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The Effect of Windowed Environment and Natural Light Conditions on Delirium in the Intensive Care Unit: A Prospective Observational Cohort Study

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Abstract

Background

Delirium frequently complicates critical illness and is associated with adverse outcomes. While natural daylight exposure may support circadian integrity and potentially reduce delirium, evidence comparing windowed and windowless intensive care unit (ICU) environments remains heterogeneous. We investigated whether admission to a windowed versus a windowless ICU was associated with incident delirium.

Methods

In this prospective, comparative observational cohort study, consecutive adults expected to stay ≥ 48 hours without baseline delirium were enrolled across two ICUs within the same hospital—one with natural daylight (windowed) and one without (windowless). Incident delirium was assessed daily using the Confusion Assessment Method for the ICU (CAM-ICU) for up to seven days. The primary outcome was incident delirium. To rigorously account for baseline imbalances, the association was evaluated using multivariable logistic regression and propensity-score-based sensitivity analyses (inverse probability of treatment weighting, doubly robust estimation, and matching).

Results

Among 102 patients (windowless n = 53; windowed n = 49), baseline illness severity was higher in the windowless group (median APACHE II 14 vs. 12, p = 0.009). Incident delirium occurred in 23/53 (43.4%) windowless-ICU patients compared to 10/49 (20.4%) windowed-ICU patients (unadjusted OR 2.99, 95% CI 1.24–7.22; p = 0.023). After adjustment for age, APACHE II, and mechanical ventilation, this association was substantially attenuated (adjusted OR 0.44, 95% CI 0.17–1.18; p = 0.105). Furthermore, propensity-score analyses balancing all observed baseline covariates yielded estimates closely approaching the null (OR ≈ 0.93–1.01). Nevertheless, the cumulative number of delirium days was independently associated with increased ICU mortality (adjusted OR 1.56 per day, 95% CI 1.04–2.34; p = 0.030), regardless of the baseline APACHE II score.

Conclusions

Care in a windowed ICU was associated with a lower unadjusted incidence of delirium; however, this association was largely driven by baseline imbalances in illness severity. Confounder-balanced analyses do not support a causal protective effect of the windowed environment on delirium incidence in this cohort. These findings emphasize the necessity of rigorous confounder adjustment in environmental ICU studies, while reaffirming that delirium burden is an independent predictor of mortality.

Clinical Trial Number:

Not applicable.

Introduction

Delirium is a common and severe acute neuropsychiatric syndrome in critically ill patients, characterized by fluctuating disturbances in attention, awareness, and cognition [1]. In mechanically ventilated patients in the intensive care unit (ICU), its incidence can reach up to 60–80% [2]. Beyond its immediate clinical manifestations, ICU delirium is consistently associated with adverse outcomes, including prolonged mechanical ventilation, increased ICU and hospital length of stay, higher short-term and long-term mortality, and persistent cognitive impairment among survivors [2, 3].

The pathophysiology of delirium in the ICU is multifactorial, arising from a complex interplay between predisposing patient vulnerabilities (e.g., advanced age, preexisting cognitive impairment) and acute precipitating factors (e.g., sepsis, mechanical ventilation, sedatives, and analgesics) [4, 5]. Circadian disruption has emerged as a critical biological pathway in this process [6, 7]. The ICU environment severely disrupts the circadian pacemaker—the suprachiasmatic nucleus—due to continuous artificial lighting, limited access to natural daylight, high noise levels, frequent nighttime care interventions, and the chronobiotic effects of sedative medications [6, 8, 9]. The resulting circadian desynchrony, often reflected by the loss of normal melatonin and cortisol rhythms, is closely linked to sleep fragmentation and delirium [7].

Consequently, mitigating environmental triggers has become a key focus of multicomponent non-pharmacological delirium prevention strategies, as emphasized by contemporary clinical guidelines [5]. Because natural light is the principal *zeitgeber* (environmental synchronizer) for the circadian system, exposure to natural daylight in windowed ICU rooms has been proposed as a biologically plausible, modifiable target to support circadian entrainment and prevent delirium [10, 11].

