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An open intensive care unit (ICU) model is a viable option for the acute expansion of ICU capacity in the state sector: A study of a needs-based strategy during the COVID-19 pandemic in a tertiary ICU in South Africa

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Background. Both open and closed intensive care unit (ICU) models are used in South Africa (SA). The literature is unclear with regard to which model is superior. The COVID-19 pandemic led to a critical care resource crisis that necessitated expansion of critical care capacity, often beyond the resources required to meet the structure of a closed ICU in the institutions using that model.
Objectives. This retrospective study aimed to compare the outcomes of non-COVID patients in a closed ICU setting and a temporary open unit that ran parallel to it during the pandemic, in order to assess this type of resource expansion as a viable option.
Methods. Data from the Intensive Care Electronic Record System in the Greys Hospital ICU in Pietermaritzburg, SA, were analysed for patients aged ≥12 years admitted to either the open or the closed ICU between April and August 2020. Data missing from the database were completed by referring to the medical records office. The primary outcome assessed was mortality, while secondary outcomes included adverse events and hospital length of stay.
Results. There was no significant mortality difference between the ICU components (16.9% in the open-model group v. 15.1% in the closed-model group; p=0.769). The incidence of adverse events also did not differ (45.5% in the open model v. 38.9% in the closed model; p=0.357).
Conclusion. Patients requiring ICU admission have complex conditions or have undergone extensive surgery, necessitating specialised treatment and careful monitoring. In the event of an acute surge event, expanding ICU capacity by adding an open-model component in a setting that traditionally runs closed models may be an effective strategy to assist in the management of critically ill patients without significantly affecting outcomes.
Keywords. COVID-19, resource expansion, ICU, South Africa.

Afr J Thoracic Crit Care Med 2025;31(1):e2004. https://doi.org/10.7196/AJTCCM.2025.v31i1.2004

Study synopsis
What the study adds. This retrospective study compared outcomes of non-COVID patients in a closed intensive care unit (ICU) v. a temporary open unit during the pandemic. The efficacy of open v. closed ICU models remains uncertain in the South African context. The study offers insights into the effectiveness of open and closed ICU models, particularly in the context of crises during which institutions may face a critical care resource shortage.
Implications of the findi gs. The study suggests that incorporating open ICU units during crises can manage patient surges effectively without compromising outcomes. It contributes to the existing literature by providing practical implications for resource management, clinical practice and future research, ensuring quality patient care while optimising critical care capacity.

Critical care services are a scarce resource in South Africa (SA), especially in the state sector. This scarcity is largely due to the lack of trained intensive care unit (ICU) personnel.[1] Open and/or closed ICU models are favoured in various centres to manage human resources more effectively.[2] The literature varies in terms of which model is associated with better outcomes. Our centre has traditionally used a closed ICU model. The onset of the COVID-19 pandemic necessitated restructuring of existing resources in order to manage the significant increase in patient load while maximising staff efficiency. This demand led to our centre running both models in parallel in separate wards, creating a unique opportunity for direct comparison. There has been a longstanding debate over the role of intensivists in the management of critically ill patients and their impact on patient outcomes.[3] It has been hypothesised that a closed-model ICU is associated with improved clinical outcomes compared with an open ICU.

Naidoo *et al.*[4] performed a desk-top audit of all public and private sector ICUs in SA from 2008 to 2009. The majority of ICU beds were located in three provinces, namely Gauteng (49%), KwaZulu-Natal (14%) and Western Cape (15%). These represented 78% of the country's ICU beds, catering for 54% of the population. Eastern Cape, North West and Limpopo provinces had far fewer ICU beds. The figures translated to an overall bed-to-population ratio of ~1:10 000, with large variations across the provinces.

The open ICU model describes an ICU in which patients are admitted under the care of an internist, family physician, surgeon, or any other primary attending physician, with intensivist involvement by elective consultation.[5] Intensivists may play a *de facto* primary role in the management of some patients, but only at the discretion of the admitting physician, and have no over-reaching authority over patient care. Although the primary physician may have less expertise in critical care medicine, it is argued that their longer relationship with the patient may provide improved care. However, this model lends itself to greater variability in patient management.[5-7]

A closed ICU model is defined as a unit in which all patients are cared for by a dedicated team of adequately trained intensive care physicians, available 24 hours a day, in collaboration with primary base-discipline clinicians. The admissions and discharges are controlled by an on-site ICU physician in most closed ICU models. It is hypothesised that this model improves patient care and leads to more efficient resource management.[5,8]

It is imperative to have an understanding of both model types and to weigh up the risks and benefits of these models in relation to the local patient population.

