

# Design of Australasian intensive care units: time for change or time for more research?

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Hospitals are expensive to build. In Victoria, a budget of \$583 million was allocated for capital works for hospitals, health, aged care and community services in 2007–2008, of which about \$300 million was to be for construction and infrastructure.<sup>1</sup> The capital works program for New South Wales Health was \$714 million for 2007–2008, out of an estimated total health expenditure of \$11.9 billion, with an estimated \$2.4 billion to be spent over the next 4 years.<sup>2</sup> Queensland had a capital program for health infrastructure of \$635 million in 2007–2008, but the exact amount to be spent on building construction has not been disclosed.<sup>3</sup> However, the amount spent in Australasia was relatively small when compared with the estimated \$46 billion spent on health care construction in the public and private sectors in the United States in 2007.<sup>4</sup> The exact amount spent specifically on construction of intensive care units is not known, but is likely to be significant given that, historically, about 1% of the US gross domestic product was spent on ICU patients, and ICUs in the US consumed 22% of total hospital costs.<sup>5</sup> Given the great expense, it is imperative that future construction or renovation of ICUs is performed wisely.

The Joint Faculty of Intensive Care Medicine made recommendations on the minimum standards required for ICUs in 1994.<sup>6</sup> The document stipulated that adult ICUs should have at least 20 m<sup>2</sup> of floor space for each bedspace, and recommended that at least one wash basin be available for every two beds, with one basin for each bedspace being preferred, and that at least one single room be available for every six open-space beds. The Guidelines for intensive care unit design from the American College of Critical Care Medicine and Society of Critical Care Medicine,<sup>7</sup> published in 1995, considered eight to 12 beds per ICU the best number from a functional perspective. This document stipulated the need for isolation rooms but left the required numbers dependent on the patient population and local health department requirements. The preferred ICU design allowed direct line of vision between the patient and a central nursing station. Many other recommendations were made, but both documents were conspicuous for the paucity of referenced scientific data supporting their guidelines.

No studies have demonstrated that the physical environment in non-ICU specialty units has improved patient outcomes. Coronary care units reduce mortality, but this probably results from the increased use of medical treat-

## ABSTRACT

Recommendations exist to guide the design and construction of adult intensive care units, but current guidelines are hampered by the paucity of high-quality research. Much of the current literature on ICU design has focused on patient-centred outcomes, such as nosocomial infections, aspects of psychological and physiological well-being, and patient satisfaction, but the design of the ICU environment also affects health care workers. The literature seems to favour the use of single rooms rather than an open-plan ICU design, with the major benefits being to infection control, but this notion is controversial. For most aspects of ICU design, more research is required before definite conclusions can be drawn. This article discusses the application of evidence-based design to improve the ICU environment and reviews some of the controversial issues and concepts.

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ments known to improve outcome, such as reperfusion therapy.<sup>8,9</sup> Specialised stroke units have been shown to reduce mortality and dependency,<sup>10,11</sup> but the benefits probably derive from the processes of care, such as appropriate imaging, allied health involvement, and appropriate management and prevention of complications, such as use of deep venous thromboprophylaxis and prevention of aspiration.<sup>12–14</sup> ICUs are thought to improve patient outcomes, but only recently has objective evidence become available to support this notion.<sup>15–17</sup>

In research examining the effect of health care environments, the advent of evidence-based medicine<sup>18,19</sup> has led to the idea of "evidence-based design".<sup>20</sup> Several questions can be asked of evidence-based design in regard to the ICU environment. The first is whether the design of the ICU has any effect on outcomes? Patient-centred outcomes are generally deemed the most important, but other important outcomes include those relevant to health care providers and staff. The second question is whether, if such research is available, is it of sufficient quality to allow firm recommendations to guide the future construction of ICUs? If it is not of sufficient quality, is it time for more research to be conducted?

### Effect of ICU design on patient-related factors

Little research has been conducted specifically on the effect of ICU design on outcomes. Most studies of hospital design have been in the non-ICU setting.<sup>21,22</sup>

### Infection control

The notion that ICU design can have an impact on infection control remains controversial. In Australasia, about 12 patients per 100 ICU admissions are diagnosed with severe sepsis.<sup>23</sup> At any one time, up to 20% of ICU patients have an ICU-acquired infection, of which pneumonia and urinary tract infection are the most common.<sup>24-26</sup> Nosocomial infections are usually transmitted by direct contact, with some transmitted in the air, but much of the research in this area has been in the non-ICU setting. A major problem with research on nosocomial infection is the vast array of confounding risk factors.<sup>27</sup>

There is now a large body of evidence that hand hygiene is the most important single measure for preventing the transmission of health care-associated pathogens, with a significant number of studies performed in the adult ICU setting.<sup>28,29</sup> Gloves provide some hand protection from acquiring microorganisms, but contaminated glove surfaces can still be significantly colonised.<sup>30</sup> The use of gowns in addition to hand washing and gloves to reduce nosocomial infection is controversial, with studies showing mixed results.<sup>31-36</sup>

A systematic review of the literature on hand washing identified that no single approach significantly improved adherence to hand-washing procedures.<sup>37</sup> The availability of sinks to facilitate hand washing has been studied with conflicting results. A study of two ICUs — a medical ICU with a 1:1 ratio of sinks to beds and a surgical ICU with a ratio of 1:4 — showed that nurses were more likely to wash their hands where the ratio was 1:1.<sup>38</sup> Physicians were observed in this study, but their results were not analysed as their compliance with hand washing was so poor. Conversely, a 49-week non-ICU study of hand-washing behaviour during a relocation from an old hospital with sink-to-bed ratios varying from 1:1 to 8:33, to a new hospital with 1:1 ratios, showed worse compliance (6% versus 12%) in the new hospital.<sup>39</sup> The reason was unclear. Workloads and patient-to-staff ratios remained the same, and glove use remained similar, but the use of alcohol-based alternatives for hand hygiene was not examined. Another study of 1500 observations in 14 patients units, including seven ICUs, where sink-to-bed ratios varied from 1:1 to 1:6, showed no statistical difference in overall adherence rate with hand hygiene with better sink availability,<sup>40</sup> but other factors which may have influenced the results, such as workload and use of alcohol-based alternative de-germers, were not measured. An Australian study of

a hospital relocation, comparing an older hospital with hand-washing facilities up to 30 m away from patient care areas and a new hospital designed so that no clinical activity occurred more than 5 m from a hand-washing station, and staff passed a sink on both entering and leaving a patient's room, showed a small improvement in hand-washing behaviour 1 month after the relocation, but no significant change after 9 months in the new facility.<sup>41</sup> Alcohol hand-rubs were not used at this hospital. The conclusion from this study was that hand-washing compliance required significantly more than just provision of physical facilities.

A study of 238 hours of observation on the use of a non-touch automated sink demonstrated that staff washed their hands more thoroughly, but significantly less often, with the automated sink.<sup>42</sup> A probable contributor to poor adherence was a programmed 15-second interruption to water flow, during which time users were expected to lather their hands. Staff found the delay unacceptably long, especially during busy shifts, and avoided using the automated sink. Water temperature variation due to plumbing problems also discouraged use of the automated system. Combining automated sinks with an education and feedback program, though initially improving adherence, demonstrated no major improvement in behaviour after 2 months.<sup>43</sup> This result appears consistent with those of other studies which show that education programs for hand washing result in immediate change, but subsequent decline in adherence.<sup>44</sup> These studies demonstrate that modifying human behaviour is not as simple as making tasks easier by modifying the physical environment. Administrative and educational strategies also need to be perfected.

