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Creating Synergy: The Partnership Between Infection Prevention & Control and Architectural Design for a Healthier Hospital

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Abstract. The symbiotic relationship between healthy hospital design and infection prevention and control (IPC) is crucial to developing a safe healthcare environment. Collaborative efforts in mitigating the risk of hospital-acquired infections (HAIs) are needed and will decrease morbidity, mortality rates, and costs. HAIs not only impact patient health but also tarnish the reputation of healthcare institutions. This paper delves into the distinctions between exogenous-derived and endogenous-derived HAIs, elucidating their sources, transmission mechanisms, and preventive strategies. Exogenous-derived HAIs can be prevented by a well-designed hospital layout which minimize contamination. Endogenous-derived HAIs originate from the patient's own microbial flora, necessitating tailored infection prevention strategies such as antimicrobial prophylaxis. Standard precautions and transmission-based precautions, as outlined by the Centers for Disease Control and Prevention (CDC), form the cornerstone of infection control efforts. Hospital design should facilitate compliance with these measures, ensuring a microbial-safe environment conducive to patient recovery. Interdisciplinary collaboration between architects, healthcare professionals, and infection control experts are needed to integrate infection control principles into hospital design processes effectively. Key considerations include optimizing patient flows, separating clean and dirty materials, and implementing robust ventilation systems to mitigate airborne transmission risks. Furthermore, selecting appropriate surface materials resistant to microbial growth and enabling effective cleaning and disinfection protocols are important to maintain a microbial safe hospital environment. Most importantly, the shift towards single-occupancy rooms represents a significant stride in infection prevention, minimizing the risk of cross-contamination compared to multi-occupancy wards. Scientific evidence supports the efficacy of single-occupancy rooms in reducing microbial contamination and preventing HAIs.

Keywords. Environmental microbiology; Hospital design and construction; Patient's rooms; Health Facility Environment; Prevention and control

1. Introduction; hospital-acquired infections and design of the hospital

Healthy hospital design and infection prevention & control (IPC) are not adversaries but rather allies in ensuring a safe and conducive healthcare environment. Their collaboration is crucial for patient safety, in this paper confined to reducing the risk of hospital-acquired infections (HAIs) and enhance the well-being of patients. HAIs, also known as healthcare-associated infections, pose a significant and urgent threat to patient safety. These infections are acquired by patients during their hospitalization, their visit to the outpatient clinic, or receiving treatment or diagnostics within healthcare facilities, and accounts for both inpatients and outpatients.

The urgency of addressing hospital-acquired infections stems from several critical factors. HAIs contribute to increased morbidity and mortality rates. Vulnerable patients, already grappling with underlying health conditions, face heightened risks when exposed to infections in healthcare settings. Moreover, the consequences of HAIs extend beyond immediate health implications. Patients who acquire infections during their hospital stay often experience prolonged hospitalizations and additional medical interventions, leading to elevated healthcare costs. The financial burden on both patients and healthcare providers underscores the urgency of addressing and preventing these infections [1].

The overuse of antibiotics to treat HAIs contributes to the emergence of antibiotic-resistant bacteria. This global concern diminishes the efficacy of existing antibiotics and complicates the treatment of common infections [2]. Addressing HAIs is crucial in preventing the spread of antibiotic resistance and preserving the effectiveness of these life-saving drugs. HAIs also impact the overall quality and reputation of healthcare institutions. The occurrence of infections within healthcare facilities damages the reputation of these institutions and erodes public trust. Ensuring a microbial safe environment is vital for maintaining the quality of healthcare services and upholding the integrity of healthcare providers. Recognizing the preventable nature of HAIs emphasizes the urgency to implement and enforce stringent measures [3]. Proper hygiene practices, adherence to established protocols, and robust infection control are essential components of efforts to minimize the risk of infections spreading within healthcare settings. In summary, the urgency of addressing hospital-acquired infections arises from their immediate threats to patient well-being, the strain they place on healthcare resources, the risk of antibiotic resistance, and even legal implications. Proactive measures and a commitment to stringent infection control practices are imperative in mitigating the risks associated with HAIs.