Early critical care units were staffed by physicians whose primary specialties were anaesthesiology or internal medicine. More recently, critical care medicine has become a recognised subspecialty. An understanding of physiology in critically ill patients and evidence-based practice is essential in the management of ICU patients.[9]

This study aimed to examine outcomes of patients admitted to an open unit v. a closed unit during the COVID-19 pandemic (study period April - August 2020), specifically with regard to morbidity, mortality and hospital length of stay.

Methods

Clinical setting

Greys Hospital in Pietermaritzburg, SA, runs a closed-model tertiary ICU providing advanced organ support with 11 active ventilator beds serving 4.5 million people. During the height of the first wave of the COVID-19 pandemic, the unit capacity was expanded to 16 beds, which were partitioned into a 7-bed COVID ICU and a 9-bed non-COVID ICU. A further 6 non-COVID beds were opened in the cardiac care unit, which were run in an open ICU model. Both units were staffed by experienced ICU nurses. The closed-model unit was managed by intensivist-led teams. In the open-model unit, patients were exclusively managed by the respective treating base-discipline consultant. Intensivists were consulted for advice on an *ad hoc* basis. Referrals were managed by the closed ICU team, who dealt with triage and bed allocation in both units. These referrals were entered into the Intensive Care Electronic Record System (ICES) at Greys Hospital, which has been active for ~10 years and captures data pertaining to referrals, admissions and discharges. The ICES falls under ethics class approval number BCA 211/14. Ethics approval for this study was granted by the Biomedical Research Ethics Committee, University of KwaZulu-Natal (ref. no. BREC/00004106/2022).

Study procedure

The ICES was interrogated for all non-COVID admissions to the ICU from 1 April to 31 August 2020. Further data were obtained from physical patient records as needed. Patients had to be aged ≥12 years for inclusion into the study. Both units were adult ICUs, and the occasional paediatric admission (<12 years) does not reflect the burden of paediatric ICU admissions. The following data were collected: age, sex, comorbidities, type of surgery, readmissions, acute admission, emergency or elective surgery, and in-hospital morbidity and mortality.

Mortality was defined as in-hospital mortality (i.e. death from any cause during admission). Adverse events were captured by the treating clinician. Most of these fell into the categories respiratory, cardiovascular, renal, central nervous system, iatrogenic and venous thromboembolism. Patients requiring ICU admission were triaged using the Society of Critical Care Medicine (SCCM) score, whereby they are classified according to the severity of their illness, background pathology and prognosis into groups I - IV[10] (see Supplementary Table 1, available at http://coding.samedical.org/file/2328). Acute Physiologic Assessment and Chronic Health Evaluation (APACHE II) scores and APACHE II predicted mortality were calculated.[11]

Statistical analysis

The data were extracted from the critical care database and exported as an Excel spreadsheet, version 16.93.1 (Microsoft Corp., USA), for preparation. Data were analysed using R version 4.2.2 (R Foundation for Statistical Computing, Austria).

Descriptive statistics was performed for the overall sample as well as for each subgroup. Categorical variables were described in terms of frequencies and percentages. Continuous variables were described according to distribution. Normally distributed variables were described in terms of means and standard deviations and non-normal data in terms of medians and interquartile ranges (IQRs).

Categorical data were compared using the χ^2 test (or Fisher's exact test where appropriate). The alpha level was set at 0.05. When data were non-normally distributed, the Wilcoxon test was used for comparison. Differences were expressed as odds ratios (ORs) with 95% confidence intervals (CIs) when *p*-values were significant.

