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Incidence and predictors of ventilator-associated pneumonia using a competing risk analysis: a single-center prospective cohort study in Egypt

Mohamed Elsheikh[1,2], Akira Kuriyama[1*], Yoshihito Goto[1,3], Yoshimitsu Takahashi[1], Mayumi Toyama[1], Yoshitaka Nishikawa[1], Mohamed Ahmed El Heniedy[4], Yasser Mohamed Abdelraouf[5], Hiroshi Okada[6] and Takeo Nakayama[1]

Abstract

Background Ventilator-associated pneumonia (VAP) is a challenging nosocomial problem in low- and middle-income countries (LMICs) that face barriers to healthcare delivery and resource availability. This study aimed to examine the incidence and predictors of VAP in Egypt as an example of an LMIC while considering death as a competing event.

Methods The study included patients aged ≥ 18 years who underwent mechanical ventilation (MV) in an intensive care unit (ICU) at a tertiary care, university hospital in Egypt between May 2020 and January 2023. We excluded patients who died or were transferred from the ICU within 48 h of admission. We determined the VAP incidence based on clinical suspicion, radiological findings, and positive lower respiratory tract microbiological cultures. The multivariate Fine-Gray subdistribution hazard model was used to examine the predictors of VAP while considering death as a competing event.

Results Overall, 315 patients were included in this analysis. Sixty-two patients (19.7%) developed VAP (17.1 per 1000 ventilator days). The Fine-Gray subdistribution hazard model, after adjustment for potential confounders, revealed that emergency surgery (subdistribution hazard ratio [SHR]: 2.11, 95% confidence interval [CI]: 1.25–3.56), reintubation (SHR: 3.74, 95% CI: 2.23–6.28), blood transfusion (SHR: 2.23, 95% CI: 1.32–3.75), and increased duration of MV (SHR: 1.04, 95% CI: 1.03–1.06) were independent risk factors for VAP development. However, the new use of corticosteroids was not associated with VAP development (SHR: 0.94, 95% CI: 0.56–1.57). *Klebsiella pneumoniae* was the most common causative microorganism, followed by *Pseudomonas aeruginosa*.

Conclusion The incidence of VAP in Egypt was high, even in the ICU at a university hospital. Emergency surgery, reintubation, blood transfusion, and increased duration of MV were independently associated with VAP. Robust antimicrobial stewardship and infection control strategies are urgently needed in Egypt.

*Correspondence:
Akira Kuriyama
ak.bellyrub+005@gmail.com

Full list of author information is available at the end of the article

Keywords Developing countries, Incidence, Pneumonia, ventilator-associated, Respiration, artificial, Risk factors, Fine-Gray competing risk regression model, Subdistribution hazard ratio.

Introduction

Ventilator-associated pneumonia (VAP) is defined as pneumonia that develops more than 48 h after endotracheal intubation [1]. It is associated with an increased duration of mechanical ventilation (MV), longer stays in the intensive care unit (ICU), and higher mortality [2, 3]. VAP also poses a substantial economic burden [4, 5]: the VAP-associated cost in acute-care hospitals in the United States was estimated to be 3 billion USD in 2012 [6].

There is a disparity in the epidemiology of VAP across countries. Hospitals in high-income countries (HICs) have lower VAP rates than those in low- and middle-income countries (LMICs) [7]. A combination of surveillance and infection prevention and control (IPC) policies has reduced the incidence of VAP in HICs [8]. Conversely, the VAP incidence in LMICs remains a challenge because these countries often face unique barriers to healthcare delivery and resource availability [9]. Furthermore, the burden of VAP in LMICs remains unknown because of the lack of standardized infection definitions and the scarcity of IPC organizations and legal infrastructure [10].

Similarly, the limited studies on VAP in Egypt have some limitations: they have mostly cross-sectional designs that focus on VAP prevalence, lack age specification, have a small sample size, and rarely investigate predictors of VAP [11]. To our knowledge, no prospective cohort study with a sufficient sample size has examined the epidemiology of VAP among mechanically ventilated adults in Egypt.

Hence, this study aimed to examine the incidence of VAP and its predictors in mechanically ventilated adult patients in an Egyptian ICU. In this study, we did not include patients with coronavirus disease 2019 (COVID-19). We also assessed the type of pathogen and prevalence of multidrug-resistant (MDR) bacteria responsible for VAP.

