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Comparing single-patient and multi-patient room intensive care units: a multicenter cohort study on architectural differences and clinical significance in South Korea

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Background: The design of intensive care units (ICUs) is increasingly acknowledged as a crucial factor affecting patient outcomes. Transitioning from multi-bed patient rooms (MPRs) to single-bed patient rooms (SPRs) aims to improve infection control, patient privacy, and quality of care. However, concerns remain regarding potential patient isolation and reduced staff situational awareness. This study aims to evaluate clinical outcomes in SPR-structured ICUs compared to mixed SPR and MPR ICUs.

Methods: This multicenter retrospective cohort study was conducted across three university-affiliated tertiary hospitals between April 2022 and August 2023. The study population included ICU patients aged ≥18 years, excluding those admitted to cardiac and neonatal ICUs. Outcomes assessed included ICU mortality and severity scores based on Simplified Acute Physiology Score 3 and Acute Physiology and Chronic Health Evaluation II scores.

Results: This study included 3,179 ICU patients across three sites: site A consisted exclusively of SPRs, while sites B and C had mixed SPR and MPR arrangements. ICU mortality rates were 8.3%, 15.2%, and 9.7% for sites A, B, and C, respectively (P<0.001). Propensity score matching and logistic regression analysis demonstrated that SPRs were associated with significantly reduced ICU mortality (adjusted odds ratio, 0.54; 95% CI, 0.40–0.73).

Conclusions: SPRs were associated with a protective effect, reducing ICU mortality. Clinical outcomes in ICUs appear to be influenced by structural design improvements alongside other clinical factors.

Key Words: communicable disease control; hospital design and construction; hospital mortality; intensive care units; patient safety

Original Article

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INTRODUCTION

The design of intensive care units (ICUs) is increasingly recognized as a critical factor influencing patient outcomes. In recent years, evidence-based design has driven significant changes in ICU architecture, most notably the transition from multi-bed patient rooms (MPRs) to single-bed patient rooms (SPRs) [1,2]. This shift has been motivated by the potential benefits of SPRs, such as reduced nosocomial infections, improved patient privacy, and enhanced family involvement [2,3]. Various studies have explored the relationship between ICU design and patient outcomes, emphasizing the significant impact of architectural features on mortality and morbidity rates. For example, Leaf et al. [4] demonstrated that ICU rooms with high visibility from nursing stations were associated with lower patient mortality, highlighting the critical role of direct patient observation. This finding suggests that improved visibility in SPRs may facilitate faster detection of clinical deterioration and prompt interventions. Notably, the transition to SPRs has been associated with various advantages for both the healthcare system and patients. For instance, SPR design has been associated with lower rates of delirium among ICU patients, a key factor in improving patient outcomes and reducing the length of hospital stays [5]. From a cost perspective, Sadatsafavi et al. [3] demonstrated that the financial savings from reduced nosocomial infections in SPRs significantly outweigh the increased construction and operational costs.

However, concerns have been raised regarding the potential drawbacks of SPRs, such as increased patient isolation, which can complicate care coordination and monitoring. Additionally, the physical separation inherent to SPRs may impair situational awareness among staff, leading to delayed response in emergencies [1,4,6]. Interestingly, Pettit et al. [7] reported that in certain patient populations, such as trauma patients, ICU room placement did not significantly affect mortality rates after adjusting for patient acuity. Notably, before statistical adjustment, patients assigned to high-visibility rooms had higher mortality rates than those in low-visibility rooms.

In recent years, the introduction of SPR-ICUs in South Korea has marked a departure from traditional MPR-ICUs [8]. However, in South Korea, few studies have examined the long-term operation of SPR-ICUs staffed by dedicated intensivists. Jung et al. [9] reported a reduction in infection rates following the remodeling of a mixed-room ICU into an SPR-ICU. However, differences in baseline characteristics between the pre- and post-renovation groups complicate the interpretation of these findings. Therefore, it is essential to evaluate and report the clinical outcomes associated with ICU design changes. This study aims to assess the clinical improvements observed in newly implemented SPR-structured ICUs compared to traditional MPR-ICUs.

KEY MESSAGES

- Transitioning from multi-patient rooms to single-bed patient rooms (SPRs) in intensive care units (ICUs) can reduce patient mortality.
- This study found a 46% reduction in ICU mortality after adjusting for patient severity.
- This study highlights the need for healthcare policies that prioritize ICU designs incorporating SPRs.
- These designs should also focus on enhancing staff visibility, optimizing workflows, and ensuring adequate staffing for high-quality care.

