Relationship Between ICU Design and Mortality

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Many ICUs are rife with legends of differential survival among ICU rooms. These perceptions raise the possibility that ICU architecture may influence the clinical outcomes of ICU patients. Architectural design of health-care facilities can influence patient safety; however, there are no data that determine whether patients cared for in ICU beds that are poorly visualized from a central nursing station have outcomes that differ from those admitted to rooms with greater visibility to nursing staff and physicians. Multiple strategies have evolved to improve patient safety in ICUs, but we are unaware of any strategy that considers the impact of ICU design on patient outcomes.

In the present study, we compared clinical outcomes among patients assigned to medical ICU (MICU) rooms with unimpeded visibility of patients from a central nursing station to patients assigned to rooms with poor visibility from a central nursing station. The objective was to determine whether patient visibility correlates with mortality and/or various secondary clinical outcomes.

**Material and Methods**

**MICU Description and Physical Layout**

The MICU at New York Presbyterian Hospital/Columbia University Medical Center is an organizationally closed ICU staffed by first-year and second-year internal medicine residents who work with a pulmonary/critical care fellow and a pulmonary/...
critical care attending 7 days per week. The ICU attending staff consist of six board-certified intensivists who each care for patients approximately 8 weeks per year. These physicians provide up to 45 weeks of critical care service each year as full-time faculty of Columbia University. These physicians regularly interact with one another to standardize the delivery of critical care and, where possible, use standardized patient care protocols to limit variation of care among attending physicians. The residents rotate on an in-house call schedule every fourth night and are supervised at night by in-house attending intensivists. The MICU accepts patients 24 h per day and admits directly from the emergency room, general hospital wards, other ICUs, and outside hospitals.

Nurses are assigned to patients on a 1:2 or 1:3 ratio and work 12-h shifts. Patients receiving continuous renal replacement therapies are sometimes staffed at a 1:1 ratio. Severity of illness is not otherwise factored into nursing assignments. On a fully staffed day, there are six or seven nurses in the MICU. During work breaks (60 min for lunch and twice daily 15-min respite), a nurse’s patients are covered by a nursing colleague with a similar patient load, such that his or her patient load transiently increases to 1:3 or higher for 180 min per patient each day (90 min/shift \times 2 shifts/day). This transient reallocation of nursing resources applies to all patients, irrespective of room visibility.

The MICU nursing staff are managed by a single patient-care coordinator who is responsible for 24 total MICU beds in two adjacent units. The MICU is also staffed 24 h each day by a respiratory therapist who has no other clinical responsibilities outside the MICU. Additional support staff include doctor of pharmacy, who is present in the MICU Monday to Friday during the day and is available continuously by phone, and a unit secretary, who is present 24 h each day.

Architecturally, the MICU contains 12 nonuniform rooms that are arranged in a rectangle around a central nursing station (Fig 1). Patient beds are positioned against the back wall of each room, facing the door, with approximately equal spacing on either side. In this study, rooms were categorized as low-visible rooms (LVRs) or high-visible rooms (HVRs). LVRs were defined as those in which a direct line of sight between an observer and any part of the patient could not be established from anywhere within the central nursing station. By this criterion, rooms 22, 28, 36, and 38 are not directly visible from the central nursing station and are thus designated LVRs. All other rooms are designated high-visible rooms. *The central nursing station includes computer stations and desk space 3 to 4 feet in height, above which is open space (ie, no walls). LVRs = low-visible rooms; HVRs = high-visible rooms.

The central nursing station is a major focal point for both physicians and nurses. With the exception of daily walk-rounds in the morning, most physician-related activities take place from within the central nursing station. These activities include checking laboratories and imaging, reviewing charts, writing notes, and most nonround discussions. With regard to nursing activity, location is more variable. Most nurses carry out administrative tasks (such as charting) from within the central nursing station; however, some nurses also use one of two mobile computer stations that are typically used outside patient rooms. Additionally, all patient rooms have a fully functional, wall-mounted computer and keyboard that can be used for charting if needed.

At the south end of the central nursing station (Fig 1), there are two computer monitors that serve as repeaters for real-time data displayed on bedside monitors. Vital signs displayed include heart rate, BP, respiratory rate, pulse oximetry, and, in some settings, hemodynamic measurements such as central venous pressure. Nurses and physicians are alerted to abnormalities in vital signs by electronic alarms; however, there is no dedicated health-care provider who monitors these data or alarms.