Methods

Study design and setting

This single-center prospective cohort study was conducted in the ICU of the emergency medicine and traumatology department at Tanta University Emergency Hospital in Egypt between May 2020 and January 2023 (33 months). Tanta University Emergency Hospital is a 450-bed tertiary care center that provides care for approximately 220,000 patients annually. The ICU has 12 beds equipped with 12 mechanical ventilators and annually accommodates approximately 300 patients admitted mainly from the emergency department (ED). The ICU team, which included a consultant, a specialist, and resident physicians, followed up with our patients daily and collected data, if necessary. We designed an informative medical sheet with all possible VAP-related variables. We double-checked each data entry weekly to minimize errors and ensure data integrity.

Our hospital ensured compliance with VAP prevention and control strategies by maintaining sufficient equipment and supplies, allocating adequate time for implementing prevention strategies, and allowing nurses to upgrade their knowledge and skills. Most of the VAP prevention bundle strategies are applied in this ICU, including strict hand hygiene before airway management, daily interruption of sedation, readiness-to-extubate assessment, elevation of the head of the bed to 30–45°, avoidance of elective changes of ventilator circuits, stress ulcer prophylaxis, and oral hygiene with chlorhexidine [12]. We adhered to the updated strategies to prevent VAP in 2014 [12] but did not follow the update published in 2022 during the study period [13].

Participant selection

Patients aged ≥ 18 years who were endotracheally intubated and mechanically ventilated during the study period were included in the study. Patients who died or were transferred from the ICU within 48 h of MV were excluded.

Measurement

The following variables were recorded in the ED and ICU. During the primary survey in the ED, the following factors were assessed: initial mental status, need for emergency intubation, presence of shock (systolic blood pressure of < 90 mmHg and/or serum lactate level of > 4 mmol/L) [14, 15], and number of injured organs in the trauma (monotrauma or polytrauma). An altered mental status was defined as a Glasgow Coma Score of < 9. On admission to the ICU, patient characteristics were recorded, such as age, sex, smoking, alcohol intake, underlying diseases, and provisional diagnosis. Furthermore, the patients' Acute Physiology and Chronic Health Evaluation (APACHE) II scores in the ICU were calculated [16]. Since this study was conducted during the COVID-19 pandemic, we screened all participants for COVID-19 infection using the COVID-19 Reporting and Data System (CO-RADS) classification. Our patients were either CO-RAD 1 or 2 [17]. Our ICU was not designed to admit any patients with COVID-19 during the pandemic. ICU admission was categorized as medical, trauma, and postoperative.

Furthermore, the following variables concerning clinical events were recorded: the need for emergency surgery (surgery for trauma-associated life-threatening conditions or those related to the abdomen such as perforated viscus and bowel obstruction); acute kidney injury (AKI) diagnosed based on the Kidney Disease Improving Global Outcomes (KDIGO) guidelines [18]; need for hemodialysis, the indications for which included end-stage kidney disease and acute AKI; insertion of a nasogastric tube; and need for reintubation and tracheostomy. New use of corticosteroids and transfusions of blood products, such as red blood cells, fresh frozen plasma, platelets, or cryoprecipitate in any amount, either in the ED or ICU, was also determined. Additionally, the duration of MV before successful extubation, VAP development, and length of ICU stay in days were determined.

A diagnosis of VAP was established when the following three criteria were met: clinical suspicion, radiological findings (new or progressive pulmonary infiltrates), and positive microbiological cultures of specimens obtained from the lower respiratory tract [1, 8, 19]. VAP was clinically suspected when any of the following signs were present: fever, tachypnea, hemoptysis, increased purulent sputum, decreased breath sounds, bronchospasm, worsening hypoxemia, and leukocytosis; however, none of these signs were sufficient for establishing a diagnosis of VAP [19]. Chest computed tomography (CT) was performed when a patient was fit for transfer to the CT unit. Portable chest radiography was otherwise used for diagnosis. Once VAP was suspected, microbiological bacterial sampling was routinely performed via noninvasive endotracheal tube aspiration from the lower respiratory tract. We occasionally screened for viruses or fungi as causative pathogens of VAP; however, in this study, viral or fungal infections were not suspected or screened for in any case. VAP was classified as early- or late-onset, depending on whether it developed within or after the first 96 h [1]. We defined MDR as non-susceptible bacteria to at least one agent in three or more antimicrobial categories [20].

Statistical analysis

Continuous variables are presented as mean (standard deviation) or median (interquartile range [IQR]), whereas categorical variables are shown as numbers (%). Fisher's exact test was used to compare categorical variables between the groups, whereas the Wilcoxon rank sum test or the t-test was performed for continuous variables as appropriate. The primary outcome measure was the incidence of VAP. The incidence rate (IR) of VAP per 1,000 ventilator days was calculated by dividing the number of VAP cases by the total patient-time at risk (duration of MV).

