The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity

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A visit to a U.S. hospital is 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, 2000; 2001). According to the Institute of Medicine in its landmark *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*" (IOM, 2001). Problems with U.S. health care not only influence patients; they impact staff. Registered nurses have a turnover rate averaging 20 percent (Joint Commission on Accreditation of Healthcare Organizations, 2002).

At the same time, the United States is facing one of the largest hospital building booms in US history. As a result of a confluence of the need to replace aging 1970s hospitals, population shifts in the United States, the graying of the baby boom generation, and the introduction of new technologies, the United States will spend more than $16 billion for hospital construction in 2004, and this will rise to more than $20 billion per year by the end of the decade (Babwin, 2002). These hospitals will remain in place for decades.

This once-in-lifetime construction program provides an opportunity to rethink hospital design, and especially to consider how improved hospital design can help reduce staff stress and fatigue and increase effectiveness in delivering care, improve patient safety, reduce patient and family stress and improve outcomes and improve overall healthcare quality.

Just as medicine has increasingly moved toward "evidence-based medicine," where clinical choices are informed by research, healthcare design is increasingly guided by rigorous research linking the physical environment of hospitals to patients and staff outcomes and is moving toward "evidence-based design" (Hamilton, 2003). This report assesses the state of the science that links characteristics of the physical setting to patient and staff outcomes:

- What can research tell us about "good" and "bad" hospital design?
- Is there compelling scientifically credible evidence that design genuinely impacts staff and clinical outcomes?
- Can improved design make hospitals less risky and stressful for patients, their families, and for staff?

In this project, research teams from Texas A&M University and Georgia Tech combed through several thousand scientific articles and identified more than 600 studies—most in top peer-reviewed journals—that establish how hospital design can impact clinical

outcomes. The team found scientific studies that document the impact of a range of design characteristics, such as single-rooms versus multi-bed rooms, reduced noise, improved lighting, better ventilation, better ergonomic designs, supportive workplaces and improved layout that can help reduce errors, reduce stress, improve sleep, reduce pain and drugs, and improve other outcomes. The team discovered that, not only is there a very large body of evidence to guide hospital design, but a very strong one. A growing scientific literature is confirming that the conventional ways that hospitals are designed contributes to stress and danger, or more positively, that this level of risk and stress is unnecessary: improved physical settings can be an important tool in making hospitals safer, more healing, and better places to work.

RESEARCH PROCESS

The research teams searched through scores of databases and in libraries at Texas A&M, Georgia Institute of Technology, University of Michigan, and elsewhere. The team was looking for studies that are:

- Rigorous, in that they use appropriate research methods that allow reasonable comparisons, and discarding of alternative hypotheses. The research studies were assessed on their rigor, quality of research design, sample sizes, and degree of control.

- High impact, in that the outcomes they explore are of importance to healthcare decision-makers, patients, clinicians, and society.

In 1998, Haya Rubin and her colleagues Amanda Owens and Greta Golden found 84 studies produced since 1968 that met similar criteria (Rubin, Owens, & Golden, 1998). Reviewing the research literature six years later, the team estimated that they would find around 125 rigorous studies. We found more than 600.

RESULTS

The research team found rigorous studies that link the physical environment to patient and staff outcomes in four areas:

1. Reduce staff stress and fatigue and increase effectiveness in delivering care
2. Improve patient safety
3. Reduce stress and improve outcomes
4. Improve overall healthcare quality

I. Reduce Staff Stress and Fatigue and Increase Effectiveness in Delivering Care

There is a growing nurse shortage, and this directly threatens patient safety. And the existing hospital-based nursing force is aging. Registered nurses in the United States average more than 43 years old and will average 50 by 2010 and have a turnover rate

averaging 20 percent per year (JCAHO, 2002). The Joint Commission on Accreditation of Healthcare Organizations (JCAHO), in their 2002 report, *Health Care at the Crossroads: Strategies for Addressing the Evolving Nursing Crisis*, noted that a shortage of nurses in America's hospitals is putting patient lives in danger. JCAHO examined 1,609 hospital reports of patient deaths and injuries since 1996 and found that low nursing staff levels were a contributing factor in 24 percent of the cases. The JCAHO report and surveys of nursing found that physical working conditions, along with support and compensation, are key contributors to turnover and burnout. Environmental support for work has become more critical as the typical patient is more seriously ill, patient loads increase, technology changes, and documentation requirements increase.

While reducing staff stress and fatigue through a healing and supportive environment seems like an obvious goal, there are relatively few studies that have dealt with this issue in any detail. More attention has been given to patient outcomes. However, the following sections review several studies that do document (a) effects of healthcare environments on staff health and safety and (b) improving workplaces to increase staff effectiveness, reduce errors, and increase staff satisfaction. Each section also suggests directions for further research.

Improve Staff Health and Safety through Environmental Measures

Nurses, physicians, and other healthcare employees work under extremely stressful physical conditions. Several studies deal with healthcare employees' risk of contracting infectious diseases from patients due to airborne and surface contamination (Jiang et al., 2003; Kromhout et al., 2000; Kumari et al., 1998; Smedbold et al., 2002). A recent study conducted in the wake of the SARS epidemic in China found that isolating SARS cases in wards with good ventilation could reduce the viral load of the ward and might be the key to preventing outbreaks of SARS among healthcare workers, along with strict personal protection measures in isolation units (Jiang et al., 2003). Another study in Norway found correlations between environmental factors and nasal symptoms of 115 females who worked at 36 geriatric nursing departments. They found significant decrease in nasal inflammation in relation to presence of *Aspergillus fumigatus* in ventilation supply and elevated room temperatures (Smedbold et al., 2002). An evaluation of 17 acute-care or university hospitals in Canada shows that tuberculosis (TB) infection among healthcare workers was associated with ventilation of general or nonisolation patient rooms of less than two air exchanges per hour. The evaluation included all personnel who worked at least two days per week in the respiratory and physiotherapy departments (Menzies, Fanning, Yuan, & Fitzgerald, 2000). This study, like the others, supports the importance of adequate ventilation with good maintenance for ensuring both staff and patient safety in hospitals. Several good studies demonstrating the risk of the sick building syndrome in hospitals also have been compiled within the 2003 *Guidelines for Environmental Infection Control in Healthcare Facilities* by the US Centers for Disease Control and Prevention (CDC) and the Healthcare Infection Control Practices Advisory Committee (HICPAC) (Sehulster & Chinn, 2003).

Nursing staff members are also open to risk of injury from medical equipment such as high-intensity surgical-light sources. One study found that a light source used during surgery could potentially cause retinal damage in surgical staff (Fox & Henson, 1996). Much research has examined the effects of noise on patients, but comparatively few studies are available for healthcare staff. There is evidence that staff perceive higher sound levels as stressful (Bayo, Garcia, & Garcia, 1995; Norbeck, 1985). Importantly, noise-induced stress in nurses correlates with reported emotional exhaustion or burnout (Topf & Dillon, 1988). A recent study by Blomkvist et al. (in press, 2004) examined the effects of higher versus lower noise levels on the same group of coronary intensive-care nurses over a period of months. Lower noise levels were linked with a number of positive effects on staff, including reduced perceived work demands, increased workplace social support, improved quality of care for patients, and better speech intelligibility.

Poor ergonomic design of patient beds and nurses' stations leads to back stress, fatigue, and other injuries among nursing staff. In one nursing home study, Garg and Owen evaluated manual tasks deemed stressful by nursing staff and used the information to select patient-transferring devices and to modify toilets and shower rooms. This nursing intervention resulted in a reduction of back injuries of almost 50 percent, from 83 per 200,000 work hours to 47 per 200,000 work hours. Also, in the four months after the intervention, there were no injuries resulting in lost or restricted workdays (Garg & Owen, 1992).