However, clinical evidence comparing windowed and windowless ICU environments remains heterogeneous. A retrospective cohort study by Lee et al. reported a lower incidence of delirium in patients treated in windowed rooms [12]. Conversely, a prospective study by Smonig et al. involving invasively ventilated patients found no significant difference in overall delirium incidence, although hyperactive symptoms requiring antipsychotic treatment were less frequent in the natural light group [13]. Furthermore, a randomized controlled trial evaluating dynamic high-intensity artificial light therapy failed to demonstrate a consistent reduction in ICU-acquired delirium incidence or duration [14]. This inconsistency in the literature may reflect unmeasured differences in actual light exposure at the patient's eye level, variations in sedation depth, differences in case mix, or the frequency of delirium assessment.

Crucially, the presence of a window is not only a proxy for natural light exposure but may also correlate with other architectural or care-process differences within an ICU. Patients admitted to windowless

rooms may systematically differ in baseline illness severity compared to those in windowed rooms.

Therefore, we conducted a prospective observational cohort study to investigate whether admission to a windowed ICU, compared to a windowless ICU within the same hospital, was associated with incident delirium during the first seven days of admission. We utilized a prespecified multivariable model and confounder-balancing sensitivity analyses (including propensity score methods) to rigorously characterize the strength and robustness of this association, adjusting for baseline illness severity. Consistent with the observational, non-randomized design, we aimed to report associations rather than causal effects.

Methods

Study Design and Setting

This prospective, comparative observational cohort study was conducted between January 6, 2026, and April 6, 2026, in two adult ICUs within the Department of Anesthesiology and Reanimation at the University of Health Sciences, Haydarpaşa Numune Training and Research Hospital (Istanbul, Turkey). The study was approved by the institutional Non-Interventional Clinical Research Ethics Committee (Approval No: HNEAH-GOAEK/KK/2026/5, dated January 6, 2026) and was conducted in compliance with the Declaration of Helsinki. Written informed consent was obtained from all patients or their legally authorized representatives if the patient lacked decision-making capacity.

The hospital architecture provided a unique opportunity to compare two structurally distinct ICU environments operating under the same departmental protocols, nursing staff, and medical team. Patients were admitted to one of two units:

1. **Windowed ICU:** Patient rooms had exterior windows providing exposure to natural daytime light.
2. **Windowless ICU:** Patient areas lacked exterior windows and relied exclusively on artificial (fluorescent) lighting throughout the day.

Admission to either ICU was determined strictly by routine bed availability at the time of admission and was not influenced by the investigators. No randomization was performed. Ambient light intensity (e.g., illuminance or spectral composition) was not objectively measured; the exposure was defined structurally as the presence or absence of a window.

Participants

Consecutive adult patients (≥18 years) admitted to either ICU were eligible if their expected ICU length of stay was ≥48 hours, their admission Richmond Agitation-Sedation Scale (RASS) score was ≥−3, and they were free of delirium at the time of the first assessment.

Patients were excluded if they had moderate-to-severe dementia, acute ischemic or hemorrhagic stroke, traumatic brain injury, brain death, advanced neurodegenerative disease (e.g., severe Parkinson's

disease), severe uncorrected visual or hearing impairment precluding delirium assessment, or lack of fluency in Turkish without an interpreter. Patients who required deep sedation or were comatose (RASS −4 or −5) at admission, as well as those who were delirious prior to or at the first ICU assessment, were also excluded.

Data Collection and Delirium Assessment

Demographic data, admission diagnoses, comorbidities, day-1 Sequential Organ Failure Assessment (SOFA) scores, and 24-hour Acute Physiology and Chronic Health Evaluation (APACHE) II scores were recorded. Daily treatment data included the use of invasive or non-invasive mechanical ventilation, vasopressors, sedatives, and analgesics.

