Minimizing the Potential for Nosocomial Pneumonia: Architectural, Engineering, and Environmental Considerations for the Intensive Care Unit

G. du Moulin

The development of pneumonia in seriously ill patients remains an important concern of intensive care medicine. The design of the intensive care unit will have a direct effect upon the potential for infection. Persons involved in this design should consider engineering and architectural elements that will ultimately contribute to lower rates of infection. These include components to regulate the atmosphere, such as ventilation systems and temperature and humidity controls. Sources of contaminated water and the amplification mechanisms need to be addressed and minimized in the final designs. Architectural elements such as treatment space and lighting encourage optimal patient management and workable staffing patterns. Personnel who treat seriously ill patients should be part of the planning and design process in the construction and renovation of intensive care facilities.

The concept of intensive care has developed as an extension of recovery rooms and as a consequence of the added expertise in establishing specialized units for the treatment of epidemic diseases such as poliomyelitis. In the 1920s and 1930s, some German hospitals created special units (“Abteilung für Frischoperierte und Schwerkranke”) that would ensure constant surveillance of patients by qualified staff and concentrate therapeutic equipment resources.

The number of intensive care unit beds is projected to rise from the current level of 2–6% in U.S. hospitals to possibly 8–12%, based on demographic analyses for U.S. populations. More intensive care units will need to be designed and built to meet this increasing demand.

The loss of normal host defenses in the intensive care patient signals a protracted battle to prevent pulmonary infection. While initially sterile, the respiratory tract will quickly develop a succession of microflora, usually beginning as gram-positive and ending ultimately with gram-negative species. The sources of bacteria that initially colonize and infect the lungs are the patient’s own microorganisms, skin flora and fecal flora. The gastric environment provides a secondary source of organisms that tend to propagate as the patient undergoes treatment for stress bleeding. The patient will then be exposed to organisms transmitted by direct contact with contaminated staff, visitors, or patient equipment. Finally, the inanimate environment comprising the air, water, food, floors, walls and ceilings contribute bacteria and fungi that tend to be resistant to antibiotics. Ultimately, approximately 60% of nosocomial pulmonary infections are caused by gram-negative organisms, 20% are caused by gram-positive organisms, including the methicillin-resistant staphylococci, and 5% are caused by fungi. The remainder of nosocomial pneumonias are due to other pathogens, including Legionella pneumophila and, of recent concern, Mycobacterium avium complex, particularly in those patients with AIDS.

While the environment cannot be made bacteria-free, those who care for intensive care patients should understand the factors that can minimize the potential for infection through sound therapeutic management and a thorough understanding of the complex microbial environment to which patients are exposed. These include early wound closure, prevention of septic complications, adequate nutrition and control of the external environment. In the following discussion, I would like to examine control of the external environment from the standpoint of intensive care unit function and design, and place into perspective those elements that should be considered in the protection of the intensive care patient from pulmonary infection. From a microbiological standpoint, the design of intensive care units should take into account the following principles of microbiologic contamination control eloquently stated by Greene and Vesley: a) prevention of the entry of microbes into the intensive care environment; b) destruction
of the organisms that are present in this environment; c) prevention of microbial growth; and d) blockage of the environmental transmission routes, such as air, fomites, ingestible vehicles, and, of course, exclusion of insect or rodent vectors.

Atmosphere of the Intensive Care Unit

Ventilation

Ventilation systems in intensive care units have been and continue to be a controversial issue (17). Bacterial, fungal and viral infections have been transmitted to patients and health care workers via nonexistent or faulty air handling systems. Josephson reported airborne transmission of nosocomial varicella from localized zoster (18). Three of six susceptible health care workers developed disease, two of whom never had any direct contact with the source case. Of interest in this case was that the index patient's room was under slight negative pressure (24 ft³/min at the crack under the closed door as measured by thermal anemometer).

Centralized, filtered, unrecirculating air handling systems with an efficient preventive maintenance program should keep airborne organisms at a minimum. The major elements for ventilation systems in critical care areas are the air pressure differential between the patient's room relative to the unit, the filtration of air, including the efficiency of filtration, and the rate at which the air is replaced. Air pressure differential in a patient's room can have either positive or negative pressure with respect to the rest of the unit (19, 20). Since the ultimate goal is to protect the patient from exogenous airborne bacteria, a plenum or positive pressure ventilation should be chosen so that an outward flow of 50 ft/min through the open door can be maintained. In units in which a patient has a contagious infection, one would choose exhaust ventilation or negative pressure. Some rooms come equipped with both negative and positive ventilation, which can be activated by tripping a switch on the wall (19).

The air ventilating a patient's room should be filtered to remove foreign particles. High-efficiency particle-arresting (HEPA) filters are well suited for this purpose and are used extensively. These devices are capable of removing from the air particles > 0.3 microns in size with a > 99.97% efficiency. The Anderson Air Sampler (Anderson 2000, Atlanta, USA) is used in our institution to determine the level of airborne microorganisms after certain maintenance events such as filter changes are performed. Ventilation should be provided at a rate ranging from 8–20 exchanges per hour (21). Twelve exchanges of air per hour through HEPA filters is considered minimal in the intensive care unit (22).

Seriously burned patients requiring intensive care can be managed in a bacterially controlled environment (23). Developed at the Massachusetts General Hospital and evaluated extensively at the Shriners Burn Institute, bacteria controlled nursing units (BCNU) have been shown to be significantly more effective in preventing bacterial cross-contamination.

The most sophisticated form of ventilation offered to intensive care patients is the laminar air flow room, usually used in conjunction with HEPA filtration (20, 23–26). This form of air handling comprises the movement of filtered air in a unidirectional laminar distribution, usually at a velocity of between 30 and 50 ft/min. This produces low turbulence, sterile air. The environment of laminar air flow is very expensive to establish and maintain and does not necessarily decrease infection significantly by itself. Some air sampling studies have shown that cross-infection is markedly reduced. The use of laminar air flow facilities has been associated with increased nursing requirements as well as psychological disturbances in patients maintained in these near-sterile environments.

Window air conditioning units are discouraged in favor of centralized units because of the latter's better record of preventive maintenance by hospital environmental staff and the former's individual need for attention. The direct connection of the window units to the outside results in the concentration and dissemination of fungal spores into the patient's room (6). Filtered unrecirculated air conditioning in conjunction with a well-run maintenance program is sufficient to minimize airborne contamination.

Two additional facts must be kept in mind for those designing ventilation systems for intensive care units. Fresh air intakes on hospital exterior walls or roofs must be placed away from the areas where trucking and kitchen exhausts can accumulate and be drawn back into the hospital. Fresh air intakes should also be located far from effluents from ventilation discharge outlets, incinerators and boiler stacks. In those institutions upon which heliports have been built, rotor-wash from arriving and departing aircraft can wreak havoc on intake filters with subsequent contamination of the entire air handling system (Gardner, S. et al., 26th Interscience Conference on Antimicrobial Agents and Chemotherapy, New Orleans, 1986, Abstract no. 742).

Microbiologic contamination of compressed air and other gases has been demonstrated (27). In one investigation, lower levels of bacteria were found in air generated from oil-free compressors. We purge all gas outlets as part of an ongoing program in all patient rooms that are either newly constructed or recently renovated. Compressed air in tanks or from