The evidence supporting isolation of patients in single rooms to prevent nosocomial infections or colonisation with multidrug-resistant organisms is conflicting. A large retrospective German study of 164 ICUs, 280 000 patients and 1 000 000 patient-days demonstrated that isolation of patients in private rooms was significantly protective (odds ratio [OR], 0.36) for nosocomial methicillin-resistant *Staphylococcus aureus* (MRSA) infection.<sup>45</sup> Conversely, a significantly smaller, but prospective, study in two hospitals in the United Kingdom — of 800 patients and 10 000 patient-days — showed no reduction in MRSA cross infection when comparing patients in single rooms with those in cohorted bays.<sup>46</sup> A systematic review of the use of isolation to manage MRSA found no randomised controlled trials and 38 interrupted time series studies, of which only six were thought to provide strong evidence.<sup>47</sup> Four of the six studies showed reduction in MRSA through isolation, but only one of the studies was conducted in an ICU, and only two used single rooms, with the other studies using nurse cohorting and an isolation ward. Given the low rates of MRSA infection, it is estimated that to conclusively demonstrate a

50% reduction in MRSA infections from using single rooms a randomised controlled trial with 42 000 patients in each group would be needed.<sup>45</sup>

A retrospective study of *Acinetobacter baumannii* showed reduced rates of colonisation when a surgical ICU was remodelled from a combination of isolation and open rooms to isolation rooms only.<sup>48</sup> Conversely, in another study, an outbreak of 136 cases of *A. baumannii* infection in a general ICU was eventually contained without the isolation of affected patients in single rooms.<sup>49</sup> An American study of *S. aureus*, *Escherichia coli*, *Pseudomonas*, *Klebsiella*, *Acinetobacter* and *Serratia* spp during the conversion of an ICU from an open unit to isolation rooms demonstrated no difference in the incidence of colonisation and infection.<sup>50</sup> Non-essential traffic in the vicinity of patients was reduced, but no significant difference was seen in hand-washing behaviour after the conversion. The effect of the use of single rooms on vancomycin-resistant enterococcal infection or colonisation has not been studied, but the major risk factor for the acquisition of this organism is still antibiotic overuse.<sup>51</sup>

A few studies have investigated the role of single rooms in treating patients with burn injuries. A retrospective study of 2500 patients with large burns demonstrated a lower incidence of gram-negative bacteraemia, a longer time before the development of gram-negative bacteraemia, and lower mortality rates in patients treated in single-bed isolation compared with open wards.<sup>52</sup> Another retrospective study of 61 patients with burns who were defined as at high risk of colonisation with multiresistant microorganisms showed no instances of cross contamination or outbreaks following the use of a quarantine and isolation unit for these patients.<sup>53</sup> Unfortunately, cross contamination from patients who were subsequently discovered to be colonised with multiresistant microorganisms but were not admitted to the isolation unit and were managed on the usual ward was not studied.

Currently, in patients receiving haematopoietic stem cell transplantation in the non-ICU setting, the use of single rooms is considered the standard of care, despite the lack of high-quality evidence, with only a small proportion of patients not receiving special accommodation.<sup>54</sup> A retrospective international registry study of 6000 patients with leukaemia receiving bone marrow transplantation showed that patients treated in high-efficiency particle air filtration (HEPA) or laminar airflow rooms had significantly reduced transplant-related mortality in the first 100 days (relative risk, 0.80) when compared with conventional protective isolation in a single room.<sup>55</sup> Conversely, a systematic review of the use of HEPA in immunosuppressed patients revealed only eight randomised and eight non-randomised studies worthy of consideration,<sup>54</sup> with the meta-analyses showing

a significant decrease in mortality rates and fungal infection only in the non-randomised studies, and no overall statistical difference when the results were pooled.

Patients admitted to hospitals during the worldwide epidemic of severe acute respiratory syndrome (SARS) in 2003 were initially thought to be highly contagious and therefore managed with strict infection control measures and isolation to minimise cross infection.<sup>56</sup> Over 8000 patients in 28 countries contracted the disease.<sup>57</sup> The Canadian outbreak resulted in 438 cases, 51% in health care workers.<sup>58</sup> Many hospitals had shortages of single isolation rooms, and some countries built temporary isolation wards to house these patients.<sup>59</sup> A review of the literature following the outbreaks demonstrated that failure to implement barrier precautions was the major cause of nosocomial transmission of SARS.<sup>60</sup> The risk of SARS was also attributed to proximity to infected patients, with those with exposures of less than 1 metre at highest risk. However, a Taiwanese study of 23 probable SARS patients showed that, with the use of stringent control measures combined with negative-pressure rooms, the spread of SARS was limited to a single health care worker.<sup>61</sup> However, overall there are too few quality data to conclude that isolation rooms significantly reduce transmission of SARS above and beyond the use of personal protective equipment.

Finally, contact isolation of patients in single rooms can also have potentially adverse effects. Rehabilitation can be seriously hampered as access to paramedical areas is restricted, and contact with rehabilitation staff becomes more difficult and time consuming, and there can be significant psychological effects from social isolation and reduced sensory stimulation.<sup>62</sup> One study showed that health care workers were half as likely to enter the rooms of patients in isolation, possibly indicating that these patients may receive less care.<sup>63</sup>

In summary, the optimal design of an ICU to maximise infection control remains controversial. Given that hand hygiene is the most important method to prevent the transmission of health care-associated pathogens, it seems reasonable that the ratio of hand-washing sinks to beds be 1 : 1, and that sinks be located in areas to maximise compliance with hand washing, such as at the entry and exit points to bed areas. It is clear that these measures must also be accompanied by an ongoing education and administrative strategy to ensure adherence to infection control plans. The evidence seems to favour the use of single rooms rather than open bays to prevent the transmission of health care-associated pathogens, but this benefit appears minimal, and almost certainly depends on implementation and adherence to additional infection control measures.

### Psychological and physiological well-being

ICUs may have potentially harmful psychological and physiological effects on patients. A study of 10 healthy volunteers admitted to a Japanese ICU for 4 days and 3 nights showed that their psychological test scores for depression, fatigue, confusion and general health all worsened during their ICU stay.<sup>64</sup> The volunteers were not allowed access to visitors, radios or televisions during the study, and qualitative assessment showed more negative than positive views regarding most aspects of their ICU experience.

Several studies have examined the effect of ICU design on ICU delirium. Patients who develop delirium in the ICU have significantly longer hospital stays and higher mortality, and are more expensive to treat.<sup>65,66</sup> A small retrospective study showed that the number of patients who developed delirium in an ICU built without windows was two to three times more than the number in an ICU with windows.<sup>67</sup> This effect has been attributed to prolonged sleep and sensory deprivation, and the influence of light on circadian rhythms.<sup>68</sup> Another retrospective UK study found that patients in a windowless ICU had a less accurate memory of their ICU stay, were less orientated, and had double the incidence of hallucinations and delusions.<sup>69</sup> The justification for windowless construction at the time was the assumption that building costs were lower, that all ICU patients were unconscious and unaware of their surroundings, and that, if and when they became conscious, their subsequent stay in the unit was short.<sup>70</sup> However, in the first year of use of that ICU, 84% of patients were found to be substantially conscious for all or most of their stay. Another justification for the use of windows is that light can still enter the room during the day in the case of a power failure.

The impact of alterations to circadian rhythms on ICU patients is unknown. Most of the body's biological systems — be they physiological, such as heart rate or temperature, psychological, such as pain perception threshold, or pharmacological, such as serotonin or melatonin production — display a circadian rhythm.<sup>68</sup> Melatonin production and metabolism is sensitive to light, as well as to other stressors, such as immobilisation, cold and noise. Lights turned on for as little as 20 minutes during normal sleep can cause melatonin levels to fall.<sup>68</sup> Melatonin can disappear completely with constant light, but the exact lighting intensity that causes this is uncertain.