To minimize inter-rater variability, a single trained investigator (Y.S.) performed all delirium assessments once daily at 10:00 AM. The assessment process involved a two-step approach: first, the patient's level of arousal and sedation was evaluated using the RASS [15]. If the RASS score was between −3 and +4, the Confusion Assessment Method for the ICU (CAM-ICU) was administered [16]. The CAM-ICU was not performed if the patient was deeply sedated or comatose (RASS −4 or −5). Patients were assessed daily for a maximum of 7 days or until ICU discharge or death, whichever occurred first.

Outcomes

The primary outcome was incident delirium, defined as at least one CAM-ICU-positive assessment during the 7-day follow-up period.

Secondary outcomes included:

- **Delirium burden:** Defined both as the absolute number of CAM-ICU-positive days per patient across the full cohort and the proportion of evaluable patient-days that were CAM-ICU-positive.
- **Time to first delirium:** The day of the first CAM-ICU-positive assessment among those who developed delirium.
- **ICU length of stay (LOS)** and **ICU mortality**.

Statistical Analysis

The original sample size calculation specified a minimum of 52 patients to detect a standardized effect size of 0.8 with 80% power and a two-sided alpha of 0.05. Enrollment continued consecutively through the 3-month study period, resulting in a final cohort of 102 patients.

Continuous variables were assessed for normality using the Shapiro-Wilk test and reported as means ± standard deviations or medians [interquartile ranges, IQR] accordingly. Categorical variables were reported as frequencies (percentages). Baseline comparisons utilized Student's t-test, the Mann-Whitney U test, or the Chi-square/Fisher’s exact test. For the primary outcome, the unadjusted association was evaluated using a Chi-square test, reporting the odds ratio (OR) and risk ratio (RR) with 95% confidence

intervals (CIs). Cumulative delirium incidence over the 7-day period was estimated using the Kaplan-Meier method and compared with the log-rank test.

To adjust for baseline imbalances between the two ICU cohorts, a prespecified multivariable logistic regression model was constructed for the primary outcome, incorporating ICU type, age, APACHE II score, and the presence of mechanical ventilation. The number of covariates was constrained to maintain approximately 8 events per variable, given the 33 observed delirium events. SOFA was excluded from the multivariable model due to its correlation with APACHE II. Furthermore, to rigorously test the robustness of the adjusted association across a broader set of covariates, exploratory propensity-score-based sensitivity analyses (including inverse probability of treatment weighting, doubly robust estimation, and 1:1 nearest-neighbor matching) were conducted.

Secondary outcomes, including the association of delirium days with ICU mortality, were evaluated using the Mann-Whitney U test and exploratory logistic regression models. All statistical tests were two-sided, with $p < 0.05$ considered statistically significant. Primary statistical analyses were performed using IBM SPSS Statistics (version 26.0; IBM Corp., Armonk, NY, USA).

Results

Baseline Characteristics

A total of 102 patients met the inclusion criteria and were analyzed: 53 in the windowless ICU and 49 in the windowed ICU. Baseline characteristics, including age, sex, body mass index, admission category, and comorbidity burden, were broadly similar between the two groups (Table 1). However, baseline severity of illness was significantly higher in the windowless group, with higher median APACHE II scores (14.0 [IQR 11.0–21.0] vs. 12.0 [IQR 8.0–16.0]; p=0.009) and SOFA scores (4.0 [IQR 2.0–6.0] vs. 3.0 [IQR 2.0–5.0]; p=0.016). Additionally, the use of mechanical ventilation on day 1 was more frequent in the windowless ICU (56.6% vs. 32.7%; p=0.026).

Primary Outcome: Incident Delirium

Incident delirium developed in 23 of 53 patients (43.4%) in the windowless ICU compared to 10 of 49 patients (20.4%) in the windowed ICU (Table 2, Figure 1). The crude, unadjusted incidence favored the windowed environment (OR 0.33, 95% CI 0.14–0.81; risk ratio 0.47, 95% CI 0.25–0.89; p=0.023).

