Journal of Intensive Medicine 3 (2023) 155–164

Contents lists available at ScienceDirect

Journal of Intensive Medicine

journal homepage: www.elsevier.com/locate/jointm

Original Article

The impact of daylight and window views on length of stay among patients with heart disease: A retrospective study in a cardiac intensive care unit

Roxana Jafarifiroozabadi[1,*], Anjali Joseph[2,3,4,5], William Bridges[6], Andrea Franks[7]

[1] College of Architecture and Design, Lawrence Technological University, Southfield, MI 48075, USA
[2] Spartanburg Regional Healthcare System Endowed Chair in Architecture + Health Design, Clemson University, Clemson, SC 29634, USA
[3] Center for Health Facilities Design and Testing, Clemson University, Clemson, SC 29634, USA
[4] School of Architecture, Clemson University, Clemson, SC 29634, USA
[5] Industrial Engineering, Clemson University, Clemson, SC 29634, USA
[6] School of Mathematical and Statistical Sciences, Clemson University, Clemson, SC 29634, USA
[7] Clinical and Nursing Research, AnMed Health, Anderson, SC 29621, USA

ARTICLE INFO

Keywords:
Heart disease
Daylight
Window views
Length of stay
Cardiac intensive care unit

ABSTRACT

Background: Heart disease is the leading cause of death in the United States. The length of stay (LOS) is a well-established parameter used to evaluate health outcomes among critically ill patients with heart disease in cardiac intensive care units (CICUs). While evidence suggests that the presence of daylight and window views can positively influence patients' LOS, no studies to date have differentiated the impact of daylight from window views on heart disease patients. Also, existing research studies on the impact of daylight and window views have failed to account for key clinical and demographic variables that can impact the benefit of such interventions in CICUs.

Methods: This retrospective study investigated the impact of access to daylight *vs.* window views on CICU patients' LOS. The study CICU is located in a hospital in the southeast United States and has rooms of the same size with different types of access to daylight and window views, including rooms with daylight and window views (with the patient bed located parallel to full-height, south-facing windows), rooms with daylight and no window views (with the patient bed located perpendicular to the windows), and windowless rooms. Data from electronic health records (EHRs) for the time-period September 2015 to September 2019 (n=2936) were analyzed to investigate the impact of room type on patients' CICU LOS. Linear regression models were developed for the outcome of interest, controlling for potential confounding variables.

Results: Ultimately, 2319 patients were finally included in the study analysis. Findings indicated that patients receiving mechanical ventilation in rooms with access to daylight and window views had shorter LOS durations (16.8 h) than those in windowless rooms. Sensitivity analysis for a subset of patients with LOS ≤3 days revealed that parallel bed placement to the windows and providing access to both daylight and window views significantly reduced their LOS compared to windowless rooms in the unit (P=0.007). Also, parallel bed placement to the window significantly reduced LOS in this patient subset for those with an experience of delirium (P=0.019), dementia (P=0.008), anxiety history (P=0.009), obesity (P=0.003), and those receiving palliative care (P=0.006) or mechanical ventilation (P=0.033).

Conclusions: Findings from this study could help architects make design decisions and determine optimal CICU room layouts. Identifying the patients who benefit most from direct access to daylight and window views may also help CICU stakeholders with patient assignments and hospital training programs.

Introduction

The length of stay (LOS) in the hospital and intensive care unit (ICU) has been identified as a key factor impacting health outcomes among patients with heart disease.[1] Patients with an extended LOS (greater number of days in the hospital) are an important subpopulation for health care organizations as they are prone to greater readmission risks and tend to consume a disproportionate amount of available resources in the ICU.[1,2] Further, longer ICU stays are among the most critical risk fac-

* Corresponding author: Roxana Jafarifiroozabadi, Lawrence Technological University, Southfield, MI 48075, USA.
E-mail address: rjafarifi@ltu.edu (R. Jafarifiroozabadi).

https://doi.org/10.1016/j.jointm.2022.11.002
Received 21 June 2022; Received in revised form 1 November 2022; Accepted 11 November 2022. Managing Editor: Jingling Bao
Available online 28 December 2022

tors for adverse health outcomes, and even a single additional night spent at the hospital can increase the odds of hospital-acquired infections, adverse drug reactions, pressure ulcers, and delirium.[3,4]

To date, several studies have investigated the impact of medical or organizational interventions on improving the LOS of patients admitted to ICUs. However, little research has been conducted on the environmental factors in the cardiac intensive care unit (CICU) and their role in improving heart disease patients' LOS and recovery after admission. Existing studies suggest that exposure to daylight and window views can positively impact patients' recovery and health outcomes during inpatient hospital stays in general.[5–10] The theory of supportive design and the biophilia hypothesis have also emphasized that having views of the natural surroundings, including trees, plants, and water, through windows can support improved physiological and psychological health outcomes among patients.[11,12] From a biological standpoint, the impacts of daylight exposure on patients' health, circadian rhythm, and psychological symptoms have been explained through physiological mechanisms caused by incident daylight exposure of the retina and serotonin secretion in the body.[13,14]

Despite the existing evidence of the positive impacts of daylight and view exposure on patient recovery, there is a paucity of research concerning the relationship between these factors and patient LOS in the CICU environment. A few studies have examined the impact of daylight and window views on health outcomes in the ICU and patient hospital room environment to date. Though some of these studies report a significant relationship between exposure to daylight or window views and decreased LOS,[7,15] others suggest there is no significant relationship among these variables,[8,9,16–18] and so the findings largely remain inconclusive. Also, there are inconsistencies in the type of control variables considered in the existing studies. Although health outcomes among ICU patients are highly affected by patients' clinical characteristics and medical treatments,[7,8,16,19] only a few of these studies have adequately accounted for the clinical and demographic risk factors associated with different patient populations. More importantly, these studies failed to differentiate the impact of exposure to daylight from the impact of window views, and it is not clear which factor is more influential in improving patients' CICU LOS. Existing studies have either focused on the impact of daylight exposure without controlling for the confounding effect of view exposure through windows on patients' LOS, [7,15,16] examined the impact of access to window views on LOS [9,11] without controlling for the confounding effect of daylight exposure, or investigated the impact of both factors simultaneously on ICU patients.[8,20]

Addressing the gaps related to differentiating the impacts of daylight *vs.* window view exposure is particularly important for health care designers in urban settings seeking to make informed design decisions regarding optimal window implementation in CICU rooms and for hospital stakeholders aiming to expand ICU beds while facing space constraints that preclude access to daylight or window views in patient rooms.[9] Also, federal architectural guidelines and recommendations made by the Society of Critical Care Medicine lack specifications regarding meaningful stimuli provided by windows in ICU rooms.[21,22] To address the gaps mentioned above, this study aims to investigate CICU LOS among patients in three room types in a CICU with different daylighting and viewing accommodations to understand which environmental factors (daylight *vs.* window views) would best support patients' health and recovery while controlling for patients' clinical characteristics and medical treatments based on their electronic health records (EHRs).