Study Design

Data were collected between January 1, 2008, and December 31, 2008, and were analyzed retrospectively with approval of the Columbia University Institutional Review Board. Patients were assigned to rooms by the MICU charge nurse, based on room availability. No room allocation was made based on the severity of illness or admitting diagnosis; however, a small number of patients were admitted to negative pressure rooms (rooms 22, 28, or 38) for respiratory isolation.

The names, medical record numbers, and date/time of admission of all patients admitted to the MICU during the data collection period were recorded in a log book. Comparison of data in the log book with hospital computerized records revealed no missed patients during the data collection period. The MICU critical care fellows maintained a concurrent log book with Acute Physiology and Chronic Health Evaluation (APACHE) II scores, primary diagnoses, ICU survival, and resuscitation status. APACHE II scores were calculated by first-year residents 24 h after admission to the MICU with the use of a web-based scoring tool. To facilitate disease-specific comparisons, patients were grouped into one of six frequent admission categories: sepsis/septic shock, respiratory failure, cardiac disease (including cardiac arrest,
cardiogenic shock, congestive heart failure, and hypertensive urgency/emergency), gastrointestinal bleed, neurologic disorders (including seizures and altered mental status of unclear cause), and other (including renal failure, liver failure, electrolyte imbalance, diabetic ketoacidosis, drug overdose, alcohol withdrawal, angioedema, and drug desensitization). Resuscitation status was defined as either full code or do not resuscitate. In the latter case, cardiopulmonary resuscitation, including chest compressions and defibrillation, were withheld in the event of cardiac arrest.

Outcome Measures

The primary outcome measure was hospital mortality, which was defined as death occurring prior to discharge from the hospital. Secondary outcome measures included ICU mortality (defined as death occurring in the MICU), ICU length of stay (LOS), and ventilator-free days at hospital day 28. ICU LOS was defined as the number of days spent in the MICU prior to death, transfer to the general hospital wards, or discharge from the hospital. Ventilator-free days were defined as 28 minus the number of ventilator-dependent days, assuming survival to 28 days or discharge from the hospital. Patients who died before 28 days were assigned as death occurring in the MICU, ICU mortality, ICU LOS, and ventilator-free days at hospital day 28. ICU LOS was defined as the number of days spent in the MICU prior to death, transfer to the general hospital wards, or discharge from the hospital. Patients who died before 28 days were assigned a score of zero to avoid the confounding effect of mortality.

Subgroup analyses of the primary and secondary outcome measures were performed based on tertiles of APACHE II scores. To facilitate statistical analysis, tertiles were created based on the distribution of scores to include approximately equal numbers of patients in each group.

Additional variables investigated were the effects of admission diagnosis, time of admission (day vs night), and resuscitation status on hospital mortality. Day admissions were defined as those admitted to the MICU between 6:00 AM and 6:00 PM, whereas night admissions were defined as those admitted between 6:00 PM and 6:00 AM.

Statistical Analysis

Statistical analysis was performed with Microsoft Excel 2007 (Redmond, WA) and SAS 2008 (SAS Institute Inc.; Cary, NC). Normally distributed continuous data, as determined using the Kolmogorov-Smirnov test, were reported as mean ± SD, and differences between groups were assessed by unpaired Student t test. Skewed continuous data were reported as median and interquartile range (25-75 percentiles), and differences between groups were assessed by the Mann-Whitney U test. Binary variables were reported as ratios and percentages, and differences between groups were assessed by Fisher exact test or the χ² test. Finally, a logistic regression model was created, using fixed selection, to evaluate the effect of room location on the primary outcome after adjusting for other potentially important prognostic variables, including APACHE II score, time of admission, primary diagnosis, and resuscitation status. All comparisons were two tailed, with P < .05 considered significant. For the logistic regression model, results are reported as odds ratios and 95% CIs.

RESULTS

A total of 700 patients were admitted to the MICU during the review period. Among these, 36 patients were transferred from one MICU room to another and were excluded from the analysis. The most common reason for inter-MICU room transfer was for respiratory isolation. The remaining 664 patients were included in the analysis.

Baseline Characteristics

Patients in the two groups were well balanced with regard to baseline demographic and clinical characteristics (Table 1). Specifically, there were no significant differences between patients assigned to HVRs vs LVRs with regard to age, gender, APACHE II score, requirement for mechanical ventilation, admission diagnosis, or resuscitation status.

