Do Windows or Natural Views Affect Outcomes or Costs Among Patients in ICUs?

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Objective: To determine whether potential exposure to natural light via windows or to more pleasing views through windows affects outcomes or costs among critically ill patients.
Design: Retrospective cohort study.
Setting: An academic hospital in Philadelphia, PA.
Patients: Six thousand hundred thirty-eight patients admitted to a 24-bed medical ICU and 6,631 patients admitted to a 24-bed surgical ICU from July 1, 2006, to June 30, 2010.
Interventions: Assignment to medical ICU rooms with vs. without windows and to surgical ICU rooms with natural vs. industrial views based on bed availability.
Measurements and Main Results: In primary analyses adjusting for patient characteristics, medical ICU patients admitted to rooms with ($n = 4{,}093$) vs. without ($n = 2{,}243$) windows did not differ in rates of ICU ($p = 0.25$) or in-hospital ($p = 0.94$) mortality, ICU readmissions ($p = 0.37$), or delirium ($p = 0.56$). Surgical ICU patients admitted to rooms with natural ($n = 3{,}072$) vs. industrial ($n = 3{,}588$) views experienced slightly shorter ICU lengths of stay and slightly lower variable costs. Instrumental variable analyses based on initial bed assignment and exposure time did not show any differences in any outcomes in either the medical ICU or surgical ICU cohorts, and none of the differences noted in primary analyses remained statistically significant when adjusting for multiple comparisons. In a prespecified subgroup analysis among patients with ICU length of stay greater than 72 hours, MICU windows were associated with reduced ICU ($p = 0.02$) and hospital mortality ($p = 0.04$); these results did not meet criteria for significance after adjustment for multiple comparisons.
Conclusions: ICU rooms with windows or natural views do not improve outcomes or reduce costs of in-hospital care for general populations of medical and surgical ICU patients. Future work is needed to determine whether targeting light from windows directly toward patients influences outcomes and to explore these effects in patients at high risk for adverse outcomes. (*Crit Care Med* 2013; 41:XX–XX)
Key Words: environmental interventions; health care costs; ICU outcomes; windows

Efforts to modify structural elements of critical care settings hold great potential for improving outcomes and reducing costs among patients in ICUs (1–4). Although most investigators have focused on the effects of different ICU staffing practices (2, 5, 6), the influences of ICUs' physical environments on clinical and economic outcomes are beginning to be evaluated. Some studies suggest that light level, season, room directionality, and visual environments may affect outcomes, including ventilator-free days, delirium, length of stay (LOS), and use of analgesics in specific populations (7–10). However, other studies have not identified such relationships (11–13).

Despite recent elucidation of the conceptual and biological frameworks for how direct light exposure may influence the

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Dr. Halpern had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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course of critical illness (14), the real-world impact of possible light exposure afforded by being in an ICU room with a window has not been evaluated among a large sample of general ICU patients. Additionally, despite an early observation that postcholecystectomy patients recovering in surgical ICU (SICU) rooms with natural views (i.e., containing trees) rather than industrial views (i.e., walls) experienced improved outcomes (9), the potentially important psychological benefits of having a more pleasing view from one's hospital room have not been reproduced.

These gaps in knowledge are particularly important given federal architectural guidelines mandating windows in every newly constructed hospital room (15), longstanding recommendations by the Society of Critical Care Medicine that windows be present in all ICU rooms (16), recent guidelines for ICU design (17), and the challenges faced by urban hospitals wishing to expand their ICU beds given space constraints that preclude windowed rooms. Thus, to address the mandate of new construction containing windows, we sought to quantify how a patient's exposure to windows and the views afforded through them affect clinical and economic outcomes in cohorts of general medical ICU (MICU) and SICU patients.

METHODS

We included electronic records of all patients admitted to MICU and SICU rooms in a tertiary-care hospital in Philadelphia, PA, from July 1, 2006, to June 30, 2010. To maintain observation independence, we analyzed only index ICU admissions during a hospitalization.

In the MICU, 17 rooms had windows and seven did not: four windowed rooms had natural views of trees, six had other potentially "pleasing" views (city skyline), and seven had industrial views (**Supplemental Fig. 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/A624). In the SICU, all 24 rooms had windows, with 11 having natural views and 13 having industrial views (**Supplemental Fig. 2**, Supplemental Digital Content 1, http://links.lww.com/CCM/A624). Windowed rooms were further categorized as having half- or full-width windows. Both the MICU and SICU have policies encouraging window shades to be consistently open during the day and closed at night in efforts to optimize orientation.

Patients "exposed" to either windows or natural views were classified as 1) those who remained in their initially assigned bed throughout their ICU stays or 2) those who were changed from "exposed" to "unexposed" rooms (or vice versa) during their ICU stays. In primary, intention-to-treat analyses, we included all patients according to original room assignments. In secondary, per-protocol analyses, the group of patients who changed rooms was excluded because decisions to switch rooms may have been influenced by patient characteristics and trajectories. We prospectively specified two subgroups for restricted analyses, hypothesizing that the effects of windows and natural views would be particularly strong among 1) patients admitted during days with at least 12 hrs of sunlight (**Supplemental Table 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/A624) and 2) patients who were in the ICU for at least 72 hrs.