Methods

Study population

This retrospective study was conducted in a CICU of a medical center in South Carolina. All patients aged ≥18 years directly admitted to the hospital's CICU between September 2015 and September 2019 (n=2936) with admitting diagnoses of myocardial infarction (International Classification of Diseases, 10th Revision [ICD-10] codes: I21 or I22), cardiac arrhythmia (ICD-10 code: I49), hypertension (ICD-10 codes: I10–I16), chronic ischemic heart disease (ICD-10 code: I25), or heart failure (ICD-10 codes: I50, I50.23, or I50.33) were eligible for inclusion in this study. Direct admission to the CICU was defined as having a room and a bed in the CICU during the first hospital day. Utilization of the aforementioned ICD-10 codes ensured that patients with acute and chronic heart failure, as well as those with a status of pre– or post–percutaneous coronary intervention, were included. Patients were excluded from this study for the following reasons: (1) admittance to the CICU from a unit other than the emergency department, (2) switched rooms in the unit or were readmitted to the CICU during a single hospital stay, (3) experienced visual loss during their CICU stay, and (4) underwent a surgical procedure using an open approach (e.g., coronary artery bypass grafting) or underwent another procedure in the operating room requiring general anesthesia (all the rooms accommodating these patients in the CICU were windowless).

Clinical definitions and data sources

Data regarding patients' CICU LOS were recorded as part of the hospital protocol and were obtained from patients' EHRs (Epic Systems, Verona, WI, USA). Institutional review board (IRB) approval was obtained (IRB approval No. Pro00083942) prior to securing data from EHRs. In addition, data regarding patient characteristics were exported from EHRs to control for the confounding impact of these factors on the relationship between independent and dependent variables. These variables – which included patients' severity of illness (SOI) and risk of mortality (ROM), with scores in the range of 1–4 points to indicate minor, moderate, major, or extreme levels – were also obtained directly from EHRs.[23] Other confounding variables coded by the investigators based on EHR notes included patients' demographic information (e.g., age, sex, race, marital status, and insurance), admission source (health care facility, non–health care facility, or clinic office), admission status (elective, emergency, or urgent), and diagnosis-related group type (medical *vs.* percutaneous surgical interventions) as well as patients' clinical characteristics, such as primary diagnosis type, hospital-acquired infections, respiratory failure, cirrhosis, cardiogenic shock, receiving palliative care, receiving mechanical ventilation, analgesic medication (opioids or benzodiazepine), and medical history (e.g., alcohol or nicotine use, anxiety or depression symptoms, diabetes, obesity, and dementia). Opioids, sedatives, and narcotics were administered to patients in accordance with the sedation protocols in the CICU. The overall morphine equivalent opioid

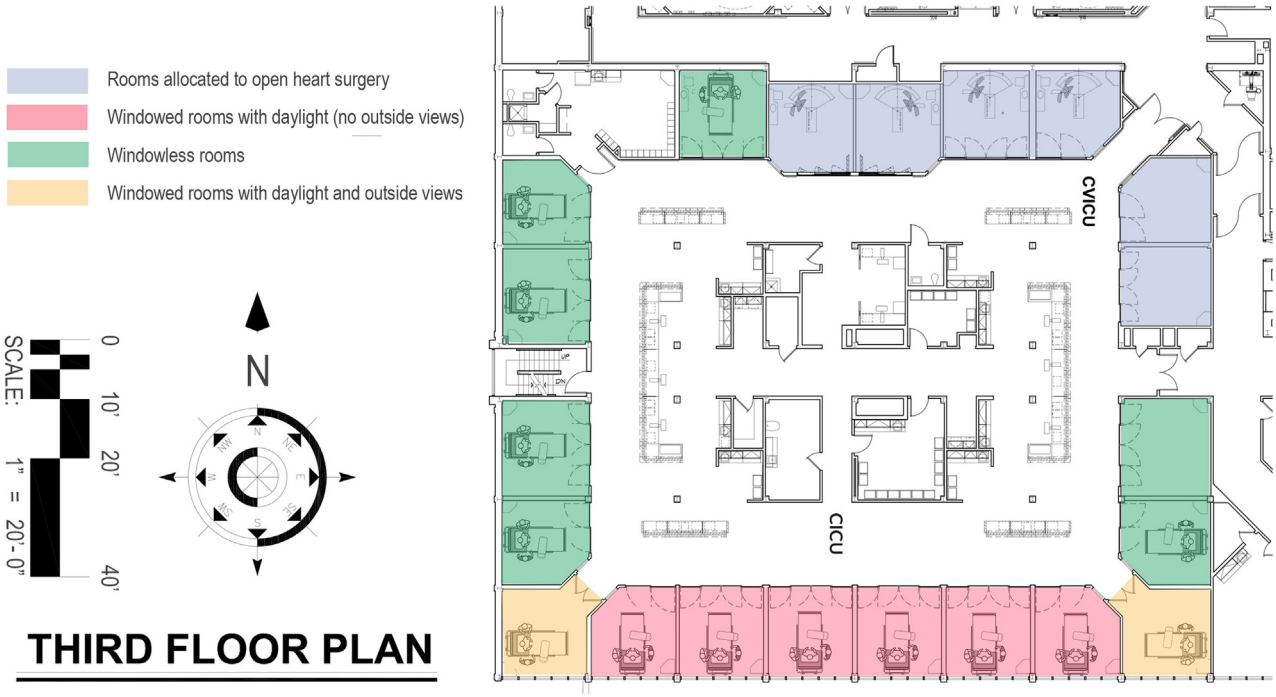


Figure 1. The locations of the three types of CICU rooms with different access to daylight and window views for non-surgical patients are indicated with different colors. The gray rooms are allocated to surgical patients. CICU: Cardiac intensive care unit; CVICU: Cardiovascular intensive care unit.

Figure 2. The three types of CICU rooms with different access to daylight and window views due to changes in bed orientation.

analgesics (milligrams) and the lorazepam equivalent of benzodiazepine medication (milligrams) administered to patients were also calculated based on the guidelines by McCaffery and Pasero.[24]

Setting

The study CICU is located on the third floor of a medical center in the southeast United States and has 15 single rooms for non-surgical patients of approximately the same size (210 ft^2) but with different levels of access to daylight and views due to variations in the patient bed orientation toward the windows (Figure 1). The single room types included (1) room type A, where the patient bed is parallel to the window, providing access to daylight and window views; (2) room type B, where the head of the patient bed is against the window, providing access to daylight but no access to window views; and (3) room type C, which is a windowless room. All windowed rooms have south-facing, full-height windows and provide access to daylight (Figure 2). Views of the city skyline are only available for pa-

tients with their beds placed parallel to the windows (room type A).