So how to combat HAIs by hospital design? For this, it is important to explore the distinctions between two types of HAIs: exogenous-derived and endogenous-derived, as these have their own sources, transmission mechanisms, and solutions in patient care and infection control [4]. Understanding the differences between exogenous-derived and endogenous-derived HAIs is crucial for implementing effective infection control measures, and thus a comprehensive understanding is needed for effective prevention and management. Architects and designers of hospital buildings and their inventory are hereby informed and understand these common principles of infection prevention and sources of transmission.

Exogenous-derived HAIs originate from external sources, and are typically transmitted through contaminated surfaces, medical equipment, or the hands of healthcare workers. During their stay, patients can contaminate the wet (e.g., sinks) or dry (e.g., nightstand) hospital environment with microorganisms, which then are a source for other patients. As exogenous-derived infections arise externally in the healthcare environment, the prevention lies in changing this environment: The percentage of exogenous HAI is about 20-40% of all HAIs [5, 6]. Moreover, as compared to endogenous HAIS, exogenous HAIs are in theory preventable when the design, the hospital surfaces and the hands of personnel are free from pathogens.

A well-designed hospital layout, with respect to infection prevention can contribute to minimizing the risk of exogenous HAIs. In short, the microorganisms causing exogenous HAI or exogenous colonization which can lead to HAI later, are from other patients or, although less frequently, from personnel. Transmission occurs through direct contact, droplets or airborne particles.

Endogenous-derived HAIs originate from the patient's own microbial flora and occur more frequently when the patient's immune system is compromised or when the microbial balance is disrupted. Endogenous-derived HAIs call for different infection prevention strategies, such as antimicrobial prophylaxis, skin disinfection before indwelling devices, or surgery. For both exogenous and endogenous HAI, many kinds of HAI can occur such as bloodstream infections, catheter related infections, urinary tract infections, surgical site infections and pneumonia.

Standard precautions and transmission-based precautions are the two types of precautions that exist, according to the Healthcare Infection Control Practices Advisory Committee (HICPAC) from the Centers for Disease Control and Prevention (CDC) [3]. Standard precautions are to be applied to all patients regardless of the suspected or confirmed presence of an infectious microorganism. In other words, in the field of infection control, every patient is seen as a carrier of pathogens. Standard precautions make use of common-sense practices and personal protective equipment (PPE) that protect healthcare personnel from infection and prevent the spread of infection from patient to patient. This is based on the premise that all patients and all body fluids are contagious and can transmit to the environment, including hands, and then to other patients (Table 1).

Table 1. General measures applied to all patients in the hospital (based on: 'CDC: standard precautions' [7]. PPE: personal protective equipment.

General measures where its quality depends on design
Hand hygiene by following 5 moments indicated by WHO [8]
PPE (gloves, gown, mask, eye protection) in case of expectation of exposure to infectious material
Respiratory hygiene/cough etiquette principles
Clean and disinfect the environment
Clean and disinfect patient care equipment and devices
Proper handling of needles and other sharps

Transmission-based precautions are for patients known or suspected of having a transmissible infectious microorganisms that are not prevented by only applying general precautions; in other words; more and other measures are needed, next to the general precautions, to prevent transmission [3]. Transmission-based precautions or measures often go with isolation. Hospital design should encourage the compliance of both general and transmission-based measures. For an overview of transmission-based measures and examples, see Table 2 (contact, droplet, airborne, universal (protective)).

Table 2. General measures applied to all patients in the hospital (based on: 'CDC: transmission based precautions' [9]. Note: combinations of types of isolations may be needed to ensure adequate prevention. Abbreviations: NA; Not applicable, PPE: personal protective equipment, VRE; Vancomycin-resistant *Enterococcus faecium*; RSV; Respiratory Syncytial Virus FFP2; Filtering Face Piece, protection level 2, BMT; bone marrow transplantation.