Most studies looking at light in the ICU have been set in neonatal ICUs, where light has an important role in the development of sight.<sup>71</sup> However, light as a source of significant energy can be harmful, with the risk related to wavelength, intensity and duration, as well as characteristics of organs sensitive to light injury, such as the eye.<sup>71</sup>

A problem with research in the area of lighting is the difficulty of constructing a study that can differentiate the

circadian phase response to light from the response to changes in daily routine, such as food and water intake, posture and sleep, or the stress of being sick.<sup>72</sup> Light intensity levels less than 1500 lux are thought not to affect the human circadian rhythm, and it is postulated that light intensities need to reach 5000 to 12000 lux before they have a significant impact.<sup>72,73</sup> One study showed that light intensities in the ICU could exceed 5000 lux during the day and reach 1400 lux at night.<sup>68</sup> In contrast, light intensity outdoors on a bright sunny day can reach 100 000 lux.<sup>68</sup> Interestingly, a Cochrane analysis of 20 studies of bright light therapy for non-seasonal depression showed no significant statistical difference from control groups when the results were pooled, but significant efficacy of bright light compared with the control when the two high-quality studies were analysed separately.<sup>74</sup> A retrospective study of 600 patients admitted to a cardiac ICU showed a decreased length of stay and decreased mortality in patients admitted to a sunny room with daytime light intensities between 1200 and 2500 lux compared with a dark room with intensities of 200 to 400 lux.<sup>75</sup> A non-randomised prospective study of 89 patients in a post-anaesthesia care unit who had undergone spinal surgery showed that patients exposed to higher levels and duration of sunlight (73 000 lux-hours versus 50 000 lux-hours) had reduced analgesic use and cost.<sup>76</sup> A postulated mechanism for this effect is an increase in serotonin levels, which occurs after light exposure, and the effect this has on pain modulation.

The presence of windows in ICUs may be beneficial not just through light, but also through the views provided. A landmark study credited with initiating much of the current interest in hospital design was a small retrospective study of 46 patients who had undergone cholecystectomy.<sup>77</sup> Patients assigned to rooms with windows looking out on a natural scene had a shorter postoperative hospital stay, took fewer analgesics and received fewer “negative” comments from nurses in the patient notes when compared with patients in rooms facing a brick building.

In summary, the ICU environment can have a negative impact on a patient's psychological and physiological well-being, but little research has been performed in this area. Windows that allow sunlight and views of a natural environment are probably beneficial for ICU patients, but there also appears to be a duration and intensity of environmental light which, when exceeded, is likely to cause harm.

### Sleep

It has been known for some time that disturbed, fragmented or insufficient sleep in critically ill patients is associated with adverse consequences.<sup>78-81</sup> In the ICU, sleep deprivation is associated with neuropsychological effects,

such as delusions, hallucinations, anxiety and depression; respiratory effects, such as decreased forced vital capacity, decreased hypercapnic and hypoxic respiratory response; and immunological effects, such as suppressed antibody responses.<sup>78-81</sup>

On the tenet that sleep deprivation is harmful, many strategies have been implemented to improve sleep quality in the ICU, some focusing on ICU design. Many strategies aim to modify noise, but its relative contribution to sleep disruption is probably not as significant as previously thought. A continuous polysomnography study of 22 ICU patients demonstrated that environmental noise was responsible for only 17% of the awakenings from sleep.<sup>82</sup>

Studies examining the hypothesis that single rooms provide a better sleep environment than multibed rooms have shown mixed results. A study of seven male patients and six healthy male volunteers, all subjected to 24-hour polysomnography testing while in an ICU with single rooms and open-plan beds, showed that the healthy volunteers had significantly better sleep quality than the sicker ICU patients, even though both groups were subjected to the same ICU environmental conditions, suggesting that poor sleep may actually be related to the underlying medical condition.<sup>83</sup> This study did demonstrate that mean and maximum decibel levels were significantly lower in the single-bed ICU rooms (43 dB versus 51 dB and 49 dB versus 61 dB, respectively, at night), and participants had improved total sleep and night sleep time in the single room. Despite this finding, sleep architecture and arousal and awakening indices in single rooms were not significantly different from those in the open bays. A reason contributing to the lack of difference may be that there were eight patient-care interactions per hour of sleep, 18% of which resulted in sleep disruption. Conversely, a study comparing a three-bed medical ICU room, a three-bed respiratory ICU room and a single-bed respiratory ICU room showed no significant difference in overall average sound levels over a 7-day period.<sup>73</sup> Although single rooms theoretically block some environmental noise, they do not block noise emanating from the room itself, and may actually amplify or reflect locally produced sounds.

Much ICU noise is generated at the patient's bedside by alarms, machines and people, but the use of human behaviour interventions to counteract this has also produced mixed results. A study of the use of noise reduction strategies, such as setting pagers to vibrate mode, limiting phone calls, conducting teaching and patient-care conferences away from nursing stations, and closing doors to single ICU rooms showed that, after staff education, overall noise actually increased slightly (2–4 dB), and that shutting single-room doors increased the noise inside slightly (1–2 dB).<sup>84</sup> In contrast, several ICU studies have demonstrated improve-

ments after instituting behaviour modifications to reduce noise. One study used the systematic closure of doors, limitation of nursing activities during the night, use of torch only light, not using telephones, intercoms, and radios at night, and lowering conversation volume, and demonstrated improved sleep based on nursing questionnaires.<sup>85</sup> Another study in a respiratory and medical ICU used similar strategies to reduce noise, and managed to reduce the number of sound peaks louder or equal to 80 A-weighted decibels (dBA) by 34%, but only managed to reduce the mean peak sound levels from 80 dBA to 78 dBA.<sup>86</sup> Neither study used polysomnography to examine sleep.

Other changes to ICU design that may improve sleep quality include the use of sound-absorbing ceiling tiles and carpets, but the effect on patients has not been studied directly in the ICU setting. A sleep study on 12 healthy volunteers in a three-bed room in an empty, refurbished surgical ward compared normal sound-reflecting plaster tiles to sound-absorbing tiles, and used predetermined sound recordings ranging from 27 to 58 dB.<sup>87</sup> Results showed that sound reverberation time was reduced, and participants had significantly less arousal to stimuli when sound-absorbing tiles were used, but no significant overall differences were found in total sleep time or distribution of sleep stages.

Overall, the merits of using different ICU design interventions for improving sleep quality remain unknown. Modifying the acoustic environment with sound-absorbing materials needs to be studied further. It is clear that the use of single rooms as the only intervention may not necessarily reduce noise, and that noise is only one of many modifiable contributors to poor sleep.

### Patient satisfaction

In addition to survival, quality of life, preservation of function and prevention of functional decline, other patient-centred outcomes, such as patient experiences, may also be important as outcome measures for ICU care. The ICU is a hostile environment, with patients complaining of a vast array of problems during their stay, including impaired cognitive functioning, discomfort and communication difficulties.<sup>88</sup> Many factors contribute to patient dissatisfaction with ICU care, but there are currently no large published studies of patient satisfaction specifically with ICU design. Much of the published literature examining patient satisfaction with hospital care is in the non-ICU setting.

A French study of 533 general hospital patients, most of whom were medical patients, showed that those who stayed in private rooms expressed greater satisfaction with the hospital environment, ancillary staff, information and overall quality of care (OR, 1.8–2.0).<sup>89</sup> Unpublished health care research from private organisations based in the US

seems to indicate that patient satisfaction in the general hospital environment is better when the room is not shared with another patient.<sup>90</sup> Patients housed in well-decorated and appointed hotel-style hospital rooms, with inclusions such as wood furniture, decorator art and carpeted floors, rate most dimensions of their hospital experience more favourably than patients in usual hospital rooms, furnished with typical metal beds, inexpensive chairs and no artwork.<sup>91</sup> Patients housed in the well-decorated rooms also rated their attending physician more favourably, and there was a non-statistically significant increase in their ratings of nursing care. A survey of 273 orthopaedic ward patients and 151 psychiatric ward patients comparing older-style wards to refurbished wards in the same hospitals again showed higher ratings for the treatment they received and the staff who delivered it when the patients were housed in the newer surroundings.<sup>92</sup>

However, not all patients are satisfied with single rooms. Disadvantages of single rooms may include less companionship and increased loneliness, as indicated by many patients in hospices preferring shared rooms.<sup>93,94</sup>

Overall, there is no published research specifically examining the views and preferences of ICU patients and their families in regards to ICU design. The non-ICU literature seems to suggest satisfaction is improved with the use of single rooms that are well appointed or newer, but it is still uncertain whether these conclusions can be generalised to the ICU environment.

### Effect of ICU design on health care workers

Most research on the effect of ICU design on outcomes has focused on patients. Little research has been performed on the possible adverse effects of the ICU environment on staff health and well-being.