Thus, reducing staff stress by ergonomic interventions, as well as careful consideration of other issues such as air quality, noise, and light, can have significant impact on staff health. In addition, it is also likely to send a message that maintaining health and safety of staff members is an important goal for the organization.

Increase Staff Effectiveness, Reduce Errors, and Increase Staff Satisfaction by Designing Better Workplaces

Jobs by nurses, physicians, and others often require a complex choreography of direct patient care, critical communications, charting, filling meds, access to technology and information, and other tasks. Many hospital settings have not been rethought as jobs have changed, and, as a result, the design of hospitals often increases staff stress and reduces their effectiveness in delivering care. While much research in the hospital setting has been aimed at patients, there is a growing and convincing body of evidence suggesting that improved designs can make the jobs of staff much easier.

Nurses spend a lot of time walking. According to one study, almost 28.9 percent of nursing staff time was spent walking (Burgio, Engel, Hawkins, McCorick, & Scheve, 1990). This came second only to patient-care activities, which accounted for 56.9 percent of observed behavior. At least four studies have shown that the type of unit layout (e.g. radial, single corridor, double corridor) influences amount of walking among nursing staff (Shepley, 2002; Shepley & Davies, 2003; Sturdavant, 1960; Trites, Galbraith, Sturdavant, & Leckwart, 1970), and two studies showed that time saved walking was translated into more time spent on patient-care activities and interaction with family

members. Sturdavant (1960) found that fewer trips were made to patient rooms in radial units as nurses were able to better supervise patients visually from the nursing station, though the average time spent with patients was the same in radial as well as single-corridor designs. Shepley and colleagues (2003) found that nursing staff in the radial unit walked significantly less than staff in the rectangular unit (4.7 steps per minute versus 7.9 steps per minute). However, Shepley and her colleagues noted that radial designs might provide less flexibility in managing patient loads. Trites and colleagues (1970) found that a decrease in the percentage of time spent walking by staff in radial units was correlated to an increase in the percentage of time spent in patient-care activities. Also, the majority of the staff surveyed preferred to work in the radial units. Hendrich's research showed that decentralized nurses stations reduced staff walking and increased patient-care time, especially when supplies also were decentralized and placed near the nurses' station (Hendrich, 2003; IOM, 2004). Centralized location of supplies, however, could double staff walking and substantially reduce care time irrespective of whether nurses stations were decentralized (Hendrich, 2003)

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 work flow and reduce waiting times, as well as increase patient satisfaction with the service (Pierce, Rogers, Sharp, & Musulin, 1990). Other studies that compared delivery times in decentralized and centralized pharmacy systems found medication delivery times are reduced by more than 50 percent by using decentralized drug-dose distribution systems (Hibbard, Bosso, Sward, & Baum, 1981; Reynolds, Johnson, & Longe, 1978).

Other aspects of the environment, such as lighting levels and auditory or visual distractions, can also affect staff effectiveness while performing critical tasks such as dispensing medical prescriptions. There are relatively few studies that have examined the effect of environmental factors on medication errors, though this is clearly an area of great interest and future research potential. This is discussed in greater detail in the following section.

II. Improve Patient Safety

Hospital-Acquired Infections

One critically important way that evidence-based design improves safety is by reducing risk from hospital-acquired infections. The research team identified more than 120 studies linking infection to the built environment of the hospital. Transmission of infection to patients occurs through two general routes: airborne and contact. The research literature shows that the design of the physical environment strongly impacts hospital-acquired infection rates by affecting both airborne and contact transmission routes. The literature suggests a clear pattern wherein infection rates are lower when there is very good air quality and patients are in single-bed rather than multi-bed rooms. Also, there is some evidence that providing numerous, easily accessible alcohol-based hand-rub

dispensers or hand washing sinks can increase hand washing compliance and thereby reduce contact contamination.

Reducing Infections Caused by Airborne Pathogens

Evidence from many studies leaves no doubt that hospital air quality and ventilation play decisive roles in affecting air concentrations of pathogens such as fungal spores (*Aspergillus*) and, in this way, have major effects on infection rates.

Source of airborne infections: Well-conducted research has linked all of the following to air quality and infection rates: type of air filter, direction of airflow and air pressure, air changes per hour in room, humidity, and ventilation system cleaning and maintenance (Lutz, 2003; McDonald et al., 1998). For example, in one study where six patients and one nurse were involved with an outbreak of epidemic methicillin-resistant *Staphylococcus aureus* (EMRSA-15), an environmental source was suspected, and the ventilation grilles in two patient bays were found to be harboring EMRSA-15 (Kumari et al., 1998). The ventilation system, at that time, was working on an intermittent cycle from 4:00 p.m. to 8:00 p.m. Daily shutdown of the system created negative pressure, sucking air in from the ward environment into the ventilation system and contaminating the outlet grilles. The contaminated air blew back into the ward when the ventilation system was started. In another case, the source of infection was the exhaust ducting of the adjacent isolation room ventilation system that allowed the contaminants to enter the unit via a partially open window positioned above a particular bed.

Several studies have identified hospital construction and renovation activities as the sources of airborne infection outbreaks due to dust or particulate generation (Humphreys et al., 1991; Iwen, Davis, Reed, Winfield, & Hinrichs, 1994; Loo et al., 1996; Opal et al., 1986; Oren, Haddad, Finkelstein, & Rowe, 2001). In one study, high spore counts were found within and outside construction sites in a hospital. After control measures were instituted, no further cases of disseminated aspergillosis were identified (Opal et al., 1986). In another study, a nosocomial (hospital-induced) outbreak of invasive pulmonary aspergillosis (IPA) occurred in acute leukemia patients treated in a regular ward with natural ventilation during extensive hospital construction and renovation. The observed infection rate was 50 percent. At this point, some of the patients were moved to a new hematology ward with high-efficiency particulate air (HEPA) filters. During the following three years, none of the patients hospitalized exclusively in the hematology ward developed IPA, although 29% of leukemia patients still housed in the regular ward contracted IPA (Oren et al., 2001).

Controlling and preventing airborne infection: There is convincing evidence that immunocompromised and other high-acuity patient groups have lower incidence of infection when housed in a HEPA-filtered isolation room (Passweg et al., 1998; Sherertz, et al., 1987; Sherertz & Sullivan, 1985). In one study, bone-marrow transplant recipients were found to have a tenfold greater incidence of nosocomial *Aspergillus* infection, compared to other immunocompromised patient populations, when assigned beds outside of a HEPA-filtered environment (Sherertz, et al., 1987). Air contamination is least 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, Gluckman, Gerber, Perol, & Hirsch, 1989; Dharan & Pittet, 2002; Friberg, Ardnor, & Lundholm, 2003; Hahn et al., 2002; Sherertz, et al., 1987). (Laminar flows are very even, smooth, low velocity airflows that are used in cleanrooms 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.) HEPA filters are suggested for healthcare facilities by the CDC and HICPAC, but are either required or strongly recommended in all construction and renovation areas (Sehulster & Chinn, 2003).

Effective prevention or control measures during construction and renovation activities include, for example, portable HEPA filters, installing barriers between the patient care and construction areas, negative air pressure in construction/renovation areas relative to patient-care spaces, and sealing 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, De Dooy, Van Laer, Jansens, & Ieven, 2000; Opal et al., 1986; Oren et al., 2001). A strong study by Humphreys (1991) demonstrates that HEPA filters are not *by themselves* an adequate control measure, and must be employed in conjunction with other measures such as enhanced cleaning, the sealing of windows, and barriers. Cornet et al. (1999) concludes that carefully directed airflow (e.g. 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

Reducing Infections by Increasing Hand Washing

Although infection caused by airborne transmission poses a major safety problem, most infections are now acquired in the hospital via the contact pathway (Bauer, Ofner, Just, Just, & Daschner, 1990; IOM, 2004). It is well-established that the hands of healthcare staff are the principal cause of contact transmission from patient to patient (Larson, 1988). The importance of assiduous hand washing by healthcare workers, accordingly, 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 very 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 wash 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 & 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, Manning, Bell, Banerjee, & Jarvis, 1997).

