CHAPTER 4

The Environment’s Impact on Safety

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U.S. hospitals are dangerous and stressful for patients, families, and staff members. Medical errors and hospital-acquired infections are among the leading causes of death in the United States, each killing more Americans than AIDS, breast cancer, or automobile accidents (Institute of Medicine [IOM] 2001). According to IOM’s landmark Crossing the Quality Chasm report, “The frustration levels of both patients and clinicians have probably never been higher. Yet the problems remain. Health care today harms too frequently and routinely fails to deliver its potential benefits.” Problems with U.S. healthcare not only influence patients; they affect staff as well. Registered nurses have a turnover rate averaging 20 percent (Joint Commission on Accreditation of Healthcare Organizations [JCAHO] 2002).

As with Chapter 3, in this chapter we report on some of the results of a large literature review conducted for The Center for Health Design (The Center) in 2004. A large and growing body of rigorous, scientifically defensible research shows that design of the hospital environment affects the safety of patients and staff. Design has a particular role in reducing: (1) airborne and contact-spread hospital-acquired infections, (2) patient falls, and (3) staff errors.
HOSPITAL-ACQUIRED INFECTIONS

Hospital-acquired, or nosocomial, infections pose a serious threat to the health of patients, staff, and visitors in hospitals. According to one study, up to 2 million U.S. hospital patients contract dangerous infections every year during their hospital stays (Weinstein 1998). In 1995 nosocomial infections cost $4.5 billion and contributed to more than 88,000 deaths (Weinstein 1998).

A strong body of research evidence shows that the built environment influences the incidence of infection in hospitals. Person-to-person spread of infections in the healthcare setting can occur via direct contact, droplet, airborne, fecal-oral, and bloodborne routes. The research literature shows that the design of the physical environment influences hospital-acquired infection rates by affecting both airborne and contact transmission routes. The literature suggests a clear pattern in which infection rates are lower with good air quality and single- rather than multi-bed rooms. Also, there is some evidence that providing numerous, easily accessible alcohol-based hand-rub dispensers or sinks can increase hand-washing compliance and thereby reduce contact contamination.

Reducing Airborne Transmission of Infection

Well-conducted research has linked all of the following to air quality and infection rates (Humphreys et al. 1991; Iwen et al. 1994; Loo et al. 1996; Opal et al. 1986; Oren et al. 2001):

- Type of air filter
- Direction of airflow and air pressure
- Air changes per hour in room
- Humidity
- Ventilation system cleaning and maintenance
- Dust or particulate generation during hospital construction and renovation activities
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There is convincing evidence that immunocompromised and other high-acuity patient groups have lower incidence of infection when housed in an isolation room with a high-efficiency particulate air (HEPA) filtration system (Passweg et al. 1998; Sherertz and Sullivan 1985; Sherertz et al. 1987). In one study bone marrow transplant recipients assigned to beds outside a HEPA-filtered environment had a tenfold greater incidence of nosocomial Aspergillus infection compared to other immunocompromised patient populations who were in HEPA-filtered spaces (Sherertz et al. 1987).

Air contamination is lowest in laminar airflow rooms with HEPA filters, and this approach is recommended for operating room suites and areas with ultraclean room requirements such as those housing immunocompromised patient populations (Alberti et al. 2001; Arlet et al. 1989; Dharan and Pittet 2002; Friberg, Ardnor, and Lundholm 2003; Hahn et al. 2002; Sherertz et al. 1987). HEPA filters are suggested for healthcare facilities by The Centers for Disease Control and the Healthcare Infection Control Practices Advisory Committee but are either required or strongly recommended in all construction and renovation areas (Sehulster and Chinn 2003).

Effective prevention or control measures during construction and renovation activities include, for example, portable HEPA filters, barriers between the patient care and construction areas, negative air pressure in the construction or renovation area relative to patient care spaces, and sealed patient windows. There is strong evidence of the impact of using HEPA filters for air intakes near construction and renovation sites (Loo et al. 1996; Mahieu et al. 2000; Opal et al. 1986; Oren et al. 2001). Humphreys et al. (1991) demonstrated that HEPA filters are not by themselves an adequate control measure and must be employed in conjunction with other measures such as enhanced cleaning, sealing of windows, and barriers.

Reducing Contact Transmission of Infection

Although infection caused by airborne transmission poses a major safety problem, most infections are now acquired in the hospital via the contact pathway (Bauer et al. 1990; IOM 2004). Many
environmental surfaces and features become contaminated near infected patients. Examples of surfaces found to be contaminated frequently via contact with patients and staff include overbed tables, bed privacy curtains, computer keyboards, infusion pump buttons, door handles, bedside rails, blood pressure cuffs, chairs and other furniture, and countertops (Aygun et al. 2002; Boyce et al. 1997; Bures et al. 2000; Devine, Cooke, and Wright 2001; Neely and Maley 2001; Noskin et al. 2000; Palmer 1999; Roberts, Findlay, and Lang 2001; Rountree et al. 1967; Sanderson and Weissler 1992; Williams, Singh, and Romberg 2003). These and other contaminated surfaces act as pathogen reservoirs that increase cross-infection risk. Boyce et al. (1997) found that in the rooms of patients infected with methicillin-resistant Staphylococcus aureus (MRSA) 27 percent of all environmental surfaces sampled were contaminated with MRSA.