### Infection control

Studies of nosocomial infections in hospital staff have focused mostly on SARS and tuberculosis. As previously mentioned, basic infection control measures and personal protective equipment seem the mainstay for restricting the spread of SARS to hospital staff, and there is currently little evidence that the design of the environment, such as the use of isolation rooms, provides additional protection.<sup>60,61</sup>

A few studies have examined the transmission of tuberculosis in the ICU, and several have looked at nosocomial transmission to health care workers rather than patients.<sup>95</sup> A literature review of nosocomial transmission of tuberculosis identified delayed diagnosis as the biggest risk factor.<sup>95</sup> High levels of air recirculation or positive-pressure room ventilation were also described as contributing in several case series of nosocomial tuberculosis transmission. A study of 1300 health

care workers at 17 hospitals in Canada showed that the risk for tuberculin conversion was associated with a hazard ratio of 3.4 among clinical personnel who worked in non-isolation rooms that had fewer than two air exchanges per hour when compared with rooms that had more than two air exchanges per hour.<sup>96</sup> A study in a hospital with a high incidence of tuberculosis, examining the effect of implementing infection control measures for tuberculosis (including patient isolation, construction of negative-pressure respiratory isolation rooms, and use of submicron masks) showed a decrease in tuberculin skin test conversions in health care workers from 3.3% to 0.4% over 2 years.<sup>97</sup> Air exchange rates for the negative-pressure rooms in this study were 4.9 exchanges per hour, but the individual effects of each engineering, administrative and personal respiratory protective measure were difficult to assess, as all were introduced simultaneously. Of note, only 14% of patients placed in respiratory isolation had culture-confirmed tuberculosis, suggesting probable overisolation of patients.

The case for isolation rooms, combined with negative-pressure ventilation for patients at high risk for tuberculosis, is strong, but again there are insufficient data to conclude that the observed protective effects are not a result of the increased use of personal protective equipment such as masks, or other non-engineering related measures.

Little information is available on the effect on health care workers of colonisation with multiresistant organisms, and no studies have been done on ICU staff. A study of a patient with severe burns who was colonised with multiresistant *A. baumannii* showed that, after institution of strict hygiene measures and contact isolation (including managing the patient in a single room with an anteroom and a private bathroom, and daily cleaning of rooms and disinfection of surfaces), the organism was found in only 0.7% of 1900 post-contact screening swabs and 4% of 400 environmental swabs.<sup>98</sup> In all cases, staff with positive cultures became negative after hand disinfection. Again, the role of ICU design in preventing spread of this organism is unknown, with education and motivation of staff deemed the most important aspect of prevention in this study.

In summary, little research has been performed on the effect of ICU design on nosocomial infections in health care workers. The use of negative-pressure isolation rooms with high air exchange rates in patients with tuberculosis may prevent spread to staff, but personal respiratory protective equipment probably provides the most effective protection. There is little evidence that single rooms prevent other nosocomial infections occurring in staff.

### Medical errors

The most studied form of error committed by staff in the ICU is medication error, with the frequency ranging from

1.2 to 947 errors per 1000 patient-days.<sup>99</sup> Research into medication error is notoriously complicated by differences in error detection methods and definitions, and variations in processes, function and staffing. In the ICU, the use of pharmacists, full-time specialist intensivists, and standardised drug preparations and protocols all reduce medication errors.<sup>100-102</sup>

A systematic review of computerised physician order entry systems and clinical decision support systems showed significant reductions in medication errors overall, ranging from 13% to 81%.<sup>103</sup> Two of the studies reviewed were large randomised controlled trials with 2100 and 7400 patients, respectively. The Veterans Health Administration in the US implemented an internally developed computerised bar-coded "point-of-care" system to dispense medications in 1994, and showed error reduction rates of up to 86%.<sup>104,105</sup> Problems with the system included concerns about cost, and increased workload and decreased efficiency caused by the extra steps required to dispense medications. However, overall nursing satisfaction with the bar-code system remained constantly favourable in one study over 12 months.<sup>105</sup>

Computers may also be used for automated event detection. A study of a computerised system for correlating infections with antibiotic use looked at 4600 patients and detected 90% of nosocomial infections, compared with 76% detected by manual surveillance, with the false-positive diagnosis rate being similar.<sup>106</sup> The computerised alerts identified 36 patients receiving antibiotics to which the organism was resistant, 32 patients not receiving appropriate antibiotics, 31 who could have received less expensive antibiotics, and 142 out of 156 patients who received cephalosporins for longer than required. In the cases in which inappropriate antibiotic prophylaxis was not identified, the computerised surgical data had been incorrectly entered.

Transfer and movement of patients between wards or rooms has been associated with increased staff workloads and increased medication errors. A study of a hospital renovation that combined a coronary critical care unit and a coronary step-down unit to form a single acuity-adaptable unit, where patients spent their entire admission in the same room, showed that patient transports decreased by 90%, and medication errors decreased by 70% following the change.<sup>107</sup>

The intensity of lighting may have an influence on medication errors, but this has not been studied in the ICU. An outpatient pharmacy study examining three levels of illumination showed that, out of 10 888 prescriptions filled by pharmacists, errors were significantly lower (2.6% versus 3.8%) when illumination with 146 foot-candle lighting was used, compared with baseline 45 foot-candle lighting, but

not when 102 foot-candle lighting was used.<sup>108</sup> Errors were also linearly associated with workload.

Overall, little research has examined errors made by health care workers in the ICU. Medication errors are likely to be reduced by the implementation of computerised ordering systems and medication bar-coding systems, by adequate lighting, and by minimising patient transfers, but some of these concepts require more research.

### Psychological and physiological well-being

Stress is a major problem in ICU staff. A UK study of 627 ICU doctors (85% consultants) showed that 29% scored on a general health questionnaire above the threshold indicative of psychiatric morbidity, and 12% scored above the threshold for depression,<sup>109</sup> while a study of 350 nurses showed 24% of ICU nurses tested positive for symptoms of post-traumatic stress disorder, compared with only 14% of general nurses.<sup>110</sup> Symptoms of depression were also found in 31% of ICU nurses. Sources of psychological stress for staff are numerous, most associated with the politics of working in a large organisation, such as dealing with administration, work schedules, staff shortages, bed management, organisation problems, little free time, the nature of support structures, and the organisation of patient care.<sup>111-113</sup>

The "sick-building syndrome" has long been described as a reaction to the working environment.<sup>112</sup> Many causes have been suggested, including chemicals in construction material or furnishings, excess airborne particulate matter, excess carbon dioxide, bacteria in air from contaminated humidifiers, poor circulation of air or excessive air movement, extremes of thermal comfort, lack of negative ions, excessive noise and poor lighting.<sup>114,115</sup> Most research examining the effect of the environment on worker health has been in industries other than health care.

There is some evidence that internal noise pollution in hospitals may be high enough to interfere with the ability of hospital staff to function.<sup>116</sup> Significant annoyance with noise was described by 61% of hospital workers in a Spanish survey, with hospital workers, visitors and patients accounting for 32%, 31% and 17%, respectively, of the hospital noise.<sup>116</sup> An acoustic room study of the effect of prerecorded operating theatre noise, averaging 77 dBA, on anaesthetic residents showed reduced mental efficiency and short-term memory with the higher noise levels.<sup>117</sup> A study of 100 critical care nurses showed that noise was positively related to "burnout", as defined on stress inventories, after adjustment for other stressors; the top three disturbing noises were beeping monitors, equipment alarms and telephones.<sup>118</sup> A smaller study of 11 nurses in a paediatric ICU, demonstrated that every 10 dB increase in average sound levels was associated with a 6 beats per

minute increase in average heart rate, and a 27-point increase in subjective stress ratings on a stress rating questionnaire.<sup>119</sup> However, salivary amylase (used in that study as a marker of catecholamine response to stress because of its correlation with serum noradrenaline concentrations) showed no significant difference. Interestingly, two-patient rooms were found to be louder than four-patient rooms, an effect explained by the doors to the two-patient rooms being closed more often, not allowing noise to disperse, and the children who were sicker and intubated (and therefore not crying) being housed in the four-patient rooms.