The Fine-Gray subdistribution hazard model was used to measure the association of various exposure variables with the incidence of VAP while considering death as a competing event. This model is more suitable for predictions in the presence of competing events [21]. The strength of the association between each variable and the outcome was assessed using the subdistribution hazard ratio associated with the cumulative incidence function of each binary exposure variable. The survival time in days from MV initiation to the diagnosis of VAP or death was determined. Patients who did not develop VAP and survived were censored. The following five exposure variables were defined as potential predictors of VAP based on clinical significance and previous literature: emergency surgery [22], reintubation [22], blood transfusion [23], use of corticosteroids [23], and duration of MV [22, 23].

Multicollinearity was assessed by analyzing the variance inflation factors (VIFs). Collinearity was considered negligible when the VIF values were less than 5 [24]. Accordingly, five final models were established, each with one potential predictor, adjusted for the following variables: shock on admission, polytrauma, the need for hemodialysis, and tracheostomy. A directed acyclic graph (DAG) was used to determine the adjusted variables appropriately [25].

Statistical analyses were performed using the JMP Pro 17 (JMP Statistical Discovery LLC, Cary, NC, USA), STATA 15.1 (Stata, College Station, TX, USA) software, and R software version 4.4.0 (R Core Team, Vienna, Austria) using "tidyverse" and "tidycmprsk" packages. Statistical significance was defined as a two-tailed P-value of <0.05. This study was approved by the ethics committee of the Faculty of Medicine at Tanta University, Egypt (No. 33247/07/19) and the institutional review board of Kyoto University (R4018). Written informed consent was obtained from all participants or their relatives. The description of this study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines [26].

Results

Characteristics of the study participants

Overall, 824 patients were admitted to the ICU, among whom 385 met the inclusion criteria. After excluding 70 patients who died or were transferred from the ICU within 48 h, 315 patients were finally included in the analysis (Fig. 1).

The patients' baseline characteristics are shown in Table 1 and Online Supplementary Table. The patients' mean age was 48 years, and 86 (27.3%) were female. The reasons for ICU admission were as follows: trauma (179, 56.8%), medical reasons (113, 35.9%), and postoperative admission (23, 7.3%). Eighty patients (25.4%) were in