Education programs to increase hand washing adherence have yielded disappointing or, at best, mixed results. Some investigations have found that education interventions generate no increase at all in hand washing. Even intensive education or training

programs (classes, group feedback, for example) produce only transient increases in hand washing (Conly, Hill, Ross, Lertzman, & Louie, 1989; Dorsey, Cydulka, & Emerman, 1996; Dubbert, Dolce, Richter, Miller, & Chapman, 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. Is there evidence suggesting improved hospital design can be effective in elevating hand washing?

Effect of number and location of sinks/dispensers on hand washing: The research team identified six studies that examined whether hand washing is improved by increasing the ratio of the number of sinks or hand-cleaner dispensers to beds and/or by placing sinks or hand-cleaner dispensers in more accessible locations (Cohen, Saiman, Cimiotti, & Larson, 2003; Graham, 1990; Kaplan & McGuckin, 1986; Muto, Sistrom, & Farr, 2000; Pittet et al., 2000; Vernon, Trick, Welbel, Peterson, & Weinstein, 2003). These studies, on balance, offer support, though 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 bedside usually improves adherence. As an example, a study by 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. Cohen et al. (2003) likewise reported improved adherence in association with the installation of numerous alcohol-gel dispensers. By contrast, Muto et al. (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/soap) identified a positive relationship between observed frequency of hand washing and a higher ratio of sinks to beds (Kaplan & McGuckin, 1986; Vernon et al., 2003). Providing automated water/soap sinks, however, appears not to increase hand washing rates compared to traditional non-automated sinks (Larson, et al., 1991; Larson, Bryan, Adler, & Blane, 1997).

Further, three studies offer convincing and important evidence that providing single-patient rooms with a conveniently located sink in each room reduces nosocomial infection rates in intensive care units, such as neonatal intensive care (NICU) or burn units, compared to when the same staff and comparable patients are in multibed open units with few sinks (Goldmann, Durbin, & Freeman, 1981; McManus, A. T., Mason, McManus, & Pruitt, 1994; McManus, A. T., McManus, Mason, Aitcheson, & Pruitt, 1985; 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 nonsignificant tendency for hand washing to increase (from 16 percent to 30 percent) but no decline in infection incidence (Preston, Larson, & 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.

Despite the encouraging overall pattern of findings in these studies, it is not clear how much of the effectiveness in terms of increased hand washing or reduced infection rates can be attributed to the installation of more numerous and/or accessible sinks and alcohol-gel dispensers. Future research should include controlled experiments that systematically vary the number and location of hand-cleaning stations or dispensers. There is also a conspicuous need for studies that define *accessible* locations for hand-cleaning stations in an evidence-based manner—that is, on the basis of empirical analysis of staff movement paths, visual fields, interactions with patients and families, and work processes. In this regard, the neglect of *human factors* knowledge and research methods is a major weakness of the hand washing research and, more generally, of the infection control literature. Research teams should include a human factors specialist and often an environmental psychologist. The urgent need to increase hand washing frequency underscores the high priority that should be accorded this research direction.

Reducing Infections with Single-Bed Rooms

The research team identified at least 16 studies relevant to the question of whether nosocomial infection rates differ between single-bed and multi-bed rooms. The findings collectively provide a strong pattern of evidence indicating that infection rates are usually lower in single-bed rooms. Different mechanisms or factors have been identified or implicated as contributing to lower infection incidence in single rooms. 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. A strong study by 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 reduce mortality (McManus, A. T. et al., 1994; McManus, A.T., Mason, McManus, & Pruitt, 1992; Shirani et al., 1986; Thompson, Meredith, & Molnar, 2002). Studies of cross-infection for contagious airborne diseases (influenza, measles, TB, for example) have found, as would be expected, that placing patients in single rooms is safer than housing them in multibed spaces (Gardner, Court, Brocklebank, Downham, & Weightman, 1973; McKendrick & Emond, 1976).

Severe Acute Respiratory Syndrome (SARS) outbreaks in Asia and Canada dramatically highlighted the shortcomings of multibed 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 & Baguley, 2003). The pervasiveness in Canadian and Asian hospitals of multibed spaces in 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 & Baguley, 2003).

In addition to clear advantages in reducing airborne transmission, several studies show that single-bed rooms also lessen risk of infections acquired by contact. As background for understanding how single rooms can lessen contact spread, it should first be mentioned that 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, Potter-Bynoe, Chenevert, & King, 1997; Bures, Fishbain, Uyehara, Parker, & Berg, 2000; Devine, Cooke, & Wright, 2001; Neely & Maley, 2001; Noskin, Bednarz, Suriano, Reiner, & Peterson, 2000; Palmer, 1999; Roberts, Findlay, & Lang, 2001; Rountree, Beard, Loewenthal, May, & Renwick, 1967; Sanderson & Weissler, 1992; Williams, Singh, & Romberg, 2003). These and other contaminated surfaces and features 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

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 multioccupancy rooms. Circumstantial support for this point is provided by research on contamination of nurses in units having patients infected by MRSA. 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.

In a study of MRSA infections in NICUs, Jernigan et al. (1996) reported that risk was lowered by isolation in single-bed rooms; high risk was associated with spatial proximity to an infected patient and shared exposure to caregivers. Ben-Abraham et al. (2002) found that nosocomial infection frequency was much lower in a single-bed pediatric intensive care unit than a unit with multi-bed rooms. The investigators tentatively concluded that single-bed rooms helped to limit person-to-person spread of pathogens between pediatric patients. Having a roommate has been identified as a risk factor for nosocomial diarrhea and gastroenteritis (Chang, V. T. & Nelson, 2000; Pegues & Woernle, 1993).

To summarize briefly, there is a convincing pattern of evidence across many studies indicating that single-bed rooms lower nosocomial infection rates. Singles appear to limit person-to-person and person-surface-person spread of infection in part because they are far easier to decontaminate thoroughly than multibed rooms after patients are discharged. Also, single rooms with a conveniently located sink or alcohol-gel dispenser in each room may heighten hand washing compliance compared to multibed rooms with few sinks. Finally, single rooms are clearly superior to multi-bed rooms with respect to reducing airborne transmission of pathogens.

Reducing Medication Errors

The research team identified three rigorous studies that link environmental factors, such as lighting, distractions, and interruptions, with errors in prescribing or dispensing medications (Booker & Roseman, 1995; Buchanan, Barker, Gibson, Jiang, & Pearson, 1991; Flynn et al., 1999). Although there are relatively few studies in this area, the findings suggest a promising research direction that merits further exploration, considering the vital importance of preventing medical errors in hospitals. Results from a large-scale study of the effects of different illumination levels on pharmacists' prescription-dispensing error rates strongly suggested that such errors are reduced when work-surface light levels are relatively high (Buchanan et al., 1991). In this study, three different illumination levels were evaluated (450 lux, 1,100 lux, 1,500 lux). Medication-dispensing error rates were significantly lower (2.6 percent) at an illumination level of 1,500 lux (highest level), compared to an error rate of 3.8 percent at 450 lux. Two investigations of medication dispensing errors by hospital pharmacists found that error rates increased sharply for prescriptions when an interruption or distraction occurred, such as a telephone call (Flynn et al., 1999; Kistner, Keith, Sergeant, & Hokanson, 1994). Thus, lighting levels, frequent interruptions or distractions during work, and inadequate private space for performing work can be expected to worsen medication errors. The process of improving systems and processes to reduce medication errors in hospitals should include an assessment of the environment in which staff members perform their activities. Additional research is required to confirm the findings from studies as well as to identify ways to design better working environments that may reduce or prevent the likelihood of such errors occurring.