A study examining the effect of changing ceiling tiles from sound-reflecting (plaster) to sound-absorbing (resin-bonded glass wool) on nursing staff in a coronary care unit showed that reverberation times improved, and sound levels dropped by 5–6 dB in the noisy areas.<sup>120</sup> In 142 questionnaires, staff reported that speech became more intelligible, and they felt more relaxed and less irritable with the sound-absorbing ceiling, but a Hawthorne effect could not be excluded.

Lighting has been thought a possible factor in the sick-building syndrome. A study of 106 office workers in two buildings demonstrated a possible association of work-related headache and lethargy with lower lighting levels and higher glare indices.<sup>121</sup> The study found it difficult to differentiate between potential confounders, such as room size, ceiling heights, window sizes, the use of blinds, and type of ventilation system, but most workers in both buildings disliked fluorescent lighting.

The effect of lighting on staff in ICUs has only been studied in neonatal ICUs. A study of a neonatal ICU renovation, where existing fluorescent lighting was augmented with halogen spotlights with variable intensity control (from 12 to 193 lux), found that 61% of staff thought the environment was better for the caregivers, but 35% thought additional lighting was needed for procedures.<sup>122</sup> These results cannot be generalised to adult ICUs, which have different requirements.

Up to 90% of air may be recirculated in an air-conditioned building to conserve energy, and lack of fresh air has been blamed for the symptoms of sick-building syndrome.<sup>114</sup> Several studies implicate air conditioning in increasing the prevalence of respiratory symptoms and other non-specific complaints, such as lethargy, and headache, but interpreting cohort studies in this area is biased by the effect of heightened awareness or “mass hysteria”.<sup>123</sup> A study of the effects of contamination of a hospital air supply caused by the proximity of an air intake vent to exhaust vents from the hospital kitchen, offices and a research laboratory, showed that exposed employees had a slightly increased prevalence of work-related rhinitis, bron-

chitis and rashes, but the effect was small.<sup>124</sup> There was no statistical difference in overall symptom prevalence, and the exposed employees’ overall health was not significantly worse than that of employees from non-exposure areas.

There is reasonable evidence that residential air-filtration systems can reduce the incidence of asthma. A systematic review of 10 randomised controlled trials examining air filtration by residential HEPA filters in asthma showed a small but statistically significant decrease in total symptoms and sleep disturbance with the use of domestic air filters.<sup>125</sup> However, the use of HEPA filters in hospitals for preventing asthma has not been studied.

Overall, stress appears to be a significant problem for staff in ICUs, with many causes. The working environment can have an adverse effect on staff, and there is some evidence that modifying the environment through sound reduction, the use of natural light and lighting control may have benefits for staff.

### Injuries

Little research has been performed on injury prevention in the ICU. Nurses have high levels of manual handling-associated injuries, with an annual prevalence of back injury of 40%–50% and a lifetime prevalence of 35%–80%.<sup>126</sup> An Australian study showed 76% of manual-handling injuries were back injuries, and 68% of manual-handling injuries were directly associated with patient care.<sup>126</sup> Mechanical lifting devices decrease the incidence of patient-transfer injuries, but can cause different types of musculoskeletal injuries.<sup>127</sup> An ICU survey of nursing staff after the installation of ceiling-mounted patient lifts that allowed full room coverage showed reduced fatigue, pain and frustration, and decreased doctor visits, medication use, and time off work due to injuries incurred by bedside patient care and patient transfers.<sup>127</sup> Workers compensation claims decreased by 70% in the first year, and the injury rate remained low over a 2-year period.

### Satisfaction

Little research has been performed on staff satisfaction with ICU design. Problems with generalising satisfaction findings to ICUs are that most research has been conducted in non-ICU settings, and satisfaction depends on many other factors, such as the type of patients cared for, autonomy, support, and relationships of staff with peers.<sup>111</sup> A survey of nurses working in medical and surgical wards found that most nurses clearly favoured single-occupancy rooms compared with double-occupancy rooms.<sup>128</sup> The perceived benefits of single room included improvements in space, interactions with family, accommodation of family, privacy and confidentiality for examination and history taking, and patient comfort, as well as fewer medication and dietary

errors. A survey of neonatal ICU nurses showed a similar preference for single rooms, but the consistent proviso was that safety depended on staffing levels.<sup>129</sup> A concern about single rooms was the isolation of staff and decreased patient visibility when staffing is inadequate. Other concerns included decreased contact with physicians, who were thought to be more easily accessible in an open unit, and increased physical workloads, due to extra walking, a problem that could be minimised by staffing ratios of no more than 2 : 1. Workload issues are of significant importance given that hospital mortality of ICU patients is directly related to ICU peak occupancy and the ratio of occupied to appropriately staffed beds.<sup>130</sup>

### Conclusions

Despite a substantial body of literature examining the effects of the design of the hospital environment on outcomes, little research has been performed in the ICU. High-quality studies are difficult to conduct in this area, and few have been performed. The design features that improve outcomes for patients, family and staff in the ICU are still controversial, and even less is known about Australasian conditions.

The current evidence available to guide the design of ICUs seems to favour the use of single rooms combined with strict infection control procedures and individual sinks in easily accessible locations to minimise nosocomial infections in patients and staff, but the benefits of single rooms for other outcomes remain uncertain. Environmental factors such as noise and light can have adverse effects on both patients and staff, and some design interventions appear to have benefits, but many design modifications are ineffective unless concurrent administrative and education strategies are also instituted, and staff numbers and staff workloads are reasonable.

Lastly, for many aspects of ICU design, there are no published studies to support recommendations. Examples include how best to care for family and visitors, the appropriate location of the ICU within the hospital, and the layout and appropriate location of facilities within the ICU; the main controversy is the concept of centralisation versus decentralisation.

Overall, current evidence leaves significant uncertainty about the optimal design of ICUs, and more research is needed. Expenditure and investment in the construction of ICUs, and the potential adverse consequences of design mistakes, are too great to allow the current designs to be repeated without question. Special consideration needs to be given to the requirements of patients, families and staff in Australasian ICUs, as these may differ from the requirements in other countries, where much of the current research on hospital and ICU design has been conducted.

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### References

- 1 Victorian State Budget 2007–08. Strategy and outlook — Budget Paper 2. Chapter 1: financial policy objectives and strategy. Available at: <http://www.budget.vic.gov.au/CA2572B00081B35D/pages/strategy-and-outlook> (accessed Oct 2007).
- 2 NSW Treasury 2007–08 Budget Papers. Budget Paper Number 3. Budget Estimates. Minister for Health. Section 31 — Department of Health. Available at: <http://www.treasury.nsw.gov.au/bp07-08/bp3/bp3> (accessed Oct 2007).
- 3 Queensland Government. State Budget 2007–08. Budget Paper 3. Capital statement — 2. State Capital Program — planning and priorities. Available at: <http://www.budget.qld.gov.au/budget-papers/bp3.shtml> (accessed Oct 2007).
- 4 US Census Bureau. Manufacturing, mining and construction statistics — construction spending. May 2007. Available at: <http://www.census.gov/const/www/c30index.html> (accessed Oct 2007).
- 5 Halpern NA, Bettles L, Greenstein R. Federal and nationwide intensive care units and healthcare costs: 1986–1992. *Crit Care Med* 1994; 22: 2001–7.
- 6 Joint Faculty of Intensive Care Medicine. Minimum standards for intensive care units Melbourne: JFICM, 1994, revised 1997. Available at: <http://www.jficm.anzca.edu.au/publications/policy/index.htm> (accessed Oct 2007).
- 7 Guidelines/Practice Parameters Committee of the American College of Critical Care Medicine and Society of Critical Care Medicine. Guidelines for intensive care unit design. *Crit Care Med* 1995; 23: 582–8.
- 8 Rotstein Z, Mandelzweig L, Lavi B, et al. Does the coronary care unit improve prognosis of patients with acute myocardial infarction? *Eur Heart J* 1999; 20: 813–8.
- 9 Saitto C, Ancona C, Fusco D, et al. Outcome of patients with cardiac diseases admitted to coronary care units. *Med Care* 2004; 42: 147–54.
- 10 Stroke Unit Trialists' Collaboration. Organised inpatient (stroke unit) care for stroke. *Cochrane Database Syst Rev* 2001; (3): CD000197. DOI: 10.1002/14651858.CD000197.
- 11 Stroke Unit Trialists' Collaboration. Collaborative systematic review of the randomised trials of organized inpatient (stroke unit) care after stroke. *BMJ* 1997; 314: 1151–9.
- 12 Stroke Unit Trialists' Collaboration. How do stroke units improve patient outcomes? A collaborative systematic review of the randomised trials. *Stroke* 1997; 28: 2139–44.
- 13 Cadilhac DA, Ibrahim J, Pearce DC, et al. Multicenter comparison of processes of care between stroke units and conventional care wards in Australia. *Stroke* 2004; 35: 1035–40.
- 14 Evans A, Perez I, Harraf F, et al. Can differences in management processes explain different outcomes between stroke unit and stroke-team care? *Lancet* 2001; 358: 1586–92.
- 15 Simchen E, Sprung CL, Galai N, et al. Survival of critically ill patients hospitalized in and out of intensive care. *Crit Care Med* 2007; 35: 449–57.
- 16 Simchen E, Sprung CL, Galai N, et al. Survival of critically ill patients hospitalized in and out of intensive care units under paucity of intensive care unit beds. *Crit Care Med* 2004; 32: 1654–61.