MATERIALS AND METHODS

Study Design and Population

This multicenter retrospective cohort study was approved by the Institutional Review Boards (IRBs) of the three university-affiliated tertiary hospitals in South Korea (site A: 2310-115-119; site B: 2023-11-012; site C: 2023-12-005). The requirement for informed consent was waived due to the noninterventional nature of the study. The study included patients aged ≥18 years who were admitted to the ICU and was conducted between April 2022 and August 2023. However, patients in the cardiac ICU (CICU), which operates independently, were excluded from the study population. CICU manages patients undergoing coronary interventions, leading to high patient turnover and distinct clinical profiles. Additionally, patients requiring extracorporeal membrane oxygenation (ECMO) were managed separately based on ECMO modality; specifically, patients receiving veno-arterial ECMO were primarily admitted to the surgical ICU (SICU) and managed by thoracic surgeons, while patients undergoing veno-venous ECMO were managed in the medical ICU (MICU) jointly by pulmonologists and thoracic surgeons in participating hospitals. Study sites A, B, and C are located in Gyeonggi Province, Seoul, and Jeju Province, respectively. All hospitals had a capacity of approximately 700 beds. The ICU at Site A consisted of 10 MICU beds and 10 SICU beds, expandable to 30 beds. During the study period, only 20 beds were in use, as the hospital has been operational for less than 3 years. The MICU and SICU were structurally connected, allowing for flexible bed allocation during shortages. All ICU beds at Site A were SPRs, with two negative pressure isolation rooms, each equipped with an anteroom. Four nursing stations were strategically placed along the SPRs, each supported by dedicated nursing carts and computers for optimal visual and auditory monitoring of patients within the SPRs. The ICU at Site B comprised 35 beds catering to both medical and surgical patients. All beds were in a single consolidated ICU without formal subdivisions, facilitating multidisciplinary care and flexible bed allocation during shortages. Of these 35 beds, four were specialized SPRs with negative pressure isolation equipment with anterooms, while three were general-type SPRs. The remaining beds were arranged in MPRs and organized around central support areas and nursing stations, creating a unified and efficient design. The ICU at Site C consisted of 12 beds designated for the SICU and 19 beds for the MICU, including three negative-pressure isolation SPRs and five general SPRs. Site C provided a structurally distinct layout, with the SICU and MICU functionally and physically separated by walls. This layout may enhance both infection control and workflow by creating distinct zones for each unit, minimizing cross-contamination risks and allowing specialized care for surgical and medical patients. The structural separation ensures independent operation for each unit, with dedicated nursing stations and support areas.

Data Collection, Endpoints, and Statistical Analysis

Patient characteristics were obtained from electronic medical records by the medical records management department under the approval of the IRB of each institute. The following variables were analyzed: length of hospital and ICU stay, nurse-to-patient ratio, physician-to-patient ratio, number of patients who received continuous renal replacement therapy, number of patients treated with mechanical ventilator support, number of patients who underwent tracheostomy performed either at ICU admission or during the ICU stay, as well as severity scores (Simplified Acute Physiology Score [SAPS] 3 and Acute Physiology and Chronic Health Evaluation [APACHE] II score) [10-12], and mortality rates. The primary endpoints were ICU and in-hospital mortality. Secondary endpoints included patient severity scores, staffing ratios, trends in therapeutic interventions, and the distribution of patients in SPRs or MPRs during their ICU stay. Patients who moved between SPRs and MPRs within the same ICU were grouped under the MPR category.

Continuous variables were analyzed using either the Student t-test or the Mann-Whitney test, as appropriate. Categorical variables were evaluated using Pearson's chi-square test or Fisher's exact test, as appropriate. Differences in infection rates across the three sites were assessed using analysis of variance [13]. To reduce confounding effects in group comparisons, propensity score matching (PSM) analysis [14] was performed using the nearest neighbor matching algorithm with a caliper of 0.1. Matching variables included age, sex, hospital and ICU length of stay, mode of admission, pre-ICU location and reason for admission, tracheostomy procedure, application of mechanical ventilator or continuous renal replacement therapy, and patient severity. Multivariable logistic regression [15] was applied to estimate the odds of mortality based on patient severity scores or room type. All statistical analyses were conducted using R (R Core Team [2023], R: a language and environment for statistical computing; R Foundation for Statistical Computing), with P-value <0.05 considered statistically significant.