Type of isolation	Single room	Airborne Infection Isolation Room	PPE	Cleaning and Disinfection	Example
Contact precautions	Yes	No	Gloves/gown	On indication	VRE
Droplet precautions	Yes	No	Respiratory mask	On indication	RSV
Airborne precautions	NA	Yes	FFP2 mask	On indication	Tuberculosis
Protective isolation	NA	Yes	No	Yes	Neutropenic allogenic BMT
Universal isolation	NA	Yes	FFP2	Yes	BMT and airborne infectious disease (Measles, Varicella, Tuberculosis)

The effectiveness of the hospital's professional output relies on the collaboration of various professions. Therefore, the quality-of-service provision is an important factor in achieving excellent task performance. In other words, the built facility should facilitate rather than hinder the proper functioning of professionals. To achieve this, logistics and infrastructure should support personnel in their tasks and minimize errors. Involvement of professionals in the planning stage is therefore of utmost importance and indispensable for the high-quality delivery of medical care. Restricting or reducing space during the planning of the building is a significant flaw, yet it is often observed. When space is not adapted to the needs of professionals, the work becomes complicated, and the likelihood of errors increases, including the risk on HAI. The solution lies in adapting space to the collaborative tasks and work of professionals. For this, the professionals such as clinical microbiologists and infection prevention and control practitioners on one hand should meet the architects and designer professionals on the other hand and they should get to know each other, collaborate, and agree on the aspects for creating future microbial safe hospitals.

In this paper, first we will highlight the most important aspects of the needs of infection prevention that can be addressed through hospital design. We will explain how the design of the hospital environment can help to prevent exogenous HAI. To achieve these objectives, we will highlight the most important prerequisites and situations concerning infection prevention at the hospital level, ward level, and patient room level. Second, as single-occupancy rooms or multi-bedrooms are the most debated issue in designing a hospital, we questioned how to prove from the perspective of IPC, the need for single-occupancy rooms and its effect on patient safety. Evidence-based design is nowadays more frequently being used to design the most appropriate hospital. We used the principles of evidence-based medicine (EBM) on showing the effects of single-occupancy rooms on transmission of microorganisms by applying the methodology of a before-after study design on the following study question: Are single-occupancy rooms microbial safer compared to multi-bedrooms? A summary of our published findings are given and discussed [10, 11].

2. What is important on hospital level with respect to prevention of HAI?

Hospital design should consider the flow of patients, staff, and materials. In addition to enhancing the overall efficiency of healthcare delivery by establishing distinct flows, the risk of cross-contamination during transport or while in the same area should be factored in when designing these flows. For each aspect, patients, personnel, and materials, it should be assessed whether they can be combined in one space or if separation is necessary.

In general, goods are packaged during transport, allowing dirty and clean items to follow the same routes. However, when goods are not properly packaged, such as in an open box or cart, clean materials and waste removal should not intersect to prevent contamination of the clean items. There is no infection prevention rationale for separating the flow and transport routes of patients and personnel. The likelihood of pathogen transmission in common hospital areas like corridors, stairs, and elevators is relatively low, as no procedures are performed, and there is minimal direct contact with personnel. Exposure times are also limited. However, corridors must allow for the unobstructed transport of beds, wheelchairs, and individuals. Employee routes should ensure direct access to their wardrobes, promoting the use of service clothes. Therefore, wardrobes should be positioned as close as possible to the workplace.

3. What is important on ward level with respect to prevention of HAI?

Separation of clean and dirty materials is one of the key principles of infection prevention and control [12]. To keep these separated, distinctive storage room should be assigned. It is well known that a shortage of storage room leads to improper storage by not separating clean from dirty [13].

It is important that airflow is adjusted within the ward and also to the outside of the ward where patients are being treated, ensuring that air cannot flow from one room to another to prevent the transmission of airborne infections. The ventilation system must be built with the understanding that every patient room can harbor an airborne infectious patient who may not be recognized and thus not placed into airborne isolation. The ventilation system must create a slightly negative pressure per patient room and avoid mixing air by recirculating it from one room to another. Poorly designed airflow can potentially contribute to the spread of airborne pathogens not only between rooms but also between wards [14, 15]. Each ward should have the capability to place patients into an airborne isolation room (AIIR). The hospital should establish a risk assessment plan to estimate the number of airborne isolation rooms needed for the patient population, considering that this population will change over the years of hospital use [13]. Planning for the number of AIIRs should be based on the local epidemiology and risk assessment for the airborne disease such as tuberculosis, chickenpox and measles [16].