We assessed six clinical outcomes: ICU and in-hospital mortality; ICU readmissions, defined as a patient readmitted to the same ICU within 72 hours following an index ICU admission (18); ICU and hospital LOS; and delirium. For SICU patients, nurse practitioners screened patients each day to determine whether they met prespecified criteria for delirium based on the new and rapid onset of disturbed consciousness and/or perceptual disturbance. For MICU patients, one author (R.K.) performed retrospective chart reviews among a 7% random sample of patients (n = 430), chosen so as to provide 80% power to detect at least a 15% absolute difference in the proportions of patients experiencing delirium in windowed vs. nonwindowed MICU rooms. Delirium was declared if keywords associated with actual delirium (delirium, mental status change, inattention, disorientation, hallucinations, agitation, inappropriate behavior, confusion, etc.) (19, 20) were documented by physicians or nurses on at least two separate days. Finally, we evaluated fixed, variable, and total hospitalization costs based on institutional billing records.

Analyses

We estimated the odds of ICU and in-hospital mortality, ICU readmissions, and delirium using logistic regression (21). Ordinary least squares and median regressions (22) were used to assess differences in ICU and hospital LOS and in costs, respectively. Costs included those accrued during and after the ICU stay, up through hospital discharge (23).

After performing unadjusted analyses, we adjusted for patient race, sex, age, and source of ICU admission in our primary adjusted analyses. These variables were selected for model inclusion because each was related to mortality in unadjusted analyses at a p value less than 0.2 (24). We performed two additional analyses in the SICU population to test the assumption that initial bed assignment was essentially random. First, we compared Acute Physiology and Chronic Health Evaluation (APACHE)-IV (25) scores among patients admitted to rooms with natural vs. industrial views. APACHE-IV scores were available for 4,325 patients admitted to the SICU from May 2007 to July 2010. Second we reran each model (unadjusted, adjusted, and restricted to patients admitted during days with at least 12 hrs of sunlight or to those with ICU stays of at least 72 hrs) after further adjusting for patients' APACHE-IV score.

Finally, although few patients switched beds during their ICU stay (see Results), we assessed the possibility that the per-protocol analyses could be subject to selection bias by performing an instrumental variable (IV) analysis (26). In this analysis, all patients were included and the exposure variable was the proportion of the ICU stay that each patient spent "exposed" to a window or natural view. More precisely, the exposure was 0 in nonwindowed or industrial view room for the entire ICU stay, 0.5 in one type of room initially and then switched to another type of room, and 1 in windowed

TABLE 1. Patient Characteristics (Intent-to-Treat Population)

Variables	Medical ICU Window (*n* = 4,093)	Medical ICU No Window (*n* = 2,243)	*p*	Surgical ICU Natural View (*n* = 3,072)	Surgical ICU Industrial View (*n* = 3,588)	*p*
Male	2,143 (52%)	1,079 (48%)	0.72	1,824 (59%)	2,157 (60%)	0.54
Mean age (SD)	57.2 (17.2)	56.9 (17.3)	0.48	57.4 (19.1)	56.8 (18.6)	0.18
Race						
African-American	1,785 (44%)	993 (44%)		800 (26%)	953 (27%)	
Caucasian (reference)	1,914 (47%)	1,018 (45%)	0.47	1,837 (60%)	2,118 (59%)	0.82
Other	250 (6%)	130 (6%)		435 (14%)	517 (14%)	
Previous location						
Emergency department	2,008 (49%)	1,084 (49%)		726 (25%)	804 (24%)	
Floor	1,171 (29%)	662 (30%)		405 (14%)	478 (14%)	
Outside hospital (reference)	595 (15%)	336 (15%)	0.74	375 (13%)	438 (13%)	0.50
Postanesthesia care unit	Not applicable	Not applicable		1,266 (43%)	1,472 (43%)	
Other[a]	286 (7%)	146 (7%)		147 (5%)	202 (6%)	

[a]Medical ICU "Other" includes another ICU or procedure suite. Surgical ICU "Other" includes another ICU and procedure suite.

or natural view room for the entire ICU stay. An IV analysis with a valid IV controls for both measured and unmeasured confounders. A valid IV is a variable that 1) is associated with the exposure, 2) is independent of unmeasured confounding, and 3) only affects the outcome through its effect on the exposure (26). Our chosen IV was the type of room to which the patient was initially assigned, that is, 0 if the patient was initially assigned to a nonwindowed or industrial view room and 1 if assigned to a windowed or natural room view. This variable may be a plausible valid IV because 1) it is strongly associated with the exposure since few patients switched room types, 2) it is plausibly independent of unmeasured confounding because initial bed assignment was based on bed availability and essentially random, and 3) it plausibly only affects outcome through its effect on the exposure (26).

We used Stata 11 software (Stata Corp., College Station, TX) for all analyses. We performed our analyses both with and without adjustment for multiple comparisons using the Bonferroni method. Without adjustment, statistical significance was declared for a p value less than 0.05. With adjustment, significance was declared for a p value less than 0.0056, which is the Bonferroni correction when nine outcomes are being studied. The rationale for presenting the data both ways is that the Bonferroni method is overly conservative, so by providing both, we can be certain that the "true" significance levels of each test fall between the values provided by the unadjusted and Bonferroni-adjusted estimates (27). The University of Pennsylvania Institutional Review Board approved this study.

RESULTS

A flowchart summarizing the study cohorts used in each analysis is presented in **Supplemental Table 2** (Supplemental Digital Content 1, http://links.lww.com/CCM/A624). The 4,093 patients admitted to windowed MICU rooms were similar to the 2,243 patients admitted to nonwindowed rooms on all covariates measured in the entire sample (**Table 1**). The 3,072 patients admitted to natural view SICU rooms were similar to the 3,588 patients admitted to industrial view rooms (Table 1). Very few patients switched from their original room assignment during the study period: only 28 MICU patients (0.4%) changed from a windowed to nonwindowed room and 198 SICU patients (3.1%) changed views or vice versa.

