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Quality improvement of Dutch ICUs from 2009 to 2021: A registry based observational study

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ABSTRACT

Purpose: To investigate the development in quality of ICU care over time using the Dutch National Intensive Care Evaluation (NICE) registry.
Materials and methods: We included data from all ICU admissions in the Netherlands from those ICUs that submitted complete data between 2009 and 2021 to the NICE registry.
We determined median and interquartile range for eight quality indicators. To evaluate changes over time on the indicators, we performed multilevel regression analyses, once without and once with the COVID-19 years 2020 and 2021 included. Additionally we explored between-ICU heterogeneity by calculating intraclass correlation coefficients (ICC).
Results: 705,822 ICU admissions from 55 (65%) ICUs were included in the analyses. ICU length of stay (LOS), duration of mechanical ventilation (MV), readmissions, in-hospital mortality, hypoglycemia, and pressure ulcers decreased significantly between 2009 and 2019 (OR <1). After including the COVID-19 pandemic years, the significant change in MV duration, ICU LOS, and pressure ulcers disappeared. We found an ICC ≤0.07 on the quality indicators for all years, except for pressure ulcers with an ICC of 0.27 for 2009 to 2021.
Conclusions: Quality of Dutch ICU care based on seven indicators significantly improved from 2009 to 2019 and between-ICU heterogeneity is medium to small, except for pressure ulcers. The COVID-19 pandemic disturbed the trend in quality improvement, but unaltered the between-ICU heterogeneity.

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1. Introduction

Treatment developments, high resource use, and patients at high risk of adverse outcomes make intensive care medicine demanding for continuous quality assurance [1]. Patients in the Intensive Care unit (ICU) are continuously monitored and, in high income countries, most of the underlying data are automatically captured in electronic health records (EHR) [2]. National or regional ICU quality registries use sets of these data to enable benchmarking, i.e. comparing ICUs' performance based on clinical outcomes and process indicators [3-10].

Clinicians, managers, policy makers, and researchers use ICU registries to analyse, quantify, and improve the quality of ICU care [1]. Furthermore, during the COVID-19 pandemic some of those registries fulfilled an important role in rapid knowledge development on this new disease and providing information to national bodies [11-16]. The constant data collection in ICU registries provides the unique opportunity to investigate the development in quality of ICU care over time. Improved quality of care can be shown by a reduction of adverse outcomes, such as mortality and readmissions within the same hospital stay, and also by a reduction of the variance between ICUs showing less heterogeneous care. Dutch National Intensive Care Evaluation (NICE) registry data from 1997 to 2001 showed no change in median ICU length of stay (LOS), but there was an increase in crude in-hospital mortality. However, case-mix adjusted mortality decreased slightly over time [17]. Another study based on the NICE registry showed that both short-term and long-term risk-adjusted mortality decreased significantly from 2008 to 2014 in both very elderly ICU patients and patients aged <80 years in the Netherlands [18]. A study from ANZICS CORE reported on a decrease in in-hospital mortality and a slight increase in ICU LOS over the period 1993–2003 [19]. The Swedish Intensive Care Registry showed that the prevalence of night-time discharge decreased significantly between 2006 and 2015, which was associated with a significant decrease in 30-day mortality [10]. To the best of our knowledge only the German Interdisciplinary Association for Intensive Care Medicine (DIVI) showed changes on a broader set of quality measures [9]. They showed that the severity of disease on admission to the ICU, the proportion of patients on mechanical ventilation, and the workload of nurses increased between 2000 and 2010 in German ICUs, but the ICU LOS remained unchanged. The adjusted mortality of German ICUs decreased until 2005 and increased thereafter to return to the initial values of 2000.

Hence, studies on development in quality of ICU care over time are published to a low extent, were not published recently or only for subgroups, and mainly focused on trends in mortality and length of stay. Therefore, the primary aim of this study was to assess the overall trends in quality of care of ICUs between 2009 and 2019 using different types of quality indicators in the Netherlands. The second aim was to evaluate the level of variance in these quality indicators between hospitals over the years, as large variance may indicate heterogeneity between ICUs and potential room for improvement for individual ICUs. Third, we aimed to examine whether trends and variance observed for the quality indicators between 2009 and 2019 hold when we included 2020 and 2021, when the COVID-19 pandemic played an important role.

2. Materials and methods

2.1. Data collection

The data for this study were derived from the NICE registry [4] that consists of different modules. Every Dutch ICU participates in the Minimal Dataset 'MDS' module, with information on demographics, admission and discharge details, physiology and laboratory measures during the first 24 h of ICU admission, as well as outcome measures, such as in-hospital mortality and LOS [4,20]. The MDS module contains among others all variables for calculating the Acute Physiology and Chronic Health Evaluation (APACHE) IV mortality probability [21]. Currently, next to the MDS module, 62 ICUs (86%) also participate in the additional 'Quality Indicators for ICU (in Dutch KIIC)' module. This module contains structure and process indicators, i.e. availability of the intensivist, nurse to patient ratio, bed occupancy, duration of mechanical ventilation (MV), and glucose regulation [20]. All variables in the registry are described in the online NICE data dictionary [22]. To secure data quality the NICE registry implemented multiple procedures [23].

We started the present study in 2009 to align with the APACHE IV model implementation in 2008. Data from all ICUs that submitted complete data to the NICE registry over 2009–2021 were included. Patient inclusion followed the eligibility criteria as defined in the APACHE IV model for predicting in-hospital mortality [21]. Except for the calculation of the quality indicator 'readmission rate' all non-initial admissions to the ICU within the same hospital admission were excluded. The medical ethics committee of the Amsterdam UMC, University of Amsterdam stated that ethical approval for this study was not required under Dutch national law (registration number W17_162 #17.186).

2.2. Quality indicators

The quality indicator set developed by de Vos et al. [20] in 2006, was the basis for this study. We focused on the process and outcome indicators, i.e. duration of MV, ICU LOS, in-hospital mortality, hyper- and hypoglycemia (>8.0 and < 2.2 mmol/L respectively), and pressure ulcers. We added ICU readmission at any moment and readmission within 48 h after the initial ICU discharge during the same hospital stay. These were originally not included in the set from 2006, but has been reported to be important outcome indicators [24,25]. Table 1 provides a full description of the quality indicators. To visualize trends over time in severity of illness, we also plotted the APACHE IV probability (eFig. 1 in Supplementary file).

