Effect of ICU quality control indicators on VAP incidence and mortality: a Retrospective Study of 1267 hospitals in China

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Abstract

Purpose

To investigate the effects of ICU quality control indicators on the VAP morbidity and mortality in China throughout 2019

Methods

This was a retrospective study. A total of 1267 ICUs from 30 provinces in mainland China were included. Data were collected using the National Clinical Improvement System Data that reports ICU information. 10 related quality control indicators were analyzed, including 5 structural factors (patient-to-bed ratio, physician-to-bed ratio, nurse-to-bed ratio, patient-to-physician ratio, patient-to-nurse ratio), 3 process factors (unplanned endotracheal extubation rate, reintubation rate within 48h, and microbiology detection rate before antibiotic use) and 2 outcome factors (VAP morbidity and mortality). The information of most common infectious pathogens and most common used antibiotics in ICU was also collected. Generalized linear mixed models were used to analyze the association between these factors and VAP morbidity and mortality.

Results

The morbidity of VAP in these hospitals in 2019 was 5.03 (2.38, 10.25) per 1000 ventilator days, and the mortality of VAP was 11.11 (0.32, 26.00)%.

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Although evidence suggested that, when adhered to VAP care bundle, the rate of VAP infections and the healthcare costs could be significantly reduced[4, 5], the ventilator bundle compliance was not satisfactory[6, 7]. Education alone was not enough in VAP care bundle compliance[8], other methods such as checklists or real-time bundle adherence dashboard were also very important[9, 10]. And this phenomenon reminds us that, the morbidity and the mortality of VAP are more related to the ability of implementing the bundles, which reflects the quality control level of ICU. Hence, there is an urgent need for the development and implementation of new strategies with the aim of improving care quality in ICUs.

Conclusion

This study highlights the association between the ICU QC factors and VAP morbidity and mortality. The process factors rather than the structural factors need to be further improved for the QC of VAP in ICU.

Key Message

- 8 ICU QC indicators including 5 structural factors (patient-to-bed ratio, physician-to-bed ratio, nurse-to-bed ratio, patient-to-physician ratio, patient-to-nurse ratio), 3 process factors (unplanned endotracheal extubation rate, reintubation rate within 48h, and microbiology detection rate before antibiotic use) were associated with VAP morbidity.
- Only 2 process factors including unplanned endotracheal extubation rate, reintubation rate within 48h were associated with high VAP mortality, while all the 5 structural factors were not.
- The process factors rather than the structural factors need to be further improved for the QC of VAP in ICU.

Introduction

As a life-saving intervention for a variety of critical ill patients, mechanical ventilation is vastly employed in the ICU all over the world. However, ventilator-associated pneumonia (VAP) is one of the most serious nosocomial infections in critically ill patients, which is associated with substantially morbidity and mortality, and considerable economical, psychological, and social costs to patients and families[1, 2]. VAP is preventable, and combination of several core evidence-based elements, also known as VAP care bundle, is recommended. The VAP care bundle consists of 5 interventions: elevation of the head of bed between 30–45 degrees, daily sedative interruption and daily assessment of readiness to extubate, peptic ulcer prophylaxis, deep vein thrombosis prophylaxis, and daily oral care with chlorhexidine[3].

Although evidence suggested that, when adhered to VAP care bundle, the rate of VAP infections and the healthcare costs could be significantly reduced[4, 5], the ventilator bundle compliance was not satisfactory[6, 7]. Education alone was not enough in VAP care bundle compliance[8], other methods such as checklists or real-time bundle adherence dashboard were also very important[9, 10]. And this phenomenon reminds us that, the morbidity and the mortality of VAP are more related to the ability of implementing the bundles, which reflects the quality control level of ICU. Hence, there is an urgent need for the development and implementation of new strategies with the aim of improving care quality in ICUs.

The effect of quality improvement (QI) program on clinical practice is gaining more and more attention in critical care medicine. A cluster randomized trial showed that multifaceted QI interventions improved the adoption of clinical practice in ICUs[11]. Marini et al. reported that multifaceted bundle interventions shown effective reducing VAP rates in multidisciplinary ICUs[12]. An analysis of the National Clinical Improvement System Data in China highlighted the association between specific ICU structural factors and patients’ outcomes[13]. Therefore, the aim of this study was to investigate the ICU QI factors and the mortality and morbidity of VAP and identify the association between these variables and patient outcomes.
Methods

This was an observational database study in 2019, and trial protocol was approved by the Central Institutional Review Board at Peking Union Medical College Hospital (NO. SK 1828), the approval included a waiver for the informed consent of patients and physicians. The data source was the National Clinical Improvement System([https://ncisdc.medidata.cn/login.jsp](https://ncisdc.medidata.cn/login.jsp)), collected by the China-National Critical Care Quality Control Center (China-NCCQC), which is the official national department that regulates ICU quality control in China. Peking Union Medical College Hospital was approved to establish the China-NCCQC in 2012 and initiated the quality improvement of Critical Care program in 2015. Analysis of the data was permitted by China- NCCQC.