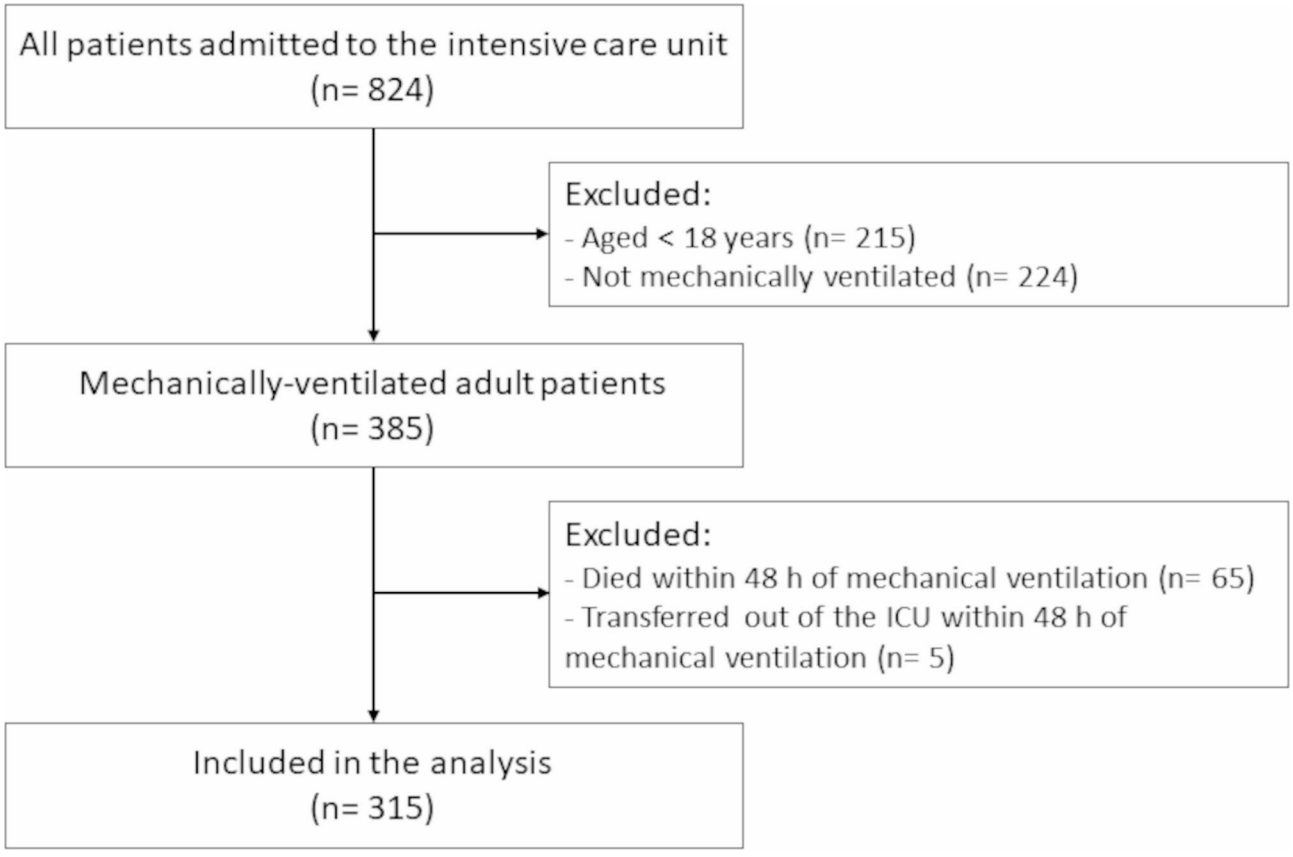

Fig. 1 Flow diagram of patient selection. Abbreviation: ICU, intensive care unit

shock on admission, 145 (46%) had polytrauma, and 120 (38.1%) and 84 (26.6%) underwent blood transfusion and emergency surgery, respectively. Overall, 110 (34.9%) and 22 (7%) patients received corticosteroids and underwent hemodialysis, respectively. Sixty-one (19.3%) patients were reintubated, and 17 (5.4%) underwent tracheostomy. The median length of ICU stay was 9 days (IQR: 6–16), with the MV duration being 7 days (IQR: 5–12). The overall mortality rate was 69.2% ($n=218$).

During the 3634 days of cumulative MV, 62 (19.7%) patients developed VAP (17.1 VAP episodes per 1000 ventilator days). No patient had more than one episode of VAP. There were 31 events each of early- and late-onset VAP. The average duration between MV initiation and VAP occurrence was 8 days, with 26 days being the longest. The mortality among patients with VAP was 62.9% ($n=39$).

The probability of VAP occurrence, with a competing risk of death, is shown in a cumulative incidence curve for each model (Fig. 2). The Fine-Gray subdistribution regression analyses with adjustment of possible confounders revealed that emergency surgery (subdistribution hazard ratio [SHR]: 2.11, 95% CI: 1.25–3.56; $P=0.005$), reintubation (SHR: 3.74, 95% CI: 2.23–6.28; $P<0.001$), blood transfusion (SHR: 2.23, 95% CI: 1.32–3.75; $P=0.003$), and increased duration of MV (SHR: 1.04, 95% CI: 1.03–1.06; $P<0.001$) were associated with the development of VAP, whereas novel use of corticosteroids was not ($P=0.81$) (Table 2).

The bacteria isolated from the respiratory samples of all patients are shown in Table 3. *Klebsiella pneumoniae* was the leading causative microorganism of VAP, followed by *Pseudomonas aeruginosa*. MDR bacteria were common, with a prevalence of 40.3%. MDR organisms were common in cases of early- and late-onset VAP, respectively (32.3% and 48.4%; $P=0.30$). *Klebsiella pneumoniae* was the most prevalent MDR bacterium in both early- and late-onset VAP. Treatment options were limited for infection with any of the MDR bacteria detected: the bacteria were sensitive only to colistin and tigecycline.

Discussion

Our study found that VAP developed in approximately 20% of mechanically ventilated patients, with an IR of 17.1 per 1000 ventilator days in the ICU of an Egyptian tertiary care hospital. We found that emergency surgery, reintubation, blood transfusion, and prolonged MV were associated with the development of VAP. This study is the first to evaluate predictors of VAP in an Egyptian setting while considering a competing event.

