The architecture of safety: hospital design

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Purpose of review

This paper reviews recent research literature reporting the effects of hospital design on patient safety.

Recent findings

Features of hospital design that are linked to patient safety in the literature include noise, air quality, lighting conditions, patient room design, unit layout, and several other interior design features. Some of these features act as latent conditions for adverse events, and impact safety outcomes directly and indirectly by impacting staff working conditions. Others act as barriers to adverse events by providing hospital staff with opportunities for preventing accidents before they occur.

Summary

Although the evidence linking hospital design to patient safety is growing, much is left to be done in this area of research. Nevertheless, the evidence reported in the literature may already be sufficient to have a positive impact on hospital design.

Keywords

adverse events, architecture, hospital design, patient safety, physical environment

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Abbreviations

HEPA high-efficiency particulate air
ICU intensive care unit

1070-5295

Introduction

A growing body of research has shown that hospital design may directly impact safety in hospitals. It may also indirectly impact safety by triggering adverse events that cause harm to patients and staff. In addition, hospital design may also impact safety in hospitals by working as a barrier to harmful events. This is an emerging field of research, and the effects of hospital design on safety are not always well understood. There is no single database in the field. High quality research articles are also rare, because many confounding variables are present. As a result, this review includes evidence that was not always generated in critical care settings. Nevertheless, all evidence presented here should also be relevant to critical care.

The role of hospital design in patient safety

Hospital design refers to the physical environment that includes the indoor environment (e.g. noise, air quality and lighting), the interior design (e.g. furniture, fixtures and materials) and the configuration (e.g. relative locations and adjacencies of spaces) of a hospital. According to the model of system accidents proposed by Reason [1], hospital design may impact patient safety, directly or indirectly, as a latent failure and a barrier.

Reason [1] argued that adverse events in hospitals are related to both active and latent failures. Active failures are unsafe acts (slips, lapses, fumbles, mistakes and procedural violations) committed by the individuals in direct contact with the patient. In contrast, latent failures create local conditions that in specific situations may lead to active failures. Latent failures may become embedded within systems as a result of wrong decisions made by designers, builders, procedure writers and top level management [2]. As a latent failure, hospital design can directly impact safety outcomes or it can impact staff outcomes negatively (e.g. staff stress, fatigue, annoyance, lack of control, lack of motivation, and lack of communication) leading to accidents and errors.

Reason [1] also argued that design barriers may be critical to preventing harmful accidents in hospitals. Whereas a poorly designed and maintained hospital provides the conditions that precipitate accidents, a well-designed hospital can have inbuilt safeguards/barriers that may make it difficult for these accidents to occur or that may help stop the chain of events before they result in accidents.

Hospital design cannot, however, be considered in isolation with regard to patient and staff safety. In almost all safety situations, hospital design interacts with a host of other factors, such as the culture of the organization, tasks and processes in place, and tools and technology. This paper primarily focuses on the role of hospital design while recognizing the contributing role played by other critical factors.

Direct impacts on patient safety

Aspects of hospital design such as air quality, lighting, patient room design and other interior design elements can directly impact safety outcomes such as nosocomial infections, patient falls and medical errors.

Air quality and nosocomial infections

Airborne infections are spread when dust and pathogens are released during hospital construction [3–5,6•] and are caused by contamination and malfunction of hospital ventilation systems [7–10]. Studies in hospitals show that fungal load in the air may be linked to humidity, temperature and construction activity [6•]. High-efficiency particulate air (HEPA) filters can be highly effective in preventing airborne infections in hospitals [11]. Air contamination is least in laminar airflow rooms with HEPA filters, and this approach is recommended for such areas as operating-room suites and ultraclean rooms for immunocompromised patients [11,12,13•]. Yavuz *et al.* [13•] found lower rates of sternal surgical site infections in the newer operating rooms with laminar floor ventilation systems and automatically closing doors compared with the older operating rooms with standard plenum ventilation and doors that did not close properly.