The study examined the following hypotheses: (1) heart disease patients experience a shorter LOS in CICU rooms with access to daylight and views compared to those in windowless rooms, (2) heart disease patients experience a shorter LOS in CICU rooms with access to daylight and window views compared to those in rooms providing access to daylight only (no window views), and (3) heart disease patients experience a shorter LOS in CICU rooms with access to daylight only compared to those in windowless rooms. Also, a range of clinical and demographic factors affecting the relationship between room type and patients' CICU LOS was explored, and a linear model is presented for estimating patients' CICU LOS. IRB approval for this study was obtained prior to data preparation and analysis.

Only patients with direct admission to the CICU (which was defined as having a room and a bed in the CICU during the first hospital day) were considered for analysis according to the research protocol. Therefore, all patients admitted to the CICU from units other than the emergency department (n=48) as well as those who had switched rooms in the unit or were readmitted to the CICU during a single hospital stay (n=66) were excluded from this study. Also, patients who experienced visual loss during their CICU stay (n=4) were excluded from this study. Finally, any patient who underwent a surgical procedure using an open approach (e.g., coronary artery bypass grafting) or another procedure in the operating room that required general anesthesia was also excluded from the study (n=288); these patients were excluded because of the potential confounding impact of post-surgical complications on the outcomes of interest and because all the rooms accommodating these patients were windowless (Figure 3).

Analytical approach

A descriptive data analysis was performed to examine the distribution of patient data across the CICU rooms. Tests of normality for CICU LOS data and subsets of data were conducted using the Shapiro–Wilk test. P <0.05 implied that the distribution of the LOS data was not significantly different from a normal distribution. A series of single-factor analyses was used to determine any continuous or categorical factors that were related to room type for the CICU LOS data. The factors that were related could be potential confounding factors when examining the relationship between LOS and room type. P <0.05 was considered evidence of a statistically significant relationship between the factor and room type.

A generalized linear model (GLM) in RStudio (version 4.2.0; RStudio PBC, Boston, MA, USA) was created to examine the relationship between the CICU LOS and room type while considering any potential confounding factors. The interaction between each confounding variable and room type was included in the model to allow the different levels of the confounding factors to result in different relationships between LOS and room type. A stepwise variable selection approach (using a forward technique) was used to reduce the GLM to a set of terms that were useful for predicting CICU LOS. To examine model reliability, multicollinearity among the factors in the reduced model was assessed using the variance inflation factor. Influential data points were also identified through Cook's [25] distance and removed from the data set. Least squares mean and confidence interval values for LOS were estimated for the three room types. The least squares means approach provides estimates of the marginal means of LOS over a balanced population of confounded factors when the data are unbalanced.[26] Pairwise comparisons (with no error-rate adjustments) were also used to delineate differ-

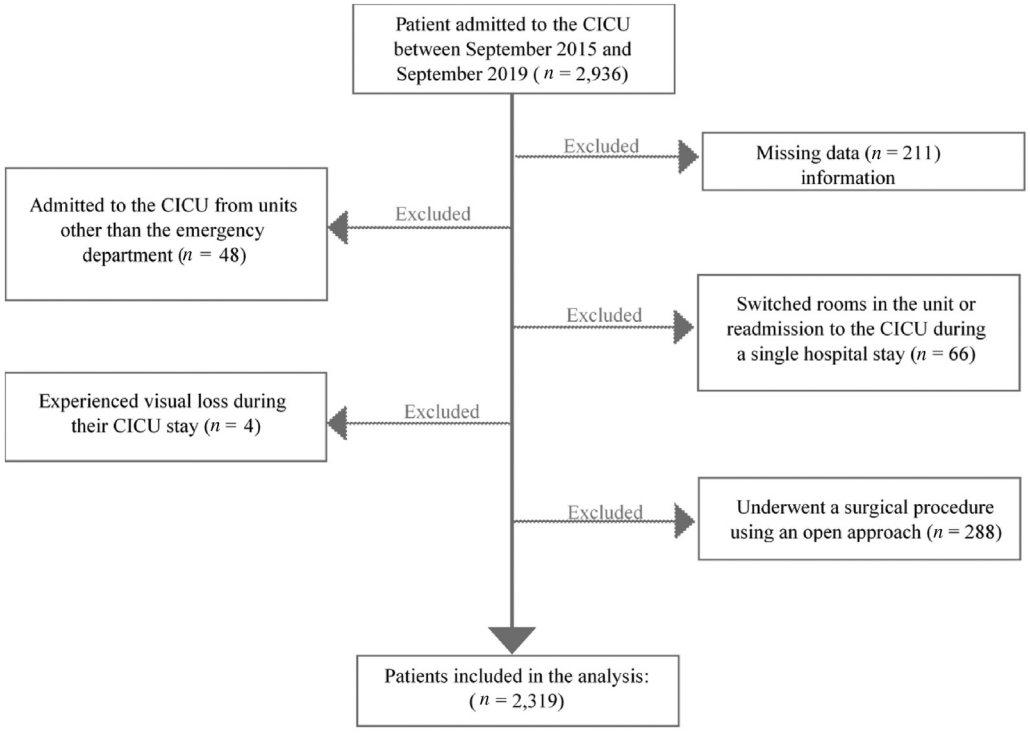
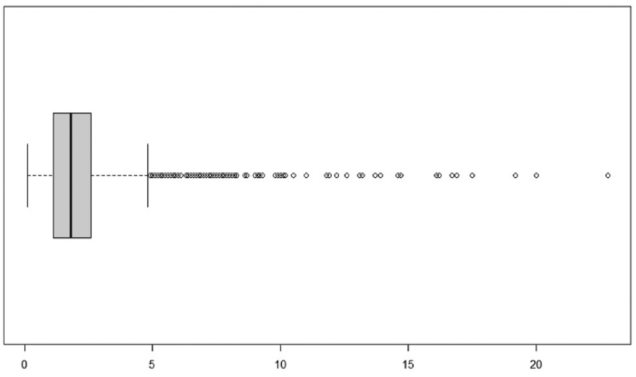


Figure 3. Flowchart describing patient selection. CICU: Cardiac intensive care unit.