Table 1 Baseline characteristics of the participants

Characteristics	Total (*n* = 315)	VAP (*n* = 62)	No VAP (*n* = 253)	*P*-value
Mean age, years (SD)	48 (19.2)	43.3 (19.5)	49.1 (19)	0.034
Female, *n* (%)	86 (27.3)	17 (27.4)	69 (27.3)	1.00
Underlying diseases, *n* (%)				
Hypertension	90 (28.5)	14 (22.6)	76 (30.0)	0.28
Diabetes mellitus	65 (20.6)	8 (12.9)	57 (22.5)	0.115
Cardiac disease	39 (12.4)	5 (8.1)	34 (13.4)	0.29
COPD	23 (7.4)	3 (4.8)	20 (7.9)	0.59
Hepatic disease	26 (8.3)	4 (6.5)	22 (8.7)	0.80
Neurological disease	43 (13.7)	4 (6.5)	39 (15.4)	0.096
Cancer	6 (1.9)	1 (1.6)	5 (2.0)	1.00
Hemodialysis	22 (7)	3 (4.8)	19 (7.5)	0.59
Surgical history, *n* (%)	52 (16.5)	12 (19.4)	40 (15.8)	0.57
Smoking, *n* (%)	110 (34.9)	23 (37.1)	87 (34.4)	0.77
Alcohol intake, *n* (%)	15 (4.7)	2 (3.2)	13 (5.1)	0.74
Reasons for ICU admission, *n* (%)				
Trauma	179 (56.8)	45 (72.6)	134 (53.0)	0.006
Medical	113 (35.9)	16 (25.8)	97 (38.3)	0.076
Postoperative	23 (7.3)	1 (1.6)	22 (8.7)	0.058
APACHE II score, mean (SD)	28.2 (15.2)	24.8 (11.2)	29.1 (15.9)	0.046
Initial impaired consciousness, *n* (%)	187 (59.4)	37 (59.7)	150 (59.3)	1.00
Emergency intubation, *n* (%)	253 (80.3)	47 (75.8)	206 (81.4)	0.37
Shock on admission, *n* (%)	80 (25.4)	17 (27.4)	63 (24.9)	0.75
Polytrauma, *n* (%)	145 (46)	35 (56.5)	110 (43.5)	0.088
Emergency surgery, *n* (%)	84 (26.6)	31 (50.0)	53 (21.0)	< 0.001
Reintubation, *n* (%)	61 (19.3)	30 (48.4)	31 (12.3)	< 0.001
Acute kidney injury, *n* (%)	48 (15.3)	11 (17.7)	37 (14.6)	0.56
Nasogastric tube insertion, *n* (%)	242 (76.9)	61 (98.4)	181 (71.5)	< 0.001
Use of corticosteroids, *n* (%)	110 (34.9)	22 (35.5)	88 (34.8)	1.00
Blood transfusion, *n* (%)	120 (38.1)	38 (61.3)	82 (32.4)	< 0.001
Median duration of MV, days (IQR)	7 (5–12)	20 (12–36)	6 (4–9)	< 0.001
Median ICU length of stay, days (IQR)	9 (6–16)	23 (17–49)	8 (5-11.5)	< 0.001
Tracheostomy, *n* (%)	17 (5.4)	9 (14.5)	8 (3.2)	0.002
Mortality, *n* (%)	218 (69.2)	39 (62.9)	179 (70.8)	0.28

Abbreviations: APACHE, Acute Physiology and Chronic Health Evaluation; COPD, Chronic obstructive pulmonary disease; ICU, Intensive care unit; MV, Mechanical ventilation; SD, Standard deviation; IQR, Interquartile range

Despite the variation in diagnostic standards and study periods, the reported IR of VAP varies across countries. For example, the IR of VAP in our study was higher than that reported in the United States and Poland (1–2.5 and 9.7 VAP episodes per 1,000 ventilator days, respectively) [27, 28]. Conversely, it was relatively lower than that in India and Mexico (22.9 and 28.8 VAP episodes per 1,000 ventilator days, respectively) and similar to that in Nepal (16.5 VAP episodes per 1,000 ventilator days) [29–31]. However, one study from Egypt showed a higher VAP IR (48.8 VAP episodes per 1,000 ventilator days), and because the patients of that study had baseline characteristics similar to those of ours, the difference in the VAP IR might be attributable to the infection control culture [32]. Similarly, there is considerable variation in the mortality rate of mechanically ventilated patients across studies and regions, which tends to be high in LMICs [33]. These observations highlight the influence of socioeconomic factors on infection control measures and emphasize the importance of addressing healthcare disparities in LMICs.

