very small. Using more 'awake' procedures (eg for brittle asthma) has been good, and these patients mostly go home the same day.

The North Tyneside site has a post-surgical recovery unit for higher risk patients providing short term high dependency care. Out of hours support is remote provided by intensivist support

The medical cover on the base hospitals site is junior and so senior decision making is provided from NSEC. The base hospitals do 24000 procedures annually of which 80% day cases - increasingly done awake, under local anaesthesia. For overnight medical cover the base hospitals have nurse practitioner led care. Medical cover is remote. Initially there were lots of calls for support from NSEC but these have reduced. The

transfers from NSEC to base hospitals are done on the basis of treatment plans. The sites are 'put to bed' effectively and there is an escalation process in place.

Surgeons have been reluctant to undertake colorectal operations locally without critical care on site. Major resections are done at NSEC, but now some 'reversals' are done in base hospitals. It might be possible to do more colorectal operations on local/base sites in future as patients with problems tend to deteriorate slowly.

The overall changes have driven efficiency on base sites.

Unexpected spin offs of COVID…

- hot /cold split meant that the trust could restart elective care post covid quickly and didn't lose as much elective time as many trusts
- Sinks at front doors of the hospitals have reduced overall infections rates
- Unexpected reduction in heart attacks on base sites

The model is continuing to evolve. Experimenting is good for problem solving. There is good organisational memory which helps - some people who started the model are still in place.

Chase Farm

This is a new build standalone cold site that has been operating for 3 years. It is has 8 theatre tables, (4 barn- style for orthopaedics and 4 doing mixed operations), 50 inpatient beds (of which 42 are single rooms). It has 3 ESRU beds, an RMO on site. No emergency care is provided on site. The service is (ACP) nurse-led. Patients are pre-assessed and placed onto fully digitised clinical pathways– similar to SWLEOC.

Other key points

- The ceiling of care has risen and riskier patients are now treated in Chase Farm
- Currently a variety of specialties – including orthopaedics, head and neck, urology, breast, general surgery, gynae, but not colorectal yet
- There is very low offsite transfer rate.
- It is moving to partner with other trusts – along the SWLEOC model. Patients already come from a wider catchment area
- Focused digital processes and pre-assessments have reduced cancellations
- Post covid, the site is delivering high volume of low complex care
- Processes are driven by patient outcomes and have delivered flexible care, good performance, good patient and staff experiences
- Rotations of staff to upskill other clinicians.

- Digitization is key. Records are shared with primary care and the highly developed systems also support virtual ward rounds, remote advice and transferrable information
- Length of stay (now measured in hours for joint replacement) is relatively short. Early discharge supported by discharge teams are effective
- Patient experience is good and testimonials are helping to build the reputation
- 97% of the orthopaedic waiting list can be delivered by this model

Annexe: A flexibility matrix for healthcare facilities

Levels of Flexibility	Types of Flexibility	Typological-Spatial Strategies
Hospital complex	Constant surface flexibility	Flexibility of access systems
		Functional flexibility of the system
		Reuse of the hospital complex
		Redundancy of space for plant
	Variable surface flexibility	Existence of unused building land
		Strategies for increasing the volume of individual buildings
	Operational flexibility	Modular, replaceable, and maintainable plant
		Presence of networked information systems
		The use of building automation and control systems (for overall management)
		The use of flexible contractual/financial arrangements
		Outsourcing of support services
Building	Constant surface flexibility	Existence of shell space for expansion
		Structural flexibility
		Oversizing of load-bearing structures
		Modifiability of the envelope
		Presence of spaces for building plant infrastructure
		Flexibility and automation of segregated pedestrian routes
	Variable surface flexibility	Oversizing of load-bearing structures
		The use of blank facades
		Possibility of modular expansion
		Tiered building
Functional Unit	Operational flexibility	Modular, replaceable, and maintainable plant
		The use of building automation and control systems (at a building level)
		Efficient programmed maintenance
		Life cycle cost
	Constant surface flexibility	The use of internal dry partitions
		The use of movable internal walls and walls with wall-mounted fittings