RESULTS

Characteristics of the Study Population

A total of 3,671 patients were admitted to the ICU and screened between April 2022 and August 2023. Among them, 404 patients admitted to the CICU were excluded. Similarly, 42 patients aged <18 years who were admitted to the ICU were excluded. Additionally, 46 patients who were readmitted to the ICU after undergoing surgery, identified as duplicates, were removed during data verification. Thus, a total of 3,179 patients were included in the final analysis (Figure 1). The distribution across the three study sites was as follows: 901 patients from site A (54.5% of male), 1,989 patients from site B (42.3% of male), and 289 patients from site C (35.3% of male). At Site A, the ICU had 66 nurses assigned to 20 beds during the study period, resulting in a nurse-to-patient ratio of approximately 3:1. The unit was staffed by five dedicated intensivists, including two pulmonologists, a surgeon-intensivist, an emergency medicine specialist, and an anesthesiologist. site B, with 35 beds, was staffed by 76 nurses, yielding a nurse-to-patient ratio of approximately 2:1. The ICU was supported by two dedicated intensivists: one pulmonologist and one emergency medicine specialist. At site C, the ICU comprised 12 SICU and 19 MICU beds, each staffed by 36 nurses. The nurse-to-patient ratio was 3:1 in the SICU and approximately 1.9:1 in the MICU. The

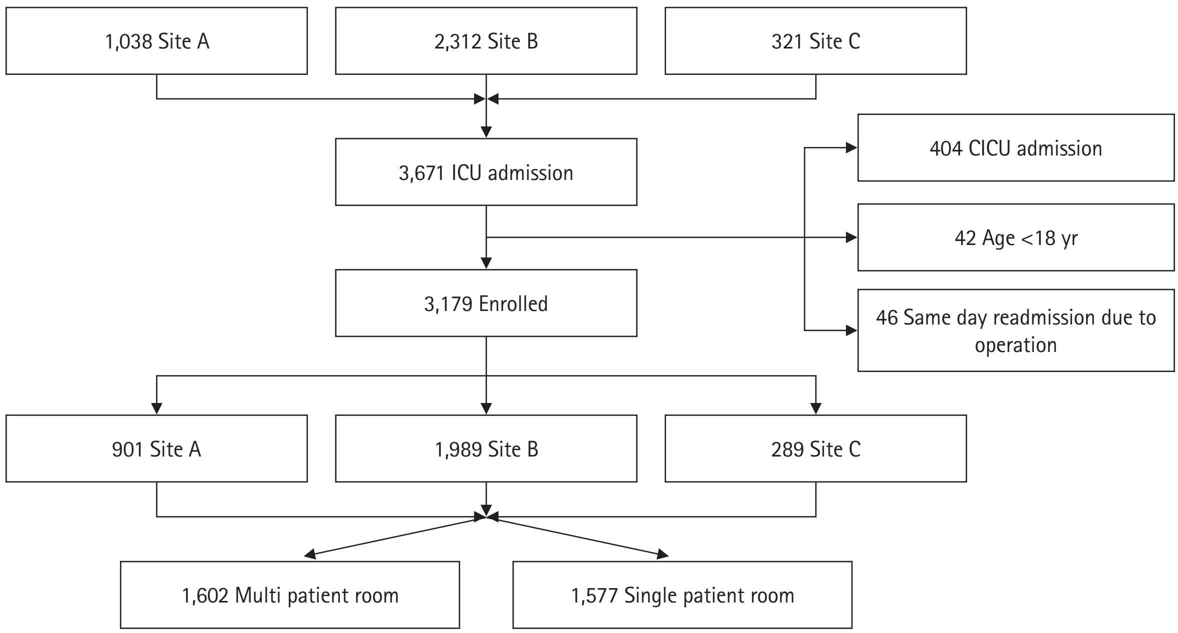

Figure 1. Flowchart diagram. ICU: intensive care unit; CICU: cardiac ICU.