Among the 4,325 patients admitted to the SICU from May 2007 to July 2010, complete covariate data were available for 4,118 (95%). APACHE-IV scores were similar among the 2,226 patients admitted to rooms with natural views and 1,892 patients admitted to rooms with industrial views (mean = 57.5 vs. 57.4; $p = 0.89$).

Effects of Windows Among MICU Patients

In primary multivariable models using the intention-to-treat population, patients admitted to windowed vs. nonwindowed MICU rooms had similar rates of ICU mortality, in-hospital mortality, ICU readmissions, and delirium (**Table 2**). Additionally, there were no differences noted in ICU or hospital LOS or in fixed, variable, or total costs (Table 2). In the secondary, per-protocol sample, similar results were obtained except that

TABLE 2. Effects of Windows in the Medical ICU and Natural Views in the Surgical ICU

Variables	Window	No Window	Unadjusted Intention-to-Treat[1,2,3]
Medical ICU			
n	4,093	2,243	6,336
In-hospital mortality[1]	853 (21%)	467 (21%)	1.00 (0.88, 1.14) $p = 0.98$
ICU mortality[1]	576 (14%)	339 (15%)	0.92 (0.79, 1.06) $p = 0.26$
Readmission within 72 hr[1]	154 (4%)	73 (3%)	1.16 (0.88, 1.54) $p = 0.30$
ICU-acquired delirium	156 (4%)	78 (3%)	1.11 (0.84, 1.45) $p = 0.50$
Hospital length of stay (hr)[2]	347.6	326.4	21.12 (−2.55, 44.79) $p = 0.08$
ICU length of stay (hr)[2]	105.8	95.2	10.62 (−0.96, 22.2) $p = 0.07$
Median fixed costs (interquartile range)[3a]	7,282 (3,755–15,499)	6,909 (3,560–14,554)	373.58 (−108.18, 855.34) $p = 0.13$
Median variable costs (interquartile range)[3b]	3,008 (1,325–7,630)	2,784 (1,249–7,344)	223.88 (−28.08, 475.84) $p = 0.08$
Median total costs (interquartile range)[3c]	10,482 (5,243–23,414)	9,946 (5,044–22,268)	536.17 (−182.65, 1254.99) $p = 0.14$
Surgical ICU			
	Natural View	**Industrial View**	
n	3,072	3,588	6,660
In-hospital mortality[1]	203 (7%)	273 (8%)	0.86 (0.71, 1.04) $p = 0.11$
ICU mortality[1]	133 (4%)	169 (5%)	0.91 (0.73, 1.15) $p = 0.46$
Readmission within 72 hr[1]	109 (4%)	113 (3%)	1.13 (0.87, 1.48) $p = 0.37$
ICU-acquired delirium	101 (3%)	100 (3%)	1.19 (0.90, 1.57) $p = 0.23$
Hospital length of stay (hr)[2]	348.6	373.8	−25.14 (−52.98, 2.7) $p = 0.08$
ICU length of stay (hr)[2]	95.9	98.3	−2.36 (−11.53, 6.82) $p = 0.61$
Median fixed costs (interquartile range)[3a]	8,055 (5,066–14,742)	8,343 (5,281–15,558)	−285.85 (−658.54, 86.84) $p = 0.13$
Median variable costs (interquartile range)[3b]	5,315 (2,454–9,545)	5,598 (2,646–10,061)	−285.45 (−568.02, −2.88) $p = 0.05$
Median total costs (interquartile range)[3c]	13,842 (8,104–24,585)	14,307 (8,365–26,274)	−470.26 (−1088.59, 148.07) $p = 0.14$

The results of separate regression models for nine outcomes, with each model estimated separately using the intent-to-treat and per-protocol samples in either the medical ICU or the surgical ICU. As outlined in the text (see Methods), a two-stage least squares instrumental variable (IV) regression on the intent-to-treat population was also conducted, in which patients who changed exposure (and thus were removed in the per-protocol analysis) were considered exposed for 50% of their ICU stay. The coefficients for the IV analysis are estimated using a linear probability model and are therefore presented as linear coefficients rather than odds ratios. Without adjustment for multiple comparisons, the threshold for statistical significance was $p < 0.05$. With adjustment, the threshold was $p < 0.0056$, which is the Bonferroni correction when nine outcomes are being studied. The Bonferroni method is overly conservative, whereas the unadjusted threshold is overly liberal. Thus, the "true" statistical significance of each test falls between the values provided by the unadjusted and Bonferroni-adjusted estimates (27). Adjusted models control for the following patient characteristics (age, sex, race, and location prior to ICU) that modified the view variable estimate by 15% or more or had an unadjusted $p < 0.2$ in univariate analyses.

[a]Total fixed costs accrued from admission to the ICU through hospital discharge, including room and board, radiology, labs, pharmacy, blood products, respiratory therapy, pathology, anesthesiology, and dialysis.

[b]Variable costs attributed to the ICU stay from radiology, labs, pharmacy, blood products, respiratory therapy, pathology, anesthesiology, and dialysis.

[c]Variable + fixed cost.