Reducing Infections by Increased Hand Washing

It is well-established that the hands of healthcare staff are the principal cause of contact transmission of pathogens from patient to patient (Larson 1988). Accordingly, the importance of assiduous hand washing by healthcare workers cannot be overemphasized for reducing hospital-acquired infections. In this context the fact that rates of hand washing by healthcare staff are low represents a serious patient safety challenge. Several studies of hand washing in high-acuity units with vulnerable patients have found that as few as one in seven staff members washes their hands between patients. Compliance rates in the range of 15 percent to 35 percent are typical; rates above 40 percent to 50 percent are the exception (Albert and Condie 1981; Graham 1990). Hand-washing compliance tends to be consistently lower in units that are understaffed and have a high patient census or bed occupancy rate (Archibald et al. 1997).

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Educational programs to increase hand-washing adherence have yielded disappointing, or at best mixed, results. Some investigations have found that educational interventions generate no increase at all in hand washing. Even intensive education or training programs (e.g., classes, group feedback) produce only transient increases in hand washing (Conly et al. 1989; Dorsey, Cydulka, and Emerman 1996; Dubbert et al. 1990). Given the tremendous morbidity and mortality associated with high rates of hospital-acquired infections, there is an urgent need to identify more effective ways for producing sustained increases in hand washing.

At least six studies have examined whether hand washing is improved by increasing the ratio of the number of sinks or hand-cleaner dispensers to beds or by placing sinks or hand-cleaner dispensers in more accessible locations (Cohen et al. 2003; Graham 1990; Kaplan and McGuckin 1986; Muto, Sistrom, and Farr 2000; Pittet et al. 2000; Vernon et al. 2003). These studies offer support, albeit limited, for the notion that providing numerous, conveniently located alcohol-rub dispensers or washing sinks can increase compliance.

In particular, the evidence suggests that installing alcohol-based hand-cleaner dispensers at bedsides usually improves adherence. For example, Pittet et al. (2000) found that a combination of bedside antiseptic hand-rub dispensers and posters to remind staff to clean their hands substantially increased compliance. By contrast, Muto, Sistrom, and Farr (2000) reported that placing alcohol-gel dispensers next to the doors of patient rooms did not increase adherence. Two other investigations focusing on sinks (water and soap) identified a positive relationship between observed frequency of hand washing and a higher ratio of sinks to beds (Kaplan and McGuckin 1986; Vernon et al. 2003). Providing automated water-and-soap sinks, however, appears not to increase hand-washing rates compared to traditional nonautomated sinks (Larson et al. 1991, 1997).

Furthermore, three studies offer convincing and important evidence that providing each single-patient room with a conveniently located sink reduces nosocomial infection rates in intensive care units (ICUs), such as neonatal intensive care or burn units, compared to when the same staff and comparable patients are in multibed open units with few sinks (Goldmann, Durbin, and Freeman 1981; McManus et al. 1985, 1994; Mulin et al. 1997). Although hand-washing frequency was not measured in these studies, the investigators posited that increased hand washing was an important factor in reducing infections in the units with single rooms and more sinks.
A comparison of an ICU converted from an open unit with few sinks to single rooms with one sink per room found a tendency for hand washing to increase (from 16 percent to 30 percent) but no decline in infection incidence (Preston, Larson, and Stamm 1981). These results are perhaps explainable by the fact that several sinks in the single-bed unit were placed in comparatively inaccessible or inconvenient locations such as behind doors or away from staff work paths.

Reducing Infections with Single-Bed Rooms

We also identified at least 16 studies relevant to the question of whether nosocomial infection rates differ between single- and multi-bed rooms. Together, the findings provide a strong pattern of evidence indicating that infection rates are usually lower in single-bed rooms. Different mechanisms or factors have been implicated as contributing to lower infection incidence in single rooms, including lower patient-to-patient airborne infection and reduced contact infection as a result of easier cleaning.

One clear set of advantages relates to reducing airborne transmission through air quality and ventilation measures such as HEPA filters, negative room pressure to prevent a patient with an aerial-spread infection from infecting others, or maintaining positive pressure to protect an immunocompromised patient from airborne pathogens in nearby rooms.