To account for the baseline differences in illness severity, a prespecified multivariable logistic regression model was performed (Table 3). After adjusting for age, APACHE II score, and mechanical ventilation, the association between windowed ICU status and lower delirium risk was attenuated and no longer reached statistical significance (adjusted OR 0.44, 95% CI 0.17–1.18; p=0.105). In this model, advancing age (adjusted OR 1.045 per year; p=0.032) and higher APACHE II scores (adjusted OR 1.095 per point; p=0.038) remained independent risk factors for delirium.

Sensitivity analyses balancing all observed baseline covariates through propensity score methods (inverse probability of treatment weighting, doubly robust estimation, and 1:1 matching) yielded effect estimates closely approaching the null (OR range ≈ 0.93–1.01). This indicates that the apparent protective effect in the unadjusted analysis was largely driven by the baseline imbalance in illness severity between the two units.

Delirium Burden and Timing

Across the full cohort, the absolute number of delirium days was significantly lower in the windowed group (median 0 [IQR 0–0] vs. 0 [IQR 0–1]; p=0.021). The proportion of CAM-ICU-positive days among all evaluable patient-days was 9.2% (23/250) in the windowed ICU versus 19.4% (50/258) in the windowless ICU (p=0.020). However, among the 33 patients who actually developed delirium, the median duration of the delirium episode did not differ significantly between the groups (2.0 days [IQR 1.8–3.2] windowed vs. 2.0 days [IQR 1.0–3.0] windowless; p=0.638). Furthermore, the median day of first CAM-ICU positivity among affected patients was identical (day 3) in both groups. The cumulative incidence of delirium over the 7-day follow-up period was significantly higher in the windowless group (56.0%) compared to the windowed group (25.8%) (log-rank test $\chi^2 = 7.33$; $p = 0.007$; Figure 2).

Regarding motor subtypes among delirious patients, the hyperactive phenotype (RASS > 0) was the most frequently observed subtype in the windowless ICU (16/23, 69.6%). In the windowed ICU, hyperactive (4/10, 40.0%) and hypoactive (4/10, 40.0%) phenotypes were observed at equal frequencies.

Secondary Clinical Outcomes

There was no significant difference between the windowless and windowed ICUs in terms of median ICU length of stay (5 vs. 6 days; p=0.879) or ICU mortality (18.9% vs. 12.2%; OR 1.67, 95% CI 0.56–4.99; p=0.518).

Delirium occurrence, irrespective of the ICU type, was strongly associated with adverse clinical outcomes. Patients who developed delirium had a significantly longer ICU stay (7 vs. 4 days; p=0.020) and a higher unadjusted mortality rate (30.3% vs. 8.7%; p=0.012). In an exploratory multivariable model adjusting for baseline APACHE II scores, the absolute number of delirium days (delirium burden) remained an independent predictor of ICU mortality (Table 3). Each additional day of delirium was associated with an increased odds of death (adjusted OR 1.56, 95% CI 1.04–2.34; p=0.030), demonstrating that delirium duration contributes to mortality regardless of initial disease severity.

Discussion

In this prospective observational cohort study, we investigated the association between admission to a windowed versus a windowless ICU and the development of incident delirium. Our crude analysis revealed that patients in the windowed ICU had a significantly lower incidence of delirium compared to those in the windowless ICU (20.4% vs. 43.4%). However, patients admitted to the windowless ICU

presented with significantly higher baseline severity of illness scores (APACHE II and SOFA). When rigorously adjusted for these baseline imbalances using multivariable logistic regression and propensity-score-based sensitivity analyses, the protective effect of the windowed environment was substantially attenuated and did not reach statistical significance. Importantly, regardless of the ICU environment, the duration of delirium (delirium burden) remained an independent predictor of ICU mortality.

Our unadjusted findings align with the results of Lee et al., who reported a lower incidence of delirium in windowed ICU rooms in a retrospective cohort [12]. However, our confounder-adjusted analyses paint a more nuanced picture, consistent with the prospective findings of Smonig et al. [13]. They found that natural light exposure did not significantly reduce the overall incidence of delirium in invasively ventilated patients, although it did reduce the frequency of hyperactive symptoms requiring antipsychotics. In our study, while the overall adjusted incidence did not differ significantly, we observed a descriptive shift in motor subtypes: the hyperactive phenotype was less predominant in the windowed ICU (40.0% vs. 69.6% in the windowless ICU). This suggests that while natural light may not entirely prevent the onset of delirium—which is heavily driven by acute illness severity and baseline vulnerability—it might modulate the clinical phenotype, potentially by providing circadian cues that mitigate extreme agitation.