Sample		Instrumental Variable Analysis[4]	
Adjusted Intention-to-Treat[1,2,3]	Adjusted Per-Protocol[1,2,3]	Unadjusted Instrumental Variable[4] Intention-to-Treat	Adjusted 2 Instrumental Variable[4] Intention-to-Treat
6,288	6,090	6,336	6,288
1.00 (0.88, 1.14) $p = 0.94$	1.01 (0.89, 1.16) $p = 0.84$	0.00 (−0.02, 0.02) $p = 0.98$	0.00 (−0.02, 0.02) $p = 0.93$
0.91 (0.79, 1.06) $p = 0.25$	0.93 (0.80, 1.08) $p = 0.38$	−0.01 (−0.03, 0.01) $p = 0.26$	0.00 (−0.03, 0.01) $p = 0.24$
1.14 (0.85, 1.51) $p = 0.37$	1.14 (0.85, 1.52) $p = 0.39$	0.01 (0.00, 0.02) $p = 0.30$	0.00 (−0.01, 0.01) $p = 0.38$
1.08 (0.83, 1.43) $p = 0.56$	1.09 (0.83, 1.46) $p = 0.53$	0.00 (−0.01, 0.01) $p = 0.50$	0.00 (−0.01, 0.01) $p = 0.56$
20.52 (−2.95, 43.99) $p = 0.09$	45.71 (22.64, 68.79) $p < 0.01$	21.98 (−2.63, 46.6) $p = 0.08$	21.36 (−3.04, 45.77) $p = 0.09$
10.69 (−0.86, 22.25) $p = 0.07$	30.85 (20.29, 41.41) $p < 0.01$	11.05 (−0.98, 23.09) $p = 0.07$	11.13 (−0.88, 23.15) $p = 0.07$
217.03 (−279.21, 713.27) $p = 0.39$	547.33 (66.88, 1027.78) $p = 0.03$	1122.26 (−113.31, 2357.83) $p = 0.08$	1087.35 (−140.06, 2314.77) $p = 0.08$
102.52 (−162.19, 367.23) $p = 0.45$	264.62 (11.85, 517.39) $p = 0.04$	622.12 (−388.70, 1632.93) $p = 0.23$	657.71 (−344.36, 1659.79) $p = 0.20$
275.77 (−524.46, 1,076) $p = 0.50$	803.19 (43.32, 1563.06) $p = 0.04$	1744.38 (−412.23, 3900.99) $p = 0.11$	1745.07 (−394.83, 3884.96) $p = 0.11$
6,310	6,282	6,660	6,310
0.84 (0.69, 1.02) $p = 0.08$	0.84 (0.69, 1.02) $p = 0.08$	−0.01 (−0.02, 0) $p = 0.11$	−0.01 (−0.02, 0) $p = 0.08$
0.90 (0.70, 1.14) $p = 0.36$	0.90 (0.70, 1.14) $p = 0.36$	0.00 (−0.01, 0.01) $p = 0.46$	0.00 (−0.02, 0.01) $p = 0.36$
1.05 (0.79, 1.38) $p = 0.75$	1.05 (0.79, 1.38) $p = 0.74$	0.00 (0.00, 0.01) $p = 0.37$	0.00 (−0.01, 0.01) $p = 0.74$
1.15 (0.86, 1.54) $p = 0.34$	1.13 (0.84, 1.52) $p = 0.43$	0.01 (0.00, 0.01) $p = 0.23$	0.00 (0, 0.01) $p = 0.33$
−28.98 (−58.06, 0.10) $p = 0.05$	−30.66 (−59.67, −1.66) $p = 0.04$	−25.26 (−53.22, 2.70) $p = 0.08$	−29.11 (−58.31, 0.09) $p = 0.05$
−3.35 (−12.87, 6.17) $p = 0.49$	−4.33 (−13.27, 4.62) $p = 0.34$	−2.37 (−11.58, 6.85) $p = 0.61$	−3.36 (−12.92, 6.20) $p = 0.49$
−203.32 (−627.56, 220.93) $p = 0.35$	−204.89 (−626.21, 216.43) $p = 0.34$	−293.42 (−1265.20, 678.37) $p = 0.55$	−467.23 (−1472.69, 538.23) $p = 0.36$
−324.44 (−633.18, −15.70) $p = 0.04$	−330.58 (−639.78, −21.39) $p = 0.04$	−326.10 (−984.02, 331.82) $p = 0.33$	−563.8 (−1234.71, 107.11) $p = 0.10$
−603.09 (−1337.56, 131.37) $p = 0.11$	−607.03 (−1337.55, 123.49) $p = 0.10$	−619.52 (−2181.46, 942.43) $p = 0.44$	−1031.03 (−2644.49, 582.44) $p = 0.21$

Regression specifications were chosen based on the distribution of the outcome:

[1]Logistic regression (results expressed as odds ratios) for binary outcomes (0= no, 1 = yes), for death in a hospital or the ICU, readmission to the ICU within 72 hr [bouceback], and documented delirium.

[2]Linear regression model for the continuous measure of hospital and ICU length of stay.

[3]Median [quantile] regression based on the skewed right distributions of the three cost outcomes, although similar results were found using linear models that contrasts the mean cost (22).

[4]Two stage least squares instrumental variable regression analysis using the proportion of time in ICU that patient was exposed to a window or natural view as an instrumental variable.