Primary Outcome

Hospital mortality rates of patients assigned to HVRs and LVRs are shown in Figure 2. No difference in overall survival between patients assigned to HVRs and LVRs was detected. However, patients with the greatest severity of illness (APACHE II > 30) had significantly higher hospital mortality rates when assigned to LVRs than similarly ill patients assigned to HVRs (82.1% and 64.0%, n = 39 and 75, respectively; P = .046). Mean APACHE II scores for patients with scores > 30 were similar for LVRs and HVRs.

Secondary Outcomes

ICU mortality, ICU LOS, and ventilator-free days for patients assigned to HVRs and LVRs are shown in Table 2. For each of these secondary outcomes, subgroup analyses based on APACHE II stratification were also performed (data not shown). Although there was no significant difference in ICU mortality between patients assigned to HVRs and LVRs in the overall analysis, the subgroup of patients with an APACHE II > 30 had a significantly higher ICU mortality if assigned to an LVR as compared with an HVR (66.7% and 46.7%, n = 39 and 75, respectively, P = .042), a finding similar to that observed for the primary outcome. For ICU LOS and ventilator-free days, no differences were detected between patients assigned to HVRs and LVRs in both the overall and the subgroup analyses.

Effect of Admission Diagnosis, Resuscitation Status, and Time of Admission

The effect of admission diagnosis, resuscitation status, and time of admission on hospital mortality is shown in Table 3. None of these variables was associated with differences in hospital mortality between patients assigned to HVRs vs LVRs.

Logistic Regression

Using a logistic regression model, the association between room location and hospital mortality in patients with APACHE II > 30 was further analyzed. The simple effect of the APACHE II score on hospital mortality was significant (odds ratio 1.13; 95% CI,
1.10-1.15; P < .001); however, room location was not
(odds ratio 1.01; 95% CI 0.72-1.43; P = .94). APACHE II scores were then dichotomized as “≤30” = 0 vs
“>30” = 1. When APACHE II >30 and room location were entered, along with the interaction of those
two terms, into a logistic regression model, both the
simple effect of APACHE II >30 and the interaction
between APACHE II >30 and room location were
significant predictors of hospital mortality: APACHE
II >30 (odds ratio 6.89; 95% CI, 4.42-10.75; P < .001);
interaction of APACHE II >30 and room location
(odds ratio 3.14; 95% CI, 1.12-8.52; P = .04).

Two other factors were also significant univariate
predictors of hospital mortality: resuscitation status
(P = .04) and primary diagnosis (P < .001). When
these factors were included in the model, APACHE II
>30 and the interaction of APACHE II >30 and
room location remained significant: APACHE II >30
(odds ratio 4.11; 95% CI, 2.38-7.08; P < .001); inter-
action of APACHE II >30 and room location (odds
ratio 3.39; 95% CI, 1.19-9.68; P = .02). Several pri-
mary diagnoses were also significant predictors of
hospital mortality when compared with gastrointesti-
nal bleed, which had the lowest rate of mortality:
cardiac disease (odds ratio 3.16; 95% CI, 1.41-7.08;
P = .005); respiratory failure (odds ratio 2.25; 95% CI,
1.24-4.06; P = .007); sepsis/septic shock (odds ratio
2.84; 95% CI 1.53-5.26; P = .001); and neurologic
disorders (odds ratio 3.51; 95% CI, 1.40-8.80; P = .007).

Resuscitation status (do not resuscitate on admission
vs full code) was just above significance (odds ratio
2.52; 95% CI, 0.99-6.36; P = .051) when the other
factors were included in the model.

## Discussion

In many ICUs there exist perceptions that specific
rooms have mortality rates that are higher than others.
To our knowledge, there are no reports that correlate
survival with ICU design. Guidelines for ICU design
specify that “patients must be situated so that direct or
indirect (eg, by video monitoring) visualization by
health-care providers is possible at all time. The
preferred design is to allow direct visualization of the
patient from a nursing station.”

Despite such guidelines, many ICUs have patient rooms that are not well
visualized from nursing stations. Until now, the signifi-
cance of this architectural influence was unknown.