2.3. Statistical analysis

2.3.1. Overall quality improvement

To assess the development in quality of care in Dutch ICUs we first calculated the yearly indicator scores per hospital and subsequently the median and interquartile range (IQR) per year for all ICUs together. We visualized these data in boxplots. We estimated average change per year with 95% confidence intervals (CI) using multilevel linear regression analyses for continuous outcomes, and we estimated odds ratios (OR) with 95%CI using logistic mixed effects analyses for binary outcomes. To evaluate whether any change over time persisted when the COVID-19 years were included, we performed the analyses separately over the years 2009–2019 and over the years 2009–2021. ICU was included in the models as random effect, as patients are clustered within ICUs. Time (in years) was included as fixed and random slope variable and the quality indicator as the outcome variable. We adjusted all analyses for APACHE IV mortality probability [26] to account for differences in case-mix, which can even change over time. The distributions of duration of MV and ICU LOS are skewed to the right, therefore, we applied log-transformation to these outcomes. As sensitivity analysis we repeated the multivariate analyses in which the initial models were extended with adjustment for the factors age, gender, admission type, and the number of comorbidities. Although the APACHE IV model already account for several comorbidities, we included the number of comorbidities as factor to correct for the presence of more than one comorbidity simultaneously and to also account for the comorbidities that are available in the NICE registry but are not included in the APACHE IV model. The comorbidities that were included in these additional sensitivity analysis were: acquired immunodeficiency syndrome, immunological insufficiency, chronic renal insufficiency, chronic dialysis, chronic respiratory insufficiency, chronic obstructive pulmonary disease, metastasized neoplasm, hematological malignancy, diabetes, cirrhosis, and chronic cardiovascular insufficiency. To adjust for multiple testing a *p*-value of

Table 1
Description of the quality indicators.

Indicator	Description	Measurement scale	Level of measurement
Duration of mechanical ventilation	The number of 24-h periods during which mechanically ventilated ICU patients have been mechanically ventilated	Continuous (24-h periods)	Admission
ICU length of stay	The number of 24-h periods that ICU patients have been treated in the ICU	Continuous (24-h periods)	Admission
ICU Readmission	Number of ICU patients that were admitted to the ICU a second (or third) time after ICU discharge from the initial ICU admission, within the same hospital stay	Binary (0/1)	Unique patients
ICU Readmission within 48 h	Number of ICU patients that were admitted to the ICU a second (or third) time within 48 h after ICU discharge from the initial ICU admission, within the same hospital stay		
Hospital mortality	Number of ICU patients deceased in the hospital	Binary (0/1)	Admission
Hyperglycemia	Number of ICU patients with an hyperglycemia (glucose level above 8.0 mmol/L)	Binary (0/1)	Admission
Hypoglycemia	Number of ICU patients with an hypoglycemia (glucose level below 2.2 mmol/L)	Binary (0/1)	Admission
Incidence of pressure ulcers	Number of ICU patients with incidence of pressure ulcer, newly developed stage 3 or 4, or deterioration to stage 3 or 4	Binary (0/1)	Admission

$<$0.01 was considered significant.

2.3.2. Heterogeneity between ICUs

To assess potential differences in outcome between ICUs, we calculated intraclass correlation coefficients (ICC) for each year per indicator. The ICC quantifies the extent of homogeneity within clusters and heterogeneity between ICUs by determining the ratio of between-ICU heterogeneity to total variance [27]. An ICC of 1 would indicate identical outcomes for all ICU admissions (i.e. 100% of individual differences are at the ICU level), while an ICC of 0 represents no shared ICU-related outcome level. We used ICC values of 0.01, 0.05, and 0.20 to represent small, medium, and large levels of between-cluster heterogeneity, respectively [28-30]. Linear regression analyses were conducted to evaluate any changes in the ICC over time, with the ICC per year serving as the dependent variable and time (in years) as the independent variable.

All statistical analyses were performed using R version 4.0.3 (R Foundation for Statistical Computing; Vienna, Austria) and subsequently the packages *lme4* version 1.1.27.1, *performance* (*icc* function) version 0.9.1, and *ggplot2* version 3.3.5.

3. Results

For 1,007,461 ICU admissions the MDS was collected between January 1, 2009 and December 31, 2021. Figure 1 shows the number of included ICUs and admissions per indicator after excluding ICUs without complete data throughout all thirteen years and applying the exclusion criteria. In total 705,822 ICU admissions from 55 (65%) ICUs were included. Their characteristics are presented in Table 2. The excluded ICUs are smaller in size and are mainly of hospital type non-teaching, but age, gender and admission type of their patient population is similar compared to the included ICUs (eTable 1).

3.1. Trends in the quality indicators

3.1.1. Duration of mechanical ventilation

Fig. 2A and Table 3 show that the median duration of MV significantly decreased throughout the years, from 0.79 24 h-periods in 2009 to 0.64 24 h-periods in 2019 ($p < 0.001$). When including the COVID-19 years 2020 and 2021 in the model the significant improvement disappeared ($p = 0.17$). The ICC for MV between 2009 and 2019 was 0.04 and remained 0.04 when the COVID-19 years were included. The yearly ICC for duration of MV showed no change for 2009 to 2019 (beta = 0.001; $p = 0.4$), and not for 2009 to 2021 (beta = 0.002; $p = 0.08$, Fig. 3).

3.1.2. ICU Length of stay

Average ICU LOS decreased between 2009 and 2019 (Fig. 2B) from 3.4 24-h periods in 2009 to 2.9 24-h periods ($p = 0.006$) in 2019. The multilevel analysis confirmed this decrease in the mean ratio of ICU LOS of 0.99 per year from 2009 to 2019 (Table 3). When including the COVID-19 years 2020 and 2021, this significance disappeared ($p = 0.5$). The ICC of the multilevel model was 0.02 for 2009 to 2019 and remained 0.02 when we included the COVID-19 years. The yearly ICC showed no change for ICU LOS between 2009 and 2019 (beta = 0.0001; $p = 0.7$), and between 2009 and 2021 (beta = −0.0002; $p = 0.47$, Fig. 3).