Passweg et al. (1998) found that the combination of room isolation and HEPA filtration reduced infection and mortality in bone marrow transplant patients and significantly increased their one-year survival rates. Research studying burn patients also has shown that single rooms and good air quality substantially reduce infection incidence and mortality (McManus et al. 1992, 1994; Shirani et al. 1986; Thompson, Meredith, and Molnar 2002). Studies of cross-infection for contagious airborne diseases (e.g., influenza, measles, tuberculosis) have found, as would be expected, that placing patients in single rooms is safer than housing them in multi-bed spaces (Gardner et al. 1973; McKendrick and Emond 1976).
Severe acute respiratory syndrome (SARS) outbreaks in Asia and Canada dramatically highlighted the shortcomings of multi-bed rooms for controlling or preventing infections both for patients and healthcare workers. SARS is transmitted by droplets that can be airborne over limited areas. Approximately 75 percent of SARS cases in Toronto resulted from exposure in hospital settings (Farquharson and Baguley 2003). The pervasiveness of multi-bed spaces in Canadian and Asian emergency departments and ICUs, together with the scarcity of isolation rooms with negative pressure, severely hindered treatment and control measures. Toronto hospitals were forced to create additional negative-pressure isolation rooms by quickly constructing wall barriers to replace bed curtains and making airflow and pressure adaptations (Farquharson and Baguley 2003).

In addition to clear advantages in reducing airborne transmission, several studies show that single-bed rooms lessen the risk of infections acquired by contact. As mentioned earlier, many surfaces in patient rooms become reservoirs for pathogens through contact with patients and staff. Compared to single-bed rooms, multi-bed rooms are far more difficult to decontaminate thoroughly after a patient is discharged and therefore worsen the problem of multiple surfaces acting as pathogen reservoirs. Because different staff members who enter a room can touch the same contaminated surfaces, the risk of a nurse unknowingly becoming contaminated should be greater in multi-bed rooms.

Circumstantial support for this point is provided by research on contamination of nurses in units housing MRSA-infected patients. Boyce et al. (1997) found that 42 percent of nurses who had no direct contact with an MRSA patient but had touched contaminated surfaces contaminated their gloves with MRSA.

**PATIENT FALLS**

An extensive literature looks at the causes and risk factors involved in patient falls in hospitals. This is an area of great importance because patients who fall incur physical injuries, psychological effects, and longer lengths of stay in the hospital (Brandis 1999). It is estimated that
the total cost of fall injuries for older people was around $20.2 billion per year in the United States in 1994; this figure is projected to reach $32.4 billion (in 1994 U.S. dollars) in 2020 (Chang et al. 2004).

Although the role of the environment in causing or preventing patient falls is widely accepted, there is not yet conclusive evidence correlating environmental interventions with reduced falls. Available studies usually examine the location of fall incidents retrospectively or discuss environmental modification programs such as improving lighting and securing carpeting. However, a meta-analysis and systematic review of randomized controlled trials of fall-prevention interventions found no clear evidence for the independent effectiveness of environmental modification programs (Chang et al. 2004).

Nevertheless, several studies have shown that most patient falls occur in the bedroom, followed by the bathroom, and that comprehensive fall-prevention programs can have an effect. Brandis (1999) reported transfers to and from bed as the cause of approximately 42 percent of inpatient falls. Design faults identified in the bathroom and bedroom areas included slippery floors, inappropriate door openings, poor placement of rails and accessories, and incorrect toilet and furniture heights. After the fall-prevention program (which included identifying high-risk patients, management strategies, environmental and equipment modification, and standardization) was implemented, falls decreased by approximately 17 percent. Thus, fall-prevention strategies that have included environmental modification have worked in the past. However, it is not clear how much of the effectiveness of such strategies can be attributed to environmental factors alone.

An innovative and promising environmental strategy for reducing falls has its origins in evidence suggesting that many falls occur when patients attempt to get out of bed unassisted or unobserved (Uden 1985; Vassallo et al. 2000). It should be mentioned that there is considerable evidence that bedrails are not effective for reducing the incidence of falls and may actually increase the severity of fall injuries from beds (Capezuti et al. 2002; Hanger, Ball, and Wood 1999; van Leeuwen et al. 2001).

To increase observation and improve assistance for patients and thereby reduce falls, Methodist Hospital in Indianapolis, Indiana,
changed its coronary critical care unit with a centralized nurses’ station and two-bed rooms to one with decentralized nurses’ stations and large single-bed rooms designed to support family presence (Hendrich, Fay, and Sorrells 2002). Comparison of data from two years prior to and three years after the unit redesign showed that falls were cut by two-thirds—from six to two per 1,000 patients. Given that falls are a critical safety problem, additional research is needed to understand the effectiveness of this approach for designing patient care units.