Levels of Flexibility	Types of Flexibility	Typological-Spatial Strategies
		The use of movable internal partitions
		Presence of spaces for service building infrastructure
	Variable surface flexibility	Possibility of extending the entire functional unit upwards/sideways
		Presence of verandas/setbacks
	Operational flexibility	Plan with the flexibility of use
Individual Room	Constant surface flexibility	Functional flexibility of the room
	Variable surface flexibility	The possibility of extensions upwards/sideways
	Flexibility of use	Providing for multifunctional rooms
		Plant for multifunctionality
		Information systems services for multifunctionality
	Adaptivity to the user	The use of movable furniture and vertical screening
		Customizable humanization of the room

Covid lessons learned- Ventilation overview

Caveats: These are generic insights into the issues faced at trust level with ventilation systems before during and post pandemic and the likely reasoning behind this, including the clinical risk factors for consideration and the risk profile attached will vary. Droplet and aerosol production were the risk factors in the exposure of staff, and patients to the virus, mainly from respiratory excretion from infected patients, staff and visitors. It wasn't initially clear which procedures were classified as aerosol generating procedures leading to confusion.

Many healthcare buildings at the start of the pandemic, were already not compliant with current standards, and it was not possible financially to bring these units up to specification financially. In addition to this, the disruption to the area was also not feasible for the works to be carried out, this led to infection control teams in creating an ad-hoc risk management strategy in many organisations based on information available at the time.

Mechanical ventilation is often designed into a building at the outset of the building design itself, and rectifying it post build is very often difficult due to space constraints and costly. There are some aspects of retrofitting a system that can happen at local level, but bigger units, such that would supply areas requiring specialist ventilation, i.e. theatres, as these would require significant plant space as it would likely be utilised with other critical services such as water, electricity, and temperature control.

Infection control requirements

Health and safety at work act 1974, legally enforces the responsibility to ensure people are kept safe in the work environment, and this includes cumulative exposure from airborne pathogens, gases etc which can be harmful and can be present in a space in any given time. It is important to protect all staff and patients in a space, hence the requirement for to ensure that the air quality is being carefully managed. Transmission via the air has been clearly documented to occur between an infectious person and a host of individuals in the space, that includes clinical, non-clinical, contracted staff, visitors, volunteers and support staff such as Estates and Facilities. The Health Technical Memorandum and Health Building notes are the standards by which healthcare infrastructure should be guided by.

Mechanical ventilation, where installed and maintained properly aims to reduces airborne contamination through the dilution of the air supply volume in a space and ensuring appropriately extracting it away from the area. In the Health Technical memorandum 03/01 it identifies the areas where dilution of airborne particles is important, such as removal of airborne pathogens, and removal of harmful gases and odours and heat build up. Critical areas include theatres, recovery, critical care, isolation facilities and clean rooms and aseptic suites and containment areas such as pathology laboratories.

Other areas where are previously did not require high levels of air dilution, took on a higher significance, due to the requirement to accommodate a higher number of patients with respiratory based illness, and insufficient isolation facilities to manage airborne spread.

New areas of risk clinically were created, in terms of clinical activity which produces aerosols but did not fall within the areas where there was specialist ventilation in place. The generation of infectious aerosols outside of critical care and emergency departments, such as intubation for surgery, endoscopy procedure such as bronchoscopy, respiratory clinics, cardiac stress tests, dental procedures all of which resulted in infection prevention and control teams carrying out further risk assessments for the management of those spaces and the fallow times required between patients and staff re-entering the rooms, in order to prevent exposure.

The types of mechanical ventilation that will be required varies between adult and paediatric settings, for example radiology is an area which in paediatric settings often requires intubation, however has different requirements in adult settings.