CICU LOS Box plot	Statistics
Lower whisker	0.1
Lower hinge (Q1)	1.1
Median	1.8
Upper hinge (Q3)	2.6
Upper whisker	4.8
Number of observations (n)	2319

Figure 4. Distribution of the CICU LOS data.
CICU: Cardiac intensive care unit; LOS: Length of stay.

ences in the mean CICU LOS among the room types based on the GLM model. The analysis in this study was performed in RStudio (version 4.2.0). Additionally, sensitivity analyses were conducted to further investigate the GLM model using subsets of patient data based on the CICU LOS.[27]

Results

Based on the inclusion and exclusion criteria defined in this study, 617 data points were excluded from analyses (Figure 3). Ultimately, 2319 patients were finally included in the study analysis. As illustrated in Figure 4, a typical CICU LOS of 3 days was observed to be approximately equal to the CICU LOS at the 75th percentile in the present data set and thus was deemed consistent with findings of existing studies of cardiac patients in ICU settings. [2,28] Moreover, the distribution of data for the subset of patients with a typical CICU LOS (n=1907) was closer to a normal distribution compared to the distribution of data for all CICU patients (Figure 5).

Patient data

Among patients assigned to CICU rooms, 12.7% of the CICU patients were hospitalized in type A rooms (n=294), 41.8% were hospitalized in type B rooms (n=969), and 45.5% were hospitalized in type C rooms (n=1056). Analysis of variance showed no significant difference (P=0.698) in the average patient age across type A (M = 65.3), type B (M = 64.4), and type C rooms (M = 64.5). Patient data (Table 1) were also balanced with respect to demographics, admission information, medical history, and clinical characteristics (χ^2 test, all $P > 0.05$). Non-parametric Kruskal–Wallis tests did not reveal any significant differences between patients assigned to the rooms in terms of exposure to opioids, sedatives, or narcotic medications (all $P > 0.05$).

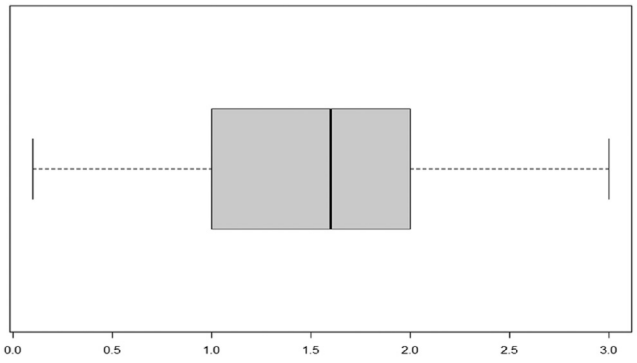
Room type and patients' CICU LOS

A GLM model was created to investigate the impact of different room types and patients' LOS in the CICU. As illustrated

Table 1
Summary of patient data across CICU rooms.

All CICU Patients	*n*	Room A	Room B	Room C
Demographics				
Gender				
Female	980	11.1%	40.2%	48.7%
Male	1339	13.8%	43.0%	43.2%
Marital				
Married	1026	13.4%	42.0%	44.6%
Other	91	14.3%	49.5%	36.2%
Single	1202	12.0%	41.0%	47.0%
Race				
Black	560	12.7%	40.9%	46.4%
Caucasian/White	1731	12.7%	41.8%	45.5%
Other	28	10.7%	57.1%	32.2%
Insurance				
Medicaid	166	15.1%	45.2%	39.7%
Medicare	1498	12.6%	41.4%	46.0%
Private/Commercial	386	13.7%	42.0%	44.3%
Self-pay/Charity	269	10.4%	41.6%	48.0%
Admission Information				
Source				
Health Care Facility	102	14.7%	38.2%	47.1%
Non-healthcare Facility	1318	13.2%	41.9%	44.9%
Physician/Clinic Office	899	11.7%	42.1%	46.2%
Status				
Elective	160	10.6%	41.9%	47.5%
Emergency	1631	12.6%	42.7%	44.7%
Urgent	528	13.5%	39.0%	47.5%
DRG				
Medical	1501	12.7%	40.7%	46.6%
Surgical	818	12.6%	43.8%	43.6%
Medical History				
Alcohol use	89	11.2%	40.5%	48.3%
Nicotine use	1317	12.1%	41.2%	46.7%
Anxiety	326	12.6%	42.3%	45.1%
Depression	193	12.4%	42.0%	45.6%
Diabetes	1006	12.4%	41.7%	45.9%
Obesity	471	10.8%	41.8%	47.4%
Dementia	143	15.4%	44.1%	40.5%
Medication Intake				
Opioid				
Fentanyl	117	14.5%	51.3%	34.2%
Morphine	175	12.6%	42.9%	44.5%
Hydromorphone	44	14.0%	45.0%	41.0%
Benzodiazepine				
Lorazepam	46	19.6%	41.3%	39.1%
Midazolam	111	10.8%	45.9%	43.3%
Propofol	22	13.6%	27.3%	59.1%
Haloperidol	7	1/7	2/7	4/7
Clinical Characteristics				
Diagnosis				
Cardiac Arrhythmia	396	14.4%	42.9%	42.7%
Chronic Ischemic Heart Disease	163	11.0%	45.4%	43.6%
Heart Failure	170	8.8%	35.9%	55.3%
Hypertension	758	12.7%	40.9%	46.4%
Myocardial Infarction	667	13.2%	42.9%	43.9%
Other	165	12.1%	41.2%	46.7%
SOI				
Level 1	310	13.9%	41.6%	44.5%
Level 2	841	11.8%	42.5%	45.7%
Level 3	800	13.3%	39.7%	47.0%
Level 4	368	12.5%	44.8%	42.7%
ROM				
Level 1	552	10.7%	40.6%	48.7%
Level 2	734	13.8%	42.4%	43.8%
Level 3	640	13.9%	39.4%	46.7%
Level 4	393	11.5%	46.3%	42.2%
Delirium	35	14.3%	31.4%	54.3%
Hospital-acquired infections	385	11.4%	43.4%	45.2%
Pain	211	13.3%	37.0%	49.7%
Palliative Care	98	12.2%	49.0%	38.8%
Mechanical Ventilation	275	10.2%	43.6%	46.2%
Cirrhosis	29	24.1%	48.3%	27.6%
Respiratory Failure	342	12.3%	36.0%	51.7%
Cardiogenic shock	104	11.5%	51.0%	37.5%

CICU: Cardiac intensive care unit; ROM: Risk of mortality; SOI: Severity of illness.



CICU LOS Box plot	Statistics
Lower whisker	0.1
Lower hinge	1
Median	1.6
Upper hinge	2
Upper whisker	3
Number of observations (n)	1907
Outliers (CICU LOS)	Numeric (0)

Figure 5. Distribution of data for patients with a typical LOS (≤3 days). CICU: Cardiac intensive care unit; LOS: Length of stay.

in Table 2, room type was not significantly associated with patients' CICU LOS. Based on the least squares means estimated from the GLM, the average CICU LOS was 2.8 days in type A rooms (with access to daylight and window views) as opposed to an average of 3.1 days in type B rooms (with access to daylight but no window views) or an average of 3.5 days in type C room (windowless rooms). These findings indicated that patients in type A rooms stayed 16.8 h and 7.2 h less in the CICU than patients in type C and B rooms, respectively. Pairwise comparisons based on the GLM model revealed that the differences in CICU LOS across the room types were not statistically significant. Nevertheless, the findings indicated that CICU LOS was significantly shorter among patients who received mechanical ventilation in type A rooms compared to type C rooms (P=0.003). In addition to room type, the model revealed significant associations between patients' age (P=0.013), cardiogenic shock (P = 0.001), hospital-acquired infections (P <0.001), receiving mechanical ventilation (P <0.001), SOI level (P <0.001 for SOI levels 3–4), a diagnosis of hypertension (P <0.001), a diagnosis of heart failure (P=0.003), a diagnosis of chronic heart disease (P=0.007), and their CICU LOS (Table 2).