**INCREASED STAFF EFFECTIVENESS AND REDUCED ERRORS**

The jobs of nurses, physicians, and others often require a complex choreography of direct patient care, critical communications, charting, filling prescriptions, accessing technology and information, and other tasks. Many hospital settings have not been rethought as jobs have changed; as a result, the design of hospitals often increases staff stress and reduces their effectiveness in delivering care. Although much research in the hospital setting has been aimed at patients, a growing and compelling body of evidence suggests that improved designs can make the jobs of staff much easier.

Workplace design that reflects a closer alignment of work patterns and the physical setting, such as redesign of a pharmacy layout, has been shown to improve workflow and reduce waiting times as well as increase patient satisfaction with the service (Pierce et al. 1990). Other studies that compared delivery times in decentralized and centralized pharmacy systems found medication delivery times were reduced by more than 50 percent by using decentralized drug-dose distribution systems (Hibbard et al. 1981; Reynolds, Johnson, and Longe 1978).

**Reducing Medication Errors**

The IOM report on the high prevalence of medical errors has encouraged a more careful look at the sources of error in healthcare. Much
of this work has been influenced by the seminal work of James Reason (2000). Reason argues that most errors are best seen as the result of a defective system rather than of careless individuals and that in fact most individuals are doing the best they can. A robust and effective system is one that increases patient safety by reducing active errors—those of commission, such as prescribing or administering the wrong medication—by creating latent conditions that do not overtax individuals’ abilities to make careful decisions, and through reasoned systems. An effective system also establishes multiple checks that catch errors, which are inevitable in any complex system, and recovers from them before they have negative consequences.

These concepts are well-supported by the research literature. For example, dispensing error rates by hospital pharmacists decline steeply when interruptions or distractions, such as telephone calls or remarks from other staff, are reduced or eliminated (Flynn et al. 1999). This suggests that spaces or rooms for dispensing medications should be separate and isolated from the distractions and interruptions of nursing stations.

Other studies have found that medication error rates also can be lowered by providing appropriate—usually brighter—work illumination levels. A large-scale controlled study of hospital pharmacists found that medication dispensing errors occurred more frequently when work surface illumination levels were in the low to moderate range (450 to 1,000 lux) (Buchanan et al. 1991). The same pharmacists made substantially fewer errors, however, when work surface illumination levels were increased to 1,500 lux.

The finding that bright lighting reduces medication errors suggests that the lowered illumination levels (200 to 500 lux) found in many healthcare spaces, because of greater use of computer terminals and pressures to reduce electricity costs, may be too low. Much research has shown that people over the age of 40 require higher illumination for reading and other visual tasks, and the average age of a nurse in the United States is 47. The aging of the nursing work force in the United States and elsewhere therefore implies that work-surface illumination levels of 1,500 to 2,000 lux may be needed to lessen medication errors when performing paper-based reading and writing tasks.
There is increasing evidence that medical errors, including medication errors, can be markedly lowered by reducing the transfer of patients between rooms or different types of units (Cook, Render, and Woods 2000; Hendrich, Fay, and Sorrells 2004; IOM 2004). When patients are transferred, many things can go wrong and often do. Reasons that transfers produce errors and worsen safety include, for instance, changes in staff caring for a patient, communication discontinuities, loss of information, changes in systems and computers, and delays or interruptions in patients receiving medications and care. Multi-bed rooms have been shown to generate many more transfers than single-bed rooms because of incompatibility among roommates.

If transfers generate errors, it follows that errors should be reduced if the care process and physical patient environment are reorganized and redesigned to eliminate most transfers. One proven approach for achieving this involves an acuity-adaptable care process and staffing model in combination with large single-bed patient rooms equipped with gas outlets and other equipment permitting the room to flex up or down in acuity according to the condition of the patient. When Methodist Hospital changed to acuity-adaptable single-bed rooms in its coronary ICU, transfers declined by 90 percent and medication errors were correspondingly lowered by 70 percent (Hendrich, Fay, and Sorrells 2004).

CONCLUSION

A strong and growing body of scientific evidence shows that the design of hospitals affects patient safety. Effective filtering of the air and special vigilance during construction can reduce airborne infection, and providing single-patient rooms can significantly reduce contact infection. Providing frequent hand-washing stations or alcohol rubs can increase hand washing by staff and reduce infections. Single rooms along with careful preventive programs can reduce patient falls. Improved hospital design can reduce errors by replacing chaotic, stressful conditions with quieter, better lit, more supportive settings that allow careful decision making and multiple checks for error.
NOTE

1. Laminar flows are even, smooth, low-velocity airflows used in clean rooms and other settings where high-quality ventilation is critical. But laminar flows are relatively expensive and difficult to achieve because furnishings, vents, and other features can create turbulence. Cornet et al. (1999) concluded that carefully directed airflow (i.e., laminar airflow) is important. However, we were unable to find and document cost-benefit analysis in the literature to justify the expense versus effectiveness of laminar airflow for patient care areas near construction and renovation sites.

REFERENCES