There is mounting evidence that the transfer of patients between rooms or different units is a source of medication errors (Cook, Render, & Woods, 2000). Reasons why errors plague room transfers include delays, communication discontinuities among staff, loss of information, and changes in computers or systems. The solution implied is to create an acuity-adaptable care process and patient rooms that substantially reduce transfers. When Methodist Hospital in Indianapolis, Indiana, changed from two-bed rooms in coronary intensive care to acuity-adaptable single-bed rooms, transfers declined 90 percent and medication errors were lowered by 67 percent (Hendrich, Fay, & Sorrells, 2002; 2004). Reducing transfers also saves much staff time, shortens patient stays, and reduces costs (IOM, 2004). Further studies and demonstration projects are needed to ascertain the safety advantages of acuity-adaptable rooms for other types of units and patient categories.

Reduce Patient Falls

There is a very large literature that 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 have greater 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, and is projected to reach $32.4 billion (in 1994 U.S. dollars) in 2020 (Chang, 2004). While the role of the environment in causing or preventing patient falls is widely accepted, there is not yet evidence conclusively tying environmental interventions with reduced falls. Available studies usually examine the location of fall incidents retrospectively or discuss environmental-modification programs such as improving lighting, securing carpeting, and so on. However, a meta-analysis and systematic review of randomized controlled trials of fall-prevention interventions found that there was no clear evidence for the independent effectiveness of environmental-modification programs (Chang, 2004).

Nonetheless, 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 42.2 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, there was an overall decrease of 17.3 percent in falls. 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, Azeem, Pirwani, Sharma, & Allen, 2000). It should be mentioned that considerable evidence has shown that bedrails are ineffective for reducing the incidence of falls and may increase the severity of fall injuries from beds (Capezuti, Maislin, Strumpf, & Evans, 2002; Hanger, Ball, & Wood, 1999; van Leeuwen, Bennett, West, Wiles, & Grasso, 2001). To increase observation and improve assistance for patients and thereby reduce falls, Methodist Hospital in Indianapolis, Indiana, changed from a coronary critical care unit with centralized nurses stations and two-bed rooms to one having decentralized nurses stations and large single-bed rooms designed to support family presence (Hendrich, et al., 2002). Comparison of data from two years prior and three years after the new unit design showed that falls were cut by 2/3—from six-per-thousand patients to two-per-thousand. Given that falls are a critical safety problem, additional research is needed to understand the effectiveness of this approach for designing patient-care units.

Improve Patient Confidentiality and Privacy

Confidentiality has emerged as a priority issue in light of research showing that physicians and nurses very frequently breach patient confidentiality and privacy by talking in spaces where they are overhead by other patients or persons (Ubel, Zell, & Miller, 1995). The seriousness of the problem is underscored, for example, by a study of an emergency department at a university hospital that showed that 100 percent of physicians and other clinical personnel committed confidentiality and privacy breaches

(Mlinek & Pierce, 1997). HIPAA, the Health Insurance Portability and Accountability Act of 1998, has further elevated the importance of providing reasonable safeguards to protect the confidentiality of staff conversations with and about patients.

Although the importance of the built environment for patient confidentiality may seem self-evident, only a few studies have directly examined the role of unit design or architecture. A study by Barlas et al. (2001) compared auditory and visual privacy for emergency department patients assigned to either multibed spaces with curtain partitions or rooms with solid walls. Those with curtains reported having far less auditory and visual privacy than patients with walls. An important finding was that 5 percent of the patients in curtained spaces reported they withheld portions of their medical history and refused parts of their physical examination because of lack of privacy (Barlas et al., 2001). None of the patients in rooms with walls reported withholding information. The fact that some emergency department patients with curtains withheld information suggests that lack of privacy can reduce patient safety. Additional convincing evidence of the importance of the emergency department physical environment comes from a study that documented frequent breaches of auditory and visual privacy and confidentiality in areas with curtains compared to rooms with solid walls (Mlinek & Pierce, 1997). A recent questionnaire study of staff in four West Coast hospitals found that nurses overwhelmingly judged single rooms to be superior to double rooms for examining a patient (85 percent) and for collecting a patient's history (82 percent) (Chaudhury, Mahmood, & Valente, 2003).

There is a clear need for additional studies that examine privacy and confidentiality breaches associated with the physical environment in single versus double rooms, multibed spaces in ICUs and other types of units, and in spaces such as waiting rooms and nurses' stations. As well, priority should be accorded to generating more research that investigates how the quality of communication and information *from* patients *to* physicians and nurses is affected by the unit architecture.

Analysis of patient satisfaction data made available by Press Ganey (2003) for this report leaves no doubt that patients in single-bed rooms, compared to those with a roommate, are consistently much more satisfied with "concern for your privacy." The satisfaction data were obtained from 2,122,439 patients who received care during 2003 in 1,462 healthcare facilities (Press Ganey, 2003). Fifty-six percent of the patients were in single rooms; 44 percent had a roommate. Greater satisfaction with privacy in single rooms was evident across all major patient categories and types of unit and across different age and gender groups. Satisfaction with privacy was 4.5 percent higher on average nationally in single rooms than doubles—a substantial difference considering that it can be difficult for hospitals to increase satisfaction scores by even 1 percent to 2 percent.

III. Reduce Stress and Improve Outcomes

Reduce Noise

The research team identified more than 130 references focusing on noise in hospitals in the research literature. Studies tend to fall into three broad categories: those that measure noise levels in hospital spaces but do not assess outcomes, studies of the effectiveness of environmental and/or organizational interventions in reducing noise, and investigations of the effects of noise on outcomes.

World Health Organization guideline values for continuous background noise in hospital patient rooms are 35 dB, with nighttime peaks in wards not to exceed 40 dB (Berglund, Lindvall, & Schwela, 1999). These guidelines notwithstanding, many studies have shown that hospital background noise levels fall in far higher ranges. Background noise levels typically are 45 dB to 68 dB, with peaks frequently exceeding 85 dB to 90 dB (Aaron et al., 1996; Allaouchiche, Duflo, Debon, Bergeret, & Chassard, 2002; Blomkvist et al., in press, 2004; Falk & Woods, 1973; Hilton, 1985; McLaughlin, McLaughlin, Elliott, & Campalani, 1996; Robertson, Cooper-Peel, & Vos, 1998). In judging these noise levels, it is worth noting that the decibel scale is logarithmic; each 10 dB increase represents approximately a doubling in the perceived sound level. A 60 dB sound, accordingly, is perceived as roughly four times as loud as a 40 dB sound. Medical equipment and staff voices often produce 70 dB to 75 dB levels measured at the patient's head, which approach the noise level in a busy restaurant (Blomkvist et al., in press, 2004). Noises from alarms and certain equipment exceed 90 dB (for example, portable X-ray machine), which is comparable to walking next to a busy highway when a motorcycle or large truck passes. A study in a NICU measured peak levels once per minute and found that 31 percent of peaks exceed 90 dB (Robertson et al., 1998). Noise peaks in hospitals can be extraordinarily loud. A recent study recorded 113 dB during shift changes at a large hospital (Cmiel, Karr, Gasser, Oliphant, & Neveau, 2004). Operating room noises from drills, saws, and other equipment are in the range of 100 dB to 110 dB, presenting a significant risk for noise-induced hearing loss (Hodge & Thompson, 1990; Love, 2003; Nott & West, 2003).