3.1.3. Readmissions

Fig. 2C shows that the average readmission rate per year decreased from 6.4% in 2009 to 4.7% in 2019. The multilevel analysis showed a significant decrease ($p < 0.001$) between 2009 and 2019 as well as between 2009 and 2021 (Table 3). The ICC for readmissions between 2009 and 2019 and 2009 to 2021 was 0.02. The yearly ICC, showed no change between 2009 and 2019 (beta = 0.002; $p = 0.09$), and between 2009 and 2021 (beta = 0.001; $p = 0.07$, Fig. 3).

3.1.4. Readmissions within 48 h

Fig. 2D shows that the average readmission rate within 48 h per year decreased from 2.5% in 2009 to 2.0% in 2019. The multilevel analysis showed a significant decrease ($p < 0.001$) between 2009 and 2019 as well as between 2009 and 2021 (Table 3). The ICC for readmissions within 48 h between 2009 and 2019 was 0 and between 2009 and 2021 0.03. The yearly ICC, showed no change between 2009 and 2019 (beta = 0.001; $p = 0.37$), and between 2009 and 2021 (beta = 0.001; $p = 0.14$, Fig. 3).

3.1.5. In-hospital mortality

Fig. 2E shows a decreased average in-hospital mortality rate per ICU per year from 15.4% in 2009 to 11.8% in 2019. The multilevel analysis showed a significant decrease ($p < 0.001$) for in-hospital mortality (Table 3) between 2009 and 2019 and between 2009 and 2021. The ICC for mortality was 0.02 between 2009 and 2019, and remained the same when the COVID-19 years were included. The ICC calculated per year, did not change between 2009 and 2019 (beta = 0.0003; $p = 0.2$), and between 2009 and 2021 (beta = 0.00003; $p = 0.88$, Fig. 3).

3.1.6. Hyperglycemia (>8.0 mmol/L)

The percentage of patients with hyperglycemia remained stable over time, with a median of 74.5% between 2009 and 2019 ($p = 0.01$), and 74.8% between 2009 and 2021 ($p = 0.65$, Fig. 2F and Table 3). The ICC was 0.07 for 2009 to 2019 and 0.06 for 2009 to 2021. For hyperglycemia the yearly ICC remained unchanged for both 2009 to 2019 (beta = −0.003; $p = 0.39$) as for 2009 to 2021 (beta = −0.003; $p = 0.19$, Fig. 3).

3.1.7. Hypoglycemia (<2.2 mmol/L)

Fig. 2G shows that the percentage of patients with hypoglycemia decreased over time from 2.35% in 2009 to 0.82% in 2019 ($p < 0.001$). When the COVID-19 years were included we also found a significant

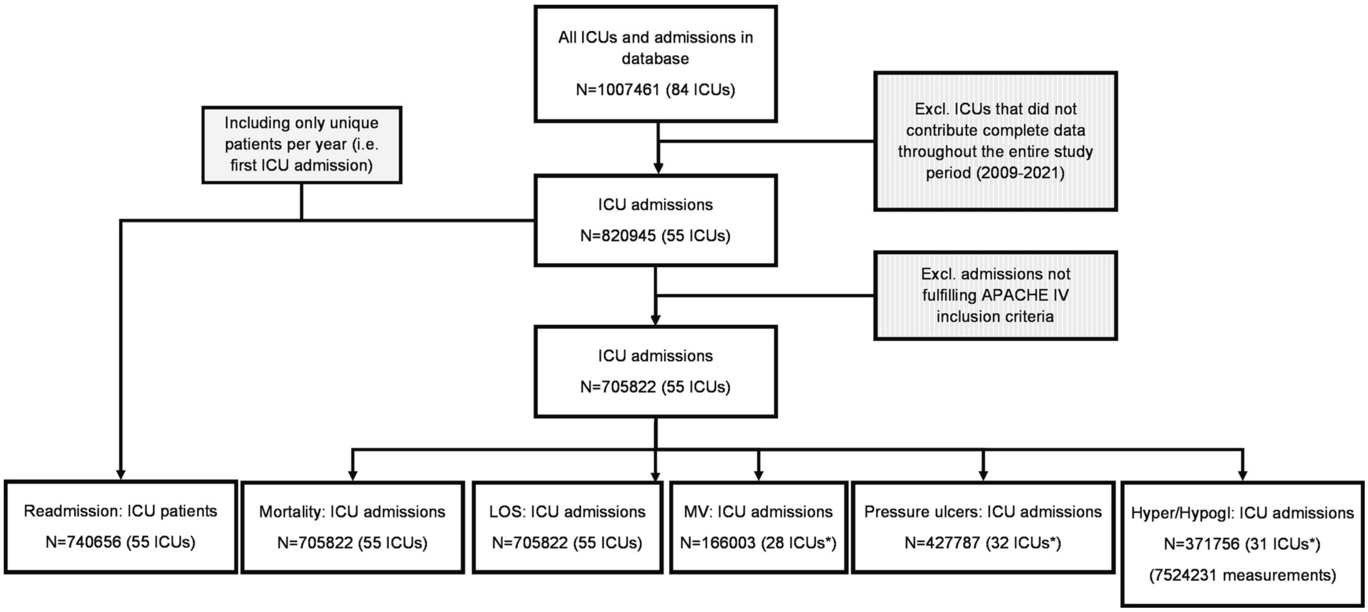

Fig. 1. Flow diagram of ICU and patient inclusion.
* Only ICUs that participated in the additional KIIC module and contributed complete data for that indicator are included.

Table 2
Characteristics of included ICUs and patients.