## REVIEWS

- 17 Bone RC, McElwee NE, Eubanks DH, Gluck EH. Analysis of indications for intensive care unit admission. Clinical efficacy assessment project: American College of Physicians. *Chest* 1993; 104: 1806-11.
- 18 Sackett DL, Haynes R, Guyatt G, Tugwell P, editors. Clinical epidemiology: a basic science for clinical medicine. 2nd ed. Boston: Little, Brown, 1991.
- 19 Sackett D, Strauss S, Richardson W, et al. Evidence-based medicine: how to practice and teach EBM. London: Churchill Livingstone, 2000.
- 20 Hamilton K. The four levels of evidence-based design practice. *Healthcare Design* 2003; 3: 18-26.
- 21 Ulrich R, Quan X, Zimring C, et al. The role of the physical environment in the hospital of the 21st century: a once-in-a-lifetime opportunity. Available at: [http://www.healthdesign.org/research/reports/physical\\_envirom.php](http://www.healthdesign.org/research/reports/physical_envirom.php) (accessed Oct 2007).
- 22 Chaudhury H, Mahmood A, Valente M. Advantages and disadvantages of single- versus multiple-occupancy rooms in acute care environments. A review and analysis of the literature. *Environ Behav* 2005; 37: 760-86.
- 23 Finfer S, Bellomo R, Lipman J, et al. Adult-population incidence of severe sepsis in Australian and New Zealand intensive care units. *Intensive Care Med* 2004; 30: 589-96.
- 24 Vincent JL, Bihari DJ, Suter PM, et al. The prevalence of nosocomial infection in intensive care units in Europe: results of the European Prevalence of Infection in Intensive Care (EPIC) Study. *JAMA* 1995; 274: 639-44.
- 25 Legras A, Malvy D, Quinioux AI, et al. Nosocomial infections: prospective survey of incidence in five French intensive care units. *Intensive Care Med* 1998; 24: 1040-6.
- 26 Richards MJ, Edwards JR, Culver DH, Gaynes RP. Nosocomial infections in medical intensive care units in the United States. *Crit Care Med* 1999; 27: 887-92.
- 27 Fridkin SK, Welbel SF, Weinstein RA. Magnitude and prevention of nosocomial infections in the intensive care unit. *Infect Dis Clin North Am* 1997; 11: 479-96.
- 28 Boyce JM, Pittet D; Healthcare Infection Control Practices Advisory Committee; HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Guideline for Hand Hygiene in Health-Care Settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Society for Healthcare Epidemiology of America/Association for Professionals in Infection Control/Infectious Diseases Society of America. *MMWR Recomm Rep* 2002; 51:1-45.
- 29 Pittet D, Allegranzi B, Sax H, et al. Evidence-based model for hand transmission during patient care and the role of improved practices. *Lancet Infect Dis* 2006; 6: 641-52.
- 30 Pittet D, Dharan S, Touveneau S, et al. Bacterial contamination of the hands of hospital staff during routine patient care. *Arch Intern Med* 1999; 159: 821-6.
- 31 Safdar N, Marx J, Meyer NA, Maki DG. Effectiveness of preemptive barrier precautions in controlling nosocomial colonization and infection by methicillin-resistant *Staphylococcus aureus* in a burn unit. *Am J Infect Control* 2006; 34: 476-83.
- 32 Lai KK, Kelly AL, Melvin ZS, et al. Failure to eradicate vancomycin-resistant Enterococci in a university hospital and the cost of barrier precautions. *Infect Control Hosp Epidemiol* 1998; 19: 647-52.
- 33 Puzniak LA, Leet T, Mayfield J, et al. To gown or not to gown: the effect on acquisition of vancomycin-resistant Enterococci. *Clin Infect Dis* 2002; 35: 18-25.
- 34 Srinivasan A, Song X, Ross T, et al. A prospective study to determine whether cover gowns in addition to gloves decrease nosocomial transmission of vancomycin-resistant Enterococci in an intensive care unit. *Infect Control Hosp Epidemiol* 2002; 23: 424-8.
- 35 Grant J, Ramman-Haddad L, Mibman MD. The role of gowns in preventing nosocomial transmission of methicillin-resistant *Staphylococcus aureus* (MRSA): Gown use in MRSA control. *Infect Control Hosp Epidemiol* 2006; 27: 191-4.
- 36 Slaughter S, Hayden MK, Nathan C, et al. A comparison of the effect of universal use of gloves and gowns with that of glove use alone on acquisition of vancomycin-resistant Enterococci in a medical intensive care unit. *Ann Intern Med* 1996; 125: 448-56.
- 37 Naikoba S, Hayward A. The effectiveness of interventions aimed at increasing handwashing in healthcare workers — a systematic review. *J Hosp Infect* 2001; 47: 173-80.
- 38 Kaplan LM, McGuckin M. Increasing handwashing compliance with more accessible sinks. *Infect Control* 1986; 7: 408-10.
- 39 Lankford MG, Zembower TR, Trick W, et al. Influence of role models and hospital design on hand hygiene of health care workers. *Emerg Infect Dis* 2003; 9: 217-23.
- 40 Vernon MO, Trick WE, Welbel SF, et al. Adherence with hand hygiene: does number of sinks matter? *Infect Control Hosp Epidemiol* 2003; 24: 224-5.
- 41 Whitby M, McLaws ML. Handwashing in healthcare workers: accessibility of sink location does not improve compliance. *J Hosp Infect* 2004; 58: 247-53.
- 42 Larson E, McGeer A, Quraishi A, et al. Effect of an automated sink on handwashing practices and attitudes in high-risk units. *Infect Control Hosp Epidemiol* 1991; 12: 422-8.
- 43 Larson EL, Bryan JL, Adler LM, Blane C. A multifaceted approach to changing handwashing behavior. *Am J Infect Control* 1997; 25: 3-10.
- 44 Dubbert PM, Dolce J, Richter W, et al. Increasing ICU staff handwashing: effects of education and group feedback. *Infect Control Hosp Epidemiol* 1990; 11: 191-3.
- 45 Gastmeier P, Schwab F, Geffers C, Ruden H. To isolate or not to isolate? Analysis of data from the German Nosocomial Infection Surveillance System regarding the placement of patients with methicillin-resistant *Staphylococcus aureus* in private rooms in intensive care units. *Infect Control Hosp Epidemiol* 2004; 25: 109-13.
- 46 Cepeda JA, Whitehouse T, Cooper B, et al. Isolation of patients in single rooms or cohorts to reduce spread of MRSA in intensive-care units: prospective two-centre study. *Lancet* 2005; 365: 295-304.
- 47 Cooper BS, Stone SP, Kibbler CC, et al. Isolation measures in the hospital management of methicillin-resistant *Staphylococcus aureus* (MRSA): systematic review of the literature. *BMJ* 2004; 329: 533-41.
- 48 Mulin B, Rouget C, Clement C, et al. Association of private isolation rooms with ventilator-associated *Acinetobacter baumannii* pneumonia in a surgical intensive care unit. *Infect Control Hosp Epidemiol* 1997; 18: 499-503.
- 49 Wilks M, Wilson A, Warwick S, et al. Control of an outbreak of multidrug-resistant *Acinetobacter baumannii-calcoaceticus* colonization and infection in an intensive care unit (ICU) without closing the ICU or placing patients in isolation. *Infect Control Hosp Epidemiol* 2006; 27: 654-8.
- 50 Preston GA, Larson EL, Stamm WE. The effect of private isolation rooms on patient care practices, colonization and infection in an intensive care unit. *Am J Med* 1981; 70: 641-5.
- 51 Muto CA, Jernigan JA, Ostrowsky BE, et al. SHEA guideline for preventing nosocomial transmission of multidrug-resistant strains of *Staphylococcus aureus* and Enterococcus. *Infect Control Hosp Epidemiol* 2003; 24: 362-86.
- 52 McManus AT, Mason AD, McManus WF, Pruitt BA. A decade of reduced gram-negative infections and mortality associated with improved isolation of burned patients. *Arch Surg* 1994; 129: 1306-9.