Results

During the study period, 203 patients met the inclusion criteria. Of these, 126 (14 patients per bed over the study period) were admitted to the closed unit and 77 (13 patients per bed) to the open unit. The median (IQR) age of the sample was 38 (26 - 53) years. Females accounted for 46.8% of the group. Ninety patients (44.3%) had at least one comorbid illness. The median APACHE II score was 7 (3 - 13). Overall, 51.7% of the patients (n=105) were classified as SCCM I, 36.0% (n=73) as SCCM II and 12.3% (n=25) as SCCM III. Non-COVID medical admissions accounted for 22.2% of admissions overall. General surgical patients accounted for the most admissions (n=73; 36.0%). Patients in the closed and open groups were similar in terms of age, sex, comorbid profile and APACHE II score. However, the open ICU received a higher proportion of patients categorised as SCCM III than the closed ICU (20.8% v. 7.1%, respectively). This difference was statistically significant (OR 0.29; 95% CI 0.12 - 0.69). The odds of admitting a trauma patient to the closed ICU were 2.4 times greater than for the open ICU (95% CI 1.2 - 4.9). There were no differences in place of admission among general surgical, medical, and obstetrics and gynaecology patients. These findings are detailed in Table 1.

Outcomes

The overall mortality rate was 15.8% (*n*=32). This was similar between the two ICU models (15.1% for the closed group and 16.9% for the open group; *p*=0.769). Median (IQR) ICU length of stay was 3 (2 - 6.8) days in the closed group and 4 (2 - 7) days in the open group. This trend did not reach statistical significance (*p*=0.635). Eighty-four patients (41.4%) suffered at least one adverse event. The most common events were respiratory (*n*=23; 11.2%), followed by renal (*n*=16; 7.9%). Iatrogenic complications occurred in 13 patients (6.4%). Of these 13 iatrogenic complications, 7 (5.6% of patients in the unit) were in the closed ICU (2 central line insertion-related pneumothoraces, 2 dislodged epidurals, 1 hand cellulitis secondary to an intravenous line, 1 endotracheal tube dislodgement, and 1 hypotension from a magnesium sulphate infusion), while 6 (7.8%) occurred in the open ICU (3 central line insertion-related pneumothoraces, 1 hyperactive delirium not on seizure prophylaxis, 1 hypotension secondary to opioid overdose, and 1 endotracheal tube dislodgement). Overall, these outcomes were comparable between the two groups. Detailed findings are shown in Table 2.

Table 1. Non-COVID ICU admissions to Greys Hospital from April to August 2020: A comparison between patients admitted to open and closed ICU models

Characteristic	Total (*N*=203), *n* (%)*	Closed ICU (*n*=126), *n* (%)*	Open ICU (*n*=77), *n* (%)*	*p*-value	OR†	95% CI
Age (years), median (IQR)	38 (26 - 53)	40 (26 - 52)	38 (27 - 56)	0.890		
Female	95 (46.8)	57 (45.2)	38 (49.4)	0.569		
Comorbidities	90 (44.3)	53 (42.1)	37 (48.1)	0.405		
SCCM score						
I	105 (51.7)	71 (56.3)	34 (44.2)	0.092		
II	73 (36.0)	46 (36.5)	27 (35.1)	0.835		
III	25 (12.3)	9 (7.1)	16 (20.8)	0.004	0.29	0.12 - 0.69
Primary diagnosis/specialty						
Malignancy	19 (9.4)	11 (8.7)	8 (10.4)	0.694		
Attempted suicide	14 (6.9)	7 (5.6)	7 (9.1)	0.335		
Trauma	54 (26.6)	41 (32.5)	13 (16.9)	0.014	2.4	1.2 - 4.9
General surgery	73 (36.0)	42 (33.3)	31 (40.3)	0.318		
Medicine	45 (22.2)	23 (18.3)	22 (28.6)	0.086		
O&G	20 (9.9)	12 (9.5)	8 (10.4)	0.841		

ICU = intensive care unit; OR = odds ratio; CI = confidence interval; IQR = interquartile range; SCCM = Society of Critical Care Medicine; O&G = obstetrics and gynaecology.
*Except where otherwise indicated.
†Where *p*-values were <0.05, relationships were expressed as ORs with 95% CIs using logistic regression.