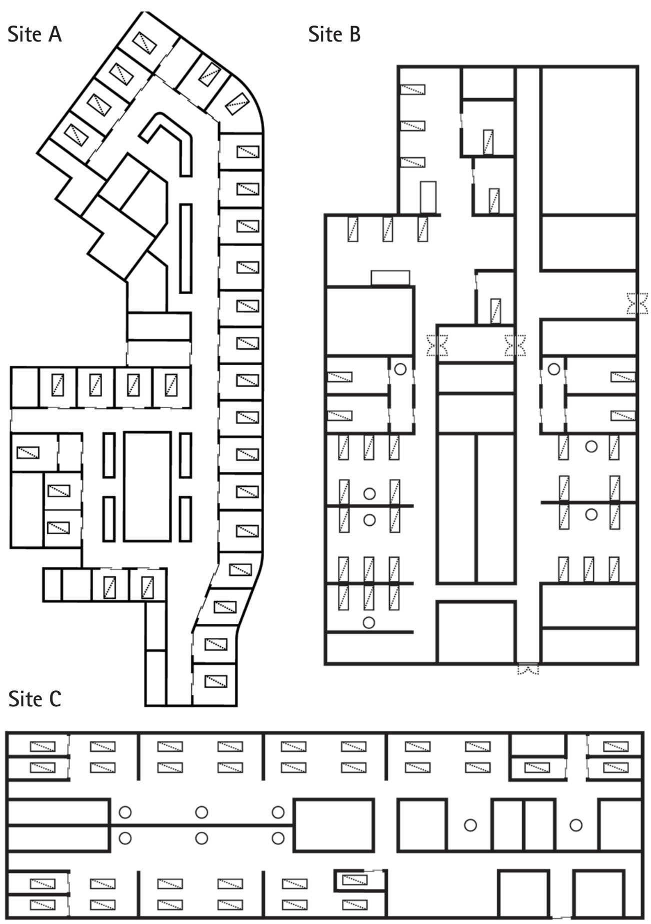

Figure 2. Floor plan of study sites A, B, and C.

MICU is operated as a closed unit [16] and overseen by two intensivists, a pulmonologist and a neurologist. In contrast, the SICU had no dedicated intensivists. The clinical departments differed among the groups: site B featured a dedicated Department of Critical Care Medicine, which was not present at sites A and C. At site C, all patients admitted to the MICU were categorized under “internal medicine,” functioning as an internal equivalent to the Department of Critical Care Medicine.

The median age of the patients was 69 years at sites A and B (interquartile range [IQR]: 59–80 and 58–79, respectively) and 64 years at site C (IQR: 52–77). All patients at Site A were admitted to SPRs, whereas 645 patients (32.43%) at site B and 30 (10.38%) patients at site C were placed in SPRs. Site C had a younger patient population, and a higher proportion of females compared to the other sites. The APACHE II scores for sites A, B, and C were 13 (7–19), 16 (8–23), and 11 (6–17), respectively, while SAPS 3 scores were 53 (44–62), 50 (34–68), and 38 (30–46), respectively. The floor plans of the ICUs at sites A, B, and C are shown in Figure 2. Additional demographic data and exploratory outcomes across the study sites are presented in Table 1.

Patients were further divided into two groups based on ICU room type: SPR (n=1,577) and MPR (n=1,602). When divided into the MPR and SPR groups, significant differences in baseline characteristics were still observed between the two groups across various variables (Table 2). The APACHE II score was

Table 1. Demographics of the study population according to the study sites

Variable	Site A (n=901)	Site B (n=1,989)	Site C (n=289)	P-value
Age (yr)	69 (59–80)	69 (58–79)	64 (52–77)	0.001
Sex (male)	491 (54.5)	841 (42.3)	102 (35.3)	<0.001
Hospital day	15 (9–27)	15 (9–29)	13 (9–20)	0.049
ICU stay (hr)	45 (21–114)	52 (23–141)	62 (36–120)	<0.001
Planned admission	277 (30.8)	1,239 (62.3)	49 (17.0)	<0.001
MV	301 (33.4)	434 (21.8)	76 (26.3)	<0.001
CRRT	83 (9.2)	172 (8.7)	21 (7.2)	0.591
Location before ICU				<0.001
ED	428 (47.6)	694 (34.9)	192 (66.4)	
General ward	452 (50.2)	1,270 (63.9)	97 (33.6)	
Other ICU	20 (2.2)	25 (1.2)	0	
Tracheostomy				<0.001
Not performed	842 (93.4)	1,864 (93.7)	273 (94.5)	
PDT	50 (5.6)	58 (2.9)	16 (5.5)	
Surgical	9 (1.0)	67 (3.4)	0	
Room type				<0.001
SPR	901 (100)	645 (32.4)	31 (10.7)	
MPR	0	1,344 (67.6)	258 (89.3)	
Reason of admission				-
Postoperative	345 (38.3)	1,416 (71.2)	49 (17.0)	
Respiratory distress	136 (15.1)	292 (14.7)	48 (16.6)	
Septic shock	134 (14.9)	122 (6.1)	53 (18.3)	
Unstable arrhythmia	12 (1.3)	22 (1.1)	43 (14.9)	
Altered mentality	111 (12.3)	46 (2.3)	36 (12.5)	
Trauma	33 (3.7)	17 (0.9)	39 (13.5)	
Others	130 (14.4)	74 (3.7)	21 (7.3)	