TABLE 3. Restricted Analyses of the Effects of Windows in the Medical ICU and Natural Views in the Surgical ICU

Variables	Adjusted Intention-to-Treat	Adjusted Per-Protocol
Patients admitted on days with at least 12 hr of sunlight, medical ICU		
n	3,346	3,247
In-hospital mortality[1]	1.00 (0.84, 1.20) $p = 0.99$	1.03 (0.85, 1.23) $p = 0.78$
ICU mortality[1]	0.92 (0.75, 1.13) $p = 0.42$	0.95 (0.77, 1.17) $p = 0.62$
Readmission within 72 hr[1]	1.04 (0.70, 1.52) $p = 0.84$	1.08 (0.72, 1.62) $p = 0.71$
ICU-acquired delirium	1.19 (0.79, 1.75) $p = 0.41$	1.19 (0.79, 1.79) $p = 0.40$
Hospital length of stay (hr)[2]	22.08 (−11.28, 55.44) $p = 0.19$	47.27 (14.37, 80.17) $p < 0.01$
ICU length of stay (hr)[2]	17.87 (0.78, 34.97) $p = 0.04$	31.58 (14.42, 48.74) $p < 0.01$
Median fixed costs (interquartile range)[3a]	464.48 (−156.61, 1085.58) $p = 0.14$	635.40 (27.29, 1243.51) $p = 0.04$
Median variable costs (interquartile range)[3b]	222.89 (−148.14, 593.93) $p = 0.24$	343.07 (−2.49, 688.63) $p = 0.05$
Median total costs (interquartile range)[3c]	881.04 (−149.55, 1911.62) $p = 0.09$	1040.59 (85.51, 1995.67) $p = 0.03$
Patients admitted on days with at least 12 hr of sunlight, surgical ICU		
n	3,418	3,407
In-hospital mortality[1]	0.92 (0.71, 1.21) $p = 0.57$	0.93 (0.71, 1.22) $p = 0.62$
ICU mortality[1]	1.03 (0.74, 1.43) $p = 0.85$	1.05 (0.75, 1.46) $p = 0.79$
Readmission within 72 hr[1]	1.16 (0.81, 1.67) $p = 0.42$	1.16 (0.81, 1.67) $p = 0.42$
ICU-acquired delirium	1.40 (0.94, 2.10) $p = 0.09$	1.36 (0.90, 2.03) $p = 0.14$
Hospital length of stay (hr)[2]	−27.01 (−55.73, 1.71) $p = 0.07$	−29.33 (−57.95, −0.72) $p = 0.04$
ICU length of stay (hr)[2]	−5.67 (−17.19, 5.86) $p = 0.34$	−6.24 (−17.72, 5.23) $p = 0.29$
Median fixed costs (interquartile range)[3a]	−268.05 (−801.15, 265.06) $p = 0.32$	−263.74 (−788.44, 260.96) $p = 0.32$
Median variable costs (interquartile range)[3b]	−264.3 (−680.54, 151.94) $p = 0.21$	−273.47 (−689.81, 142.87) $p = 0.20$
Median total costs (interquartile range)[3c]	−489.22 (−1422.25, 443.81) $p = 0.30$	−489.42 (−1406.25, 427.42) $p = 0.30$
Patients with an ICU length of stay greater than 72 hr, medical ICU		
n	2,106	1,948
In-hospital mortality[1]	0.81 (0.66, 0.99) $p = 0.04$	0.79 (0.63, 0.97) $p = 0.02$
ICU mortality[1]	0.77 (0.62, 0.95) $p = 0.02$	0.73 (0.58, 0.91) $p = 0.01$
Readmission within 72 hr[1]	1.08 (0.68, 1.72) $p = 0.74$	1.06 (0.64, 1.75) $p = 0.82$
ICU-acquired delirium	1.09 (0.74, 1.63) $p = 0.64$	1.03 (0.68, 1.55) $p = 0.90$
Hospital length of stay (hr)[2]	40.32 (−16.19, 96.84) $p = 0.16$	95.55 (37.1, 153.99) $p < 0.01$
ICU length of stay (hr)[2]	19.94 (−11.70, 51.59) $p = 0.22$	70.15 (39.39, 100.91) $p < 0.01$
Median fixed costs (interquartile range)[3a]	1208.38 (−346.52, 2763.27) $p = 0.13$	2511.49 (1033.30, 3989.68) $p < 0.01$
Median variable costs (interquartile range)[3b]	89.83 (−768.8, 948.46) $p = 0.84$	806.90 (−90.05, 1703.85) $p = 0.08$
Patients with an ICU length of stay greater than 72 hr, surgical ICU		
n	1,706	1,679
In-hospital mortality[1]	0.78 (0.59, 1.04) $p = 0.09$	0.79 (0.59, 1.04) $p = 0.09$
ICU mortality[1]	0.79 (0.56, 1.11) $p = 0.16$	0.79 (0.56, 1.11) $p = 0.16$