Characteristic	Intensive care units
Total	55
Type of hospital	
Academic	6 (10.9%)
Non-academic	
Teaching	21 (38.2%)
Non-teaching	28 (50.9%)
Number of ICU beds, mean (min – max)	16.2 (6–55)
Fte ICU nurses, mean (min – max)	54.2 (15–152)
Nurse to patient ratio, average per shift (median (IQR))	0.80 (0.73–0.91)
Bed occupancy rate, average % per shift (median (IQR))	73.0 (63.5–81.6)
	ICU admissions from 2009 to 2021
Total	705,822
Male	428,105 (60.7%)
Age (median (IQR))	66 (55–74)
Type of admission	
Medical	327,711 (46.4%)
Elective surgery	292,115 (41.4%)
Emergency surgery	85,996 (12.2%)
Mechanical ventilation in first 24 h of ICU admission	360,687 (51.1%)
Comorbidities[a]	
None	403,201 (57.1%)
One	208,559 (29.6%)
Two or more	94,062 (13.3%)
Severity of illness	
APACHE III acute physiology score (median (IQR))	38 (26–55)
APACHE IV mortality probability (median (IQR))	0.06 (0.02–0.20)

[a] Included comorbidities: acquired immunodeficiency syndrome, immunological insufficiency, chronic renal insufficiency, chronic dialysis, chronic respiratory insufficiency, chronic obstructive pulmonary disease, metastasized neoplasm, hematological malignancy, diabetes, cirrhosis, chronic cardiovascular insufficiency.

decrease (Table 3). The ICC increased from 0.05 for the years 2009 to 2019 to 0.07 when the COVID-19 years were included in the model. The trend in the yearly ICC for hypoglycemia showed no change for 2009 to 2019 (beta = −0.002; p = 0.4), and for 2009 to 2021 (beta = 0.007; p = 0.2, Fig. 3).

3.1.8. *Pressure ulcers*

Fig. 2H shows a significant decrease between 2009 and 2019 in the incidence of pressure ulcers from 1.33% in 2009 to 0.67% in 2019 (p = 0.003, Table 3). When we incorporated the COVID-19 years, the noteworthy outcome became inconspicuous. The ICC was 0.29 for 2009 to 2019 and 0.27 when we included the COVID-19 years. The yearly ICC showed an increase of 0.01 (p = 0.02) per year between 2009 and 2019, and of 0.02 (p = 0.001) between 2009 and 2021 (Fig. 3).

The sensitivity analysis (eTable 2) showed that after adjustment for age, gender, admission type, and number of comorbidities the yearly trend we found in each of the indicators remained the same.

4. Discussion

The duration of MV, ICU LOS, readmission rate, in-hospital mortality, hypoglycemia, and pressure ulcers improved significantly between 2009 and 2019. When we included the COVID-19 pandemic years the significant reduction of duration of MV, ICU LOS, and pressure ulcers was no longer observed. The overall heterogeneity between ICUs on the quality indicators was small to medium (ICC ≤0.07), except for pressure ulcers, where the ICC was 0.27 (2009–2021), suggesting ICUs can improve in pressure ulcer management. Additionally, the ICC for pressure ulcers increased significantly over time, indicating more heterogeneity between ICUs. However, for ICU LOS and hyperglycemia, even when the COVID-19 years were included in the model, the ICC became smaller over the years. This reduction of ICC for some indicators implies even more homogenous quality of care over different Dutch ICUs.

We consider homogeneity between ICUs as an important aspect of good quality of care, i.e. all patients should receive the same quality of care regardless of the ICU they were admitted to. This does not necessarily mean that the ICUs perform at the desired level. In our study however, we found that almost all indicators showed an improvement over time, which together with small heterogeneity implies improvement of quality of care over time. The significant increase in ICC for pressure ulcers over time, indicating more heterogeneity between ICUs, might be explained by different policy and practices implemented in the ICUs [31,32]. An alternate explanation for the increasing ICC for