Values are presented as median (interquartile range) or number (%).
ICU: intensive care unit; MV: mechanical ventilation; CRRT: continuous renal replacement therapy; ED: emergency department; PDT: percutaneous dilatational tracheostomy; SPR: single-bed patient room; MPR: multi-bed patient room.

15 (7–22) for the MPR group and 14 (8–21) for the SPR group. Similarly, the SAPS 3 scores for the MPR and SPR groups were 47 (33–67) and 51 (40–63), respectively

Primary Endpoints

The primary outcomes assessed were in-hospital and ICU mortality rates. The in-hospital mortality rate for patients admitted to site A was 13.1% (118 out of 901 patients), while site B reported a significantly higher rate of 21.5% (427 out of 1,989 patients). Similarly, site C showed an elevated in-hospital mortality rate of 18.0% (52 out of 289 patients). Regarding ICU mortality, site A had a rate of 8.3% (75 out of 901 patients), whereas site B had a substantially higher rate of 15.2% (303 out of 1,989 patients). Site C reported an ICU mortality rate of 9.7% (28 out of 289 patients). The differences in in-hospital and ICU mortality rates between the sites were statistically significant (P<0.001). When comparing the MPR and SPR groups, the in-hospital mortality rate for patients admitted to MPRs was 23.3% (374 out of 1,602 patients). In contrast, the mortality rate for patients at SPRs was significantly lower at 14.1% (223 out of 1,577 patients, P<0.001). Similarly, the ICU mortality rates were 16.9% (270 out of 1,602 patients) and 8.6% (136 out of 1,577 patients, P<0.001) for patients admitted to MPRs and SPRs, respectively.

Additional Statistical Analysis

Using PSM, the two groups were matched in a 1:1 ratio, resulting in 1,183 patients in each matched group. The standardized mean differences for all variables, including APACHE II and SAPS 3 scores, were below 0.1, indicating balanced matching (Table 3). Following PSM, the ICU mortality rate for patients admitted to the matched MPR group

Table 2. Demographics of the study population according to the type of room

Variable	MPR (n=1,602)	SPR (n=1,577)	P-value
Age (yr)	69 (56–79)	69 (58–79)	0.035
Sex (male)	682 (42.6)	752 (47.7)	0.004
Hospital day	14 (8–26)	16 (9–29)	0.005
ICU stay (hr)	54 (23–139)	48 (22–120)	0.007
Planned admission	879 (54.9)	686 (43.5)	<0.001
MV	379 (23.7)	432 (27.3)	0.018
CRRT	138 (8.6)	138 (8.8)	0.941
Location before ICU			0.002
ED	623(38.9)	691 (43.8)	
General ward	962 (60.0)	857 (54.4)	
Other ICU	17 (1.1)	28 (1.8)	
Tracheostomy			0.297
Not performed	1,509 (94.2)	1,470 (93.2)	
PDT	54 (3.4)	70 (4.4)	
Surgical	39 (2.4)	37 (2.3)	
Reason of admission			-
Postoperative	995 (62.1)	815 (51.7)	
Respiratory distress	255 (15.9)	221 (14.0)	
Septic shock	119 (7.4)	190 (12.0)	
Unstable arrhythmia	47 (2.9)	30 (1.9)	
Altered mentality	67 (4.2)	126 (8.0)	
Trauma	46 (2.9)	43 (2.7)	
Others	73 (4.6)	152 (9.6)	

Values are presented as median (interquartile range) or number (%).
MPR: multi-bed patient room; SPR: single-bed patient room; ICU: intensive care unit; MV: mechanical ventilation; CRRT: continuous renal replacement therapy; ED: emergency department; PDT: percutaneous dilatational tracheostomy.