During the COVID-19 pandemic, we experienced that there are procedures that increase the risk of airborne transmission if performed on someone with COVID-19 [17, 18]. Examples of these procedures are aerosol generating procedures (AGP), such as respiratory tract suctioning, tracheostomy procedures, bronchoscopy, and dental procedures [18]. This group of patients should be cared for in an AIIR as long as this treatment continues. For COVID-19 patients not being treated by AGP, contact/droplet isolation in a single room suffices to prevent transmission to other patients and personnel. The number of patients expected to be treated by this method should need to be considered as well when identifying the optimal number of AIIRs.

Considering the location of AIIR in the hospital, two choices must be considered: Firstly, airborne isolation rooms can be concentrated on a specialized ward where personnel are well equipped and trained to care for infected patients. These so-called isolation wards, designed for patients with contagious diseases, must be strategically located to minimize the risk of transmission to other areas of the hospital. Secondly, the AI rooms can be distributed across the wards, providing a nearby option for each ward to place patients in airborne isolation. There are two sides to the coin: concentration leads to easy organization of instruction, guidance, and teaching of personnel on how to handle infected patients, use the indicated PPE, and manage the isolation room with negative pressure. By distributing all rooms across the wards, the chance of compliance with indications for airborne isolation increases, as medical specialists generally prefer their patients to be nearby rather than in another ward. It is important to recognize that patients with contagious diseases will be present in every specialty; for instance, a patient with a hip fracture will be treated by orthopedic specialists who prefer to have the patient in their own ward. However, if this patient is also a carrier of a particular carrier of a particular microorganism resistant to many antibiotics, also called multidrug-resistant organism (MDRO) unrelated to the fracture, an isolation room will be necessary. Before discussions about the configuration of the wards commence, this issue must be addressed: both the number and location of AI rooms need to be decided upon at a very early stage in planning the built environment: The earlier the better, as the ventilation system must be equipped to adequately ventilate these rooms. At a later stage, changing the number or location is hardly feasible, as the ventilation system will then be a limiting factor that cannot be easily adjusted.

4. What is important on patient-room level with respect to prevention of HAI?

4.1. Isolation rooms

An isolation room is a single-occupancy room with its own sanitation facilities, equipped with an anteroom, specific air management, and constructed according to architectural requirements. An isolation room has two purposes; to protect other persons (patients and personnel) from the patient and/or to protect the patient from the non-filtered air, which can contain aspergillus spores. For this, choices have to be made for the airflow direction and filtering of incoming air. The air change per hour (ACH) improves the air quality in the room when contaminated by the patient.

The ventilation rate of a space is the number indicating how many times per hour the space is supplied with fresh air; to be calculated as; supplied fresh air (m3/hour)/volume of the space (m3) = (x/hour). Fresh air is necessary to maintain hygienic air quality (odor, (skin) particles, dust, concentration of exhaled CO_2, and other gases) and climatic air quality to ultimately achieve a healthy indoor climate.

The ACH of a space is the number indicating how many times per hour the space is supplied with air; to be calculated as; supplied air (m3/hour)/volume of the space (m3) = (x/hour). The air can consist of fresh outdoor air together with recirculated air; air from the isolation room that is filtered and mixed with fresh air returning. If no recirculation is used, then the air exchange rate is equal to the ventilation rate. To be sure no contaminated air flows into other areas, no recirculation should be used, resulting in ventilation is equal to the ACH; inflow of only fresh air. Recirculation of air can pose a risk due to filter system failure and requires continuous monitoring and maintenance.

4.2. Airborne isolation room

An airborne isolation room is intended for the isolated care of a patient colonized or infected with a microorganism transmitted via aerosols. The air pressure systems used for source isolation of patients in airborne isolation is shown in Figure 1: the negative pressure in the isolation room: the airflow goes from the corridor (0) to the anteroom (-) and then to the patient room (--). The patients' private bathroom is always under negative pressure (---) compared to the patient room to exhaust humid air.