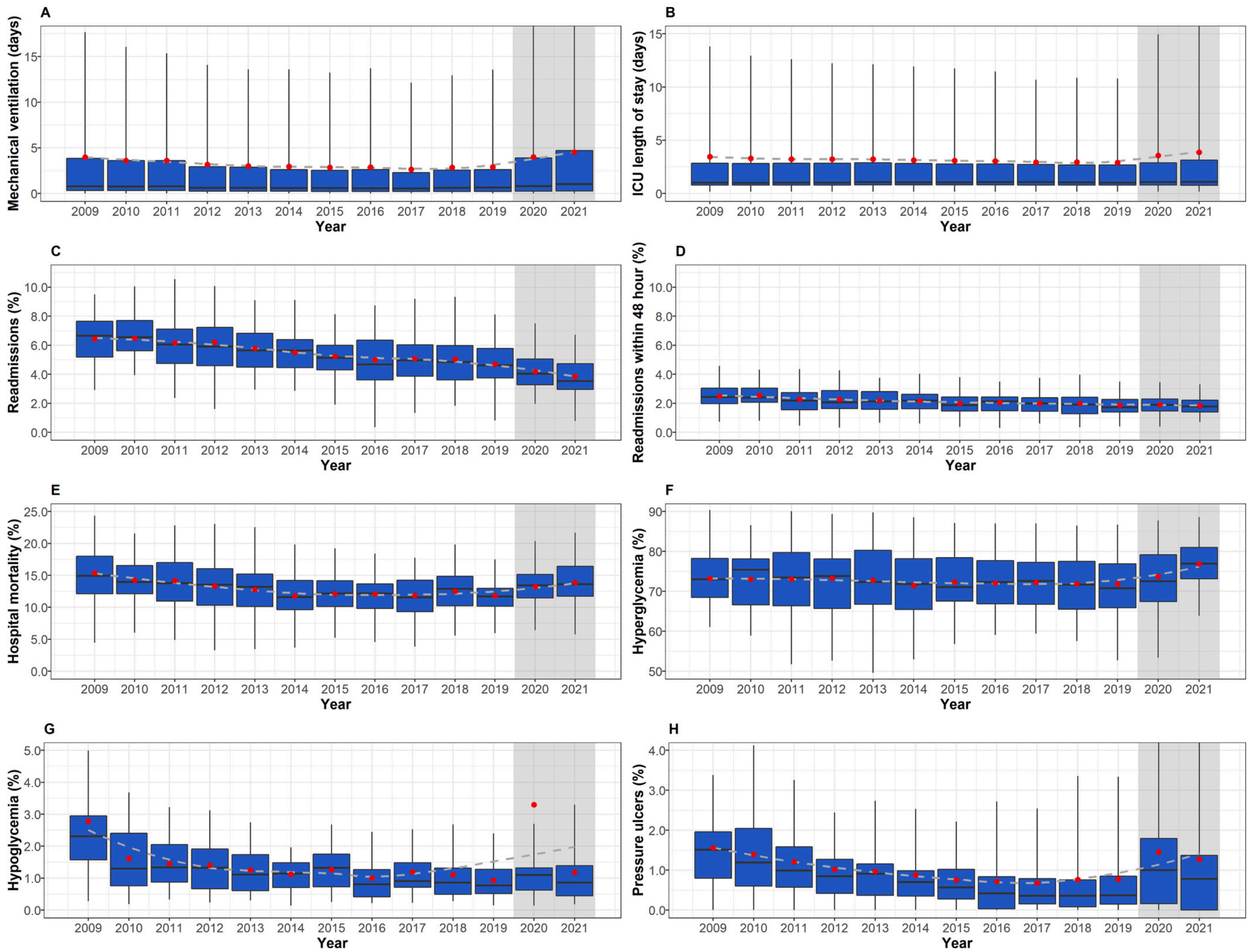

Fig. 2. Boxplot for the quality indicators per year.

Table 3
Yearly trend on each of the indicators.

Indicator	Trend per year for 2009–2019 (excl. COVID-19 years)	Trend per year for 2009–2021 (incl. COVID-19 years)
Duration of mechanical ventilation (days), mean ratio (95% CI)	0.97 (0.96–0.98)	0.99 (0.98–1.00)
ICU length of stay (days), mean ratio (95% CI)	0.99 (0.99–1.00[b])	0.99 (0.99–1.00)
ICU readmission, OR (95% CI)	0.96 (0.95–0.97)	0.96 (0.95–0.96)
ICU readmission within 48 h, OR (95% CI)	0.96 (0.94–0.97)	0.97 (0.96–0.98)
In-hospital mortality, OR (95% CI)	0.97 (0.96–0.97)	0.98 (0.97–0.99)
Hyperglycemia (>8.0 mmol/L), OR (95% CI)	0.99 (0.98–1.00)	1.00 (0.99–1.01)
Hypoglycemia (<2.2 mmol/L), OR (95% CI)	0.93 (0.90–0.96)	0.95 (0.92–0.98)
Incidence of pressure ulcers, OR (95% CI)	0.91 (0.86–0.97)	0.96 (0.91–1.01)

Abbreviations: 95%CI = confidence interval; OR = odds ratio. All indicators were adjusted for APACHE IV mortality probability. Because the dependent variables mechanical ventilation (MV) and LOS are log transformed, we report percent change in the geometric mean of LOS and MV for a 1-unit change in the independent variable (year). [b] 0.9898–0.998.

pressure ulcers could be changes in the method of registration. Prior to 2018, only patients with pressure ulcers were required to be registered, but now all patients must be actively registered. More research is needed to untangle the factors behind the increased variance. If differences in pressure ulcer management exist among ICUs, corrective measures may be necessary. In the short-term, the NICE registry will incorporate an action implementation toolbox for pressure ulcers within the feedback dashboard. This addition aims to assist local ICUs in implementing targeted improvement initiatives. Building upon our previous pain management research, which highlighted the efficacy of such a toolbox in reducing heterogeneity between ICUs and elevating the quality of care [33], this step underscores that quality registries like NICE extend beyond monitoring alone. In a broader context, quality registries such as NICE are primarily deployed to empower ICUs in enhancing the quality of care. This support is delivered through activities such as subgroup analyses and the provision of actionable suggestions for improvement. The present study underscores the supplementary value that a quality registry brings to the table: enabling the monitoring of continuous