In the present study, we report that a subgroup of
patients admitted to the MICU (the sickest patients at

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Table 1—Baseline Demographics, Admission Diagnosis, and Resuscitation Status

<table>
<thead>
<tr>
<th></th>
<th>Overall (N = 664)</th>
<th>HVRs (n = 442)</th>
<th>LVRs (n = 222)</th>
<th>P Value</th>
</tr>
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<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Age, y, mean ± SD</td>
<td>60.2 ± 17.4</td>
<td>60.4 ± 17.2</td>
<td>59.8 ± 17.9</td>
<td>.620</td>
</tr>
<tr>
<td>Female (%)</td>
<td>47.4</td>
<td>47.5</td>
<td>47.3</td>
<td>1.000</td>
</tr>
<tr>
<td>APACHE II, median (IQR)</td>
<td>20.0 (14.0-27.0)</td>
<td>19.5 (13.0-27.0)</td>
<td>20.0 (14.0-27.0)</td>
<td>.352</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>53.9</td>
<td>53.4</td>
<td>55.0</td>
<td>.703</td>
</tr>
<tr>
<td>Admission diagnosis, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sepsis/septic shock</td>
<td>163 (24.5)</td>
<td>106 (24.0)</td>
<td>57 (25.7)</td>
<td>.632</td>
</tr>
<tr>
<td>Cardiac</td>
<td>48 (7.2)</td>
<td>38 (8.6)</td>
<td>10 (4.0)</td>
<td>.058</td>
</tr>
<tr>
<td>GIB</td>
<td>141 (21.2)</td>
<td>91 (20.6)</td>
<td>50 (22.0)</td>
<td>.563</td>
</tr>
<tr>
<td>Neurologic</td>
<td>30 (4.5)</td>
<td>15 (3.3)</td>
<td>15 (6.8)</td>
<td>.073</td>
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<tr>
<td>Respiratory failure</td>
<td>218 (32.8)</td>
<td>147 (33.3)</td>
<td>71 (32.0)</td>
<td>.741</td>
</tr>
<tr>
<td>Other</td>
<td>64 (9.6)</td>
<td>45 (10.2)</td>
<td>19 (8.6)</td>
<td>.504</td>
</tr>
<tr>
<td>Resuscitation status, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DNR on admission</td>
<td>22 (3.3)</td>
<td>15 (3.4)</td>
<td>7 (3.2)</td>
<td>.870</td>
</tr>
<tr>
<td>DNR in ICU</td>
<td>120 (18.1)</td>
<td>84 (19.0)</td>
<td>36 (16.2)</td>
<td>.378</td>
</tr>
<tr>
<td>DNR total</td>
<td>142 (21.3)</td>
<td>99 (22.4)</td>
<td>43 (19.4)</td>
<td>.369</td>
</tr>
</tbody>
</table>

APACHE = Acute Physiology And Chronic Health Evaluation; DNR = do not resuscitate; GIB = gastrointestinal bleeding; HVRs = high-visible rooms; LVRs = low-visible rooms; IQR = interquartile range.
additional portable computers in the ICU may not address physician-related behavior, which is an unclear contributor to the differential survival observed in the present study. Another potential solution to LVRs is to monitor these rooms with continuous bedside video imaging, a practice that is part of a larger movement toward telemedicine and virtual ICUs that appears to be increasing in popularity as demand for ICU beds exceeds supply of ICU physicians. 5,6

A review of 19 best-practice example ICUs in the United States built between 1993 and 2003 examined several ICU design issues, including ICU layout and nursing workstation layout. 7 Among the various types of ICU layouts, 8 the most common (12 of 19) was the racetrack design, similar to the ICU in the present study, in which patient beds are located along the perimeter. This design maximizes the perimeter wall of a unit, allowing more rooms to have natural light, and also increases visibility from a central location. Regarding the layout of nursing workstations, many ICUs have replaced large centralized nursing stations with smaller decentralized workstations, located either inside or just outside patient rooms. Among the 19 ICUs studied in the review above, 7 only two had a solitary centralized nursing station without additional substations. Given the substantial amount of time spent charting (15%-25%), 9-11 an increasing emphasis on closer nurse proximity to patient rooms is likely to have beneficial effects on patient monitoring and ultimately on patient outcomes. In our ICU, the small number of mobile computer workstations and a high reliance on a centralized nursing station may have baseline, with APACHE II > 30) had significantly higher hospital and ICU mortality rates if they were assigned to LVRs rather than HVRs. No significant differences were observed between groups with regard to ICU LOS or ventilator-free days. Furthermore, there was no effect of admission diagnosis, resuscitation status, or time of admission on differences in hospital mortality rates between patients assigned to HVRs vs LVRs.