Single bedrooms and nosocomial infections

Ulrich *et al.* [14] identified 16 studies linking the number of patients in a room to nosocomial infection rates. The European Prevalence of Infection Control in Intensive Care study reported an odds ratio for infection of 1.3 in intensive care units (ICUs) with more than 11 beds compared with those with fewer than five beds. That study, however, did not report any findings related to open versus closed rooms [15]. Mullin *et al.* [16] reported a decrease in *Acinetobacter baumanii* in mechanically ventilated patients, from 28.1 to 5%, after moving from a unit with both enclosed and open patient care areas to one with all private rooms.

In general, the reported evidence shows that single-bed patient rooms with high-quality HEPA filters and with negative or positive pressure ventilation are more effective in preventing air-borne pathogens. The evidence also shows that multibed rooms are more difficult to decontaminate and have more surfaces that act as a reservoir for pathogens. On the basis of the study findings, the 2006 American Institute of Architects Guidelines for Design and Construction of Healthcare Facilities has adopted the single bed room as the standard for all new construction in the United States [17]. In addition, several other professional and scientific bodies in the United Kingdom, the United States, and Europe have published ICU design guidelines that include similar design measures to control nosocomial infections [18].

Lighting conditions and patient outcomes

A large body of literature reports different psychological and physiological effects of lighting in hospitals, some of which may be directly related to patient safety. For example, 'ICU psychosis' in adult patients can be partly attributed to bright or constant lighting conditions in ICUs that lack night/day cues. A similar phenomenon has been described among children in pediatric ICUs [19,20]. In addition, the mortality rate may be higher in dull patient rooms, with sex having differential effects [21,22]. Furthermore, poor lighting conditions may negatively impact physiological developments among infants [23]. Those studies suggest that lighting conditions should be considered more carefully in the design of patient care areas of a hospital.

Lighting conditions and medical errors

Performance on visual tasks gets better as light levels increase [24]. Buchanan *et al.* [25] found that errors in dispensing medications in a high volume outpatient pharmacy were significantly lower at an illumination level of 146 foot-candles (2.6%) as opposed to the baseline level of 45 foot candles (3.8%). In Alaska, Roseman and Booker [26] found that 58% of all medication errors among hospital workers occurred during the first quarter of the year when daylight hours were less. Studies in offices have indicated the importance of appropriate lighting levels for complex tasks requiring excellent vision [27], but no such study has been reported in hospitals.

Noise in hospitals and patient outcomes

Noise levels in most hospitals are higher than World Health Organization recommendations [28]. The level of noise in the ICU ranges from 50 to 75 dB, with peaks of up to 85 dB [29]. Parthasarathy and Tobin [30] reported that 20% of all arousals and awakenings among ICU patients are related to noise. They argued that sleep disruption can induce sympathetic activation and elevation of blood pressure, which may contribute to patient morbidity. 'ICU psychosis' in adult ICUs and in pediatric ICUs has also been partly attributed to a high level of noise in these areas [19,20]. Common sources of noise in hospitals may include telephones, alarms, trolleys, ice machines, paging systems, nurse shift change, staff caring for other patients, doors closing, staff conversations, and patients crying out or coughing [31]. Cropp *et al.* [32] counted 33 different audio signals in a respiratory critical

care unit. Ten were critical alarms requiring immediate nursing action, whereas the others did not require immediate action or were unnecessary. It is clear that patient safety as it relates to hospital noise can easily be improved if proper design and management measures are in place.

Hospital design and patient falls

A report by the Joint Commission on Accreditation of Healthcare Organizations cited the physical environment as a root cause in 50% of patient falls [33], but studies have shown contradictory evidence on the topic. A recent review and meta-analysis of randomized controlled trials did not find any evidence for the independent effectiveness of environmental modification programmes on patient falls [34•]. Some studies, however, have shown that most patient falls occurred in the patient room and that bedrails were the only design element linked strongly with falls [35••]. Other studies have shown that comprehensive multi-intervention strategies that include environmental modifications could be effective in reducing falls [35••,36–38].