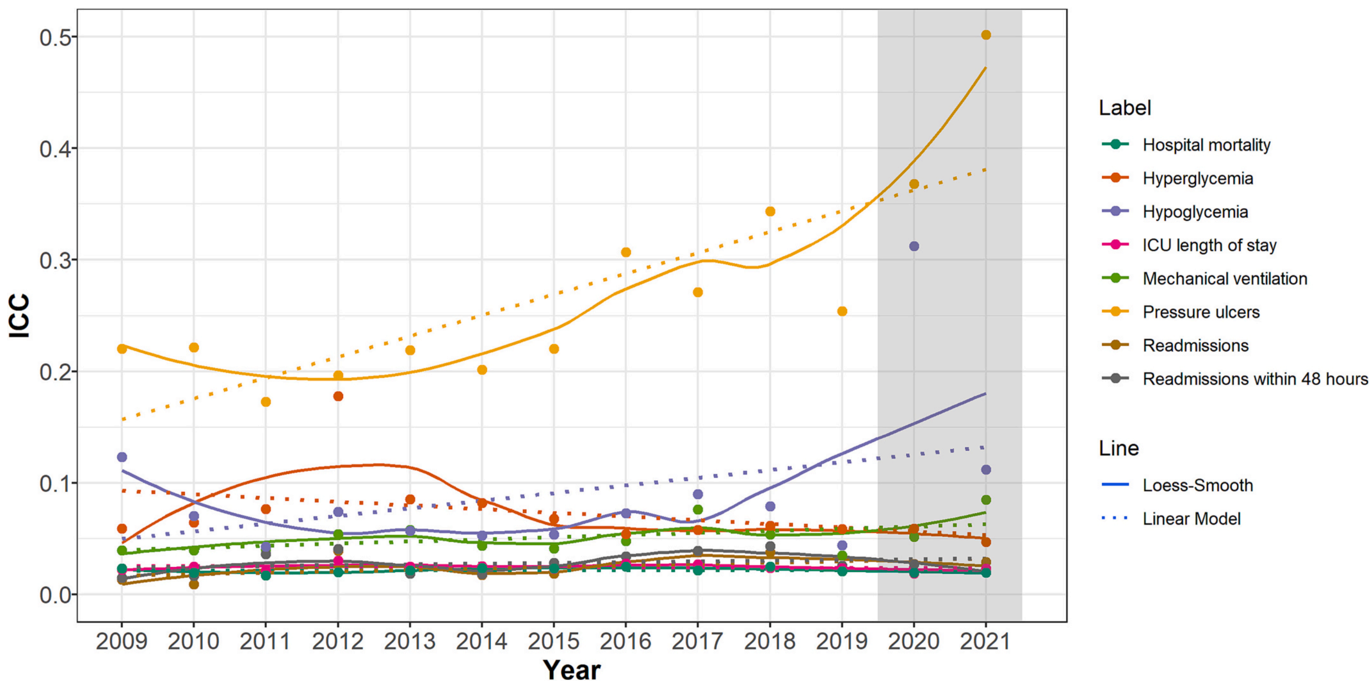

Fig. 3. The heterogeneity (ICC) between ICUs on the different indicators per year (COVID-19 years are shaded in grey).

quality enhancement over time.

Our observations that all investigated quality indicators, except hyperglycemia, decreased significantly between 2009 and 2019, indicates that quality of Dutch ICU care has improved over time. For duration of MV, ICU LOS, and in-hospital mortality this observation is in line with other studies. However, our results build upon these studies including more recent years, a longer period and not only medical admissions [19,34,35]. A possible explanation for the disappearance of significant improvements in the duration of MV, LOS ICU, and incidence of pressure ulcers when accounting for the COVID-19 years could be attributed to the higher number of severely ill patients admitted to the ICU during this period [12,36]. These patients necessitated different treatment regimens, such as longer mechanical ventilation, resulting in a shift in case-mix from patients requiring an average duration of MV to those requiring a more extended duration. Consequently, the duration of ventilation increased. Besides, ICUs had different staff due to upscaling, who may have paid less attention to these quality indicators. In our study, we found a significant decrease in readmission rates at any moment and within 48 h during the same hospital stay between the periods of 2009–2019 and 2009–2021. This finding contrasts with that of the German registry, which reported no change in readmission rates within 48 h between 2004 and 2010 (9). It is worth noting that the number of ICU beds per capita in Germany is higher than in the Netherlands, which may have contributed to this disparity (9, 36). It would be understandable that with a higher capacity the urge to dismiss patients as soon as possible is less. This in turn results in a longer duration of stay but also in less readmissions.

To the best of our knowledge, other studies examining the quality of ICU care did not provide information on ICC, which may limit the comparability of our findings with theirs. Huijben et al. (37) utilized the median odds ratio to illustrate the between-center variation among European ICUs in terms of patient treatment and outcomes for traumatic brain injury. Their findings revealed significant differences in ICU LOS and treatment protocols, which contrasts with our study results. However, it is important to note that their research examined ICUs across Europe and was focused exclusively on a specific patient group.

Our study has several strengths. First, it covers a long period of 13 years, providing insights into the quality of care described by eight indicators, over time, including the recent COVID-19 years. Second, the data we used were of high quality, with predefined variables and rigorous data quality procedures [23].

One limitation of our study is that we reported the conditional odds ratio (OR), which represents the OR between two variables at fixed levels of a third variable, such as for a patient with a constant APACHE IV probability or for a patient in the same ICU or ICUs with identical group-level effects. Although this approach may be appropriate, in situations where there is substantial heterogeneity between ICUs, the impact of the fixed effects may be relatively minor [37]. However, we conducted an additional analysis on APACHE IV mortality probability, which revealed that there is only small between-ICU heterogeneity (Appendix A in Supplementary file). Therefore, the aforementioned limitation may not have a significant impact on our findings. Furthermore, some changes in the performance indicators may be due to evolution of documentation strategies. In the last five to ten years all ICUs adopted an EHR system, which can have resulted in another way of collecting data and herewith improved outcomes [38,39]. Not all ICUs implemented an EHR system simultaneously, so the effect may become diluted over time and may not be a significant factor. Besides, changes in admission and treatment policies at the ICU, such as discharging very ill patients earlier to die at home or hospice, could have contributed to the decreased in-hospital mortality. However, we did not detect any change in the severity of illness of the population, as expressed by mortality probability, which suggests that admission policy did not change. Future research can explore differences in discharge policy by evaluating 30-day or 90-day mortality rates. Finally, the generalizability of our findings may be limited since this study was conducted only in a subset of the Dutch ICUs and in a single country. However, eTable 1 shows that the excluded ICUs are smaller in size than the included ICUs, meaning that with our subset of ICUs we were able to include the majority of all admitted ICU patients. Furthermore, the patient characteristics between the in- and- excluded ICUs are similar which suggests that it is not inconceivable that a similar amount of improvement on the indicators can be found for the excluded ICUs if complete data can be analyzed. The same applies for ICUs in other countries, if they have a comparable case-mix they could find similar results as in this study. There are already initiatives to benchmark ICUs between countries which facilitates crosscountry learning [40], but it is known that the health care systems differ from each other. Therefore, we encourage other ICU registries to replicate our analyses to evaluate their own trend in time. When ICU registries collaborate in standardizing their data by using international coding systems and information models, it will simplify the process of uniformly defining and comparing indicators among ICUs in various countries [41].

5. Conclusions

We demonstrated that the improvements in reducing duration of MV, ICU LOS, readmission rates, in-hospital mortality, hypoglycemia, and pressure ulcers were sustained over the course of 10 years, with most of these trends continuing even during the COVID-19 pandemic years. The between-ICU heterogeneity is small and stable over time. These results indicate that the quality of ICU care in the Netherlands has increased over time.