The precise mechanism(s) responsible for differential survival in LVRs vs HVRs were not discerned in this study. Whether it is due to late identification of clinical deterioration, less time spent by health-care providers at the bedside, or other undiscovered variables is unknown and requires additional study. Numerous clinical scenarios of delayed recognition of change in patient condition can be envisioned, such as climbing out of bed, attempts at self-extubation, hematemesis, disconnection of arterial lines, or even slower weaning in LVRs. Given that differential survival based on room assignment was only found among those with an APACHE II > 30, one explanation might be that these patients have a lower reserve to recover from potential insults, such as those listed above.

One potential solution in our own ICU, other than reconstructing the entire unit to eliminate the existence of LVRs, is to increase the number of mobile computer stations, thereby allowing nurses to work in greater proximity to patient rooms. This simple change would need to be coupled with cultural changes that promote less social interchange at the central nursing station. Whether such changes are possible has not been tested. Moreover, having additional portable computers in the ICU may not address physician-related behavior, which is an unclear contributor to the differential survival observed in the present study. Another potential solution to LVRs is to monitor these rooms with continuous bedside video imaging, a practice that is part of a larger movement toward telemedicine and virtual ICUs that appears to be increasing in popularity as demand for ICU beds exceeds supply of ICU physicians. 5,6

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### Table 2—ICU Mortality, ICU Length of Stay, and Ventilator-Free Days: HVR vs LVR

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>HVRs</th>
<th>LVRs</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU mortality (%)</td>
<td>131/664 (19.7)</td>
<td>85/442 (19.2)</td>
<td>46/222 (20.7)</td>
<td>.649</td>
</tr>
<tr>
<td>ICU LOS, median (IQR)</td>
<td>3.0 (1.0-6.0)</td>
<td>3.0 (1.0-6.0)</td>
<td>3.0 (2.0-7.0)</td>
<td>.147</td>
</tr>
<tr>
<td>Ventilator-free days, median (IQR)</td>
<td>26.0 (0-28.0)</td>
<td>26.0 (0-28.0)</td>
<td>25.0 (0-28.0)</td>
<td>.970</td>
</tr>
</tbody>
</table>

LOS = length of stay. See Table 1 for expansion of other abbreviations.

### Table 3—Effect of Admission Diagnosis, Resuscitation Status, and Time of Admission on Hospital Mortality

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>HVRs</th>
<th>LVRs</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admission diagnosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sepsis/septic shock</td>
<td>73/163 (44.8)</td>
<td>53/106 (50.0)</td>
<td>20/57 (35.1)</td>
<td>.068</td>
</tr>
<tr>
<td>Cardiac</td>
<td>24/48 (50.0)</td>
<td>18/38 (47.4)</td>
<td>6/10 (60.0)</td>
<td>.724</td>
</tr>
<tr>
<td>GIB</td>
<td>19/115 (16.5)</td>
<td>13/74 (17.6)</td>
<td>6/41 (14.6)</td>
<td>.685</td>
</tr>
<tr>
<td>Neurologic</td>
<td>12/30 (40.0)</td>
<td>5/15 (33.3)</td>
<td>7/15 (46.7)</td>
<td>.710</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>72/218 (33.0)</td>
<td>42/147 (28.6)</td>
<td>30/71 (42.3)</td>
<td>.044</td>
</tr>
<tr>
<td>Other</td>
<td>20/90 (22.2)</td>
<td>15/62 (24.2)</td>
<td>5/28 (17.9)</td>
<td>.592</td>
</tr>
<tr>
<td>DNR</td>
<td>93/142 (65.5)</td>
<td>60/99 (66.0)</td>
<td>33/43 (76.7)</td>
<td>.063</td>
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<tr>
<td>Time of admission</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Day</td>
<td>96/288 (33.3)</td>
<td>60/179 (33.5)</td>
<td>36/109 (33.0)</td>
<td>.932</td>
</tr>
<tr>
<td>Night</td>
<td>124/376 (33.0)</td>
<td>86/263 (29.7)</td>
<td>38/113 (33.6)</td>
<td>.861</td>
</tr>
</tbody>
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Data are hospital mortality ratios (%) for each category. See Table 1 for expansion of abbreviations.
contributed to the difference in outcomes observed between patients assigned to LVRs vs HVRs.

**Conclusions**

The limitations of this study include a modest number of patients studied over a limited period of time (1 year) and a single-center design. Despite these limitations, we believe our findings raise important questions about the influence of ICU architecture on clinical outcomes and may have implications on the design of future ICUs. Additional studies are needed to confirm and further elucidate our findings.

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**References**

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