Table 2. Non-COVID ICU admissions to Greys Hospital from April to August 2020: A comparison of patient outcomes between open and closed ICU models

Outcome	Total (*N*=203), *n* (%)*	Closed ICU (*n*=126), *n* (%)*	Open ICU (*n*=77), *n* (%)*	*p*-value
Died	32 (15.8)	19 (15.1)	13 (16.9)	0.769
LOS (days), median (IQR)	4 (2 - 7)	3 (2 - 6.8)	4 (2 - 7)	0.635
≥1 adverse event	84 (41.4)	49 (38.9)	35 (45.5)	0.357
Most common adverse events†				
Respiratory	23 (11.3)	13 (10.3)	10 (13.0)	0.560
CVS	9 (4.4)	6 (4.8)	3 (3.9)	0.771
Renal	16 (7.8)	9 (7.1)	7 (9.1)	0.617
CNS	12 (5.9)	6 (4.8)	6 (7.8)	0.374
Iatrogenic	13 (6.4)	7 (5.6)	6 (7.8)	0.528
VTE	2 (1.0)	0	2 (2.6)	0.143

*Except where otherwise indicated.
†Not all adverse events are listed.
ICU = intensive care unit; OR = odds ratio; CI = confidence interval; LOS = length of stay; IQR = interquartile range; CVS = cardiovascular system; CNS = central nervous system; VTE = venous thromboembolism.

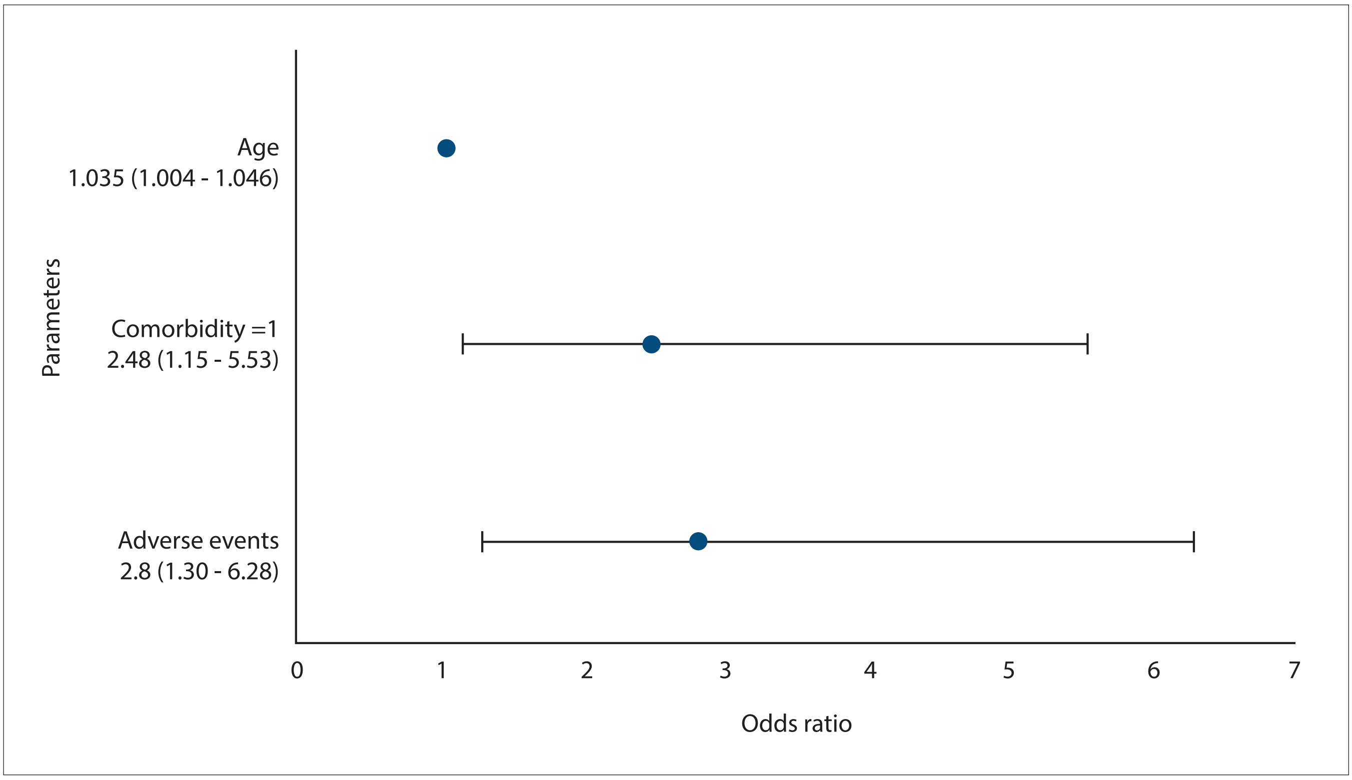

Fig. 1. Risk factors for mortality in the total sample – Forrest plot indicating significant associations between independent variables and mortality. Relationships are expressed as odds ratios with 95% confidence intervals.