Prolonged intubation is theoretically associated with an increased risk of VAP owing to alterations in the mucosal defense mechanisms of the normal airway, deterioration of swallowing function, and the presence of infectious sources in humidifiers and ventilator circuits [34]. Specifically, prolonged intubation disrupts the biofilm formed on the endotracheal tube, potentially releasing bacteria into the lower airways and increasing the risk of VAP [35]. Previous studies in both HICs and LMICs have demonstrated an increased risk of VAP associated with prolonged MV [36–38]. Consistent with previous findings,

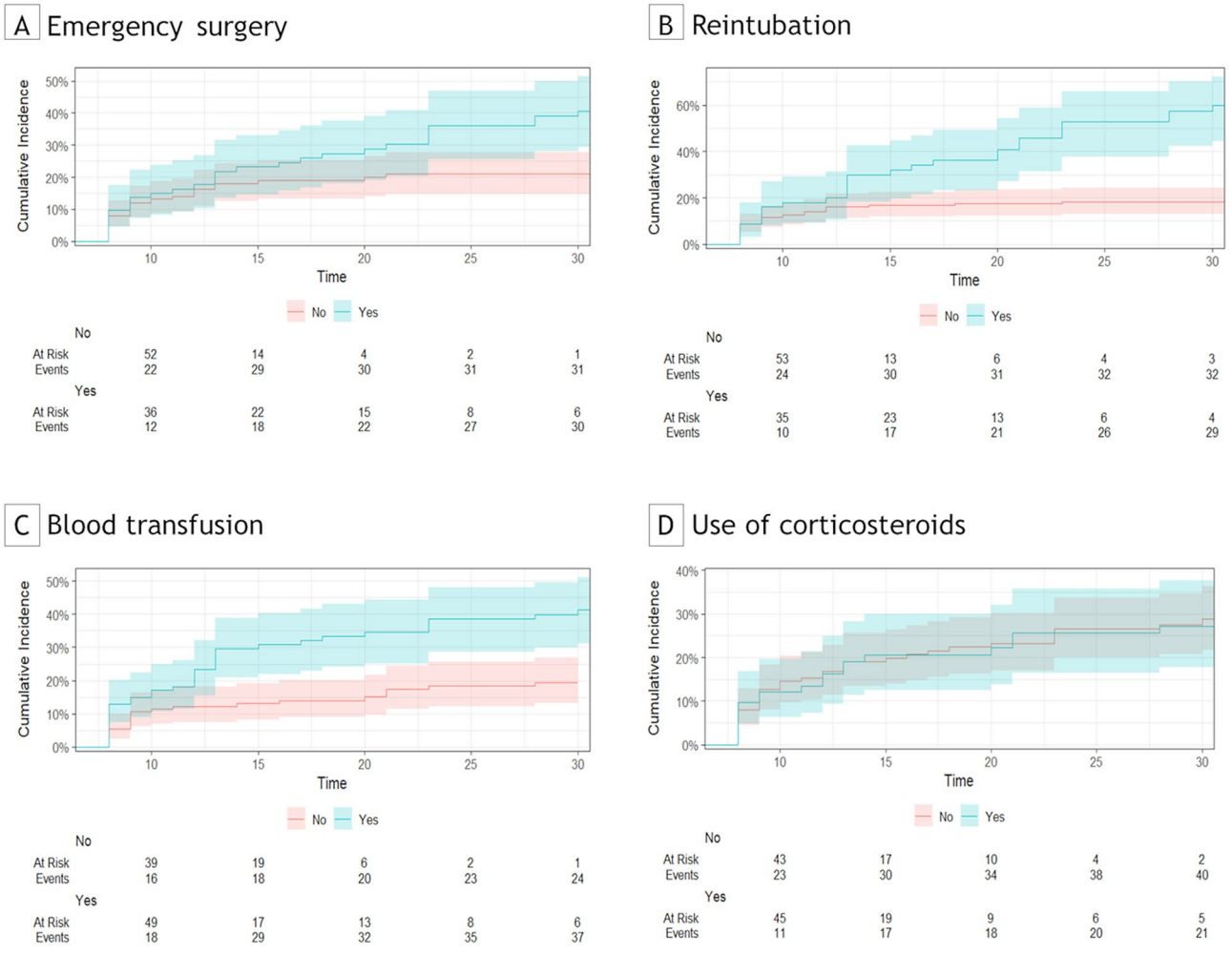

Fig. 2 Cumulative incidence of ventilator-associated pneumonia with death as a competing risk after initiating mechanical ventilation
Footnote: A cumulative incidence curve was constructed for the model with each of the following binary outcomes: **(A)** emergency surgery, **(B)** reintubation, **(C)** blood transfusion, and **(D)** use of corticosteroids each model was adjusted for the need for hemodialysis, polytrauma, shock on admission, and tracheostomy before the development of ventilator-associated pneumonia. The presence and absence of the exposure variable are indicated by "Yes" and "No," respectively, in each figure

Table 2 Fine-Gray subdistribution hazard models showing the association of variables with ventilator-associated pneumonia