Room type and patients' typical CICU LOS: a sensitivity analysis

The summary of patient data with a typical CICU LOS (≤3 days) is presented in Supplementary Table 1. Due to differences in data distribution in this subset of patients compared to all CICU patients' data, a sensitivity analysis was conducted

Table 2
GLM model for patients' CICU LOS *vs*. the typical CICU LOS (≤3 days).

	CICU LOS (all patients)				Typical CICU LOS (patients with LOS ≤3 days)			
Coefficients*	Estimate	Std. error	*t*-value	*P*-value	Estimate	Std. error	*t*-value	*P*-value
Room A	0.23	0.15	1.58	0.115	0.08	0.06	1.36	0.175
Room B	0	0.10	0.03	0.979	–0.06	0.04	–1.46	0.143
Age	–0.01	0	–2.48	0.013	0	0	–2.21	0.027
Season – spring	0.05	0.10	0.52	0.602	0.06	0.04	1.41	0.158
Season – summer	–0.18	0.10	–1.77	0.077	–0.05	0.04	–1.12	0.262
Season – winter	–0.04	0.10	–0.37	0.712	0.08	0.04	1.77	0.077
Diagnosis – chronic ischemic heart disease	–0.44	0.16	–2.69	0.007	–0.07	0.07	–0.99	0.325
Diagnosis – heart failure	–0.49	0.16	–3.00	0.003	0.11	0.08	1.43	0.152
Diagnosis – hypertension	–0.76	0.11	–6.96	<0.001	–0.11	0.05	–2.31	0.021
Diagnosis – myocardial infarction	–0.08	0.11	–0.69	0.493	0.26	0.05	5.09	<0.001
Diagnosis – other	–0.45	0.16	–2.82	0.005	0.09	0.07	1.28	0.202
Delirium – yes	0.55	0.42	1.32	0.186	0.71	0.21	3.35	0.001
Anxiety – yes	0.16	0.16	1.04	0.299	0	0.07	0.05	0.961
Obesity – yes	–0.16	0.13	–1.23	0.217	–0.04	0.05	–0.76	0.446
Cardiogenic shock – yes	0.64	0.19	3.30	0.001	–0.25	0.11	–2.35	0.019
SOI-2	0.31	0.12	2.60	0.010	0.16	0.05	3.55	<0.001
SOI-3	0.77	0.12	6.15	<0.001	0.36	0.05	7.23	<0.001
SOI-4	2.12	0.17	12.54	<0.001	0.53	0.08	7.02	<0.001
Dementia – yes	0.09	0.24	0.39	0.697	–0.05	0.11	–0.44	0.660
Hospital-acquired infections – yes	0.44	0.11	3.90	<0.001	0.12	0.05	2.38	0.017
Palliative care – yes	0.30	0.31	0.97	0.332	0.04	0.16	0.26	0.797
Mechanical ventilation – yes	0.87	0.18	4.76	<0.001	–0.15	0.09	–1.65	0.098
Room A: Mechanical ventilation – yes	–1.18	0.40	–2.98	0.003	0.17	0.18	0.94	0.346
Room B: Mechanical ventilation – yes	–0.22	0.25	–0.91	0.363	–0.15	0.12	–1.25	0.213
Room A: Delirium – yes	–0.43	0.89	–0.48	0.632	–0.55	0.40	–1.38	0.167
Room B: Delirium – yes	–0.40	0.67	–0.60	0.551	–0.99	0.33	–3.04	0.002
Room A: Obesity – yes	–0.28	0.30	–0.91	0.361	–0.27	0.13	–2.15	0.032
Room B: Obesity – yes	0.18	0.19	0.94	0.345	0.12	0.08	1.48	0.140
Room A: Dementia – yes	–0.39	0.46	–0.84	0.401	–0.19	0.20	–0.93	0.352
Room B: Dementia – yes	–0.64	0.33	–1.93	0.053	0.20	0.15	1.38	0.168
Room A: Palliative care – yes	–0.04	0.63	–0.07	0.945	–0.71	0.34	–2.10	0.036
Room B: Palliative care – yes	–0.03	0.41	–0.08	0.937	0.15	0.21	0.71	0.480
Room A: Anxiety – yes	0.33	0.33	1.00	0.318	–0.07	0.15	–0.46	0.646
Room B: Anxiety – yes	0.15	0.22	0.70	0.486	0.24	0.09	2.58	0.010

* Reference level for room type: "Room C" (windowless rooms)
CICU: Cardiac intensive care unit; GLM: Generalized linear model; LOS: Length of stay; SOI: Severity of illness; Std: Standard.

Figure 6. Interior views of CICU type A and B rooms with different access to daylight and window views. CICU: Cardiac intensive care unit.

to examine the GLM model for patients with a typical CICU LOS.[27] The results of the sensitivity analysis are also presented in Table 2. Based on the least squares means estimated from the model, the average typical CICU LOS was 1 day in type A rooms *vs.* 1.5 days or 1.8 days in type B or C rooms, respectively, for these patients. These findings indicated that patients in type A rooms stayed 19.2 h and 12 h less in the CICU than patients in type C and B rooms, respectively. Pairwise comparisons indicated that patients' typical LOS in type A rooms was significantly shorter than that of patients in type C rooms ($P = 0.007$), while no significant differences were observed between type B and A rooms ($P = 0.110$) or between type B and C rooms ($P = 0.146$). Also, the model revealed significant associations between patients' age ($P = 0.027$), an experience of delirium ($P = 0.001$), cardiogenic shock ($P = 0.019$), hospital-acquired infections ($P = 0.017$), SOI level ($P < 0.001$ for SOI levels 2–4), a diagnosis of hypertension ($P = 0.021$), a diagnosis of myocardial infarction ($P < 0.001$), and typical CICU LOS.