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CRediT authorship contribution statement

Marie-José Roos-Blom: Conceptualization, Data curation, Formal analysis, Writing – original draft. **Ferishta Bakhshi-Raiez:** Conceptualization, Writing – review & editing. **Sylvia Brinkman:** Writing – review & editing. **Sesmu Arbous:** Writing – review & editing. **Roy van den Berg:** Writing – review & editing. **Rob Bosman:** Writing – review & editing. **Bas C.T. van Bussel:** Writing – review & editing. **Michiel Erkamp:** Writing – review & editing. **Mart de Graaff:** Writing – review & editing. **Marga Hoogendoorn:** Writing – review & editing. **Dylan de Lange:** Writing – review & editing. **David Moolenaar:** Writing – review & editing. **Jan Jaap Spijkstra:** Writing – review & editing. **Ruud de Waal:** Writing – review & editing. **Dave Dongelmans:** Conceptualization, Supervision, Writing – review & editing. **Nicolette de Keizer:** Conceptualization, Supervision, Writing – review & editing.

Declaration of Competing Interest

None.

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No reprints will be ordered for this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2023.154461.

References

[1] Litton E, Guidet B, de Lange D. National registries: lessons learnt from quality improvement initiatives in intensive care. J Crit Care 2020;60:311–8. https://doi.org/10.1016/j.jcrc.2020.08.012.
[2] Carra G, Salluh JIF, da Silva Ramos FJ, Meyfroidt G. Data-driven ICU management: using big data and algorithms to improve outcomes. J Crit Care 2020;60:300–4. https://doi.org/10.1016/j.jcrc.2020.09.002.
[3] Harrison DA, Brady AR, Rowan K. Case mix, outcome and length of stay for admissions to adult, general critical care units in England, Wales and Northern Ireland: the Intensive Care National Audit & Research Centre Case mix Programme Database. Crit Care 2004;8(2):R99–111. https://doi.org/10.1186/cc2834.
[4] van de Klundert N, Holman R, Dongelmans DA, de Keizer NF. Data resource profile: the Dutch National Intensive Care Evaluation (NICE) registry of admissions to adult intensive care units. Int J Epidemiol 2015;44(6). https://doi.org/10.1093/ije/dyv291. 1850-h.
[5] Aegerter P, Auvert B, Buonamico G, Sznajder M, Beauchet A, Guidet B, et al. Organization and quality control of a clinical database on intensive care medicine in central and suburban Paris. Rev Epidemiol Sante Publique 1998;46(3):226–37.
[6] Stow PJ, Hart GK, Higlett T, George C, Herkes R, McWilliam D, et al. Development and implementation of a high-quality clinical database: the Australian and new Zealand Intensive Care Society adult patient database. J Crit Care 2006;21(2):133–41. https://doi.org/10.1016/j.jcrc.2005.11.010.
[7] Zampieri FG, Soares M, Borges LP, Salluh JIF, Ranzani OT. The Epimed monitor ICU database(R): a cloud-based national registry for adult intensive care unit patients in Brazil. Rev Bras Ter Intens 2017;29(4):418–26. https://doi.org/10.5935/0103-507X.20170062.
[8] Crit Care A. Establishing a critical care network in Asia to improve care for critically ill patients in low- and middle-income countries. Crit Care 2020;24(1):608. https://doi.org/10.1186/s13054-020-03321-7.
[9] Bingold TM, Lefering R, Zacharowski K, Waydhas C, Scheller B. Eleven years of core data set in intensive care medicine. Severity of disease and workload are increasing. Anaesthesist 2014;63(12):942–50. https://doi.org/10.1007/s00101-014-2389-5.
[10] Parenmark F, Karlstrom G, Nolin T, Fredrikson M, Walther SM. Reducing night-time discharge from intensive care. A nationwide improvement project with public display of ICU outcomes. J Crit Care 2019;49:7–13. https://doi.org/10.1016/j.jcrc.2018.09.022.
[11] Warrillow S, Austin D, Cheung W, Close E, Holley A, Horgan B, et al. ANZICS guiding principles for complex decision making during the COVID-19 pandemic. Crit Care Resusc 2020;22(2):98–102.
[12] Richards-Belle A, Orzechowska I, Gould DW, Thomas K, Doidge JC, Mouncey PR, et al. COVID-19 in critical care: epidemiology of the first epidemic wave across England, Wales and Northern Ireland. Intensive Care Med 2020;46(11):2035–47. https://doi.org/10.1007/s00134-020-06267-0.
[13] Martensson J, Engerstrom L, Walther S, Grip J, Berggren RK, Larsson E. COVID-19 critical illness in Sweden: characteristics and outcomes at a national population level. Crit Care Resusc 2020;22(4):312–20.
[14] Robert Koch-Institut. DIVI-intensivregister. https://www.intensivregister.de/#/index;; 2023 [accessed 16 March 2023].
[15] UTIs Brasileiras. COVID-19. http://www.utisbrasileiras.com.br/sari-covid-19/benchmarking-covid-19/;; 2023 [accessed 16 March 2023].
[16] Phua J, Weng L, Ling L, Egi M, Lim CM, Divatia JV, et al. Intensive care management of coronavirus disease 2019 (COVID-19): challenges and recommendations. Lancet Respir Med 2020;8(5):506–17. https://doi.org/10.1016/S2213-2600(20)30161-2.
[17] de Jonge E, Bosman RJ, van der Voort PH, Korsten HH, Scheffer GJ, de Keizer NF. Intensive care medicine in the Netherlands, 1997-2001. I. Patient population and treatment outcome. Ned Tijdschr Geneeskd 2003;147(21):1013–7.
[18] Karakus A, Haas LEM, Brinkman S, de Lange DW, de Keizer NF. Trends in short-term and 1-year mortality in very elderly intensive care patients in the Netherlands: a retrospective study from 2008 to 2014. Intensive Care Med 2017;43(10):1476–84. https://doi.org/10.1007/s00134-017-4879-9.
[19] Moran JL, Bristow P, Solomon PJ, George C, Hart GK, Australian, et al. Mortality and length-of-stay outcomes, 1993-2003, in the binational Australian and New Zealand intensive care adult patient database. Crit Care Med 2008;36(1):46–61. https://doi.org/10.1097/01.CCM.0000295313.08084.58.
[20] de Vos ML, Graafmans W, Keesman E, Westert G, van der Voort PH. Quality measurement at intensive care units: which indicators should we use? J Crit Care 2007;22(4):267–74. doi:S0883-9441(07)00008-1 [pii];10.1016/j.jcrc.2007.01.002 [doi].
[21] Zimmerman JE, Kramer AA, McNair DS, Malila FM. Acute physiology and chronic health evaluation (APACHE) IV: hospital mortality assessment for today's critically ill patients. Crit Care Med 2006;34(5):1297–310. https://doi.org/10.1097/01.CCM.0000215112.84523.F0.
[22] Dutch National Intensive Care Evaluation foundation (NICE). Data dictionary. https://stichting-nice.nl/dd/#start;; 1996–2022.
[23] Arts DG, De Keizer NF, Scheffer GJ. Defining and improving data quality in medical registries: a literature review, case study, and generic framework. J Am Med Inform Assoc 2002;9(6):600–11.
[24] Verburg IWM, de Jonge E, Peek N, de Keizer NF. The association between outcome-based quality indicators for intensive care units. PloS One 2018;13(6):e0198522. https://doi.org/10.1371/journal.pone.0198522.
[25] van Sluisveld N, Bakhshi-Raiez F, de Keizer N, Holman R, Wester G, Wollersheim H, et al. Variation in rates of ICU readmissions and post-ICU in-hospital mortality and their association with ICU discharge practices. BMC Health Serv Res 2017;17(1):281. https://doi.org/10.1186/s12913-017-2234-z.
[26] Knaus WA, Wagner DP, Draper EA, Zimmerman JE, Bergner M, Bastos PG, et al. The APACHE III prognostic system. Risk prediction of hospital mortality for critically ill hospitalized adults. Chest 1991;100(6):1619–36.
[27] Goldstein H, Browne W, Rasbash J. Partitioning variation in multilevel models. Understanding Stat 2002;1(4):223. https://doi.org/10.1207/S15328031US0104_02.
[28] Merlo J, Chaix B, Yang M, Lynch J, Rastam L. A brief conceptual tutorial on multilevel analysis in social epidemiology: interpreting neighbourhood differences and the effect of neighbourhood characteristics on individual health. J Epidemiol