The attenuation of the protective effect in our adjusted models highlights a critical methodological challenge in environmental ICU research: confounding by indication or structural allocation bias. In real-world ICU settings, patients with higher illness severity (e.g., those requiring closer nursing proximity or continuous central monitoring) may be disproportionately admitted to windowless areas depending on the unit's architectural layout. Our propensity-score analyses—which yielded estimates closely approaching the null when all observed baseline covariates were balanced—strongly indicate that the crude association was largely driven by these baseline imbalances rather than an independent causal effect of natural light.

Furthermore, we found no independent association between daily variations in routine laboratory parameters (e.g., glucose, CRP, lactate) and incident delirium when evaluated through a generalized estimating equations (GEE) framework. While neuroinflammation and metabolic stress are core components of delirium pathophysiology, our data suggest that these routine systemic markers do not reliably predict daily delirium onset independently of age and overall illness severity (APACHE II).

Despite the lack of an independent association between the windowed environment and delirium incidence, our study reaffirms the profound clinical impact of delirium. We demonstrated that the absolute number of delirium days was independently associated with an increased risk of ICU mortality, even after adjusting for the baseline APACHE II score. This emphasizes that while modifying the physical environment alone may not be sufficient for delirium prevention, comprehensive, multicomponent strategies (such as the ABCDEF bundle) aiming to reduce the duration of delirium episodes remain vital for improving patient survival [5].

Our study has several limitations. First, the non-randomized bed allocation resulted in baseline imbalances, particularly in illness severity. While we employed robust propensity-score methods to

mitigate this, unmeasured confounders cannot be entirely excluded. Second, we defined the exposure structurally (presence of a window) and did not objectively measure ambient light intensity at the patient's eye level. Factors such as bed-to-window distance and patient eye-opening state modulate the true biological effect of light. Third, our sample size of 102 patients and the limited number of delirium events (n = 33) may have restricted the statistical power to detect smaller independent protective effects. Finally, our follow-up was limited to the first seven days of the ICU stay, capturing the acute phase but potentially missing late-onset episodes.

Conclusions

In this prospective cohort study, admission to a windowed ICU was associated with a markedly lower unadjusted incidence of delirium; however, this association was largely explained by baseline imbalances in illness severity. Confounder-balanced analyses did not support an independent protective effect of the windowed environment on delirium incidence. Nevertheless, the duration of delirium remained an independent predictor of ICU mortality. Larger, randomized, or better-balanced multicenter studies incorporating objective light measurements are required to clarify the precise role of natural light in modulating ICU delirium.

Declarations

- **Ethics approval and consent to participate:** The study was approved by the Non-Interventional Clinical Research Ethics Committee of the University of Health Sciences Haydarpaşa Numune Training and Research Hospital (Approval No: HNEAH-GOAEK/KK/2026/5, dated January 6, 2026). Written informed consent was obtained from all patients or their legally authorized representatives.
- **Consent for publication:** Not applicable.
- **Availability of data and materials:** All data supporting the findings of this study are available on paper. Additional detailed datasets analyzed during the current study are available from the corresponding author on reasonable request.
- **Competing interests:** The authors declare that they have no competing interests.
- **Funding:** This research received no external funding.
- **Authors' contributions:** Y.S. contributed to study conception and design, data collection, and drafted the manuscript. S.Ş. contributed to the study design, supervised the study, and critically revised the manuscript. O.E. contributed to the study design, data interpretation, and manuscript revision. All authors read and approved the final manuscript.
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Tables