Furthermore, the GLM results indicated that CICU room type (Figure 3) affected patients with a typical CICU LOS differently depending on their clinical characteristics and medical history (i.e., there were significant interactions between these factors and room type). As illustrated in Table 3, pairwise comparisons of typical CICU LOS depicted that hospitalization in a type A room (with access to daylight and window views) significantly decreased the average typical LOS among patients with symptoms of delirium (P=0.019) or dementia (P=0.008), those with history of anxiety (P=0.009) or obesity (P=0.003), and those receiving palliative care (P=0.006) or mechanical ventilation (P=0.033) compared to hospitalization in type C rooms (windowless rooms). Moreover, a comparison of type B and A rooms (Figure 6) showed that the availability of window views in addition to daylight in type A rooms significantly reduced the CICU LOS among patients with symptoms of dementia (P=0.041), a history of obesity (P=0.033), and receiving palliative care (P=0.026).

Room type and prolonged CICU stay

A summary of data for patients with prolonged CICU LOS is presented in Supplementary Table 2. Among these individuals (n=412), 14.6% (n=60) were hospitalized in type A rooms (with access to daylight and window views), 42.2% (n=174) were hos-

Table 3
Pairwise comparisons of the typical CICU LOS among patients with certain characteristics based on the GLM model.

Coefficients	Pairwise comparison (no adjustments for error rate)	Estimate	Std. error	*t*-ratio	*P*-value
Delirium = yes	Room C – Room A	1.005	0.428	2.348	0.019
	Room C – Room B	0.777	0.337	2.309	0.021
	Room A – Room B	–0.228	0.452	–0.504	0.614
Mechanical ventilation = yes	Room C – Room A	0.6438	0.3011	2.138	0.033
	Room C – Room B	0.3555	0.2111	1.684	0.092
	Room A – Room B	–0.2883	0.3095	–0.931	0.352
Palliative care = yes	Room C – Room A	1.0868	0.392	2.776	0.006
	Room C – Room B	0.2073	0.249	0.833	0.405
	Room A – Room B	–0.8795	0.395	–2.224	0.026
Dementia = yes	Room C – Room A	0.8239	0.3084	2.671	0.008
	Room C – Room B	0.1799	0.2169	0.829	0.407
	Room A – Room B	–0.644	0.3144	–2.048	0.041
History of anxiety = yes	Room C – Room A	0.76344	0.2941	2.596	0.009
	Room C – Room B	0.16039	0.2039	0.786	0.432
	Room A – Room B	–0.60304	0.3029	–1.991	0.047
Obesity = yes	Room C – Room A	0.8648	0.2905	2.977	0.003
	Room C – Room B	0.2216	0.2017	1.098	0.272
	Room A – Room B	–0.6432	0.3005	–2.14	0.033

CICU: Cardiac intensive care unit; GLM: Generalized linear model; LOS: Length of stay; Std: Standard.

pitalized in type B rooms (with access to daylight and no window views), and 43.2% (n=178) were hospitalized in type C rooms (windowless rooms). Findings indicated that patients in type A rooms stayed, on average, 7.2 h less in the CICU (M=5.1) than those in type B (M=5.4) and type C rooms (M=5.4). Due to the smaller number of patients with prolonged CICU LOS (n=412) than those with a typical CICU LOS, the GLM model was not tested for these patients. The one-way analysis of variance for the prolonged CICU LOS by room type did not reveal any significant results (P=0.946). However, data analyses revealed that patients distributed across the rooms (n=412) were significantly different based on the presence of respiratory failure symptoms (χ^2 = 12.790, P=0.002) and receiving mechanical ventilation (χ^2 = 6.902, P=0.032) during their CICU stay. In type A rooms, 25.0% of patients showed symptoms of respiratory failure compared to 27.0% and 42.7% of patients in type B and type C rooms, respectively. Also, while only 15.0% of patients who stayed in type A rooms received mechanical ventilation, 30.5% of patients in type B rooms and 32.6% of patients in type C rooms relied on mechanical ventilation during their CICU stay.

Discussion

This study examined CICU rooms with different levels of access to daylight and window views due to patient bed orientation toward the windows and explored the relationship between rooms with daylight and window views (patient bed parallel to the window) (room type A), rooms with daylight but no access to window views (the patient head was against the window with the patient facing inside) (room type B), and windowless rooms (room type C) in the CICU. This study found that rooms providing access to both daylight and window views (room type A) could reduce CICU LOS among patients by 16.8 h compared to windowless rooms (room type C) and by 7.2 h compared to rooms providing daylight exposure only (room type B). However, these differences in CICU LOS were not statistically significant among patients. On the other hand, the sensitivity analysis of a subset of patients with a typical LOS in the CICU (≤3 days) indicated that staying in a type A room significantly reduced patients' CICU LOS (by approximately 1 day) compared to staying in a type C room. The findings suggest that type A room, where the CICU patient bed is placed parallel to the full-height, south-facing windows, is most effective in reducing CICU LOS due to providing access to both daylight and window views. This finding is in line with reports from the study by Beauchemin and Hayes,[15] in which south-facing sunny rooms were associated with shorter LOS among patients with myocardial infarction compared to dim rooms; however, these authors did not discuss window use or bed orientation in patient rooms. Also, dividing the patient population into those with an ICU stay of ≤3 days and those with a longer ICU stay for investigation in this study is in line with the existing literature.[9,29]

In addition to these findings, the present study extensively explored the impact of relevant clinical and demographic variables on the relationship between room type and patients' CICU LOS using a linear model, which has not been previously examined in the literature. The results showed that patients receiving mechanical ventilation in rooms providing access to both daylight and window views (room type A) stayed significantly less time in the unit than those in windowless rooms (room type C). Examining the linear model with a subset of patients with a typical CICU LOS (≤3 days) also indicated that mechanically ventilated patients stayed significantly less time in rooms with access to daylight and window views (room type A) compared to windowless rooms (room type C). In addition to mechanically ventilated patients, findings for delirious patients with a typical CICU LOS revealed that they stayed significantly less time in the CICU rooms providing daylight either directly or indirectly (type A or B rooms *vs.* type C rooms). This finding is in line with the study by Zaal et al. [30] that compared a pair of ICU wards and found that the average number of days with delirium was 0.4 days less among patients in the ICU ward with higher levels of daylight exposure. In contrast, a recent study investigating the impact of daylight exposure in ICU rooms on delirium among patients receiving mechanical ventilation reported no significant difference in the incidence of delirium in windowed *vs.* windowless rooms.[17] However, it should be noted that this study only targeted ICU admission related to acute respiratory failure or sepsis and did not address the patient bed orientation with respect to the windows in ICU rooms.