Unadjusted Instrumental Variable[4] Intention-to-Treat	Adjusted Instrumental Variable[4] Intention-to-Treat
3,366	3,346
0.00 (−0.03, 0.03) $p = 0.84$	0.00 (−0.03, 0.03) $p = 0.98$
−0.01 (−0.03, 0.02) $p = 0.54$	−0.01 (−0.04, 0.01) $p = 0.42$
0.00 (−0.01, 0.02) $p = 0.74$	0.00 (−0.01, 0.01) $p = 0.86$
0.04 (−0.10, 0.17) $p = 0.57$	0.02 (−0.12, 0.16) $p = 0.78$
27.06 (−7.93, 62.04) $p = 0.13$	22.90 (−11.66, 57.46) $p = 0.19$
19.66 (1.93, 37.39) $p = 0.03$	18.54 (0.83, 36.25) $p = 0.04$
1818.14 (13.20, 3623.08) $p = 0.05$	1603.88 (−186.59, 3394.35) $p = 0.08$
1534.66 (−72.82, 3142.14) $p = 0.06$	1379.03 (−217.27, 2975.34) $p = 0.09$
3352.8 (41.51, 6664.08) $p = 0.05$	2982.91 (−302.52, 6268.34) $p = 0.08$
3,591	3,418
0.00 (−0.02, 0.01) $p = 0.74$	0.00 (−0.02, 0.01) $p = 0.58$
0.00 (−0.01, 0.02) $p = 0.61$	0.00 (−0.01, 0.02) $p = 0.84$
0.01 (0.00, 0.02) $p = 0.16$	0.01 (−0.01, 0.02) $p = 0.41$
0.01 (0.00, 0.02) $p = 0.08$	0.01 (0.00, 0.02) $p = 0.09$
−23.39 (−51.35, 4.56) $p = 0.10$	−27.1 (−55.89, 1.69) $p = 0.07$
−3.8 (−15.15, 7.56) $p = 0.51$	−5.69 (−17.24, 5.87) $p = 0.33$
−622.22 (−1844.21, 599.77) $p = 0.32$	−828.57 (−2078.01, 420.88) $p = 0.19$
−486.48 (−1320.25, 347.30) $p = 0.25$	−609.96 (−1461.84, 241.91) $p = 0.16$
−1108.69 (−3085.46, 868.07) $p = 0.27$	−1438.53 (−3468.83, 591.78) $p = 0.16$
2,118	2,106
−0.05 (−0.09, 0.00) $p = 0.05$	−0.05 (−0.09, 0.00) $p = 0.04$
−0.05 (−0.09, −0.01) $p = 0.02$	−0.05 (−0.09, −0.01) $p = 0.02$
0.00 (−0.02, 0.02) $p = 0.78$	0.00 (−0.02, 0.02) $p = 0.75$
−0.07 (−0.22, 0.07) $p = 0.33$	−0.08 (−0.22, 0.06) $p = 0.26$
41.57 (−20.99, 104.13) $p = 0.19$	44.78 (−17.84, 107.41) $p = 0.16$
20.91 (−14.10, 55.93) $p = 0.24$	22.15 (−12.91, 57.21) $p = 0.22$
2353.02 (−932.82, 5638.87) $p = 0.16$	2541.03 (−744.93, 5826.99) $p = 0.13$
1175.66 (−1581.81, 3933.13) $p = 0.40$	1396.61 (−1342.23, 4135.45) $p = 0.32$
1,769	1,706
−0.02 (−0.06, 0.01) $p = 0.18$	−0.03 (−0.06, 0.00) $p = 0.08$
−0.02 (−0.04, 0.01) $p = 0.28$	−0.02 (−0.05, 0.01) $p = 0.15$

(Continued)

TABLE 3. (*Continued*). Restricted Analyses of the Effects of Windows in the Medical ICU a Views in the Surgical ICU

Variables	Adjusted Intention-to-Treat	Adjusted Per-Protocol
Readmission within 72 hr[1]	1.62 (1.02, 2.53) $p = 0.04$	1.65 (1.03, 2.61) $p = 0.04$
ICU-acquired delirium	1.42 (1, 1.99) $p = 0.05$	1.39 (0.98, 1.97) $p = 0.07$
Hospital length of stay (hr)[2]	−32.44 (−89.96, 25.07) $p = 0.27$	−37.36 (−94.67, 19.95) $p = 0.20$
ICU length of stay (hr)[2]	−1.21 (−30.33, 27.90) $p = 0.93$	−4.07 (−31.35, 23.21) $p = 0.77$
Median fixed costs (interquartile range)[3a]	121.74 (−1801.26, 2044.74) $p = 0.90$	409.13 (−1535.78, 2354.04) $p = 0.68$
Median variable costs (interquartile range)[3b]	−394.52 (−1463.32, 674.28) $p = 0.47$	−387.67 (−1455.26, 679.92) $p = 0.48$
Median total costs (interquartile range)[3c]	−248.56 (−3021.67, 2524.54) $p = 0.86$	−512.88 (−3266.05, 2240.29) $p = 0.72$

See the footnote for Table 2 for statistical elaboration on the models.

[a]Total fixed costs accrued from admission to the ICU through hospital discharge, including room and board, radiology, labs, pharmacy, blood products, respiratory therapy, pathology, anesthesiology, and dialysis.

[b]Variable costs attributed to the ICU stay from radiology, labs, pharmacy, blood products, respiratory therapy, pathology, anesthesiology, and dialysis.

[c]Variable + fixed cost.

Regression specifications were chosen based on the distribution of the outcome:

[1]Logistic regression (results expressed as odds ratios) for binary outcomes (0= no, 1 = yes), for death in a hospital or the ICU, readmission to the ICU within 72 hr [bouceback], and documented delirium.

[2]Linear regression model for the continuous measure of hospital and ICU length of stay.

[3]Median [quantile] regression based on the skewed right distributions of the three cost outcomes, although similar results were found using linear models that contrasts the mean cost (22).

[4]Two stage least squares instrumental variable regression analysis using the proportion of time in ICU that patient was exposed to a window or natural view as an instrumental variable.

patients admitted to windowed rooms had longer MICU and hospital LOS and had greater fixed, variable, and total costs (all $p < 0.001$; Table 2). No beneficial effects of windows on any clinical or economic outcomes were observed in analyses restricted to patients admitted during days with at least 12 hours of sunlight (**Table 3**). Among the subgroup of MICU patients with ICU LOS greater than 72 hours, rooms with windows were associated with reduced ICU ($p = 0.02$) and in-hospital mortality ($p = 0.04$) in intention-to-treat analyses. Similar differences were observed using intention-to-treat and IV analyses (Table 3). However, none of these differences met the threshold for statistical significance when accounting for multiple comparisons. No other outcomes differed by window exposure among this cohort of patients with long ICU stays (Table 3).