Among specific interior design elements, flooring can contribute to the incidence of falls and the severity of injuries upon impact [39•]. Donald *et al.* [40] reported fewer falls of geriatric patients on vinyl floors compared with carpeted floors in a rehabilitation ward. That study lacked sufficient power, however. Healey [41], on the other hand, reported that patients suffer more injuries when they fall on vinyl floors compared with carpeted floors. Simpson *et al.* [42] reported that subfloors may impact the injury from falls, with the risk of fracture being lower for wooden subfloors compared with concrete subfloors.

Impact of the environment on staff working conditions

A poorly designed physical environment creates latent conditions such as staff stress, fatigue, annoyance, burnout and lack of handwashing compliance that may potentially lead to adverse events in hospitals.

Noise in hospitals and staff outcomes

Studies have shown that noise is strongly related to stress and annoyance among nurses, and that noise-induced stress is related to emotional exhaustion and burnout among critical care nurses [43,44]. Healthcare staff have reported that the excessively high noise levels at work interfere with their work and impact patient comfort and recovery [45]. Blomkvist and colleagues [46] examined the effects of changing the acoustic conditions (using sound-absorbing versus sound-reflecting ceiling tiles) on the same group of nurses in a coronary ICU. During the periods of improved acoustic conditions, many positive outcomes were observed among staff, including improved speech intelligibility, reduced perceived work demands and perceived pressure and strain [46]. There is convincing evidence that noise is a latent condition for errors in hospitals and strategies must be adopted to reduce noise.

Variable acuity patient rooms and transfers

Patients are transferred from one room to another as often as three to six times during their short stay in hospital in order to receive the care that matches their level of acuity [47,48]. Delays, communication discontinuities, loss of information and changes in computers and systems during patient transfer may contribute to increased medical errors, loss of staff time and productivity [48,49].

Hendrich and colleagues [47,48] developed an innovative demonstration project called the Cardiac Comprehensive Critical Care at Clarian Methodist Hospital in Indianapolis to address patient transfer and associated errors. The project provided different levels of care in a single patient room to minimize patient transfer as acuity levels changed. For this, each patient room was equipped with an acuity adaptable headwall, and all nurses on the unit were trained to respond to patients with varying acuity levels. The impact of this 56-bed variable acuity unit on different outcomes was measured by comparing 2 years of baseline data (before the move) and 3 years of data after the move. The authors reported significant postmove improvements in many key areas: patient transfers decreased by 90%, medication errors by 70%, and there was also a drastic reduction in the number of falls. This path-breaking project demonstrated the potential impact of acuity-adaptable care in dealing with patient flow and safety issues while improving the model of care. Since this project, many hospitals across the United States have adopted some variations of the concept, although the impacts of these changes on outcomes remain to be studied.

Unit layout and staff effectiveness

Nurses spend a lot of time walking, which includes the time to locate and gather supplies and equipment and to find other staff members [50••]. One study found that 28.9% of nursing staff time was spent walking [51]. This came second only to patient-care activities, which accounted for 56.9% of staff time. Unnecessary walking leads to a waste of precious staff time and adds to fatigue and stress among staff.

Studies seem to suggest that bringing staff and supplies physically and visually closer to the patient may help reduce walking [52,53]. To take advantage of the idea, many hospitals incorporate decentralized nurses' stations and supplies' servers next to patient rooms (as opposed to locating everything at a single central location). Hendrich and colleagues [48] argued that such a layout may help reduce walking and supply trips. As a result, nursing time

may increase significantly allowing for a reduction in budgeted staffing care hours while increasing the time spent in direct patient care activities. An in-depth discussion on how various aspects of unit design, patient room design and staff areas may contribute to staff effectiveness is provided in the review of best practice examples of adult ICUs designed between 1993 and 2003 by Rashid [54••].