Looking at patients with a history of anxiety among this subset of patients also showed that direct access to daylight and views (room type A) significantly decreased the average typical LOS among patients compared to those in type B and C rooms. These findings are consistent with those of seminal studies by Ulrich [11,31] and the theory of supportive design, which addresses the link between access to views of natural elements (e.g., sky and trees) and patients' reduced stress and anxiety levels. Furthermore, patients diagnosed with certain clinical conditions, such as obesity and dementia, also benefited from direct access to daylight and views (room type A), experiencing a significant reduction in their typical CICU LOS. The literature also provides a moderate level of evidence related to the positive association between obesity and anxiety [32,33] and that between dementia, anxiety, and agitation among heart disease patients, respectively.[34–36]

The present study also revealed that type A rooms significantly decreased the average typical LOS among patients receiving palliative care compared to rooms with access to daylight only (room type B) and windowless rooms (room type C). Although evidence suggests a link between receiving palliative care and a reduction in ICU LOS among ICU patients in general,[37–39] there is a paucity of research regarding the impact of exposure to direct daylight and window views among patients with heart disease receiving palliative care in ICUs. Based on the sensitivity analysis, patients receiving palliative care in type A rooms with direct access to daylight and views had a significantly shorter typical CICU LOS than patients in other (type B or C) rooms. As the majority of available data in this study (approximately 75%) relate to patients with a typical CICU LOS of ≤3 days, the sensitivity analysis targeted this subset of patients. The findings related to patients with prolonged CICU LOS indicated that room type A is associated with significantly lower rates of respiratory failure and mechanical ventilation among patients compared to other (type B or C) rooms. However, the impact of potential confounding factors was not explored for this population, and future research can apply the GLM model developed in this study to this group of patients in the CICU.

Limitations

This study focused on a single CICU unit with a unique layout that accommodated three room types with various daylight and view conditions. Studying patients in a single CICU in South Carolina allowed the investigators to rule out the confounding effect of variations in the quality of care (e.g., CICU staff) on the outcome of interest but limits the study findings' generalization. The unit accommodated both surgical and non-surgical patients; however, all surgical patients were hospitalized in windowless rooms and therefore were excluded from this study. Moreover, since most non-surgical patients stayed in this unit for ≤3 days, the sensitivity analysis only targeted this subpopulation, and the model was not tested for those patients with prolonged CICU LOS due to the existence of fewer numbers of data points. The 3-day cut-off criterion was selected based on the dataset characteristics as well as the existing literature; however, it should be noted that the cut-off criterion for a typical *vs.* prolonged ICU stay might change depending on the population data in other settings. In addition, the dataset lacked data regarding SOI and ROM for some patients, and so a number of data points were excluded from analysis. Despite the above-mentioned limitations, this study design prevented a wide degree of heterogeneity in the patient data and resulted in more reliable findings that could be generalizable to CICU patients with a typical LOS of ≤3 days. In addition, it should be noted that the CICU in this study was located on the third floor of a hospital building in an urban setting, thus providing access to views of the city skyline for those patients in rooms with access to window views. There were also differences in patients' direct daylight exposure during daytime in the two rooms categorized as type A rooms with access to daylight and window views due to their mirrored layout. Other limitations associated with the setting in the present study included the absence of data regarding certain confounding factors, including visibility of patients from nursing stations, noise levels and privacy, and clinical information such as laboratory test data during patients' CICU stay.

Conclusions

This study investigated patients' LOS across CICU room types with different levels of daylight exposure and access to window views due to varying bed orientations in the rooms. Findings in this study delineated that patients receiving mechanical ventilation in rooms with direct access to both daylight and window views stayed significantly less time in the CICU than those in windowless CICU rooms. Also, the study showed that parallel placement of the bed to the full-height CICU windows, providing direct access to daylight and window views, significantly reduced LOS among patients with a typical CICU stay (≤3 days) compared to those in windowless rooms. This finding can help hospital stakeholders, architects, and medical planners to determine the room layout that is conducive to patient recovery and maximizes the efficiency of windows in CICUs. To build upon the present study and address the above-mentioned limitations, future research can investigate the impact of daylight and views on heart disease patients who have undergone surgery or examine the impact of other types of views (e.g., views of green space *vs.* urban settings), lighting color, and differences in the duration and time of direct daylight exposure on CICU patients.

Ethics Statement

This study was approved by the institutional review board of the Clemson University and AnMed Health (IRB approval No. Pro00083942), and the need for informed consent was waived due to the retrospective study design.

Availability of Data and Material

The datasets used for analytical purposes in the present study are available from the corresponding author upon reasonable request.

Funding

This study did not receive any funding from agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the AnMed Health research team for their contributions to this project.

Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jointm.2022.11.002.

References

[1] Vîjan AE, Daha IC, Delcea C, Dan GA. Determinants of prolonged length of hospital stay of patients with atrial fibrillation. J Clin Med 2021;10(16):3715. doi:10.3390/jcm10163715.
[2] Almashrafi A, Alsabti H, Mukaddirov M, Balan B, Aylin P. Factors associated with prolonged length of stay following cardiac surgery in a major referral hospital in Oman: a retrospective observational study. BMJ Open 2016;6(6):e010764. doi:10.1136/bmjopen-2015-010764.
[3] de Vries EN, Ramrattan MA, Smorenburg SM, Gouma DJ, Boermeester MA. The incidence and nature of in-hospital adverse events: a systematic review. Qual Saf Health Care 2008;17(3):216–23. doi:10.1136/qshc.2007.023622.
[4] Hauck K, Zhao X. How dangerous is a day in hospital? A model of adverse events and length of stay for medical inpatients. Med Care 2011;49(12):1068–75. doi:10.1097/MLR.0b013e31822efb09.
[5] Benedetti F, Colombo C, Barbini B, Campori E, Smeraldi E. Morning sunlight reduces length of hospitalization in bipolar depression. J Affect Disord 2001;62(3):221–3. doi:10.1016/s0165-0327(00)00149-x.
[6] Walch JM, Rabin BS, Day R, Williams JN, Choi K, Kang JD. The effect of sunlight on postoperative analgesic medication use: a prospective study of patients undergoing spinal surgery. Psychosom Med 2005;67(1):156–63. doi:10.1097/01.psy.0000149258.42508.70.
[7] Joarder AR, Price ADF. Impact of daylight illumination on reducing patient length of stay in hospital after coronary artery bypass graft surgery. Light Res Tech 2013;45(4):435–49. doi:10.1177/1477153512455940.
[8] Wunsch H, Gershengorn H, Mayer SA, Claassen J. The effect of window rooms on critically ill patients with subarachnoid hemorrhage admitted to intensive care. Crit Care 2011;15(2):R81. doi:10.1186/cc10075.
[9] Kohn R, Harhay MO, Cooney E, Small DS, Halpern SD. Do windows or natural views affect outcomes or costs among patients in ICUs? Crit Care Med 2013;41(7):1645–55. doi:10.1097/CCM.0b013e318287f6cb.
[10] Park MY, Chai CG, Lee HK, Moon H, Noh JS. The effects of natural daylight on length of hospital stay. Environ Health Insights 2018;12. doi:10.1177/1178630218812817.