Study population and setting

The enrolled hospitals voluntarily participated and were selected by the China-NCCQC. The selection criteria were as follows. (1) The ICU had to have more than five beds. (2) The ICU met the requirements for equipment, construction, and management of ICUs in China. (3) The ICU had to have the ability to diagnose and treat the relevant medical diseases that were evaluated as quality control items (such as VAP). A trained data collector in each ICU was required to submit and report the quality control data via the internet. The data in this study were collected between Jan 1, 2019, and Dec 31, 2019. Range checks were used to check for inconsistent or out-of-range data, prompting the user to correct or review data entries outside the pre-defined range.

Variable and measurements

The QI factors of the ICU were evaluated according to the National Clinical Quality Control Indictors for Critical Care Medicine, which were officially recommended for the assessment of ICU performance by the National Health Commission of the People's Republic of China in 2015[14]. In this study, 10 related factors were analyzed, including 5 structural factors, 3 process factors and 2 outcome factors. The structural factors included the ICU patient-to-bed ratio (calculated by the total number of ICU patients divided by the number of beds in the ICU), physician-to-bed ratio (calculated by the total number of ICU physicians divided by the number of beds in the ICU), nurse-to-bed ratio (calculated by the total number of ICU nurses divided by the number of beds in the ICU), patient-to-physician ratio (calculated by the total number of ICU patients divided by the number of ICU physicians), patient-to-nurse ratio (calculated by the total number of ICU patients divided by the number of nurse). The process factors included unplanned endotracheal extubation rate, reintubation rate within 48h, and microbiology detection rate before antibiotic use. The outcome factors included VAP morbidity rate (‰) per 1000 ventilator days and VAP mortality rate. The definition and meaning of the factors have been described previously[14]. Moreover, the information of most common pathogens and the most commonly used antibiotics of VAP in the ICU were also collected.

Data analysis

All statistical analysis were performed in SAS 9.4 (SAS Institute, Inc, Cary, NC). Normally distributed data are expressed as the mean and standard deviation and were compared using Student's t test. Nonnormally distributed data are presented as the median and interquartile range (IQR) and were analyzed using the nonparametric Mann–Whitney U test. To identify the adjusted effects of the factors on VAP morbidity and mortality, a multivariate analysis was conducted using generalized linear mixed models. The results are expressed as the p value and beta with the 95% confidence interval (CI). The cut-off values for categorizing the quality-related parameters were assigned according to the clinical implications and data distribution. Listwise deletion was used to handle missing data. In total, 1267 hospitals were included in the final analysis. All statistical tests were two-tailed, and p < 0.05 was statistically significant.

Results

Characteristics of the ICU QI factors

A total of 1267 hospitals from 30 provinces were included in this data analysis. The proportions of hospitals from each province are shown in Fig. 1. The morbidity of VAP in these hospitals was 5.03 (2.38, 10.25) per 1000 ventilator days, and the mortality of VAP was 11.11 (0.32, 26.00) %.

All the ICU factors characteristics were presented in Table 1. The median ICU patient-to-bed ratio was 37.64 (27.59, 51.55), the physician-to-bed ratio was 0.58 (0.44, 0.75), nurse-to-bed ratio was 1.88 (1.50, 2.31), the patient-to-physician ratio was 64.25 (45.63, 90.25), patient-to-nurse ratio was 20.2 (14.4, 28.62). The unplanned endotracheal extubation rate was 0.83 (0.2, 1.44) %, the reintubation rate within 48h was 1.76 (0.74, 3.52) %, and microbiology detection rate before antibiotic use was 92.86 (75.00, 100) %. The most common causative pathogen was Acinetobacter baumannii (in 39.98% hospitals), followed by Klebsiella pneumoniae (K. pneumoniae) (38.26%), Pseudomonas aeruginosa and Escherichia coli (Table 2A). In 26.90% hospitals, third-generation cephalosporin was the most commonly used antibiotics, followed by carbapenem (24.22%), penicillin and beta-lactamase inhibitor combination (20.09%), cephalosporin with beta-lactamase inhibitor (17.93%) (Table 2B).
Table 1
Characteristics of the ICU Quality Improvement factors