Effects of Views Among SICU Patients

SICU patients admitted to rooms with natural vs. industrial views had similar rates of ICU mortality, in-hospital mortality, ICU readmissions, and delirium (Tables 2 and 3) in intention-to-treat analyses. Views were not associated with differences in ICU or hospital LOS or in any cost measure. Per-protocol and restricted analyses similarly revealed no benefits of natural views (Tables 2 and 3). In the secondary analysis using 66% of the original sample ($n = 4,118$) and adjusting for APACHE-IV scores, nearly identical results were found (**Table 4**).

IV Analysis

We exploited the initial random assignment of patients to windowed rooms in the MICU and rooms with natural views in the SICU and the small percent of the sample that switched their exposure (28 in the MICU [0.4%] and 198 in the SICU [3.1%]) to estimate an IV analysis. Neither the unadjusted nor the adjusted IV analyses showed any difference between exposures in the MICU or SICU (Tables 2 and 3)

Supplementary Analyses

Neither the presence of a natural/skyline versus an industrial view among all windowed MICU and SICU rooms nor the size of the windows (half-width vs. full-width) in MICU and SICU rooms had significant effects on mortality or delirium (**Supplemental Figs. 3** and **4**, Supplemental Digital Content 1, http://links.lww.com/CCM/A624).

DISCUSSION

This study found no evidence that the presence of windows or natural views is associated with improved outcomes or reduced costs among diverse samples of critically ill patients in the short term. Because the studied MICU was constructed prior to federal mandates requiring windows in ICU rooms and patients were assigned to rooms based purely on bed availability, this study design provides the best approximation of a randomized trial of windows that is possible under current regulations. The virtually identical characteristics of patients assigned to MICU rooms with and without windows and to SICU rooms with and without natural views (Table 1), and the consistent results observed across multiple analytic approaches including an IV analysis, support the conclusion that patient selection did not influence bed assignments in these units.

Unadjusted Instrumental Variable[4] Intention-to-Treat	Adjusted Instrumental Variable[4] Intention-to-Treat
0.03 (0.01, 0.05) $p = 0.01$	0.02 (0.00, 0.04) $p = 0.04$
0.03 (0.00, 0.06) $p = 0.03$	0.03 (0.00, 0.05) $p = 0.05$
−29.46 (−86.2, 27.28) $p = 0.31$	−32.98 (−91.33, 25.38) $p = 0.27$
0.97 (−27.93, 29.88) $p = 0.95$	−1.23 (−30.77, 28.31) $p = 0.93$
193.62 (−2600.56, 2987.80) $p = 0.89$	−141.52 (−3006.86, 2723.82) $p = 0.92$
−605.38 (−2529.97, 1319.22) $p = 0.54$	−917.92 (−2857.11, 1021.26) $p = 0.35$
−411.76 (-4940.66, 4117.14) $p = 0.86$	−1059.44 (−5678.92, 3560.03) $p = 0.65$

Further strengthening our conclusion that windows and natural views provide no clinical or economic benefits during one's ICU stay is the fact that results were consistent in intention-to-treat and per-protocol analyses and across prespecified subgroups among which we had hypothesized particularly large benefits. The one exception to this observation was a potential protective effect of windows among patients with prolonged ICU stays, in whom exposure to windows or nonwindows would be protracted. These results were not significant after adjustment for multiple comparisons, but merit future investigation. An additional strength of this study, in contrast to prior studies, is its substantial power to detect differences in a broad range of outcome variables among cohorts of general MICU and SICU patients.

Despite these strengths, the generalizability of our results may be limited as they derive from a single hospital and because the data provided little clinical characterization of the patient population. However, the large sample size and lack of patient exclusions over a 4-yr study period suggest that these data may apply to other academic ICUs in urban environments. Second, we could not evaluate either the development of delirium on the hospital floor after the ICU stay or the longer term patient outcomes. However, we would expect the effects of ICU windows, if any, to manifest early; the absence of early differences in outcomes among groups makes subsequent divergence in outcomes unlikely.

Third, the differences in our contrasts between windowed and nonwindowed rooms and between natural and industrial views cannot be quantified precisely. For example, we did not measure actual levels of ambient light in each room or the orientation of light with respect to each patient's eyes. Similarly, the subgroup analysis of patients admitted during days with at least 12 hrs of sunlight is defined using seasonal definitions, and thus, the exposure captures potential daylight duration rather than actual daylight. It is also challenging to capture the amount of time each patient had open eyes during the study, and we could not capture rates of sedation, blindness, or brain injury. Thus, our study provides an assessment of the overall effectiveness of the presence of windows and natural views, but other study designs are needed to determine the specific efficacy, for example, of different light lux transmitted into critically ill patients' eyes. Initial work along these lines has revealed no specific effects of ambient light quantity (11). This observation is also supported indirectly by our finding that full windows provided no benefits relative to half windows among rooms facing the same directions (Supplemental Figs. 1 and 3, Supplemental Digital Content 1, http://links.lww.com/CCM/A624).