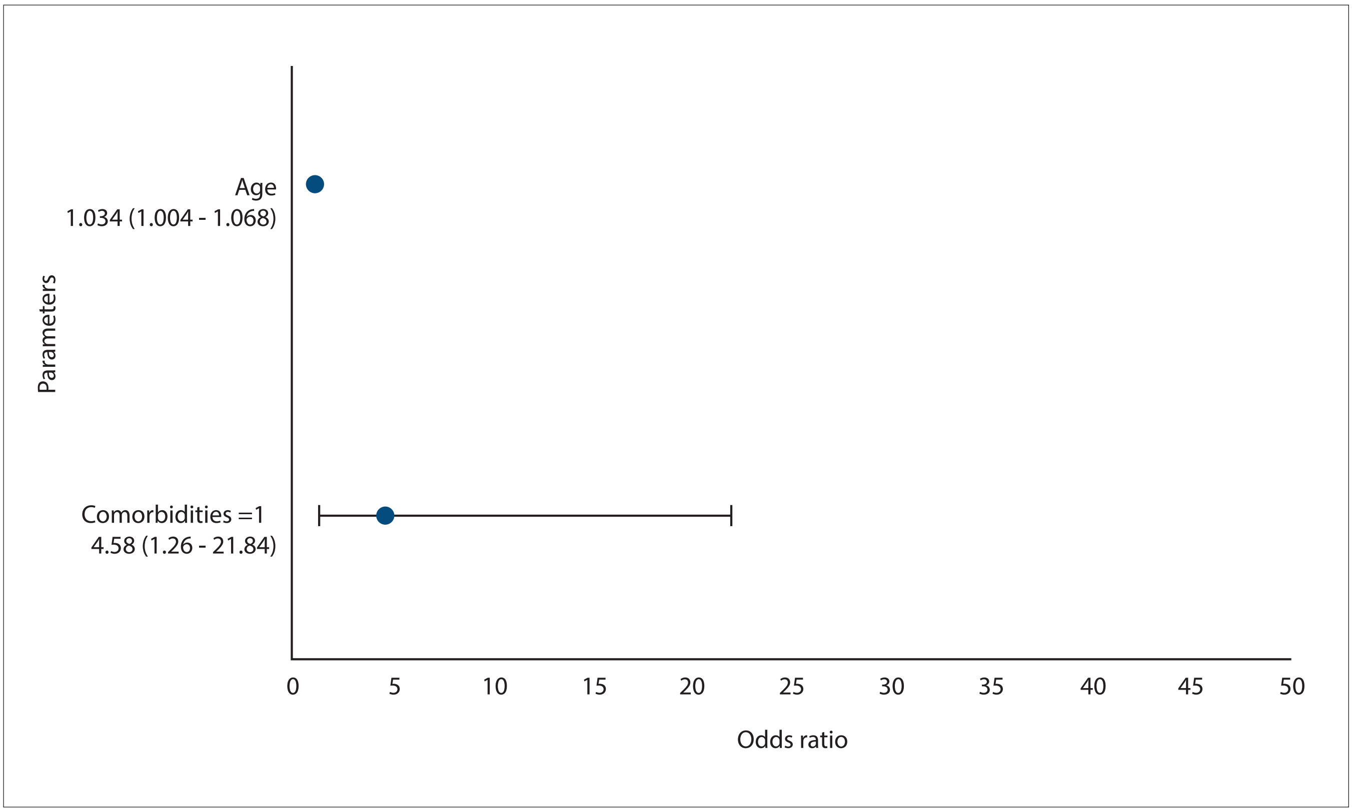

Fig. 2. Risk factors for mortality in the open ICU – Forrest plot indicating significant associations between independent variables and mortality in the open ICU model. Relationships are expressed as odds ratios with 95% confidence intervals. (ICU = intensive care unit.)

Risk factors for mortality

In the overall group, an adverse event was associated with almost three times the odds of mortality (OR 2.8; 95% CI 1.30 - 6.28). Other variables associated with mortality were having at least one comorbidity (OR 2.48; 95% CI 1.15 - 5.53) and advancing age (OR 1.035; 95% CI 1.004 - 1.046). Similarly, advancing age and the presence of comorbidities were also associated with mortality in the open ICU (OR 1.034 and 4.58, respectively). These are graphically represented in Figs 1 and 2. Of note, we found no significant associations with mortality in the closed ICU.