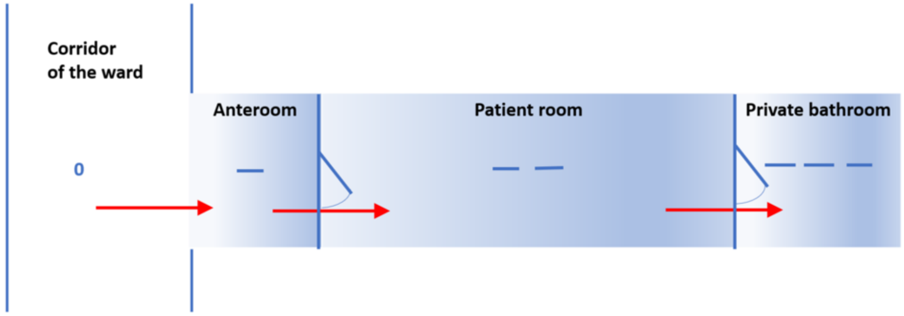

Figure 1. Schematic view of airflow direction (red arrows) in an airborne isolation room. The airflow direction creates negative pressure (blue lines) as compared to neutral pressure in the corridor (0).

4.3. Combined protective isolation and airborne isolation room: universal isolation.

A protective environment refers to isolation practices designed to decrease the risk of exposure to environmental fungal agents in allogeneic hematopoietic stem-cell transplant patients. There is increasing evidence that environmental controls decrease the risk of life-threatening fungal infections in these patients during their highest risk phase, usually the first 100 days post-transplant, or longer in the presence of graft-versus-host disease [3]. The need for such controls are especially of importance during construction activities nearby or in the hospital as these increases the number of aspergillus spores considerably. As this patient population are at increased risk for infectious diseases which are airborne or otherwise can be transmitted when a positive air pressure room is used, the use of a protective isolation room poses serious infection risk when not combined with airborne isolation; this is called universal isolation. Pure protective isolation rooms are not efficient and not recommended as whenever a patient in protective isolation has an infection, persons at the corridor are at risk of acquiring this infection due to positive room pressure. Examples of these airborne infections are tuberculosis, Varicella and MDRO.

Universal isolation rooms must have high-efficiency particulate air (HEPA) filters capable of removing particles 0.3 μm in diameter for supply (incoming) air in both the anteroom and the patient room. The air flow is directed to the room (Figure 2) creating a positive room air pressure relative to both the anteroom and the corridor, with a pressure differential of >2.5 Pa. Negative pressure in the anteroom will also prevent air form the patientroom escape to the corridor, but in this case donning of PPE should be at the corridor as the anteroom will be contaminated by air of the patient room. Air supply and exhaust grills are located so that clean, filtered air enters from one side of the room, flows across the patient's bed, exits on opposite side of the room. Self-closing doors with interlock are needed to maintain pressure differences.

No laminar flow for air supply is needed as this increases costst and inconvenience to patients and does not increase air quality in isoaltion rooms. The room must be well-sealed (including electrical outlets) with a proper construction of windows, doors, and intake and exhaust ports, all sealed to prevent flow of air from the outside. Ceilings must be smooth, free of fissures, open joints, crevices and walls are sealed above and below the ceiling. The ventilation provides ≥12 ACH. Next to strategies to minimise dust by chosing scrubbable surfaces (see below), dried and fresh flowers and potted plants are prohibited.

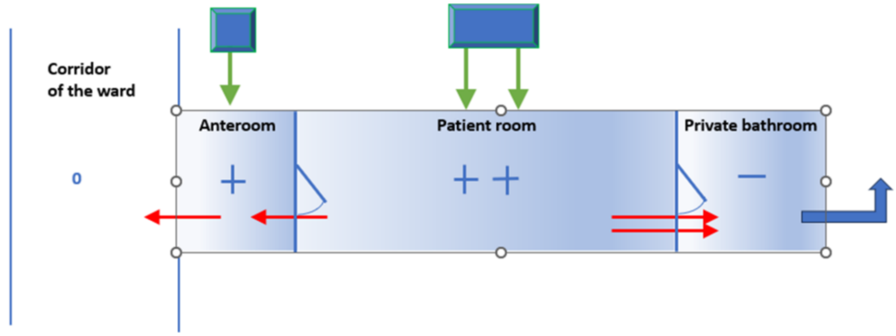

Figure 2. Schematic view of airflow direction (red arrows) in a universal isolation room. The airflow direction creates negative pressure (blue lines) as compared to neutral pressure in the corridor (0), incoming air (green arrows) is filtered by HEPA filters (blue boxes). Blue arrow; exhausted air.