Fourth, the detection of the presence of delirium in 52% of MICU patients and 3% of SICU patients likely underestimates the actual prevalences of delirium in these cohorts (28). Despite using validated methods (18, 19), MICU clinicians may not have fully recorded the associated clinical findings, making a retrospective chart review unreliable.

Finally, we could not evaluate patients', families', or providers' satisfaction with care. The presence of windows, and better views from those windows, could improve the experiences of each of these parties (17). These or other potential benefits of windows may be deemed sufficient to justify incremental costs of approximately $7,600 for adding a standard-sized window to an ICU room (SmithGroup, personal communication, January

TABLE 4. Effect of Views on Surgical ICU Patient Outcomes (Estimates Adjusted With Individual Acute Physiology and Chronic Health Evaluation-IV Scores)

	Sample			
Variables	Adjusted Per-Protocol	Adjusted Intention-to-Treat	Patients Admitted on Days With at Least 12 hr of Sunlight	Patients With an ICU Length of Stay Greater Than 72 Hr
n	4,135	4,135	2,254	1,128
In-hospital mortality[1]	0.95 (0.73, 1.23) $p = 0.72$	0.95 (0.73, 1.25) $p = 0.73$	0.98 (0.68, 1.42) $p = 0.93$	0.93 (0.64, 1.35) $p = 0.71$
ICU mortality[1]	0.95 (0.68, 1.32) $p = 0.76$	0.95 (0.68, 1.32) $p = 0.78$	1.04 (0.65, 1.68) $p = 0.86$	0.87 (0.57, 1.32) $p = 0.51$
Readmission within 72 hr[1]	1.07 (0.76, 1.52) $p = 0.68$	1.09 (0.77, 1.55) $p = 0.62$	1.16 (0.74, 1.84) $p = 0.51$	2.08 (1.16, 3.71) $p = 0.01$
ICU-acquired delirium	1.13 (0.77, 1.65) $p = 0.53$	1.20 (0.83, 1.73) $p = 0.35$	1.54 (0.94, 2.51) $p = 0.08$	1.30 (0.84, 2.01) $p = 0.25$
Hospital length of stay (hr)[2]	−6.59 (−29.14, 15.96) $p = 0.57$	−3.95 (−26.94, 19.04) $p = 0.74$	2.74 (−26.51, 31.98) $p = 0.85$	−26.23 (−84.98, 32.52) $p = 0.38$
ICU length of stay (hr)[2]	4.09 (−6.18, 14.36) $p = 0.44$	5.84 (−5.41, 17.08) $p = 0.31$	8.47 (−5.23, 22.17) $p = 0.23$	12.19 (−19.55, 43.93) $p = 0.45$
Median fixed costs (interquartile range)[3a]	5.40 (−518.49, 529.28) $p = 0.98$	24.03 (−504.3, 552.37) $p = 0.93$	122.70 (−618.27, 863.66) $p = 0.75$	239.30 (−2203.39, 2681.99) $p = 0.85$
Median variable costs (interquartile range)[3b]	−121.73 (−488.17, 244.71) $p = 0.52$	−60.46 (−428.24, 307.31) $p = 0.75$	128.15 (−384.25, 640.54) $p = 0.62$	−356.90 (−1798.65, 1084.86) $p = 0.63$
Median total costs (interquartile range)[3c]	72.67 (−788.42, 933.75) $p = 0.87$	107.32 (−778.54, 993.18) $p = 0.81$	429.02 (−779.36, 1637.40) $p = 0.49$	112.54 (−4091.80, 4316.88) $p = 0.96$

[a]Total fixed costs accrued from admission to the ICU through hospital discharge, including room and board, radiology, labs, pharmacy, blood products, respiratory therapy, pathology, anesthesiology, and dialysis.

[b]Variable costs attributed to the ICU stay from radiology, labs, pharmacy, blood products, respiratory therapy, pathology, anesthesiology, and dialysis.

[c]Variable + fixed cost.

Regression specifications were chosen based on the distribution of the outcome:

[1]Logistic regression (results expressed as odds ratios) for binary outcomes (0= no, 1 = yes), for death in a hospital or the ICU, readmission to the ICU within 72 hr [bouceback], and documented delirium.

[2]Linear regression model for the continuous measure of hospital and ICU length of stay.

[3]Median [quantile] regression based on the skewed right distributions of the three cost outcomes, although similar results were found using linear models that contrasts the mean cost (22).

[4]Two stage least squares instrumental variable regression analysis using the proportion of time in ICU that patient was exposed to a window or natural view as an instrumental variable.

2011, **Supplemental Table 3**, Supplemental Digital Content 1, http://links.lww.com/CCM/A624). However, our results suggest that decisions to add windows to rooms, or to transfer patients from nonwindowed rooms to windowed rooms, are unlikely to improve outcomes or reduce costs in the short term.

CONCLUSIONS

Despite a large sample size and broad array of outcome measures, we found no evidence that windows or natural views improve outcomes or reduce costs for MICU and SICU patients, within the limits of our study design. As with other negative trials of conceptually promising critical care interventions, it is possible that windows or natural views may provide benefits for some patients, families, or providers. For example, it is possible that windows may benefit certain subgroups of patients who lack cognitive impairment, maintain their eyes open for much of their ICU stay, have their beds oriented directly toward incoming light, and have extended ICU stays. There may also be benefits in limiting sedative use that we could not detect. However, our data suggest that even if these interventions afford benefits for such subgroups, these benefits are not of sufficient magnitude to meaningfully influence overall rates of adverse outcomes and overall high costs among critically ill patients as a whole.

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