Table 1. Baseline Characteristics According to ICU Window Status

Characteristic	Windowless ICU (n=53)	Windowed ICU (n=49)	p-value
Age, years, median [IQR]	73.0 [63.0–77.0]	67.0 [57.0–76.0]	0.241
Male sex, n (%)	27 (50.9%)	29 (59.2%)	0.524
Body mass index, kg/m², mean ± SD	26.4 ± 5.5	27.1 ± 5.2	0.505
Postoperative admission, n (%)	13 (24.5%)	16 (32.7%)	0.491
Comorbidities, n (%)			
Hypertension	31 (58.5%)	31 (63.3%)	0.771
Diabetes mellitus	17 (32.1%)	16 (32.7%)	1.000
Chronic obstructive pulmonary disease	15 (28.3%)	9 (18.4%)	0.343
Chronic kidney disease	6 (11.3%)	7 (14.3%)	0.880
Heart failure/coronary artery disease	19 (35.8%)	20 (40.8%)	0.755
Previous stroke	4 (7.5%)	5 (10.2%)	0.735
Malignancy	24 (45.3%)	21 (42.9%)	0.963
Severity of Illness			
SOFA score, median [IQR]	**4.0 [2.0–6.0]**	**3.0 [2.0–5.0]**	**0.016**
APACHE II score, median [IQR]	**14.0 [11.0–21.0]**	**12.0 [8.0–16.0]**	**0.009**
Mechanical ventilation on day 1, n (%)	**30 (56.6%)**	**16 (32.7%)**	**0.026**

Abbreviations: APACHE II, Acute Physiology and Chronic Health Evaluation II; ICU, intensive care unit; IQR, interquartile range; SD, standard deviation; SOFA, Sequential Organ Failure Assessment. P-values < 0.05 are presented in bold.

Table 2. Incident Delirium and Secondary Clinical Outcomes

Outcome	Windowless ICU (n=53)	Windowed ICU (n=49)	Odds Ratio (95% CI)*	p-value
Incident delirium, n (%)	**23 (43.4%)**	**10 (20.4%)**	**0.33 (0.14–0.81)**	**0.023**
Delirium burden (full cohort), median [IQR]	**0.0 [0.0–1.0]**	**0.0 [0.0–0.0]**	—	**0.021**
CAM-ICU positive days, n/N (%)	**50/258 (19.4%)**	**23/250 (9.2%)**	—	**0.020**
Delirium duration (among affected patients), median [IQR]	2.0 [1.0–3.0]	2.0 [1.8–3.2]	—	0.638
Day of first delirium (among affected patients), median	3.0	3.0	—	0.371
ICU length of stay (days), median [IQR]	5.0 [3.0–9.0]	6.0 [3.0–8.0]	—	0.879
ICU mortality, n (%)	10 (18.9%)	6 (12.2%)	0.60 (0.20–1.80)	0.518

**Odds ratio is for Windowed vs. Windowless ICU. P-values < 0.05 are presented in bold.*

Table 3. Multivariable Logistic Regression Models for Incident Delirium and ICU Mortality

Model and Covariates	Adjusted Odds Ratio (95% CI)	p-value
Model 1: Incident Delirium (n=102, 33 events)		
Windowed ICU (ref: Windowless)	0.44 (0.17–1.18)	0.105
Age (per 1-year increase)	**1.045 (1.00–1.09)**	**0.032**
APACHE II (per 1-point increase)	**1.095 (1.01–1.19)**	**0.038**
Mechanical ventilation on day 1	1.76 (0.76–4.06)	0.187
Model 2: ICU Mortality (n=102, 16 events)		
APACHE II (per 1-point increase)	**1.14 (1.03–1.27)**	**0.010**
Delirium burden (per additional delirium day)	**1.56 (1.04–2.34)**	**0.030**

Abbreviations: APACHE II, Acute Physiology and Chronic Health Evaluation II; CI, confidence interval; ICU, intensive care unit. P-values < 0.05 are presented in bold.