The research reviewed suggests that hospitals are excessively noisy for two general reasons (Ulrich, Lawson, & Martinez, 2003). First, noise sources are numerous, often unnecessarily so, and many are loud. Well-documented examples include paging systems, alarms, bedrails moved up/down, telephones, staff voices, ice machines, pneumatic tubes, trolleys, and noises generated by roommates. Second, environmental surfaces—floors, walls, ceilings—usually are hard and sound-reflecting, not sound-absorbing, creating poor acoustic conditions. Sound-reflecting surfaces cause noise to propagate considerable distances, traveling down corridors and into patient rooms, and adversely affecting patients and staff over larger areas. Sound-reflecting surfaces typical of hospitals cause sounds to echo, overlap, and linger or have long reverberation times (Blomkvist et al., in press, 2004; Ulrich et al., 2003).

Environmental interventions that have proven especially effective for reducing noise and improving acoustics in hospital settings include: installing high-performance sound-absorbing ceiling tiles, eliminating or reducing noise sources (for example, adopting a noiseless paging system), and providing single-bed rather than multibed rooms. In general, studies of the effectiveness of noise-reduction measures suggest that environmental or design interventions are more successful than organizational interventions such as staff education or establishing quiet hours (Gast & Baker, 1989; Moore, 1998; Walder, Francioli, Meyer, Lancon, & Romand, 2000).

A clear-cut finding in the literature is that noise levels are much lower in single-bed than multi-bed rooms. Studies of multi-bed rooms in acute care and intensive care units have shown that most noises stem from the presence of another patient (staff talking, staff caring for other patients, equipment, visitors, patient sounds such as coughing, crying out, rattling bed rails) (Baker, 1984; Southwell & Wistow, 1995; Yinnon, Ilan, Tadmor, Altarescu, & Hershko, 1992). A study of multi-bed bays in a children's hospital concluded that noise levels were so high that consideration should be given to abolishing open bay rooms (Couper et al., 1994). Further, patient satisfaction data provided for this report by Press Ganey (2003) unequivocally show that patients in single-bed rooms, compared to those with a roommate, are vastly more satisfied with the "noise levels in and around your room." The satisfaction data, as noted in an earlier section, were obtained from 2,122,439 patients who received care during 2003 in 1,462 healthcare facilities (Press Ganey, 2003). Far higher satisfaction with noise levels in single rooms was evident across all major patient categories and types of unit and across different age and gender groups. Satisfaction with noise level was 11.2 percent higher on average nationally in single rooms than doubles—a huge difference. As was noted above, it can be difficult for hospitals to achieve even 1 percent to 2 percent increases in patient satisfaction scores. The combination of findings from noise-level measurement studies and patient-satisfaction surveys highlight the great advantage of providing single rooms, compared to two-bed rooms, with respect to reducing noise.

A considerable body of research has documented negative effects of noise on patient outcomes. Several studies have focused on infants in NICUs, finding that higher noise levels, for example, decrease oxygen saturation (increasing need for oxygen support therapy), elevate blood pressure, increase heart and respiration rate, and worsen sleep (Johnson, 2001; Slevin, Farrington, Duffy, Daly, & Murphy, 2000; Zahr & de Traversay, 1995). Much research on adults and children has unequivocally shown, as might be expected, that noise is a major cause of awakenings and sleep loss (Blomkvist et al., in press, 2004; Gabor et al., 2003; Meyer et al., 1994; Parthasarathy & Tobin, 2004; Schnelle, Ouslander, Simmons, Alessi, & Gravel, 1993; Topf, 1985; Topf & Davis, 1993; Topf & Thompson, 2001; Yinnon et al., 1992). In multi-bed rooms, noises stemming from the presence of other patients often are the major cause of sleep loss. Berg (2001) found, by monitoring brain activity, that even relatively low decibel levels—38 dB to 40 dB—when coupled with longer reverberation times (sound-reflecting ceiling) significantly fragmented and worsened sleep of volunteers in patient rooms. Berg's (2001) findings have disturbing implications because most hospitals have nighttime sound peaks exceeding those of the patient rooms in his study.

Apart from worsening sleep, there is strong evidence that noise increases stress in adult patients, for example, heightening blood pressure and heart rate (Baker, 1992; Morrison, Haas, Shaffner, Garrett, & Fackler, 2003; Novaes, Aronovich, Ferraz, & Knobel, 1997; Topf & Thompson, 2001). A recent study by Blomkvist et al. (in press, 2004) examined the effects of poor versus good sound levels and acoustics on coronary intensive-care patients by periodically changing the ceiling tiles from sound-reflecting to sound-absorbing tiles. When the sound-absorbing ceiling tiles were in place, patients slept better, were less stressed (lower sympathetic arousal), and reported that nurses gave them better care. There were also indications in this study that the incidence of re-hospitalization was lower if patients had experienced the sound-absorbing rather than sound-reflecting ceiling during their hospital stay (Hagerman et al., in press, 2004). More studies are needed such as that by Blomkvist et al. (in press, 2004), which use experimental research designs and systematically vary noise conditions. Future research should also investigate the effects of noise on re-hospitalization rates and other outcomes. In sum, the main message from the research review is clear: new hospitals should be much quieter, and effective design strategies for quieting hospitals are available.

Improve Sleep

The above section reviewed many studies showing that noise levels are high in hospitals and that noise is a major cause of poorer sleep in patients. Interventions that reduce hospital noise have been found to improve sleep and reduce patient stress. As noted earlier, environmental interventions found to be most effective for reducing noise in hospital settings include: providing single-bed rather than multi-bed rooms, installing high-performance, sound-absorbing ceiling tiles, using sound-absorbing flooring where possible, and eliminating or reducing noise sources (for example, use noiseless paging, locate alarms outside patient rooms).

Reduce Spatial Disorientation

Wayfinding problems in hospitals are costly and stressful and have particular impacts on outpatients and visitors, who are often unfamiliar with the hospital and are otherwise stressed and disoriented. In a study conducted at a major regional 604-bed tertiary-care hospital, the annual cost of the wayfinding system was calculated to be more than $220,000 per year in the main hospital or $448 per bed per year in 1990. Much of this cost was the hidden costs of direction giving by people other than information staff, which occupied more than 4,500 staff hours, the equivalent of more than two full-time positions (Zimring, 1990). While almost all hospitals strongly feel the problems associated with a complicated building and poor wayfinding system, it is usually difficult to tackle this problem with a piecemeal approach. A wayfinding system, as the name implies, is not just about better signage or colored lines on floors. Rather, hospitals are seeking to provide integrated systems that include coordinated elements such as visible and easy-to-understand signs and numbers, clear and consistent verbal directions, consistent and clear paper, mail-out and electronic information and a legible physical

setting (Carpman, 1993). A wayfinding system includes four main components that work at different levels: administrative and procedural levels, external building cues, local information and global structure

Administrative and procedural information: Mail-out maps, electronic information available on the Web and at kiosks and verbal directions are organizational strategies aimed at providing key information to patients to prepare them for their hospital visit. This is not dealt with in this review.

***External building cues*:** Signs and cues that lead to the hospital, especially the parking lot, need to be considered carefully, as they are the first point of contact of the patient with the hospital (Carpman, Grant, & Simmons, 1985). For example, Carpman, Grant and Simmons conducted a video simulation study to assess the relative role of signs and seeing a destination. The hospital wanted to direct most traffic to a parking structure rather than a drop-off lane. When the researchers showed prospective visitors a simulated video showing a design alternative that allow arriving drivers to see the main pavilion with the drop-off lane, 37 percent of the respondents said that they would turn into the drop circle when they could see the entry to the garage, ignoring the signs. As a consequence, the hospital chose to redesign the entry.