was 15.4% (182 out of 1,183 patients), compared to 8.5% (100 out of 1,183 patients) in the matched SPR group, demonstrating a statistically significant difference (P<0.001). Similarly, the in-hospital mortality rate was significantly higher in the matched MPR group at 21.8% (258 out of 1,183 patients) compared to 13.7% (162 out of 1,183 patients) in the matched SPR group, with statistical significance maintained (P<0.001) (Table 4). After PSM, logistic regression analysis was performed to assess whether ICU architecture (SPR vs. MPR) was a significant predictor of mortality when controlling for bias from patient severity. After adjusting for APACHE II and SAPS 3 scores, SPR showed an adjusted odds ratio of 0.54 (95% CI, 0.40–0.73) for ICU mortality (Table 5, Figure 3) and 0.56 (95% CI, 0.43–0.72) for in-hospital mortality.

DISCUSSION

The study highlighted potential clinical improvements in SPR-structured ICUs compared to MPRs. Jung et al. [9] found that room privatization in ICUs significantly reduced the incidence of clinical infections, including bacteremia and pneumonia. This underscores the importance of consulting infection control specialists to determine the appropriate number of isolation rooms. During the coronavirus disease 2019 (COVID-19) pandemic, discussions in South Korea emphasized the need for appropriate isolation structures in ICUs [17]. Although the country had previously dealt with the Middle East Respiratory Syndrome outbreak [18], those cases were largely concentrated in a few medical facilities. In contrast, COVID-19 revealed the need for adequate isolation infrastructure across healthcare institutions nationwide. The pandemic also initiated discussions regarding the design of single-patient isolation rooms, addressing challenges such as limited isolation spaces, resource constraints, and patient transfer difficulties required for maintaining isolation [19,20]. At the time, no ICUs in South Korea were composed entirely of SPRs. However, some hospitals began operating single-patient isolation rooms as a prototype for SPRs, leading to the adoption of SPR-based designs for ICUs in newly constructed hospitals.

To assess nosocomial infections at each facility using the Korean National Healthcare-associated Infection Surveillance System [21] criteria, data were requested from infection control departments. However, access to detailed patient-specific nosocomial infection data, including cases involving multidrug-resistant organisms, was restricted in two hospitals due to legal concerns surrounding patient privacy and data security. These restrictions limited the depth of analysis on individual patient outcomes, highlighting the challenges of retrospective infection surveillance research in a legally constrained environment.

Adequate staffing is a critical factor in delivering effective patient care. Various studies have highlighted the significant impact of nursing staff and intensivists on ICU mortality rates. The Society of Critical Care Medicine Taskforce on ICU staffing [22] emphasized that adequate intensivist staffing is crucial for ensuring the quality of patient care and safety, as well as supporting education and staff well-being. They further cautioned that high staff turnover or declining care quality may indicate overworked personnel, underscoring the need to monitor intensivist-to-patient ratios to prevent burnout. Similarly, Lee et al. [23] demonstrated that optimal nurse-to-patient and

Table 3. Demographics of the study population after propensity score matching

Variable	MPR (matched) (n=1,183)	SPR (matched) (n=1,183)	P-value	SMD
Age (yr)	67±15	68±15	0.521	0.026
Sex (male)	527 (44.5)	531 (44.9)	0.901	0.007
Hospital day	23.1±27.1	24.0±26.2	0.380	0.036
ICU stay (hr)	124.9±216.7	118.3±201.9	0.444	0.031
Planned admission	604 (51.1)	605 (51.1)	1.000	0.002
MV	291 (24.6)	209 (26.1)	0.826	0.025
CRRT	94 (7.9)	82 (6.9)	0.422	0.035
Location before ICU			0.389	0.039
ED	480 (40.6)	475 (40.2)		
General ward	687 (58.1)	695 (58.7)		
Other ICU	16 (1.4)	13 (1.1)		
Tracheostomy			0.904	0.019
Not performed	1,109 (93.7)	1,110 (93.8)		
PDT	44 (3.7)	49 (3.9)		
Surgical	30 (2.5)	27 (2.3)		
Reason of admission			0.953	0.052
Postoperative	725 (61.3)	710 (60.0)		
Respiratory distress	191 (16.1)	186 (15.7)		
Septic shock	116 (9.8)	124 (10.5)		
Unstable arrhythmia	28 (2.4)	29 (2.5)		
Altered mentality	66 (5.6)	78 (6.6)		
Trauma	36 (3.0)	34 (2.9)		
Others	21 (1.8)	22 (1.9)		
APACHE II score	15.0±8.9	15.0±8.7	0.838	0.008
SAPS 3	52.4±22.0	52.4±18.3	0.921	0.004

Values are presented as mean±standard deviation or number (%).
MPR: multi-bed patient room; SPR: single-bed patient room; SMD: standardized mean difference; ICU: intensive care unit; MV: mechanical ventilation; CRRT: continuous renal replacement therapy; ED: emergency department; PDT: percutaneous dilatational tracheostomy; APACHE: Acute Physiology and Chronic Health Evaluation; SAPS: Simplified Acute Physiology Score.