Initial pandemic response

In the initial stages of the pandemic, many NHS trusts found that their ventilation systems were either not designed, installed or being maintained to the standards that they had previously understood. This meant that a large and time-consuming exercises of scoping the systems in situ, reviewing the clinical activity in the area, to identify what was required, and liaising with the Estates team needed to happen across the organisation taking them away from other critical tasks.

In some areas only air conditioning systems were in situ, these units cool the recirculated air, and therefore did not remove infectious particles from the air and can be misleading to the practitioners in that space, that the air was being cleaned when this is not often the case.

Many community areas did not have any ventilation specified for their areas, such as GP's, dentists, clinics, nursing and care homes. This significantly increased the risks and subsequent outbreaks, which due to the facilities were also difficult to control. A lot of facilities utilised natural ventilation to in effect "*air out*" the space, but there is no proven scientific method for ensuring the air is diluted effectively in natural ventilation and as stated there is often difficulty with uniformity of air dilution, influenced by temperature and fluid dynamics.

Critical Care

The surge in patients during the first and second wave of the pandemic, requiring critical care support varied in each region and hit each organisation at different times causing issues with transfer of patients and the ability to deliver the care required.

Throughout the pandemic, an increasing amount of patients were admitted to the intensive care units across the country, many of these patients requiring increased ventilatory support such as intubation, oxygen therapy such as continuous positive airway pressure (CPAP).

Many procedures were classified as aerosol generating procedures and therefore needed to be carried out in a room with sufficient air dilution rates and air exchange. This was often a challenge as in many areas they didn't have sufficient systems to manage them. The guidance on what was an acceptable fluctuated throughout the initial stages of the pandemic, as new evidence emerged. The consensus reached the region of 10 ach per hour allowing the fallow times to be cut to 15 minutes between patients. This facilitated the ability to deliver the volumes of care required.

Prior to the pandemic, the only space where this was achieved outside of theatres was in critical care, which has increased supply ventilation volume in comparison to the ward areas. This was due to the nature of clinical activity performed within that space; however many areas were required to take patients who remained positive but were well enough to be stepped down. This was a challenge as many areas were not able to safely support this level of care due to the ventilation supply within the unit, especially if required to nurse patients with different cohorts of patients in open areas such as bays, this often left staff having to wear full respiratory protection throughout the shift as it was unsafe to remove.

However, many critical care areas were not well equipped to deal with the sheer number of patients presenting at the initial stages of the pandemic. The overall space constraints led to continuous review of patients and staff managing the stepdown of known positive patients with covid, who were at the tail end of their illness, but still required isolation as they were still infectious. Some patients remained admitted for longer as many organisations within the community setting did not have sufficient capacity to accept patients due to staff sickness or self-isolation, nor the appropriate infrastructure to manage the patients safely. In some paediatric settings, some units had to defer patients elsewhere to be cared for due to the numbers of adult patients presenting overtaking the bed spaces. The critical care areas mentioned by this report were the focal point of care alongside the emergency units and resuscitation areas, but highlighted that if other areas were required for critical care delivery, an upgrade of the building services infrastructure would be required.

Theatres

In the pandemic, many hospital theatres were not being used due to staff resource being spread thin, redeployment of medical staff and nursing staff led to reduction in non-emergency surgery delivery and this has now created significant backlog. However at the time this allowed hospitals to safely manage patients and safely perform care such as intubation, oxygen therapy, mechanical ventilatory support and open suctioning on positive patients.

Theatre departments served as they were sufficiently ventilated and had sufficient medical gas supply to allow staff to safely care for the patients outside critical care environment in these newly vacated areas, but there are issues with this, as this led to increased contamination of the environment.

Many trusts, purchased air purification units to support the cleaning of the air, however the difficulty behind that was that the science behind the effectiveness of these units was emerging and therefore many areas bought units that were not helpful as an adjunct to their ventilation supply and this led to increased outbreaks between staff, as they became less compliant with their PPE usage in that space.