Figures

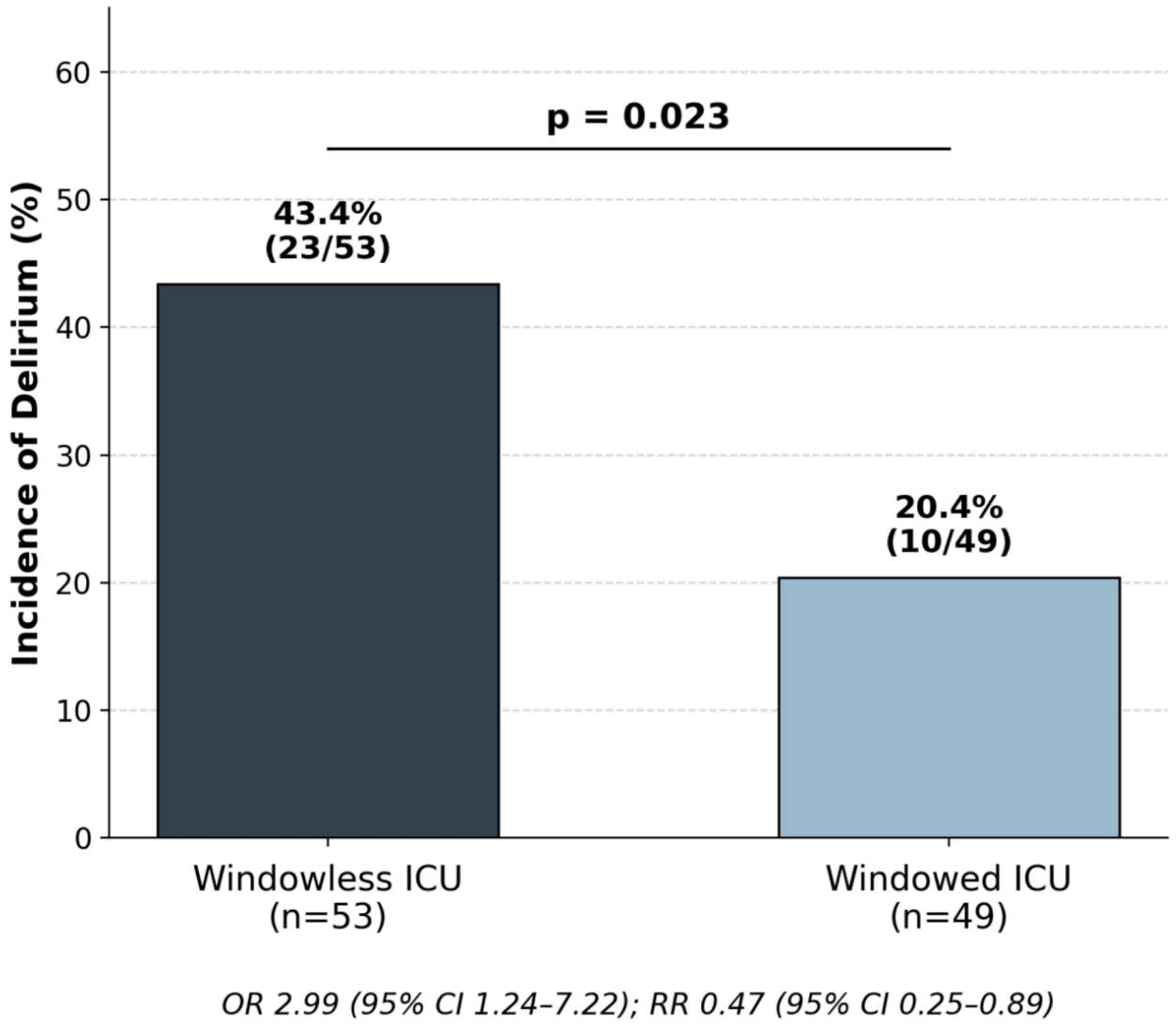


Figure 1

Incidence of delirium in the windowless and windowed ICU cohorts. The unadjusted incidence of delirium was significantly higher in the windowless group (43.4%) compared to the windowed group (20.4%) (OR 2.99, 95% CI 1.24–7.22; RR 0.47, 95% CI 0.25–0.89; p = 0.023).