<table>
<thead>
<tr>
<th>Categories</th>
<th>Variables</th>
<th>N</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Extreme value</th>
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<td>37.64</td>
<td>51.55</td>
<td>3.19–252.20</td>
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<td>physician-to-bed ratio</td>
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<td>0.44</td>
<td>0.58</td>
<td>0.75</td>
<td>0.12–3.19</td>
</tr>
<tr>
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<td>1.88</td>
<td>2.31</td>
<td>0.60–4.56</td>
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<tr>
<td></td>
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<td>64.25</td>
<td>90.25</td>
<td>6.03–541.17</td>
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<tr>
<td></td>
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<td>20.2</td>
<td>28.62</td>
<td>2.28–99.91</td>
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<td>Process factors</td>
<td>Unplanned endotracheal extubation rate (%)</td>
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<td>0</td>
<td>0.83</td>
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<td>0-96.95</td>
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<tr>
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<td>Reintubation rate in 48 hours (%)</td>
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<td>0.74</td>
<td>1.76</td>
<td>3.52</td>
<td>0-65.17</td>
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<tr>
<td></td>
<td>Microbiology detection rate before antibiotic use (%)</td>
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<td>75.00</td>
<td>92.86</td>
<td>100</td>
<td>0.98–100</td>
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<tr>
<td>Outcome factors</td>
<td>VAP morbidity (%)</td>
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<td>2.38</td>
<td>5.03</td>
<td>10.25</td>
<td>0.00–344.44</td>
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<tr>
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<td>VAP mortality (%)</td>
<td>1267</td>
<td>0.32</td>
<td>11.11</td>
<td>26.00</td>
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Table 2
Distribution of infection pathogens and antibiotics of VAP among hospitals in 30 provinces of mainland China

A. most common infection pathogens (proportion of hospitals, %)

<table>
<thead>
<tr>
<th></th>
<th>Acinetobacter baumannii</th>
<th>Klebsiella pneumoniae</th>
<th>Pseudomonas aeruginosa</th>
<th>Escherichia coli</th>
<th>Stenotrophomonas maltophilia</th>
<th>MRSA</th>
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<tr>
<td>Total</td>
<td>39.98</td>
<td>39.13</td>
<td>9.50</td>
<td>7.02</td>
<td>1.20</td>
<td>1.11</td>
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<td>Anhui</td>
<td>34.21</td>
<td>57.89</td>
<td>5.26</td>
<td>2.63</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Beijing</td>
<td>34.78</td>
<td>39.13</td>
<td>13.04</td>
<td>4.35</td>
<td>4.35</td>
<td>0.00</td>
</tr>
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<td>15.38</td>
<td>2.56</td>
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<td>0.00</td>
</tr>
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<td>16.67</td>
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<td>2.78</td>
</tr>
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<td>22.22</td>
<td>0.00</td>
<td>0.00</td>
</tr>
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<td>30.21</td>
<td>16.67</td>
<td>9.38</td>
<td>4.17</td>
<td>1.04</td>
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<td>6.67</td>
<td>17.78</td>
<td>2.22</td>
<td>2.22</td>
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<td>1.89</td>
<td>13.21</td>
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<td>0.00</td>
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<td>Hainan</td>
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<td>0.00</td>
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<tr>
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<td>13.16</td>
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<tr>
<td>Heilongjiang</td>
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<td>0.00</td>
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</tr>
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<td>Henan</td>
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<td>Inner Mongolia</td>
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<td>10.00</td>
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<td>1.59</td>
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<td>3.17</td>
</tr>
<tr>
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<td>10.53</td>
<td>5.26</td>
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</tr>
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<td>0.00</td>
<td>0.00</td>
</tr>
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<td>5.00</td>
<td>0.00</td>
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</tr>
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<td>Ningxia</td>
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<td>3.45</td>
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<td>4.49</td>
<td>1.12</td>
<td>3.37</td>
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<tr>
<td>Shanghai</td>
<td>46.67</td>
<td>46.67</td>
<td>6.67</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Shanxi</td>
<td>56.67</td>
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<td>6.67</td>
<td>3.33</td>
<td>3.33</td>
<td>3.33</td>
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<tr>
<td>Sichuan</td>
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<td>8.54</td>
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<td>0.00</td>
</tr>
<tr>
<td>Tianjin</td>
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<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>33.33</td>
<td>4.76</td>
<td>4.76</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Yunnan</td>
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<td>57.45</td>
<td>6.38</td>
<td>21.28</td>
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<td>0.00</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>20.31</td>
<td>50.00</td>
<td>23.44</td>
<td>1.56</td>
<td>1.56</td>
<td>3.13</td>
</tr>
</tbody>
</table>