Investigation procedure spaces, such as within endoscopy, and other areas where aerosol generating procedures can occur, such as respiratory clinics, also need further consideration for appropriate ventilation. The staff facilities i.e. control rooms, break rooms also do not have appropriate ventilation supply, hence the need for separation of rotas of staff in order to protect the services, this was common during the pandemic, across different services.

Isolation facilities

Isolation rooms are part of the critical control measures for the management of infectious diseases, especially in PPVL rooms where there is a set point for the supplied volume of air into the lobby, in order to prevent movement of air in the wrong direction. Isolation of infectious diseases and containment of harmful particles, including pathogens, harmful gases are two of the major reasons for the installation of mechanical ventilation. There are a few methods of isolation that is used in the acute setting, negative pressure which removes more air than supplied, positive pressure which supplies more air than the surrounding areas, and Positive pressured ventilated lobby rooms which provide a volume of air to the lobby to prevent the cross flow of air out or into the room.[7]

[7] Negative isolation ensures that the air movement does not travel in the direction of the corridor where there is a risk of exposure to the airborne pathogen, such as TB, Measles, Chickenpox, and other airborne viruses.

Positive pressure is often used to prevent air from travelling to the patient from the corridor and is most used for isolation of neutropenic and immunocompromised patients who do not have the ability to protect themselves from airborne contaminants.

Positive pressure ventilated lobby's is used to provide protection in both directions and is often used where an immunocompromised patient who is also infectious is placed, under the premise that the lobby provides an air curtain both between the patient and the corridor. This type of isolation can provide isolation to all types of patients, even non airborne isolation can be placed in this room and protect staff and patients.

Generalised areas

The pandemic caused organisational wide review of the different types of clinical activity taking place in all the spaces across the hospital. Other measures such as reduction of numbers of patients and carers allowed to visit the area, social distancing, increased frequency of cleaning were all mitigations used in the pandemic

However due to being a place of work other considerations were also required such as the staff areas, training and education spaces, meetings and other gatherings which were had to be moved to online to prevent the large mixing of different groups as in the initial stages, these actions prevented many staff born outbreaks.

It became obvious that the design of these spaces was inadequate to provide enough space for staff to socially distance. These areas also did not have any specific ventilation requirements, except to exhaust for odours and smells. It should be a consideration going forwards in design about staff wellbeing and staff rest and change areas as recommended that are required to be improved in terms of supplied building services and the required space allocation.

Conclusion

Mechanical ventilation requires strategic oversight within each organisation and should be a multi-disciplinary approach when initially designing, such as is present with water hygiene. Mechanical ventilation in the acute setting became a focal point during the pandemic as the evidence emerged to support droplet and aerosol transmission. The use of adjunct equipment such as air purification units need to be carefully risk assessed by specialists, preferably IPC professionals to ensure that they do not pose an increased risk to the occupants of the space. These units often require regular maintenance to prevent them becoming a source of infection such as regular filter changes. When designing spaces, specialist aspects such as containment, temperature control, gases removal and equipment cooling, all require consideration in respect of the type of ventilation selected.

The pandemic caused every area of the hospital to be reviewed and risk assessed, and this should continue to ensure that staff and patients alike remain at reduced risk of exposure to harmful pathogens, gases, particles. Especially when areas are changed use within the acute setting, a review of the current ventilation in place should be reviewed to ensure it meets the requirement and a risk assessment performed.

These lessons must be taken forwards for the new builds and the management of our current estates, as although covid is not currently, other high seasonal viruses still can be transmitted through respiratory secretions and aerosolization generation.

Staff spaces, such as staff rooms increasingly became apparent as an area requiring review, and also areas for wider staff groups such as porters and cleaners, estates and maintenance, and other critical staff such as catering also require improved facilities going forwards, in order to have safe spaces to use for rest, etc.

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