Community Health 2005;59(12):1022–8. https://doi.org/10.1136/jech.2004.028035.

[29] Merlo J, Chaix B, Yang M, Lynch J, Råstam L. A brief conceptual tutorial of multilevel analysis in social epidemiology: linking the statistical concept of clustering to the idea of contextual phenomenon. J Epidemiol Community Health 2005;59(6):443–9. https://doi.org/10.1136/jech.2004.023473.

[30] Sommet N, Morselli D. Keep calm and learn multilevel linear modeling: a three-step procedure using SPSS, Stata, R, and Mplus. Int Rev Soc Psychol 2021;34(1). https://doi.org/10.5334/irsp.555.

[31] Zimmerman JE, Alzola C, Von Rueden KT. The use of benchmarking to identify top performing critical care units: a preliminary assessment of their policies and practices. J Crit Care 2003;18(2):76–86. https://doi.org/10.1053/jcrc.2003.50005.

[32] Wortel SA, de Keizer NF, Abu-Hanna A, Dongelmans DA, Bakhshi-Raiez F. Number of intensivists per bed is associated with efficiency of Dutch intensive care units. J Crit Care 2021;62:223–9. https://doi.org/10.1016/j.jcrc.2020.12.008.

[33] Roos-Blom MJ, Gude WT, de Jonge E, Spijkstra JJ, van der Veer SN, Peek N, et al. Impact of audit and feedback with action implementation toolbox on improving ICU pain management: cluster-randomised controlled trial. BMJ Qual Saf 2019. https://doi.org/10.1136/bmjqs-2019-009588.

[34] Lilly CM, Swami S, Liu X, Riker RR, Badawi O. Five-year trends of critical care practice and outcomes. Chest 2017;152(4):723–35. https://doi.org/10.1016/j.chest.2017.06.050.

[35] Ingraham NE, Vakayil V, Pendleton KM, Robbins AJ, Freese RL, Palzer EF, et al. Recent trends in admission diagnosis and related mortality in the medically critically ill. J Intensive Care Med 2022;37(2):185–94. https://doi.org/10.1177/0885066620982905.

[36] Brinkman S, Termorshuizen F, Dongelmans DA, Bakhshi-Raiez F, Arbous MS, de Lange DW, et al. Comparison of outcome and characteristics between 6343 COVID-19 patients and 2256 other community-acquired viral pneumonia patients admitted to Dutch ICUs. J Crit Care 2022;68:76–82. https://doi.org/10.1016/j.jcrc.2021.12.007.

[37] Austin PC, Merlo J. Intermediate and advanced topics in multilevel logistic regression analysis. Stat Med 2017;36(20):3257–77. https://doi.org/10.1002/sim.7336.

[38] Flatow VH, Ibragimova N, Divino CM, Eshak DS, Twohig BC, Bassily-Marcus AM, et al. Quality outcomes in the surgical intensive care unit after electronic health record implementation. Appl Clin Inform 2015;6(4):611–8. https://doi.org/10.4338/ACI-2015-04-RA-0044.

[39] Han JE, Rabinovich M, Abraham P, Satyanarayana P, Liao TV, Udoji TN, et al. Effect of electronic health record implementation in critical care on survival and medication errors. Am J Med Sci 2016;351(6):576–81. https://doi.org/10.1016/j.amjms.2016.01.026.

[40] Dongelmans DA, Pilcher D, Beane A, Soares M, Del Pilar Arias Lopez M, Fernandez A, et al. Linking of global intensive care (LOGIC): an international benchmarking in critical care initiative. J Crit Care 2020;60:305–10. https://doi.org/10.1016/j.jcrc.2020.08.031.

[41] Puttmann D, de Groot R, de Keizer N, Cornet R, Elbers PWG, Dongelmans D, et al. Assessing the FAIRness of databases on the EHDEN portal: a case study on two Dutch ICU databases. Int J Med Inform 2023;176:105104. https://doi.org/10.1016/j.ijmedinf.2023.105104.