B. most common used antibiotics (proportion of hospitals, %)
Association between ICU QI factors and VAP mortality and morbidity

The results of the generalized linear model are shown in Fig. 2. Structural factors associated with lower ICU VAP morbidity included patient-to-bed ratio ($\beta = 0.002 (0.004, 0.001)$, $p = 0.0126$), nurse-to-bed ratio ($\beta = 0.146 (-0.229, 0.063)$, $p = 0.0006$), patient-to-nurse ratio ($\beta = 0.015 (0.019, 0.011)$, $p = 0.0001$); and ICU VAP morbidity was higher in hospitals with high physician-to-bed ratio ($\beta = 0.586 (0.331, 0.843)$, $p < 0.0001$) and patients-to-physician ratio ($\beta = 0.007 (0.006, 0.007)$, $p = 0.0001$). All the process factors were associated with higher ICU VAP morbidity, including unplanned endotracheal extubation rate ($\beta = 0.016 (0.015, 0.018)$, $p < 0.0001$), reintubation rate in 48 hours ($\beta = 0.017 (0.013, 0.02)$, $p < 0.0001$) and microbiology detection rate before antibiotic use ($\beta = 0.001 (0.001, 0.002)$, $p < 0.0001$).

All the structural factors were not significantly associated with VAP mortality. And process factors associated with higher VAP mortality included unplanned endotracheal extubation rate ($\beta = 0.016 (0.012, 0.02)$, $p < 0.0001$), reintubation rate in 48 hours ($\beta = 0.027 (0.02, 0.034)$, $p < 0.0001$). K. pneumoniae as the most
common pathogen was associated with higher VAP mortality ($\beta=0.12(0.048,0.192)$, $p = 0.001$), carbapenems as the most commonly used antibiotics was associated with lower VAP mortality ($\beta=-0.219(-0.307, -0.13), p<0.0001$)(Fig. 3).

**Discussion**

As one of the most common nosocomial infections in ICU, VAP constitutes a tremendous burden for the critically ill patients, and the prevention and management of VAP was paid close attention. Although the strategies of diagnosis, prevention and management have been recommended in several guidelines[15, 16], and effective implementation of VAP care bundles was associated with superior clinical and economic outcomes[5], factors affecting the effectiveness of these strategies were rarely studied. To our knowledge, this is the first national report which analyze the influencing factors of VAP mortality and morbidity from the perspective of ICU quality improvement. And we found that, not only ICU structural factors such as patient-to-bed ratio, physician-to-bed ratio, nurse-to-bed ratio, patient-to-physician ratio, and patient-to-nurse ratio were associated with VAP morbidity, but also the process factors including unplanned endotracheal extubation rate, reintubation rate in 48 hours and microbiology detection rate before antibiotic use. However, all the structural factors were not significantly associated with the ICU mortality, and only unplanned endotracheal extubation rate, reintubation rate in 48 hours were associated with higher VAP mortality. Furthermore, VAP mortality was higher in hospitals with K. pneumoniae as the most common infection pathogens, and lower in hospitals with carbapenems as the most common used antibiotics.