Table 4. Mortality rates according to the type of room after propensity score matching

	MPR (matched) (n=1,183)	SPR (matched) (n=1,183)	P-value
In-hospital mortality	258 (21.8)	162 (13.7)	<0.001
ICU mortality	182 (15.4)	100 (8.5)	<0.001

Values are presented as number (%).
MPR: multi-bed patient room; SPR: single-bed patient room; ICU: intensive care unit.

intensivist-to-patient ratios significantly reduce ICU mortality. Additionally, a study conducted across 69 ICUs in the United States [24] found that lower bed-to-nurse ratios were associated with decreased annual ICU mortality rates.

ICU design also significantly influences organizational efficiency and clinical outcomes. Guidelines [25] emphasize the importance of creating a healing environment by addressing factors such as noise control, natural lighting, ergonomic design, and infection control. However, SPR may inadvertently contribute to increased nurse fatigue and reduced visibility [4,5], potentially impacting patient care. SPRs require nurses to attend to patients in physically separate spaces, increasing walking distances, reducing the capacity to monitor multiple patients simultaneously, and heightening physical and mental strain [6,26,27]. This fragmentation of care may contribute to delayed responses in emergencies or missed early warning signs of clinical deterioration, particularly in high-acuity settings. Additionally, limited familiarity with SPR workflows may further exacerbate fatigue and reduce efficiency compared to the well-established routines of nursing teams in MPR environments [28,29].

This study explored the impacts of ICU architecture by comparing two distinct designs: a linear layout versus a centralized

Table 5. Logistic regression analysis of mortality after propensity score matching

	Crude OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
ICU mortality				
Room type (SPR)	0.51 (0.39–0.66)	<0.001	0.54 (0.40–0.73)	<0.001
APACHE II score	1.19 (1.17–1.21)	<0.001	1.12 (1.10–1.15)	<0.001
SAPS 3	1.07 (1.06–1.08)	<0.001	1.04 (1.03–1.05)	<0.001
In-Hospital mortality				
Room type (SPR)	0.57 (0.46–0.71)	<0.001	0.56 (0.43–0.72)	<0.001
APACHE II score	1.18 (1.16–1.20)	<0.001	1.12 (1.10–1.14)	<0.001
SAPS 3	1.07 (1.06–1.08)	<0.001	1.04 (1.03–1.05)	<0.001

OR: odds ratio; ICU: intensive care unit; SPR: single-bed patient room; APACHE: Acute Physiology and Chronic Health Evaluation; SAPS: Simplified Acute Physiology Score.

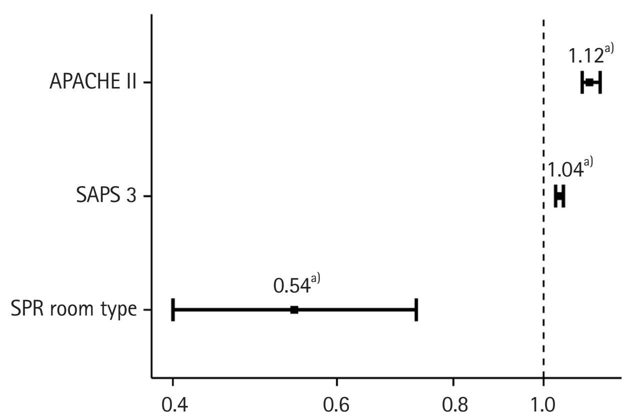

Figure 3. Odds ratio plot (intensive care unit mortality after matching). APACHE: Acute Physiology and Chronic Health Evaluation; SAPS: Simplified Acute Physiology Score; SPR: single-bed patient room. a) P<0.01.