Discussion

There is much debate as to whether closed or open ICU models have better outcomes. Regardless of the model used, acute surge events may necessitate that institutions undergo temporary reorganisation in order to meet the needs of the patient burden. The COVID-19 pandemic gave us the opportunity to assess whether closed ICUs could expand to involve open ICU components in an acute surge event without affecting patient outcomes. This process involved a direct comparison between the open and closed ICU components. Overall, we found no significant differences in mortality or length of stay, but there were some differences in admission profiles between the units.

No mortality difference

A systematic review looking at physician staffing patterns and clinical outcomes in critically ill patients found that high-intensity staffing resulted in lower mortality and reduced hospital length of stay.[6] Hospitals with lower failure to rescue rates were more likely to have board-certified intensivists and a closed-model ICU. These findings are consistent with previous studies showing that hospitals with intensivist staffing have lower mortality rates than those without, and that transition from an open to a closed ICU model reduces mortality.[12-16] However, increasing the number of intensivists in isolation does not improve mortality. Restructuring from an open to a closed unit needs a more holistic approach.

In a large multicentre retrospective US study, Levy *et al*.[17] compared mortality rates between patients who were cared for by an intensivist and those who were not. Interestingly, it was found that the patients cared for by intensivists had higher mortality rates. However, these patients were also found to be sicker and to need more procedures. Harris *et al*.[18] found improved mortality rates when units transitioned from an open to a closed model, and it has been suggested that the improvement in unit mortality was secondary to consistency in patient selection rather than to a fundamental change in clinical practice in the ICU. The literature quoted above suggesting improved mortality rates in a closed unit with consistency in patient selection emphasises the importance of protocolised ICU triage in effective resource management. In both of our units, triage was performed by the intensivist on call, who served as 'gatekeeper' to both units. This could be a reason why we found no difference in mortality between the two ICU models. These findings may also emphasise the importance of having trained and/or experienced ICU nursing staff in both models.

Risk factors for mortality

In both the overall sample and the open unit, the presence of comorbidities and advancing age were found to be risk factors for mortality. The proportion of adults and elderly in the population is gradually increasing, resulting in an increase in the number of elderly patients with serious comorbid illnesses in need of surgery. We found no significant risk factors for mortality in the closed unit. This may be a result of selection bias, as more patients categorised as SCCM III were admitted to the open unit. More trauma patients were admitted to the closed unit. In our setting, trauma patients tend to be younger and to have fewer comorbidities.

Study limitations

This was a single-centre, retrospective study with a small sample. However, the single centre reduced site-specific confounders. The study was not a direct comparison between an open and a closed ICU, as the open ICU was more of a hybrid model with intensivist-led triage and admission. The study occurred during a pandemic, altering patient demographics compared with non-pandemic times, such as a decrease in trauma cases and a different profile of non-COVID patients.

We cannot exclude the possible risk of bias when multiple referrals were received at one time and beds were available in both units. Confounders such as personal preferences of the intensivist on duty and patient acuity may have influenced decisions on where these patients were admitted.

In our hospital, we have anecdotally noted that our trauma team refers patients more timeously than other disciplines. This factor may account for the increased odds of trauma patients being admitted to available beds in the closed unit.

It is widely appreciated that trained ICU nurses form the backbone of a successful ICU. We suggest that the availability of well-trained nursing staff contributed to the non-statistically significant differences in outcomes between the two units, as the nurses were able to identify and manage complications and patient decompensation despite the absence of an intensivist in the open unit.

Conclusion

In an acute surge event requiring an increase in critical care resources, expanding bed capacity by supplementing traditionally closed ICU models with an open ICU component may be an effective strategy without significantly affecting patient outcomes.

Declaration. The research for this study was done in partial fulfilment of the requirements for ESG's MMed (Anaesth Crit Care) degree at the University of KwaZulu-Natal.

Acknowledgements. We are grateful to the Greys Hospital nurses and medical records personnel who retrieved the medical records of patients in both ICU models.

Author contributions. ESG: study design, data collection, analysis, writing of the article, revision of content and accountability for the entire work. AR: manuscript review. MTDS: study design, analysis, and direction of the overall study.

Funding. None.

Conflicts of interest. None.

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Received 6 March 2024. Accepted 6 January 2025. Published 28 March 2025.