4.4. Single-occupancy rooms

We are witnessing a shift from the traditional 'Nightingale' multi-occupancy open ward to single-occupancy rooms with private bathroom. Recently, an increasing number of hospitals have chosen single-occupancy rooms over open wards for various reasons, including privacy. Whether aimed at or not, this change has a significant impact on reducing HAIs, marking a substantial step forward in patient safety. The adoption of single-occupancy rooms accommodations has had a profound impact on reducing the transmission of infections [19]. Accumulating scientific evidence now supports the notion that single-occupancy rooms are more effective in preventing microbial contamination compared to open wards or even two-bed patient rooms. It has become evident that multiple-occupancy rooms poses a significant risk of acquiring pathogens from the contaminated room environment, linked to infections or colonization from the room's previous occupant, persisting for up to three weeks.[20] Multi-bed rooms pose a far greater risk of contamination, as more patients occupy the room simultaneously, providing an opportunity for carriers of specific pathogens to be present. Consequently, multi-occupancy rooms serve as potential sources for the next patient or roommates. In line, the absence of spatial separation between patients in multi-occupancy rooms or wards has been linked to an increased risk of respiratory viral infections and bacterial infections [21]. Studies examining cross-transmission of microorganisms in healthcare settings have revealed that surfaces closer to patients are more likely to be contaminated [20]. Additionally, patients with acute infections, particularly those whose symptoms lead to contamination of the immediate environment with body fluids containing pathogens (e.g., respiratory materials), tend to result in a higher microbial burden on environmental surfaces. This observation holds particularly true for norovirus, where studies suggest that person-to-person transmission relies on close or direct contact as well as aerosol exposure. Other researchers have noted a temporal association between fewer bloodstream infections, the detection of MDROs, and a decrease in antibiotic resistance following the redesign of patient-care units from open wards to single-occupancy rooms [22]. The confirmation that MDROs can endure in the environment for an extended period, as previously described, combined with the observed efficiency of cross-transmission in multi-occupancy rooms, has fostered a preference for single-occupancy rooms. The FGI initiated a systematic review of existing evidence on the benefits of single-patient rooms [23]. The review discovered suggestive, albeit low-quality, evidence indicating that single-patient rooms help prevent infection and enhance overall patient safety and care experience. The overall low quality of the evidence stems from the challenges associated with conducting randomized controlled trials or single-room comparisons to multiple-occupancy rooms. Creating such situations is not easily feasible, and even if possible, randomization to either single or multiple-occupancy rooms would be hindered by existing factors influencing the assignment of patients to one of these options, such as severity of illness, patient preferences, and ease for nurses, among others. Additionally, blinding in such studies is impossible. This leaves lower quality study designs as defined in EBM as the best to use, such as before-after designs or studies using a historic control.

4.5. The evidence of single-occupancy rooms in improving microbial safety; a before-after study

In 2018, our hospital transitioned from a building over 50 years old to a newly constructed facility featuring 100% single-occupancy rooms with private bathrooms. The decision to adopt single-occupancy rooms was primarily informed by expert opinion, given the limited evidence available at the time regarding its impact on infections and other patient-related outcomes. This transition presented a unique opportunity for us to investigate the effect of single-occupancy rooms on microbial safety. Additionally, we hypothesized that single-occupancy rooms would eliminate the need for intra-hospital patient transfers, such as those required for minor procedures, social considerations, or contact isolation [24]. Limiting intra-hospital patient transfers reduces patients' exposure to different hospital environments, potentially decreasing the risk of acquiring multidrug-resistant organisms (MDROs) through indirect exposure during transfers [25].

To bolster the evidence on these issues, we leveraged the move to measure the impact of single-occupancy rooms on microbial safety. We employed a before-after comparative study design, considered the highest feasible level of research quality for this investigation, despite being viewed as relatively low-level evidence in evidence-based medicine (EBM). The move to the new building served as the intervention in our study. We defined the new hospital environment as demonstrating improved microbial safety if there was reduced environmental contamination overall and/or with MDROs, and/or decreased acquisition and/or transmission of MDROs compared to the old hospital (the control).