## REVIEWS

- 53 Van Rijn RR, Kuijper EC, Kreis RW. Seven-year experience with a 'quarantine and isolation unit' for patients with burns. A retrospective analysis. *Burns* 1997; 23: 345-8.
- 54 Eckmanns T, Ruden H, Gastmeier P. The influence of high-efficiency particulate air filtration on mortality and fungal infection among highly immunosuppressed patients: a systematic review. *J Infect Dis* 2006; 193: 1408-18.
- 55 Passweg JR, Rowlings PA, Atkinson KA, et al. Influence of protective isolation on outcome of allogeneic bone marrow transplantation for leukemia. *Bone Marrow Transplantation* 1998; 21: 1231-8.
- 56 Tsang KW, Mok TY, Wong PC, Ooi GC. Severe acute respiratory syndrome (SARS) in Hong Kong. *Respirology* 2003; 8: 259-65.
- 57 World Health Organization. Epidemic and pandemic alert response. Cumulative number of reported probable cases of severe acute respiratory syndrome (SARS). Available at: <http://www.who.int/csr/sars/country/en/> (accessed Oct 2007).
- 58 Moore D, Gamage B, Bryce E, et al. Protecting health care workers from SARS and other respiratory pathogens: organizational and individual factors that affect adherence to infection control guidelines. *Am J Infect Control* 2005; 33: 88-96.
- 59 Fung C-P, Hsieh T-L, Tan K-H, et al. Rapid creation of a temporary isolation ward for patients with severe acute respiratory syndrome in Taiwan. *Infect Control Hosp Epidemiol* 2004; 25: 1026-32.
- 60 Gamage B, Moore D, Copes R, et al. Protecting health care workers from SARS and other respiratory pathogens: a review of the infection control literature. *Am J Infect Control* 2005; 33: 114-21.
- 61 Twu S-J, Chen T-J, Chen C-J, et al. Control measures for severe acute respiratory syndrome (SARS) in Taiwan. *Emerg Infect Dis* 2003; 9: 718-20.
- 62 Peel RK, Stolarek I, Elder AT. Is it time to stop searching for MRSA? Isolating patients with MRSA can have long term implications. *BMJ* 1997; 315: 58.
- 63 Kirkland KB, Weinstein JM. Adverse effects of contact isolation. *Lancet* 1999; 354: 1177-8.
- 64 Tanimoto S, Takayanagi K, Yokota H, Yamamoto Y. The psychological and physiological effects of an intensive care unit environment on healthy individuals. *Clin Perform Qual Health Care* 1999; 7: 77-82.
- 65 Thomason JWW, Shintani A, Peterson JF, et al. Intensive care unit delirium is an independent predictor of longer hospital stay: a prospective analysis of 261 non-ventilated patients. *Crit Care* 2005; 9: R375-81.
- 66 Milbrandt EB, Deppen S, Harrison PL, et al. Costs associated with delirium in mechanically ventilated patients. *Crit Care Med* 2004; 32: 955-62.
- 67 Wilson LM. Intensive care delirium. The effect of outside deprivation in a windowless unit. *Arch Intern Med* 1972; 130: 225-6.
- 68 Vinal PE. Design technology: what you need to know about circadian rhythms in healthcare design. *J Healthc Des* 1997; 9: 141-4.
- 69 Keep P, James J, Inman M. Windows in the intensive therapy unit. *Anaesthesia* 1980; 35: 257-62.
- 70 Keep PJ. Stimulus deprivation in windowless rooms. *Anaesthesia* 1977; 32: 598-602.
- 71 Graven SN. Clinical research data illuminating the relationship between the physical environment and patient medical outcomes. *J Healthc Des* 1997; 9: 15-9.
- 72 Postolache TT, Oren DA. Circadian phase shifting, alerting, and antidepressant effects of bright light treatment. *Clin Sports Med* 2005; 24: 381-413.
- 73 Meyer TJ, Eveloff SE, Bauer MS, et al. Adverse environmental conditions in the respiratory and medical ICU settings. *Chest* 1994; 105: 1211-6.
- 74 Tuunainen A, Kripke DF, Endo T. Light therapy for non-seasonal depression. *Cochrane Database Syst Rev* 2004; (2): CD004050. DOI: 10.1002/14651858.CD004050.pub2.
- 75 Beauchemin KM, Hays P. Dying in the dark: sunshine, gender and outcomes in myocardial infarction. *J R Soc Med* 1998; 91: 352-4.
- 76 Walch JM, Rabin BS, Day R, et al. The effect of sunlight on postoperative analgesic medication use: a prospective study of patients undergoing spinal surgery. *Psychosom Med* 2005; 67: 156-63.
- 77 Ulrich RS. View through a window may influence recovery from surgery. *Science* 1984; 224: 420-1.
- 78 Weinhouse GL, Schwab RJ. Sleep in the critically ill patient. *Sleep* 2006; 29: 707-16.
- 79 Schwab RJ. Disturbances of sleep in the intensive care unit. *Crit Care Clin* 1994; 10: 681-94.
- 80 Krachman SL, D'Alonzo GE, Criner GJ. Sleep in the intensive care unit. *Chest* 1995; 107: 1713-20.
- 81 Parthasarathy S, Tobin MJ. Sleep in the intensive care unit. *Intensive Care Med* 2004; 30: 197-206.
- 82 Freedman NS, Gazendam J, Levan L, et al. Abnormal sleep/wake cycles and the effect of environmental noise on sleep disruption in the intensive care unit. *Am J Respir Crit Care Med* 2001; 163: 451-7.
- 83 Gabor JY, Cooper AB, Crombach SA, et al. Contribution of the intensive care unit environment to sleep disruption in mechanically ventilated patients and healthy subjects. *Am J Respir Crit Care Med* 2003; 167: 708-15.
- 84 Moore MM, Nguyen D, Nolan SP, et al. Interventions to reduce decibel levels on patient care unit. *Am Surg* 1998; 64: 894-9.
- 85 Walder B, Francioli D, Meyer J-J, et al. Effects of guidelines implementation in a surgical intensive care unit to control nighttime light and noise levels. *Crit Care Med* 2000; 28: 2242-7.
- 86 Kahn DM, Cook TE, Carlisle CC, et al. Identification and modification of environmental noise in an ICU setting. *Chest* 1998; 114: 535-40.
- 87 Berg S. Impact of reduced reverberation time on sound-induced arousals during sleep. *Sleep* 2001; 24: 289-92.
- 88 Stein-Parbury J, McKinley S. Patients' experiences of being in an intensive care unit: a select literature review. *Am J Crit Care* 2000; 9: 20-7.
- 89 Nguyen Thi PL, Briancon S, Empereur F, Guillemin F. Factors determining inpatient satisfaction with care. *Soc Sci Med* 2002; 54: 493-504.
- 90 Kaldenberg DO. The influence of having a roommate on patient satisfaction. Press Ganey. The satisfaction monitor. Available at: [http://www.pressganey.com/products\\_services/readings\\_findings/satmon/article.php?article\\_id=63](http://www.pressganey.com/products_services/readings_findings/satmon/article.php?article_id=63) (accessed Oct 2007).
- 91 Swan JE, Richardson LD, Hutton JD. Do appealing rooms increase patient evaluations of physicians, nurses, and hospital services? *Health Care Manage Rev* 2003; 28: 254-64.
- 92 Lawson B, Phiri M. Room for improvement. *Health Serv J* 2000; 110: 24-6.
- 93 Pease NJF. Do patients and their relatives prefer single cubicles or shared wards? *Palliat Med* 2002; 16: 445-6.
- 94 Kirk S. Single or shared rooms for hospice patients? *Palliat Med* 2003; 17: 560.
- 95 Menzies D, Fanning A, Yuan L, Fitzgerald M. Tuberculosis among health care workers. *N Engl J Med* 1995; 332: 92-8.
- 96 Menzies D, Fanning A, Yuan L, et al. Hospital ventilation and risk for tuberculosis infection in Canadian health care workers. *Ann Intern Med* 2000; 133: 779-89.
- 97 Blumberg HM, Watkins DL, Berschling JD, et al. Preventing the nosocomial transmission of tuberculosis. *Ann Intern Med* 1995; 122: 658-63.