Although critical care medicine in mainland China had made great progress, there was still a large gap with developed countries in the number of ICU beds and capacity, equipment, clinician staffing, ICU technicians, and so on. The physician-to-bed ratio and nurse-to-bed ratio were recommended in the Guidelines of Construction and Management of Critical Care Medicine in China, but many hospitals didn't meet this recommendation[17]. While the number of hospitals and hospital volumes is gradually increasing during the past a few years in China, the human resources were insufficient to keep pace with the increase in the number of ICU beds[4]. Traditionally, Adequate human resource allocation is one of the core element needed to ensure the quality of medical care[18], as ICU patients are highly dependent on nursing care, a shortage of nursing staff could be associated with insufficient supervision and recognition of state changes of the patients. Saker et al.'s study found that a high nurse-to-patient ratio was independently associated with a reduced risk of in hospital mortality[19], and Li et al found the similar result[13]. In our study, high nurse-to-bed ratio was also associated with lower VAP morbidity, but other factors such as patient-to-nurse ratio, physician-to-bed ratio showed the different trend. More interestingly, all the structural factors were not associated with VAP mortality. Although we realized that, the number of patients and medical staff are in constant dynamic change in clinical practice, these structural factors such as patient-to-physician and patient-to-nurse ratio may not accurately reflect the clinical workload and could partly explain the inconsistent trend of these factors. However, on the other hand, these results also reminded us that, at least for VAP, the quantity of the medical staff was not the only decisive factor, and simply focusing on the quantity of the medical staff was not enough for improving the morbidity and mortality of VAP. A performance assessment of medical professionals in prevention of VAP showed that, only 52.6% had satisfactory performance[20], conditions were even worse in low-income countries such as Tanzania[7]. Factors which could reflect the medical performance such as process factors should be noticed.

Different from the structure factors, process factors were not only associated with the VAP morbidity, but also the VAP mortality. We found that the both the unplanned endotracheal extubation rate and reintubation rate in 48 hours were associated with a higher morbidity and mortality of VAP in ICU patients, but the microbiology detection rate before antibiotic use was only associated with higher VAP morbidity. Unplanned endotracheal extubation is a major complication of translaryngeal intubation, and sometimes can cause reintubation[21], while other causes of intubation could be recurrent pneumonia and so on. Epstein et al. reported that, 56% patients required reintubation after unplanned extubation, and it resulted in prolonged MV, longer ICU and hospital stay[21]. A systemic review in pediatric ICU founded that, risk factors associated with unplanned extubation were age, inadequate tube fixation, agitation, copious secretions, performance of patients procedures and nursing workload[22]. A study enrolled 17 unplanned extubation in 15 patients reported that patients suffered an episode of unplanned extubation had increased risk for VAP[23]. Another prospective multicenter study showed that, unplanned extubation after weaning increased the risk of nosocomial pneumonia[24]. Results obtained for 16 studies in a meta-analysis found that, reintubation was a risk factor for the development of VAP[26], and a meta-analyses of 195 studies in mainland China also found that reintubation was significantly associated with the occurrence of VAP[25]. Improvement of quality components was effective in reducing unplanned extubation[22]. There were few studies exploring the relationship between these two factors and VAP mortality, some studies showed that unplanned extubation didn't influence the ICU or hospital mortality[21, 24]. Unplanned endotracheal extubation rate and reintubation rate in 48 hours were factors that reflecting the ability of airway management from different aspects, their significant association with VAP morbidity and mortality further highlights the importance of process factors in the ICU QI program.

The information of leading infectious pathogens of VAP and the most common used antibiotics were also collected. Gram-negative organism was the main causative agents of VAP[26], pathogens such as Acinetobacter baumannii, Pseudomonas aeruginosa, and Klebsiella pneumoniae were frequently associated with VAP in ICU[27], with Acinetobacter baumannii was often the most common pathogens[28–30]. However, recent studies have shown an increase in the prevalence of Klebsiella pneumoniae [31–34], especially in the context of the prevalence of carbapenem-resistance Klebsiella pneumoniae. The data of CHINET in 2018 showed that, Klebsiella pneumoniae was the most common pathogen isolated from the lower respiratory tract, and the resistance rates of Klebsiella pneumoniae to imipenem and meropenem was increased to 25% and 26.3% respiratory from 3.0% and 2.9% in 2005[35]. Yi et al. found that, 44.0% of Klebsiella strains were carbapenem resistant, and VAP non-survivors had higher prevalence of CRKP than VAP survivors[34]. Xu et al. reported that, patients infected with CRKP have high mortality than those infected with CSKP, especially in association with ICU admission. The data in our study was similar, Acinetobacter baumannii was still the most common pathogen of VAP in 39.98% hospitals, but only a little higher than Klebsiella pneumoniae (39.13%). Considering the increasing prevalence of Klebsiella pneumoniae recently, especially the carbapenem-resistance Klebsiella pneumoniae, we wonder whether these conditions could influence the VAP mortality. In this study, the hospitals with K. pneumoniae as the most common pathogen of VAP had a significantly high mortality than those without, and we hypothesized that, increasing resistance to carbapenem may play a role, which needed further investigations.