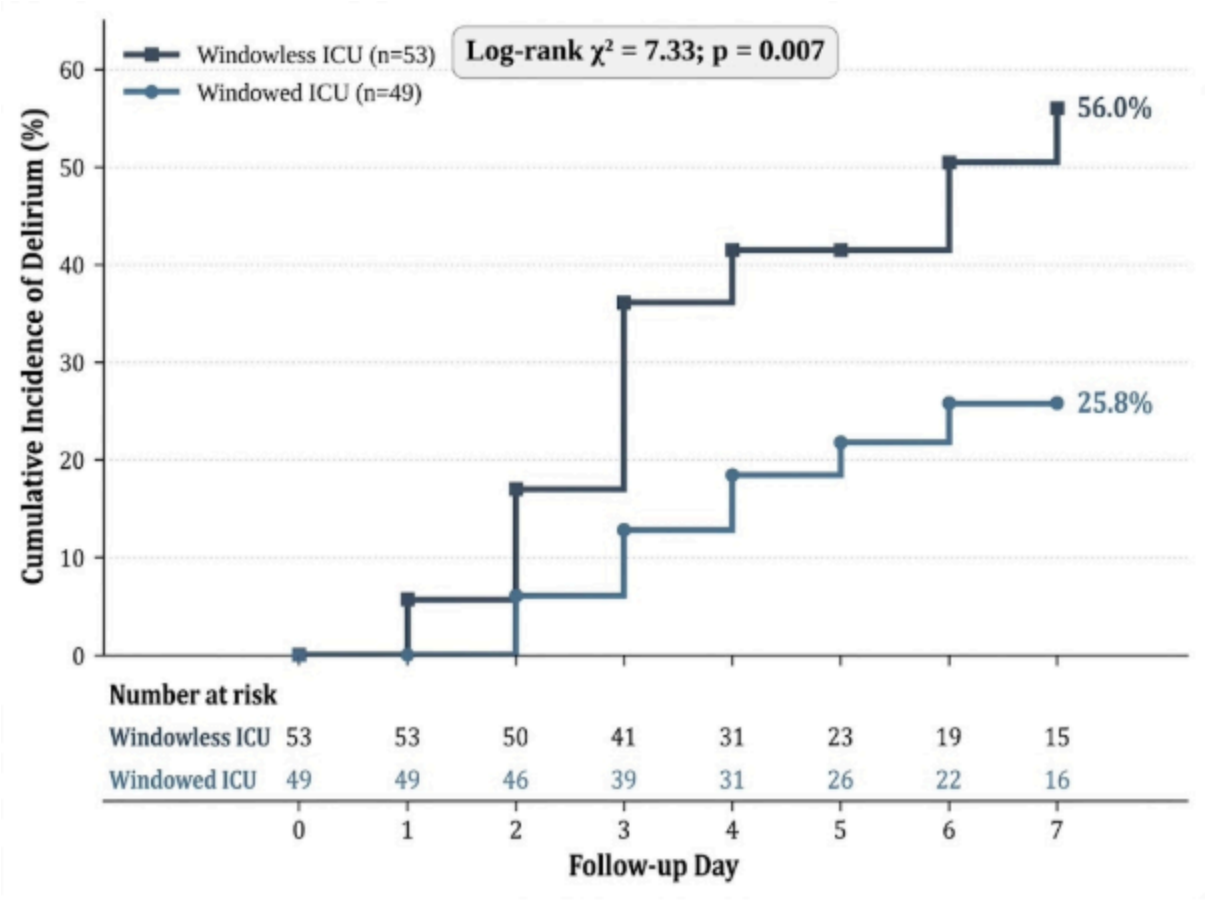


Figure 2

Kaplan-Meier estimates the cumulative incidence of delirium over the 7-day follow-up period in the windowless and windowed ICU cohorts. The cumulative incidence at day 7 was 56.0% in the windowless group and 25.8% in the windowed group (log-rank test $\chi^2 = 7.33$; $p = 0.007$).