Our study questions were formulated as follows:

1. What is the effect of transitioning to 100% single-occupancy rooms on the odds of acquiring an MDRO during hospitalization?
2. How does this transition affect the number of intra-hospital patient transfers?
3. What are the differences over time and the accumulation of bioburden or environmental contamination in these rooms?

Methods:

In both the old and new building, we tested patients on MDRO at admission and discharge to prove acquisition during stay. Intra-hospital transfers were defined as being transferred to another patient room for≥4 h, and did not include transfers to e.g., the ICU, radiology, the operating theater, or the Post Anesthesia Care Unit, since the necessity of these transfers was not impacted by the transition to 100% single-occupancy rooms.

The total environmental contamination was measured by cultures and counting colony-forming-units (CFU) and the numbers of MDRO bacteria. In the old hospital building, 10 two-person rooms, 15 four-person rooms, seven isolation rooms, 10 ICU rooms, of which two with anteroom, and nine bathrooms were sampled. In the new building 30 single-occupancy rooms, of which seven isolation rooms, 10 ICU rooms, of which two with anteroom; and 10 bathrooms belonging to single rooms were sampled. Altogether 4993 surfaces were tested; 724 in the old building and 4269 in the new building. The follow-up period of the new building was 36 months.

Results:

A total of 225 patients in the old hospital and 372 patients in the new hospital were tested for a common MDRO. The acquisition rate was low in both situations (not statistically significant). In the old hospital, approximately 25% of patients were transferred to another room during their stay, which decreased to 14% in the new building (P=0.001). Intra-hospital patient transfers were associated with ESBL-E acquisition (OR 3.18, 95% CI 1.27-7.98), with higher odds observed when patients were transferred twice or more [11]. This association was also observed by Pasricha et al, reinforcing our hypothesis that increased exposure to more square meters of the environment increases the risk of MDRO acquisition and should be minimized [26].

During the first month, CFU counts were significantly lower in the new building, but subsequently fluctuated around the same level as in the multiple-occupancy rooms. However, the number of identified MDROs in patient rooms was significantly lower in single-occupancy rooms. In the old hospital building, 24 (3.3%) sample sites were positive for 49 MDRO isolates, compared to five (0.1%) sample sites for seven MDRO isolates over the 36 month follow-up period in the new building (P<0.001) [10].

We demonstrated a significant reduction in MDROs in the new building even over three years of follow-up. Single-occupancy rooms, by design, have exposure to fewer patients, and cleaning and, when indicated, disinfection at discharge can be more effectively organized and carried out. Therefore, single rooms resulted in a safer environment compared to multi-bedrooms. This was underscored by the finding of less patient transfers being associated with less acquisition of MDRO.

Conclusions:

We advocate the imperative need to integrate infection control principles into hospital design processes. Healthy hospital design and infection prevention are essential components of a comprehensive approach to healthcare. When effectively integrated, they synergize to create an environment that promotes patient's microbial safety by reducing transmission and HAIs. In this paper, we demonstrate that hospital design profoundly impacts the incidence and spread of infections, as several key factors within the hospital environment influence the effectiveness of infection control measures.

Interdisciplinary collaboration among architects, healthcare professionals, infection control experts, and other stakeholders is vital to ensure that infection control considerations are woven into the overall hospital design. Conversely, inadequate design may heighten the risk of hospital-acquired infections and compromise patient outcomes. Attention to ventilation systems further minimizes the risk of cross-infections.

Our studies indicate that relocating to a new hospital building with 100% single-occupancy rooms significantly decreased patient transfers and MDROs in the environment. Environmental contamination and patient transfers are important factors in HAIs, making single-occupancy rooms essential for safe hospital design. Achieving this requires architects to collaborate with medical microbiologists, epidemiologists, IPC experts, and other healthcare professionals. The impact of transitioning to single-occupancy rooms on intra-hospital patient transfers was demonstrated in an intensive care unit, and our research has confirmed that this applies to other departments. Moreover, fewer patient transfers mean reduced staff workload and increased patient well-being.

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