Variable	Adjusted subdistribution hazard ratio (95% CI)	*P* value
Emergency surgery	2.11 (1.25–3.56)	0.005
Reintubation	3.74 (2.23–6.28)	< 0.001
Blood transfusion	2.23 (1.32–3.75)	0.003
Use of corticosteroids	0.94 (0.56–1.57)	0.81
Duration of mechanical ventilation	1.04 (1.03–1.06)	< 0.001

The following variables were adjusted in each Fine-Gray subdistribution hazard model: the need for hemodialysis, polytrauma, shock on admission, and tracheostomy before the development of ventilator-associated pneumonia

our study showed that prolonged ventilation was associated with a 4% increase in the daily risk of VAP. We also hypothesized that reintubation could increase the risk of VAP by facilitating the aspiration of either oropharyngeal secretions or gastric contents into the lower respiratory tract. Our multivariate analysis suggested that reintubation was also a significant risk factor for VAP (SHR: 3.74, 95% CI: 2.23–6.28), which was consistent with previous findings [29, 39].

Critically ill patients may be immunocompromised and be at a higher risk of bacterial infections via immunomodulation from medical interventions [40, 41]. For instance, blood transfusion can alter the immune system by inducing immune activation through the induction of human leukocyte antigen alloantibodies and T-cell activation or the promotion of immunosuppression through defective antigen presentation and suppression of lymphocyte

Table 3 Bacteria species identified from sputum in patients with ventilator-associated pneumonia and distribution by its onset

Pathogen	Overall (*n* = 62)	Early-onset VAP		Late-onset VAP	
		Total (*n* = 31)	MDR bacteria (*n* = 10)	Total (*n* = 31)	MDR bacteria (*n* = 15)
Klebsiella pneumoniae	35 (56.5%)	21 (60%)	8 (22.9%)	14 (40%)	9 (25.7%)
Pseudomonas aeruginosa	8 (13%)	4 (50%)	0 (0%)	4 (50%)	2 (25%)
Staphylococcus aureus	6 (9.7%)	-	-	6 (100%)	1 (16.7%)
Proteus species	4 (6.4%)	1 (25%)	0 (0%)	3 (75%)	0 (0%)
Acinetobacter baumannii	4 (6.4%)	2 (50%)	2 (50%)	2 (50%)	2 (50%)
Escherichia coli	3 (4.8%)	2 (66.7%)	0 (0%)	1 (33.3%)	1 (33.3%)
Enterobacter aerogenes	1 (1.6%)	-	-	1 (100%)	0 (0)
Macrococcus aerobic	1 (1.6%)	1 (100%)	0 (0%)	-	-

The percentage of total and MDR bacteria in early-onset and late-onset VAP are calculated using the total number of each type of bacteria as the denominator

Abbreviations: VAP, ventilator-associated pneumonia; MDR, multidrug-resistant

blastogenesis [41]. A meta-analysis suggested that a restrictive red blood cell transfusion strategy was associated with a reduced risk of healthcare-associated infections compared with a liberal transfusion strategy [42]. Previous studies have reported that blood transfusion, whether small or large, is associated with an increased risk of overall nosocomial infection and VAP [36, 43–46]. Consistent with these findings, our study suggests that any amount of blood transfused is associated with an increased risk of developing VAP. Emergency surgery triggers an abnormal systemic inflammatory reaction and releases a series of pro-inflammatory mediators, impairing immune defenses [47]. Consequently, previous studies on cardiac surgery suggested that emergency surgery was associated with the development of VAP [36, 48], which is consistent with our study findings.

Evidence on the impact of corticosteroids on VAP is scarce and conflicting [49, 50]. Patients taking corticosteroids can be susceptible to infections owing to the triggering of neutrophil apoptosis and adherence to the inner vascular wall, as well as the subsequent decline in neutrophil phagocytic and migratory capacity at inflammatory sites, impairing the clearance of opsonized bacteria [51]. Our study suggests that the novel use of corticosteroids in the ED or ICU is not associated with the development of VAP. Notably, it is possible to obtain prescribed-only medications from pharmacies without medical prescriptions in some developing countries such as Egypt [52]. Our data did not include the use of corticosteroids before admission to our ED, which precluded a rigorous investigation into the risk of VAP with corticosteroid intake; therefore, more studies are needed.