## REVIEWS

- 98 Paavilainen T, Alanen M, Makela M, et al. Infrequent isolation of multidrug-resistant *Acinetobacter baumannii* from the staff tending a colonized patient with severe burns. *Infect Control Hosp Epidemiol* 2001; 22: 14-6.
- 99 Kane-Gill S, Weber RJ. Principles and practices of medication safety in the ICU. *Crit Care Clin* 2006; 22: 273-90.
- 100 Leap LL, Cullen DJ, Clapp MD, et al. Pharmacist participation on physician rounds and adverse drug events in the intensive care unit. *JAMA* 1999; 282: 267-70.
- 101 Kucukarslan SN, Peters M, Mlynarek M, Nafziger DA. Pharmacists on rounding teams reduce preventable adverse drug events in hospital general medicine units. *Arch Intern Med* 2003; 163: 2014-8.
- 102 van den Bemt PMLA, Fijn R, van der Voort PHJ, et al. Frequency and determinants of drug administration errors in the intensive care unit. *Crit Care Med* 2002; 30: 846-50.
- 103 Kaushal R, Shojania KG, Bates DW. Effects of computerized physician order entry and clinical decision support systems on medication safety. *Arch Intern Med* 2003; 163: 1409-16.
- 104 Mills PD, Neily J, Mims E, et al. Improving the bar-coded medication administration system at the Department of Veterans Affairs. *Am J Health Syst Pharm* 2006; 63: 1442-7.
- 105 Anderson S, Wittwer W. Using bar-code point-of-care technology for patient safety. *J Healthc Qual* 2004; 26: 5-11.
- 106 Evans RS, Larsen RA, Burke JP, et al. Computer surveillance of hospital-acquired infections and antibiotic use. *JAMA* 1986; 256: 1007-11.
- 107 Hendrich AL, Sorrells AK. Effects of acuity-adaptable rooms on flow of patients and delivery of care. *Am J Crit Care* 2004; 13: 35-45.
- 108 Buchanan TL, Barker KN, Gibson JT, et al. Illumination and errors in dispensing. *Am J Hosp Pharm* 1991; 48: 2137-45.
- 109 Coomber S, Todd C, Park G, et al. Stress in UK intensive care unit doctors. *Br J Anaesth* 2002; 89: 873-81.
- 110 Mealer ML, Shelton A, Berg B, et al. Increased prevalence of post-traumatic stress disorder symptoms in critical care nurses. *Am J Respir Crit Care Med* 2007; 175: 693-7.
- 111 Nugent O, Glass CA, Krishnan KR, Bingley JD. An investigation of the relationship between environmental factors and job satisfaction in intensive nursing, with particular reference to spinal trauma. *Paraplegia* 1992; 30: 489-96.
- 112 Vives JF, Caminero GG, Oliver MB, et al. Causal and emotional factors related to work stress in ICU nursing staff. The importance of accurate measurement. *Intensive Crit Care Nurs* 1994; 10: 41-50.
- 113 Cassem NH, Hackett TP. Sources of tension for the CCU nurse. *Am J Nurs* 1992; 72: 1426-30.
- 114 Finnegan MJ, Pickering CAC, Burge PS. The sick building syndrome: prevalence studies. *BMJ* 1984; 289: 1573-5.
- 115 Niven RM, Fletcher AM, Pickering CA, et al. Building sickness syndrome in healthy and unhealthy buildings: an epidemiological and environmental assessment with cluster analysis. *Occup Environ Med* 2000; 57: 627-34.
- 116 Bayo MV, Garcia AM, Garcia A. Noise levels in an urban hospital and workers subjective responses. *Arch Environ Health* 1995; 50: 247-51.
- 117 Murthy VSSN, Malhotra SK, Bala I, Raghunathan M. Detrimental effects of noise on anaesthetists. *Can J Anaesth* 1995; 42: 608-11.
- 118 Topf M, Dillon E. Noise-induced stress as a predictor of burnout in critical care nurses. *Heart Lung* 1988; 17: 567-73.
- 119 Morrison WE, Hass EC, Shaffner DH, et al. Noise, stress, and annoyance in a pediatric intensive care unit. *Crit Care Med* 2003; 31: 113-9.
- 120 Blomkvist V, Eriksen CA, Theorell T, et al. Acoustics and psychosocial environment in intensive coronary care. *Occup Environ Med* 2005; 62: e1. DOI: 10.1136/oem.2004.017632. Available at: <http://www.occenvmed.com/cgi/content/full/62/3/e1> (accessed Oct 2007).
- 121 Robertson AS, McInnes M, Glass D, et al. Building sickness, are symptoms related to the office lighting? *Ann Occup Hyg* 1989; 33: 47-59.
- 122 Walsh-Sukys M, Reitenbach A, Hudson-Barr D, DePompei P. Reducing light and sound in the neonatal intensive care unit: an evaluation of patient safety, staff satisfaction and costs. *J Perinatol* 2001; 21: 230-5.
- 123 Robertson AS, Burge PS, Hedge A, et al. Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems. *BMJ* 1985; 291: 373-6.
- 124 Hanson RL, Dolphin B, Parkinson DK. Does contamination of "fresh" air intake cause some cases of building intolerance? *Indoor Environ* 1993; 2: 19-25.
- 125 McDonald E, Cook D, Newman T, et al. Effect of air filtration systems on asthma. A systematic review of randomized trials. *Chest* 2002; 122: 1535-42.
- 126 Retsas A, Pinikahana J. Manual handling activities and injuries among nurses: an Australian hospital study. *J Adv Nurs* 2000; 31: 875-83.
- 127 Silverwood S, Haddock M. Reduction of musculoskeletal injuries in intensive care nurses using ceiling-mounted patient lifts. *Dynamics* 2006; 17: 19-21.
- 128 Chaudhury H, Mahmood A, Valente M. Nurses' perception of single-occupancy versus multioccupancy rooms in acute care environments: an exploratory comparative assessment. *Appl Nurs Res* 2006; 19: 118-25.
- 129 Walsh WF, McCullough KL, White RD. Room for improvement: nurses' perceptions of providing care in a single room newborn intensive care setting. *Adv Neonatal Care* 2006; 6: 261-70.
- 130 Tarnow-Mordi WO, Hau C, Warden A, Shearer AJ. Hospital mortality in relation to staff workload: a 4-year study in an adult intensive care unit. *Lancet* 1985; 356: 185-9. □