layout and an ICU composed entirely of SPR versus a mix of SPRs and MPRs. However, the adoption of SPR-based ICUs in South Korea remains limited due to their relatively recent introduction. Consequently, existing SPR-structured ICUs do not fully align with international guidelines. For example, although ICUs at site A consisted entirely of SPRs with glass-fronted walls, their design restricts nurses' ability to observe patients effectively unless they are near the patient rooms. This limitation hinders efficient monitoring of patient conditions from a distance. In contrast, many advanced healthcare systems employ design strategies that enhance visibility and optimize nursing efficiency [26,28]. A common approach involves incorporating recessed walls with glass windows between adjacent rooms, enabling nurses to directly observe patients and continuously monitor vital signs without frequent movement between rooms. On the other hand, the MPR-based design at site B offers notable advantages in terms of nursing efficiency. Its centrally located nursing station provides a clear view of most patient areas, allowing nurses to monitor patients more effectively, respond more promptly, and maintain better situational awareness.

This study has some limitations that may have influenced the interpretation of its findings. First, significant differences in hospital structure, patient demographics, and institutional policies across the three hospitals complicated direct comparisons of clinical outcomes. PSM was applied to address these differences; however, residual bias may persist due to unmeasured confounding factors, such as socioeconomic status, chronic conditions, and hospital-specific operational practices. Second, patients assigned to SPRs may have been selectively placed based on factors such as clinical severity, isolation requirements, or specific diagnoses. This selection process could introduce bias in mortality comparisons despite matching efforts and logistic regression analysis. Additionally, the unequal distribution of SPR and MPR patients across hospitals, particularly the smaller sample size at site C, may have reduced statistical power and generalizability. Third, while the study demonstrated an association between SPRs and reduced mortality rate, it did not establish causality. Other variables, such as increased nurse-to-patient ratios, may have contributed to improved patient outcomes. We did not adjust for differences in nurse-to-patient or physician-to-patient ratios across hospitals. These ratios are subject to frequent fluctuations throughout the day, making it difficult to reflect real-time clinical conditions using average values without potential bias. Instead, this investigation qualitatively described staffing patterns and included ICU bed counts to illustrate institutional differences in resource allocation. Demonstrating a meaningful difference in staffing intensity of the SPR compared to the MPR model would require a significant disparity in nurse-to-patient or physician-to-patients ratios and the availability of at least two comparable ICU cohorts comprised exclusively of either SPR or MPR models. However, due to the absence of such directly comparable cohorts, we were only able to reference findings from other studies. Furthermore, the study primarily focused on ICU mortality as the main outcome, with a limited assessment of variables such as ventilator use duration, delirium, and functional recovery, which are clinically important and patient-centered indicators. Delirium data were not included in our primary analysis, though we recognize their importance. Fourth, the study did not include important metrics such as patient functional recovery, satisfaction of patient and their families, or quality of life, limiting insight into SPRs' broader impact on patient-centered care. Fifth, the economic analysis also lacked an evaluation of the long-term cost-effectiveness of SPR implementation, including potential savings from reduced infections and improved clinical outcomes relative to the initial construction and operational costs. Finally, the retrospective study design and limited study period restricted the evaluation of certain variables, including specific microbial pathogens and antibiotic resistance profiles. Legal and data security concerns further restricted access to patient-specific nosocomial infection data, limiting infection-related analyses. These limitations highlight the complexity of evaluating the impact of ICU design on clinical outcomes and emphasize the need for future research using larger, prospective studies that incorporate broader clinical, economic, and patient-centered metrics.

Future research should broaden the range of clinical, operational, and patient-centered outcomes. The following recommendations are proposed: Research should evaluate a broader range of outcome measures, including patient functional recovery, satisfaction of patients and their families, and stress levels among healthcare providers. Comparative investigations on various SPR configurations, including visibility-enhanced layouts, patient acuity, and staffing levels, should be conducted to explore strategies for improving operational efficiency while maintaining patient privacy and safety. Furthermore, studies should incorporate additional endpoints, such as re-admission rates, ventilator-free days, continuous renal replacement therapy-free days, nutritional support adequacy, and discharge disposition. Moreover, detailed economic analysis examining long-term cost-effectiveness, including potential savings from reduced infections and improved clinical outcomes, should be conducted to inform healthcare policy and investment decisions. Additionally, exploring the effects of SPR implementation on ICU staff stress levels, job satisfaction, and burnout rates could be considered [6,24,30-32].

In conclusion, transitioning from MPR to SPR in ICU architecture demonstrated a protective effect by reducing the ICU mortality rate. The analysis suggests that the positive outcomes associated with SPRs result from a complex interplay of room design, operational efficiency, and institution-specific factors.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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