The choose of antibiotics also influenced the VAP mortality. Our data showed that, 24.22% of hospitals choice carbapenems as the first choice to treat VAP, only slightly lower than the third-generation cephalosporin (26.90%). In hospitals with carbapenems as the most common used antibiotics, the VAP mortality
rate was lower. This result should be explained with caution, as the study objects here was hospital but not the patients. In Arthur et al’s study, four studies compared carbapenems with other antibiotics in VAP treatment[36]. The only study to report all-cause mortality by Freire et al showed no significant difference[37]. The other three studies showed that, treatment with carbapenems had significantly higher clinical cure when compared to non-carbapenems including tigecycline, levofloxacin, and piperacillin-tazobactam[38]. A recent meta-analysis found that, carbapenem-based empiric regimens were associated with lower mortality rates compared with non-carbapenems, largely driven by trials of VAP. But there was a trend toward increasing resistance associated with carbapenems[39]. As we known, the selection pressure of carbapenem antibiotics on Enterobacteriaceae was beneficial to the screening of carbapenem-producing strains, which may lead to the mass production of CRE strains[40]. Therefore, although results told us, carbapenem antibiotics were still a powerful means to treat VAP; they should still be used with caution.

There were a few limitations of this study. First, this was an observational study and prone to selection bias. Causal relationships can't be drawn due to the cross-sectional nature of the study. Second, the data from this study was from the National Clinical Improvement System in 2019, and the information of VAP was only a small part of the database, and detailed information associated with VAP such as the oral hygiene, subglottic secretions management was not included. Further studies were needed to identify the direct influencing factors of the incidence of VAP. Third, the association between the causative pathogens or antibiotics with VAP mortality should be explained with cautious. On the one hand, they were descriptive results of the over situation the hospitals but not the patients, on the other hands, important information such as the antibiotics resistance information of the local hospital was not available. Despite these limitations, the results of this study are highly meaningful that, they underscore the ICU process factors but not the ICU structural factors were more important and may provide more evidence for the critical care developments in China.

Conclusion
In conclusion, ICU structural factors including patient-to-bed ratio, physician-to-bed ratio, nurse-to-bed ratio, patient-to-physician ratio, patient-to-nurse ratio were associated with VAP morbidity, but not with VAP mortality. Two of the three process factors including unplanned endotracheal extubation rate, reintubation rate within 48h were associated with VAP morbidity and mortality, while microbiology detection rate before antibiotic use was only associated with VAP morbidity. The process factors rather than the structural factors need to be further improved for the QC of VAP in ICU.

Declarations
Acknowledgements
Not applicable.

Author contributions
BD and XZ designed the study. XD and LXSdrafted the manuscript. GLS and YDH carried out the data processing and statistical analysis. XDM, SFG, and DWL cared for the enrolled patients and collected all the clinical data. JQC, DDM, FZ, WZ,GQS, XYM, and LM reviewed the literature and revised the manuscript. All authors contributed to the article and approved the submitted version.

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Availability of data and materials
The datasets analyzed during the current study are available from the cor- responding author on reasonable request.

Ethics approval and consent to participate
The study protocol was approved by the institutional review board of Peking Union Medical College Hospital; the approval included a waiver for the informed consent of the patients and physicians.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Competing Interests
The authors have disclosed that they do not have any potential conflicts of interest.

References


Figures
Figure 1
Proportions of hospitals from 30 provinces in this study

<table>
<thead>
<tr>
<th>Variables</th>
<th>β (95%CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>patients-to-bed ratio</td>
<td>-0.002(-0.004, -0.001)</td>
<td>0.0126</td>
</tr>
<tr>
<td>physician-to-bed ratio</td>
<td>0.586(0.331, 0.84)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>nurse-to-bed ratio</td>
<td>-0.146(-0.229, -0.063)</td>
<td>0.0006</td>
</tr>
<tr>
<td>patient-to-physician ratio</td>
<td>0.007(0.006, 0.007)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>patient-to-nurse ratio</td>
<td>-0.015(-0.019, -0.011)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>unplanned endotracheal extubation rate</td>
<td>0.016(0.015, 0.018)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>reintubation rate in 48 hours</td>
<td>0.017(0.013, 0.02)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>microbiology detection rate before antibiotic use</td>
<td>0.001(0.001, 0.002)</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Figure 2
The adjusted effect of ICU structural factors and process factors on VAP morbidity
Figure 3
The adjusted effect of ICU structural factors and process factors on VAP mortality