***Local information*:** Once patients find their way to the building from the parking lot, they are faced with the prospect of identifying the destination. Informational handouts, information desks, you-are here maps, directories, and signage along the way are critical wayfinding aids (Carpman, Grant, & Simmons, 1983-84; Levine, Marchon, & Hanley, 1984; Nelson-Shulman, 1983-84; Wright, Hull, & Lickorish, 1993). In an experimental study, researchers found that patients who had the benefit of an information system (welcome sign, hospital information booklet, patient letter, orientation aids) upon reaching the admitting area were more self-reliant and made fewer demands on staff. In contrast, uninformed patients rated the hospital less favorably and were found to have elevated heart rates (Nelson-Shulman, 1983-84).

Information provided in you-are-here maps can be useful. However, you-are-here maps should be oriented so that the top signifies the direction of movement for ease of use. When the maps were aligned in directions other than the forward position, people not only took much longer to find their destination, but were significantly less accurate (Levine et al., 1984). Another study found that people who used signs found their destination faster than those who only used maps (Butler, Acquino, Hissong, & Scott, 1993). However, people who were given a combination of handheld maps and wall signs reached their destination more often than those who just used wall signs (Wright et al., 1993).

It is critical to design signage systems with logical room numbering and comprehensible nomenclature for departments (Carpman & Grant, 1993; Carpman, Grant, & Simmons, 1984). For example, inpatients, outpatients, and visitors to a hospital preferred simple terms such as *walkway* or *general hospital* over more complex or less-familiar terms such as *overhead link, medical pavilion* or *health-sciences complex*.

Contrary to the belief that fewer signs in hospital hallways means less clutter and hence less confusion, an experimental study in a hospital found that patients who had access to more number of signs along the way to the destination were faster, less hesitant, asked for directions a fewer number of times, and reported lower levels of stress (Carpman et al., 1984). Based on this study, the authors suggest that directional signs should be placed at or before every major intersection, at major destinations, and where a single environmental cue or a series of such cues (e.g. change in flooring material) convey the message that the individual is moving from one area into another. If there are no key decision points along a route, signs should be placed approximately every 150 feet to 250 feet.

***Global structure*:** In addition to local properties of the spaces that people move through, there are specific characteristics of the overall structure of the system of rooms and corridors that impact the paths people take (Haq & Zimring, 2003; Peponis, Zimring, & Choi, 1990). People tend to move toward spaces and through corridors that are more accessible from a greater number of spaces. Based on observations of search patterns of study participants in a hospital and use of objective measures that quantify spatial characteristics, researchers found that participants tended to move along more "integrated" routes—routes that are, on average, more accessible because they are fewer turns from all other routes in the hospital. This research suggests that it may be important to identify such integrated routes in the plan while placing important facilities and key points such as the entrance (Peponis et al., 1990).

The research supports the value of a systems approach to wayfinding. Wayfinding continues to be a pervasive problem in hospitals because it is not sufficient to consider one or two components separately. Well-designed signs are likely to be quite ineffective in a building that is highly complicated and does not provide simple cues that enable natural movement. While there are more than 17 studies that look at wayfinding in hospitals and other buildings (Brown, Wright, & Brown, 1997; Carpman & Grant, 1993; Carpman et al., 1983-84, 1984; Carpman et al., 1985; Christensen, 1979; Grover, 1971; Haq & Zimring, 2003; Levine et al., 1984; Moeser, 1988; Nelson-Shulman, 1983-84; Ortega-Andeane & Urbina-Soria, 1988; Passini, Rainville, Marchand, & Joanette, 1995; Peponis et al., 1990; Schneider, L. F. & Taylor, 1999; Weisman, 1981; Wright et al., 1993; Zimring & Templer, 1983-84), it is quite difficult to isolate single influences of design on wayfinding performance or of wayfinding on outpatient or visitor stress. The problem is exacerbated by the fact that most hospitals have existing complex buildings upon which they try to superimpose a signage system to make things work. This strategy is ineffective in most cases.

There are some very good studies that deal with designing better signage, optimal spacing and location of signage, types of information that are most effective in way finding, and so on. Similarly, other studies at the global scale have looked at the properties of the building layout that facilitate or impede movement. It is essential that these different pieces of information come together while designing new hospitals where there is opportunity to develop an effective wayfinding system at multiple levels. Additional

studies are needed to ascertain the magnitude of stress that wayfinding problems have on outpatients and family.

Reduce Depression

Several studies strongly support that bright light—both natural and artificial—can improve health outcomes such as depression, agitation, sleep, circadian rest-activity rhythms, as well as length of stay in demented patients and persons with seasonal affective disorders (SAD). At least eleven strong studies suggest that bright light is effective in reducing depression among patients with bipolar disorder or SAD. Further, seven studies show that exposure to morning light is more effective than exposure to evening light in reducing depression (Beauchemin & Hays, 1996; Benedetti, F., Colombo, C., Barbini, B., Campori, E., & Smeraldi, E., 2001; Lewy et al., 1998; Lovell, Ancoli-Israel, & Gevirtz, 1995; Terman, Terman, Lo, & Cooper, 2001; Van Someren, Kessler, Mirmiran, & Swaab, 1997; Wallace-Guy et al., 2002). An experimental study that compared the effect of morning and evening light on patients with winter depression found that morning light was *twice* as effective as evening light in treating SAD (Lewy et al., 1998). Exposure to bright morning light has been shown to reduce agitation among elderly patients with dementia. When elderly patients with dementia were exposed to 2,500 lux for two hours in the morning for two ten-day periods, their agitation reduced. Patients were significantly more agitated on non-treatment days (Lovell et al., 1995).

There is also strong evidence that exposure to bright light improves sleep and circadian rhythms. When the daytime environmental illumination level was increased in different living spaces of a dementia unit, it was found that, during increased illumination periods, the stability of the rest-activity rhythm increased in patients with intact vision, but not in visually impaired patients (Van Someren et al., 1997).

It has also been shown that patients in brightly lit rooms have a shorter length of stay compared to patients in dull rooms. Beauchemin and Hays (1996) found that patients hospitalized for severe depression reduced their stays by an average of 3.67 days if assigned to a sunny rather than a dull room overlooking spaces in shadow.

A recent randomized prospective study assessed whether the amount of sunlight in a hospital room modifies a patient's psychosocial health, quantity of analgesic medication used, and pain medication cost (Walch et al., 2004, in press). Patients undergoing elective cervical and lumbar spinal surgeries were admitted to the bright or the dim side of the inpatient surgical ward postoperatively. The outcomes measured included the standard morphine equivalent of all opioid medication used postoperatively by patients and their subsequent pharmacy cost. This strong study found that patients exposed to an increased intensity of sunlight experienced less perceived stress, less pain, took 22 percent less analgesic medication per hour and had 20 percent less pain medication costs.

Using light as an intervention to reduce depression in clinically depressed as well as non-depressed patients is a relatively inexpensive intervention that has been shown to yield consistently positive results. While many studies deal with the effects of artificial light,

natural daylight in patient rooms has also been found effective in reducing depression, reducing length of stay, and reducing intake of pain medication. Thus, an important consideration while designing hospital layouts may be to optimize exposure to morning light in patient rooms by using an east-facing orientation. This research further implies the possibility that depression might be worsened by architectural designs that block or sharply reduce natural daylight in patient rooms. A hypothetical example would be a hospital having patient-room windows looking out into a roofed atrium with few skylights and little natural daylight. In this example, deprivation of natural daylight could be extreme if patient windows were tinted to prevent users of the atrium from looking into patient rooms and violating privacy.