[11] Ulrich RS. View through a window may influence recovery from surgery. Science 1984;224(4647):420–1. doi:10.1126/science.6143402.
[12] Kellert SR, Wilson EO. The biophilia hypothesis. Washington, DC: Island Press; 1993.
[13] Brainard J, Gobel M, Scott B, Koeppen M, Eckle T. Health implications of disrupted circadian rhythms and the potential for daylight as therapy. Anesthesiology 2015;122(5):1170–5. doi:10.1097/ALN.0000000000000596.
[14] Aries MBC, Aarts MPJ, van Hoof J. Daylight and health: a review of the evidence and consequences for the built environment. Light Res Tech 2015;47(1):6–27. doi:10.1177/1477153513509258.
[15] Beauchemin KM, Hays P. Dying in the dark: sunshine, gender and outcomes in myocardial infarction. J R Soc Med 1998;91(7):352–4. doi:10.1177/014107689809100703.
[16] Verceles AC, Liu X, Terrin ML, Scharf SM, Shanholtz C, Harris A, et al. Ambient light levels and critical care outcomes. J Crit Care 2013;28(1):110 e1–8. doi:10.1016/j.jcrc.2012.04.012.
[17] Smonig R, Magalhaes E, Bouadma L, Andremont O, de Montmollin E, Essardy F, et al. Impact of natural light exposure on delirium burden in adult patients receiving invasive mechanical ventilation in the ICU: a prospective study. Ann Intensive Care 2019;9(1):120. doi:10.1186/s13613-019-0592-x.
[18] Shepley MM, Gerbi RP, Watson AE, Imgrund S, Sagha-Zadeh R. The impact of daylight and views on ICU patients and staff. HERD 2012;5(2):46–60. doi:10.1177/193758671200500205.
[19] Giménez MC, Geerdinck LM, Versteylen M, Leffers P, Meekes GJ, Herremans H, et al. Patient room lighting influences on sleep, appraisal and mood in hospitalized people. J Sleep Res 2017;26(2):236–46. doi:10.1111/jsr.12470.
[20] Shepley MMC, Rybkowski Z, Aliber J, Lange C. Ambulatory infusion suite: pre-and post-occupancy evaluation. Build Res Inf 2012;40(6):700–12. doi:10.1080/09613218.2012.709372.
[21] Thompson DR, Hamilton DK, Cadenhead CD, Swoboda SM, Schwindel SM, Anderson DC, et al. Guidelines for intensive care unit design. Crit Care Med 2012;40(5):1586–600. doi:10.1097/CCM.0b013e3182413bb2.
[22] Guidelines for intensive care unit design. Guidelines/practice parameters committee of the American college of critical care medicine, society of critical care medicine. Crit Care Med 1995;23(3):582–8.
[23] Armaignac DL, Saxena A, Rubens M, Valle CA, Williams LS, Veledar E, et al. Impact of telemedicine on mortality, length of stay, and cost among patients in progressive care units: experience from a large healthcare system. Crit Care Med 2018;46(5):728–35. doi:10.1097/CCM.0000000000002994.
[24] McCaffery M, Pasero C. Pain: clinical manual. St. Louis: Mosby; 1999. p. 795.
[25] Cook RD. Detection of influential observation in linear regression. Technometrics 1977;19(1):15–18. doi:10.1080/00401706.1977.10489493.
[26] Panepinto JA, Brousseau DC, Hillery CA, Scott JP. Variation in hospitalizations and hospital length of stay in children with vaso-occlusive crises in sickle cell disease. Pediatr Blood Cancer 2005;44(2):182–6. doi:10.1002/pbc.20180.
[27] Thabane L, Mbuagbaw L, Zhang S, Samaan Z, Marcucci M, Ye C, et al. A tutorial on sensitivity analyses in clinical trials: the what, why, when and how. BMC Med Res Methodol 2013;13:92. doi:10.1186/1471-2288-13-92.
[28] Collins TC, Daley J, Henderson WH, Khuri SF. Risk factors for prolonged length of stay after major elective surgery. Ann Surg 1999;230(2):251–9. doi:10.1097/00000658-199908000-00016.
[29] Hein OV, Birnbaum J, Wernecke K, England M, Konertz W, Spies C. Prolonged intensive care unit stay in cardiac surgery: risk factors and long-term-survival. Ann Thorac Surg 2006;81(3):880–5. doi:10.1016/j.athoracsur.2005.09.077.
[30] Zaal IJ, Spruyt CF, Peelen LM, van Eijk MM, Wientjes R, Schneider MM, et al. Intensive care unit environment may affect the course of delirium. Intensive Care Med 2013;39(3):481–8. doi:10.1007/s00134-012-2726-6.
[31] Ulrich RS. Effects of interior design on wellness: theory and recent scientific research. J Health Care Inter Des 1991;3:97–109.
[32] Gariepy G, Nitka D, Schmitz N. The association between obesity and anxiety disorders in the population: a systematic review and meta-analysis. Int J Obes (Lond) 2010;34(3):407–19. doi:10.1038/ijo.2009.252.
[33] Amiri S, Behnezhad S. Obesity and anxiety symptoms: a systematic review and meta-analysis. Neuropsychiatr 2019;33(2):72–89. doi:10.1007/s40211-019-0302-9.
[34] Reynolds L, Rodiek S, Lininger M, McCulley MA. Can a virtual nature experience reduce anxiety and agitation in people with dementia? J Hous Elderly 2018;32(2):176–93. doi:10.1080/02763893.2018.1431583.
[35] Gulpers B, Ramakers I, Hamel R, Köhler S, Oude Voshaar R, Verhey F. Anxiety as a predictor for cognitive decline and dementia: a systematic review and meta-analysis. Am J Geriatr Psychiatry 2016;24(10):823–42. doi:10.1016/j.jagp.2016.05.015.
[36] Wändell P, Carlsson AC, Li X, Sundquist J, Sundquist K. Association between relevant co-morbidities and dementia with atrial fibrillation – A national study. Arch Med Res 2019;50(2):29–35. doi:10.1016/j.arcmed.2019.05.007.
[37] Khandelwal N, Kross EK, Engelberg RA, Coe NB, Long AC, Curtis JR. Estimating the effect of palliative care interventions and advance care planning on ICU utilization: a systematic review. Crit Care Med 2015;43(5):1102–11. doi:10.1097/CCM.0000000000000852.
[38] Kyeremanteng K, Gagnon LP, Thavorn K, Heyland D, D'Egidio G. The impact of palliative care consultation in the ICU on length of stay: a systematic review and cost evaluation. J Intensive Care Med 2018;33(6):346–53. doi:10.1177/0885066616664329.
[39] Mun E, Ceria-Ulep C, Umbarger L, Nakatsuka C. Trend of decreased length of stay in the intensive care unit (ICU) and in the hospital with palliative care integration into the ICU. Perm J 2016;20(4):16–036. doi:10.7812/TPP/16-036.