The bacterial profile responsible for VAP varies across countries [7, 53, 54]. *Acinetobacter baumannii* and *Pseudomonas aeruginosa* are the most common pathogens across countries [7, 53]. *Staphylococcus aureus* is more common in HICs, whereas *Klebsiella* spp. and *Escherichia coli* are more common in LMICs [7]. Similar to these findings and some studies from LMICs (India and Egypt), we found *Klebsiella pneumoniae* to be the most common pathogen in our cohort [55, 56]. Thus, the overall MDR bacterial prevalence accounted for 40.3%; this finding was consistent with that of a previous study conducted in Egypt [56]. Commonly known MDR pathogens include *Acinetobacter baumannii* [7, 57]. Methicillin-resistant *Staphylococcus aureus* is a prevalent MDR pathogen in HICs, whereas *Acinetobacter baumannii* is more common in LMICs [7]. In contrast to previous findings, *Klebsiella pneumoniae* was the predominant MDR bacterium in our cohort. Although it is known that MDR bacteria are predominantly associated with late-onset VAP [1], evidence is conflicting regarding whether MDR is prevalent in early-onset VAP [58]. Our findings confirmed that MDR pathogens were common in both early- and late-onset VAP. Our results highlight the urgent need for robust antimicrobial stewardship and infection control strategies to combat the multi-drug resistance of *Klebsiella* species.

Our study has several strengths. First, the prospective design allowed us to accurately record relevant VAP predictors and possible confounders. Second, this is the first study to use DAG to select an appropriate set of confounding variables to adjust for when examining VAP predictors. Third, our study is one of the few that considered a competing event against VAP while performing the analysis [59]. However, this study had some limitations. First, it was a single-center study; nevertheless, because we uniformly adhered to known preventive measures, our findings may add to and reinforce the knowledge on VAP in an LMIC. Second, we routinely chose noninvasive endotracheal tube aspiration to obtain sputum cultures because of limited resources. Variations in microbial sampling methods could lead to variability in VAP incidence [60]. Therefore, the incidence of VAP in our study might have varied if bronchoalveolar lavage fluid had been chosen as the sputum sampling method. Third, we did not measure compliance with VAP prevention and control measures in our ICU. We could not

examine how compliance with these strategies affected the incidence of VAP. Fourth, we diagnosed VAP solely based on positive sputum cultures. A diagnosis of VAP is established comprehensively in real-world clinical practice, and it is possible that cases termed "culture-negative" VAP are treated with antibiotics. However, in our study, we did not find or treat any cases of VAP with negative sputum cultures.

Conclusions

We found that the incidence of VAP was high in an ICU in Egypt. After considering death as a competing event, we found that emergency surgery, reintubation, blood transfusion, and prolonged MV were independently associated with VAP. *Klebsiella pneumoniae* was the most common causative agent of VAP, and MDR bacteria were common.

Abbreviations

AKI	Acute kidney injury
APACHE	Acute Physiology and Chronic Health Evaluation
CI	Confidence interval
CO-RADS	COVID-19 Reporting and Data System
COVID-19	Coronavirus disease 2019
CT	Computed tomography
DAG	Directed acyclic graph
ED	Emergency department
HICs	High-income countries
ICU	Intensive care unit
IPC	Infection prevention and control policies
IQR	Interquartile range
IR	Incidence rate
KDIGO	Kidney Disease Improving Global Outcomes
LMICs	Low- and middle-income countries
MDR	Multi-drug resistance
MV	Mechanical ventilation
SHR	Subdistribution hazard ratio
VAP	Ventilator-associated pneumonia
VIF	Variance inflation factors

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12879-024-09909-6.

Supplementary Material 1

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Author contributions

ME conceived the study design, collected the data, analyzed, and interpreted the data, and wrote the first draft. AK conceived the study design, analyzed and interpreted the data, wrote the first draft, and prepared figures and tables. YG, YT, MT, YN, and HO conceived the study design, and analyzed and interpreted the data. MAEH collected the data. YMA conceived the study design. TN conceived the study design, and analyzed and interpreted the data. All authors critically revised the draft and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

The Faculty of Medicine Ethics Committee at Tanta University, Egypt (No. 33247/07/19) and Kyoto University Institutional Review Board (R4018) approved this study. Written informed consent was obtained from all participants or their relatives.

Author details

[1]Department of Health Informatics, Graduate School of Medicine and Public Health, Kyoto University, Kyoto, Japan
[2]Department of Emergency Medicine and Traumatology, Faculty of Medicine, Tanta University, Tanta, Egypt
[3]Clinical Research Center, National Hospital Organization Kyoto Medical Center, Kyoto, Japan
[4]Department of Vascular Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt
[5]Department of Internal Medicine, Faculty of Medicine, Tanta University, Tanta, Egypt
[6]Department of Pharmaceutical Sciences, Wakayama Medical University, Wakayama, Japan

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