Provide Nature and Positive Distraction

Positive distractions refer to a small set of environmental features or conditions that have been found by research to effectively reduce stress. Distractions can include certain types of music, companion animals such as dogs or cats, laughter or comedy, certain art, and especially nature (Ulrich, 1991). The focus here is on the last, nature. (There is an additional large research literature on music, but this is not covered in this review.)

As background relevant to assessing the credibility of nature findings in healthcare environments, it should be mentioned that many studies of populations other than hospital patients have produced strong evidence that even fairly brief encounters with real or simulated nature settings can elicit significant recovery from stress within three minutes to five minutes at most (Parsons & Hartig, 2000; Ulrich, 1999). Investigators have consistently reported that stress-reducing or restorative benefits of simply viewing nature are manifested as a constellation of positive emotional and physiological changes. Stressful or negative emotions such as fear or anger diminish while levels of pleasant feelings increase. Laboratory and clinical studies have shown that viewing nature produces stress recovery quickly evident in physiological changes, for instance, in blood pressure and heart activity (Ulrich, 1991). By comparison, considerable research has demonstrated that looking at built scenes lacking nature (rooms, buildings, parking lots) is significantly less effective in fostering restoration and may worsen stress.

Questionnaire studies have found that bedridden patients assign especially high preference to having a hospital window view of nature (Verderber, 1986). Mounting research is providing convincing evidence that visual exposure to nature improves outcomes such as stress and pain. For example, a study in a Swedish hospital found that heart-surgery patients in ICUs who were assigned a picture with a landscape scene with trees and water reported less anxiety/stress and needed fewer strong doses of pain drugs than a control group assigned no pictures (Ulrich, 1991). Another group of patients assigned an abstract picture, however, had worsened outcomes compared to the control group. Ulrich (1984) found that patients recovering from abdominal surgery recovered faster, had better emotional well-being, and required fewer strong pain medications if they had bedside windows with a nature view (looking out onto trees) than if their windows looked out onto a brick wall.

Recently, strong studies using experimental designs have produced additional convincing evidence that viewing nature reduces patient pain as well as stress. These investigations also support the interpretation that nature serves as a positive distraction (Ulrich, 1991) that reduces stress and diverts patients from focusing on their pain or distress. A randomized prospective investigation found that adult patients undergoing a painful bronchosopy procedure reported less pain if they were assigned to look at a ceiling-mounted nature scene rather than a control condition consisting of a blank ceiling (Diette, Lechtzin, Haponik, Devrotes, & Rubin, 2003). Another controlled experiment that used volunteers in a hospital assessed the effect on pain of viewing a soundless nature videotape in contrast to a static blank screen (Tse, Ng, Chung, & Wong, 2002). Subjects who watched the nature scenes evidenced a higher threshold for detecting pain and had substantially greater pain tolerance. Two studies of female cancer patients have shown that taking a virtual reality nature walk while in bed or a hospital room (through a forest with bird sounds) reduced anxiety and symptomatic distress (Schneider, S. M., Prince-Paul, Allen, Silverman, & Talaba, 2004). Research on patients suffering intense pain because of severe burns found that exposing patients to a videotape of scenic nature (forest, flowers, ocean, waterfalls) during burn dressing changes significantly reduced both anxiety and pain intensity (Miller, Hickman, & Lemasters, 1992).

The possibility that nature can improve outcomes even in patients with late-stage dementia, including Alzheimer's disease, has received some support from a quasi-experimental study that found reduced levels of agitated aggressive behavior associated with a shower bath when recorded nature sounds (birds, babbling brook) and color pictures were present (Whall et al., 1997). A well-controlled study of blood donors in a waiting room found that blood pressure and pulse were lower on days when a wall-mounted television displayed a nature videotape, compared to days with continuous daytime television programs (Ulrich, Simons, & Miles, 2003). More research is needed to identify conditions under which television can either be a stress-reducing positive distraction or a stressor in hospitals.

Gardens in healthcare environments*:* Hospital gardens not only provide restorative or calming nature views, but can also reduce stress and improve outcomes through other mechanisms, for instance, fostering access to social support and providing opportunities for positive escape and sense of control with respect to stressful clinical settings (Cooper Marcus & Barnes, 1995; Ulrich, 1999). Based on postoccupancy evaluations of four hospital gardens in California, Cooper-Marcus and Barnes (1995) concluded that many nurses and other healthcare workers used the gardens for achieving pleasant escape and recuperation from stress. Other postoccupancy studies indicate that patients and family who use hospital gardens report positive mood change and reduced stress (Whitehouse et al., 2001). These reports also suggest that gardens and nature in hospitals can heighten patient and family satisfaction with overall quality of care.

Art in healthcare environments: A small number of studies on art in hospitals has yielded findings parallel to those from nature research. Results suggest a consistent pattern wherein the great majority of patients respond positively to representational

nature art, but many react negatively to chaotic abstract art (Ulrich & Gilpin, 2003). For example, Carpman & Grant (1993) studied the preferences of 300 randomly selected inpatients and concluded that the patients consistently preferred nature images but disliked abstract art. Although nature pictures and other emotionally appropriate art elicit positive reactions, there is also evidence that inappropriate art styles or image subject matter can increase stress and worsen other outcomes (Ulrich, 1991). It should not be expected that all art is suitable for high-stress healthcare spaces, as art varies enormously in subject matter and style, and much art is emotionally challenging or provocative.

The pitfalls of displaying emotionally challenging art in healthcare environments are revealed by a study of psychiatric patients (Ulrich, 1991). The unit was extensively furnished with a diverse collection of wall-mounted paintings and prints. Interviews with patients indicated strongly negative reactions to artworks that were ambiguous, surreal, or could be interpreted in multiple ways. The same patients, however, reported having positive feelings and associations with respect to nature paintings and prints.

Provide Social Support

Many studies of several different categories of patients have indicated that social support reduces stress and improves, for example, recovery outcomes in myocardial infarction patients. Considering the well-established importance of social support, it is unfortunate that there is only a moderate amount of research concerning how hospital design can facilitate or hinder access to social support. Most studies have focused on psychiatric units and nursing homes. There is strong evidence that levels of social interaction can be increased—and presumably beneficial social support as well—by providing lounges, day rooms, and waiting rooms with comfortable movable furniture arranged in small flexible groupings. A few well-designed studies in psychiatric wards and nursing homes have found that appropriate arrangement of movable seating in dining areas enhances social interaction and also improves eating behaviors, such as increasing the amount of food consumed by geriatric patients (Melin & Gotestam, 1981; Peterson, Knapp, Rosen, & al., 1977). Much research on day rooms and waiting areas has shown that the widespread practice of arranging seating side-by-side along room walls inhibits social interaction (Holahan, 1972; Sommer & Ross, 1958). A novel study by Harris (2000) found that family and friends stayed substantially longer during visits to rehabilitation patients when patient rooms were carpeted rather than covered with vinyl flooring.

Much evidence indicates that single rooms are markedly better than multi-bed rooms for supporting or accommodating the presence of family and friends. Some research suggests that open-plan multibed rooms deter family presence and accordingly reduce social support (Sallstrom, Sandman, & Norberg, 1987). Multibed rooms greatly reduce privacy for patient-family interactions compared to single rooms and are much more likely to have restricted visiting hours. A clear advantage of single rooms in fostering social support stems from the fact they provide more space and furniture than double rooms to accommodate family presence (Chaudhury et al., 2003). A survey of staff in four hospitals that each had a mix of single and double rooms found that nurses gave high

ratings to single rooms for accommodating family members but accorded double rooms low scores (Chaudhury et al., 2003). Further, patient-satisfaction data obtained from 2,122,439 patients who received care during 2003 provide overwhelming evidence that patients in single-bed rooms, compared to those with a roommate, are much more satisfied with "accommodations and comfort for family and visitors" (Press Ganey, 2003).