Accessibility to handwashing stations and handwashing compliance

Surface transmission of pathogens accounts for a majority of nosocomial infections, and low handwashing frequency among healthcare staff (generally below 50%) is a key factor contributing to this problem [55]. Design factors that discourage handwashing include: difficulty of access, poor visibility, poor height placement, lack of redundancy, and wide spatial separation of resources that are used sequentially while washing hands [55–58].

Studies report conflicting evidence on the effects of physical design on handwashing compliance. Some studies found that handwashing compliance was greater in units with higher sink to bed ratios [59,60]. One study found no significant improvement in handwashing after a move from an open ward design to a layout with single patient rooms and higher sink to bed ratios [61]. Trick and colleagues [62•] found that hand hygiene improved during the study period in three intervention hospitals (where interventions included the increased availability of alcohol-based hand rubs, an interactive education programme and a poster campaign) but not at the control hospital (where the only intervention was the increased availability of alcohol hand rubs). Those and other studies seem to suggest that a multistrategy intervention that includes staff education as well as easy visual and physical access to sinks, standard locations of sinks in all patient rooms, comfortable sink heights and alcohol-based dispensers may be more effective in increasing handwashing compliance [55,58].

Environmental barriers/defenses to healthcare accidents

The environment potentially acts as a defense to adverse events by providing opportunities for staff and families to prevent accidents before they occur.

Visibility to patients

One important way to avert adverse events related to patients is for the staff to have the ability to observe patients continuously and provide assistance as needed. Multiple decentralized nurse work areas and charting alcoves next to patient rooms may help facilitate this activity. Such designs enable the staff to attend patients' needs without delays. In at least one prospective study, Hendrich [63] showed that falls were cut by two-thirds, from six per 1000 patients to two per 1000, after a move from an old unit with a centralized nursing station to a new unit with decentralized observation units. Additional research is needed to determine the effects of decentralization on patient safety.

Visibility to patients also seems to be related to perceived safety. In a staff survey by France *et al.* [64] at a new neonatal ICU and pediatric critical care unit at a children's hospital (designed with single patient rooms, curtains for privacy for families, larger unit size, but with poor sightlines between staff and patients), a majority of the respondents believed that the facility design made team communication and patient monitoring difficult, and that it limited social interaction among staff. Therefore, while making major facility changes it is critical to take into consideration patient needs for privacy as well as staff needs for monitoring and communication.

Presence of family

Another effective way to avert adverse events is to allow the patient's family to be a part of the patient care process. In order to understand how teamwork and communication involving the patient's family may contribute to patient safety, Uhlig and colleagues conducted multidisciplinary collaborative rounds at the patient bedside in 1999 in a cardiac surgery programme in Concord, New Hampshire [65]. These rounds also involved the patient's family. The team participated in 10-min briefings at the patient's bedside at the start of the day, and reviewed the patient's care plan, discussed medication and addressed anything that went wrong in an open, blame-free environment [53,64]. After these changes, patient mortality rates declined significantly [66].

In order to include families as active participants in the care process it is important to provide spaces for families in the patient room and on the unit where they can spend extended periods of time. Single rooms have clear advantage over multibed rooms in this regard as a result of increased privacy [14,67••]. A survey of nurses in four hospitals found that nurses gave high ratings to single rooms for accommodating family members but accorded double rooms low scores [67••]. In addition to these factors, organizational policies such as those that limit family visitation hours may influence family involvement and satisfaction with care.

Conclusion

Hospital design may help improve patient safety directly by reducing nosocomial infections, patient falls, medication errors and, sometimes, even by reducing patient morbidity and mortality. Hospital design may also help improve patient safety indirectly by reducing staff stress, staff walking and patient transfer, and by improving handwashing compliance. In contrast, very little has been reported recently on the role of hospital design as a barrier

to adverse events in hospitals. Although research on the links between hospital design and safety has increased over the past few years, there is still a need for more focused studies. Some reported contradictions on these links also need to be resolved. Meanwhile, the growing body of evidence in the field may already have an impact on how hospitals should be designed in the coming years.

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