Do patients sharing the same room provide each other with stress-reducing social support? While some patients find roommates provide comforting social support, findings from several studies indicate that the presence of a roommate usually is a source of stress rather than social support. In most cases, roommates are linked to stressors, for example, loss of privacy or having a roommate who is unfriendly, has too many visitors, or is seriously ill (Van der Ploeg, 1988; Volicer, Isenberg, & Burns, 1977). An earlier section emphasized that noise is a much greater problem in double rooms than singles, and that noises stemming from the presence of other patients are a major cause of sleep loss.

Improve Communication to Patients

Good staff communication helps reduce patient and family anxiety, promotes better care at home after discharge, and in other ways can improve outcomes. Good communication also tends to be the single most important factor affecting overall satisfaction with care across different patient categories (Press Ganey, 2003). Data obtained from 2,122,439 patients nationally in 2003 show that patients consistently report significantly higher satisfaction with communication from nurses and physicians when they are in single rooms compared to when they have one or more roommates (Press Ganey, 2003). To explain this clear and important advantage of single rooms, Kaldenburg (1999) has proposed that staff in multibed rooms are reluctant to discuss patient issues or give information within hearing of a roommate, out of respect for privacy. Growing concern for patient confidentiality and HIPAA are certain to increase the already major advantages of single rooms with respect to communication.

IV. Improve Overall Healthcare Quality

Provide Single-Bed Patient Rooms

Based on an extremely large and varied body of research reviewed in earlier sections, there can be no question that single-bed rooms have several major advantages over double rooms and open bays. To summarize briefly, these advantages include: lower nosocomial infection rates, fewer patient transfers and associated medical errors, far less noise, much better patient privacy and confidentiality, better communication from staff to patients and from patients to staff, superior accommodation of family and consistently higher satisfaction with overall quality of care.

Reduce Length of Stay

Climate and sunlight influences length of hospital stay as well as sleep-wake patterns among hospitalized patients (Beauchemin & Hays, 1996; Benedetti, Francesco, Colombo, Cristina, Barbini, Barbara, Campori, Euridice, & Smeraldi, Enrico, 2001; Federman, Drebing, Boisvert, Penk, 2000; Hebert, Dumont, & Paquet, 1998; Kecskes et al., 2003; Kinnunen, Saynajakangs, Tuuponen, & Keistinen, 2002). One research group studied the impact of the amount of natural light on the length of hospitalization of patients with unipolar and bipolar disorder. The researchers found that bipolar patients randomly assigned to the brighter, eastern rooms (exposed to direct sunlight in the morning) had a mean 3.67-day shorter hospital stay than patients in west-facing rooms (Benedetti, Francesco et al., 2001). Patients recovering from abdominal surgery had shorter stays if they had a bedside window view of nature rather than if their windows looked out onto a brick wall (Ulrich, 1984).

The large research literature on infection reviewed in an earlier section indicated that the design of the physical environment strongly impacts hospital-acquired infection rates by affecting both airborne and contact transmission routes. Evidence-based design measures, by reducing nosocomial infection rates, play a key role in shortening hospital stays.

Increase Patient Satisfaction with Quality of Care

There is strong evidence that design changes that make the environment more comfortable, aesthetically pleasing, and informative relieve stress among patients and increases satisfaction with the quality of care provided. Renovating a traditional waiting area in a neurology clinic by making small changes to the general layout, color scheme, furniture, floor covering, curtains, and providing informational material and information displays resulted in more positive environmental appraisals, improved mood, altered physiological state, and greater reported satisfaction among waiting patients (Leather, Beale, Santos, Watts, & Lee, 2003).

Patients in well-decorated and well-appointed hotel-like rooms rated their attending physicians, housekeeping, and food-service staff, the food, and the hospital better than patients in standard rooms (typical hospital beds, inexpensive family sitting chairs, and no artwork) in the same hospital. Also, they had stronger intentions to use the hospital again and would recommend the hospital to others (Swan, Richardson, & Hutton, 2003). In another study, it was found that environmental satisfaction was a significant predictor of overall satisfaction, ranking only below perceived quality of nursing and clinical care (Harris, P. B., McBride, Ross, & Curtis, 2002). Several post-occupancy evaluation studies have examined patient and staff satisfaction with the different elements of the healthcare environment such as gardens, individual wards, and patient rooms (Brown, Wright, & Brown, 1997; Heath & Gifford, 2001; Shepley, 1995, 2002; Shepley & Davies, 2003; Shepley & Wilson, 1999; Whitehouse et al., 2001). These studies yield rich context-specific data that describe which aspects of the environment were effective. Some studies show quite clearly that tacit, as well implicit, staff and organizational practices and policies influence how an environment actually functions and is perceived

by patients and staff members. The qualitative and quantitative data provided by such studies are very important in understanding the nature of the problem (e.g. why are the gardens not being used as intended?) as well in developing solutions to tackle the problem. Future research that looks at satisfaction among hospital patients should consider using these multi-method post-occupancy evaluations that use different methods to obtain objective and subjective evaluations of use and satisfaction.

CONCLUSIONS

The research team found more than 600 rigorous studies linking a range of aspects of the built environment of hospitals to staff stress and effectiveness, patient safety, patient and family stress and healing, and improved overall healthcare quality and cost. This deep and wide base of evidence suggests that, parallel to evidence-based medicine, we can move to evidence-based design (EBD). EBD refers to a process for creating healthcare buildings, informed by the best available evidence, with the goal of improving outcomes and of continuing to monitor the success of designs for subsequent decision-making. While it is difficult to conduct rigorous research on the impacts of the healthcare environment—hospitals are complex systems where it is difficult to isolate the impact of single factors and the building industry conducts little impact-based research—The Center for Health Design and other groups have made considerable progress in developing a knowledge base of evidence.

EBD is not about hospitals that are simply nicer or fancier than traditional hospitals. Rather, the focus of evidence-based design is to create hospitals that actually help patients recover and be safer, and help staff do their jobs better. EBD is a process for creating health care buildings informed by the best available evidence concerning how the physical environment can interfere with or support activities by patients, families, and staff, and how the setting provides experiences that provide a caring, effective, safe, patient-centered environment. Many of the improvements suggested by EBD are only slightly more expensive than traditional solutions, if they are more expensive at all.

The large research literature surveyed in this report point to several actions we can take immediately:

- Provide single-bed rooms in almost all situations. Adaptable-acuity single-bed rooms should be widely adopted. Single rooms have been shown to lower hospital-induced nosocomial infections, reduce room transfers and associated medical errors, greatly lessen noise, improve patient confidentiality and privacy, facilitate social support by families, improve staff communication to patients, and increase patients' overall satisfaction with health care.
- New hospitals should be much quieter to reduce stress and improve sleep and other outcomes. Noise levels will be substantially lowered by the following combination of environmental interventions: providing single-bed rooms, installing high-performance sound-absorbing ceilings, and eliminating noise sources (for example, using noiseless paging).

- Provide patients stress reducing views of nature and other positive distractions.
- Develop wayfinding systems that allow users, and particularly outpatients and visitors, to find their way efficiently and with little stress.
- Improve ventilation through the use of improved filters, attention to appropriate pressurization, and special vigilance during construction.
- Improve lighting, especially access to natural lighting and full-spectrum lighting.
- Design ward layouts and nurses stations to reduce staff walking and fatigue, increase patient care time, and support staff activities such as medication supply, communication, charting, and respite from stress.

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