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Impact of a multidimensional approach on ventilator-associated pneumonia rates in a hospital of Shanghai: Findings of the International Nosocomial Infection Control Consortium☆,☆☆,★

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Abstract
Purpose: The aim of this study was to analyze the impact of a multidimensional infection control approach on the reduction of ventilator-associated pneumonia (VAP) in intensive care units (ICUs) patients of one hospital in China.
Materials and Methods: We conducted a before-after study from January 2005 to July 2009, which was divided into baseline (phase 1) and intervention (phase 2) periods. During phase 1, active prospective outcome surveillance of VAP was performed by applying the definitions of the Centers for Disease Control and Prevention/National Health Safety Network, and the methodology of the International Nosocomial Infection Control Consortium. During phase 2, the multidimensional approach was implemented. Ventilator-associated pneumonia rates obtained in phases 1 and 2 were compared in yearly periods.
Results: We recorded data from 16 429 patients hospitalized in 3 ICUs, for a total of 74 116 ICU bed days. The VAP baseline rate was 24.1 per 1000 ventilator-days. During phase 2, the VAP rate significantly decreased to 5.7 per 1000 ventilator-days in 2009 (2009 vs 2005: relative risk, 0.31; 95% confidence interval, 0.16-0.36; $P = .0001$), amounting to a 79% cumulative VAP rate reduction.

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★ Every hospital's institutional review board agreed to the study protocol, and patient confidentiality was protected by codifying the recorded information, making it only identifiable to the infection control team.
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Conclusions: Implementing a multidimensional infection control intervention for VAP was associated with a significant cumulative reduction in the VAP rate in our ICUs.

1. Introduction

Ventilator-associated pneumonia (VAP) has been reported to be the most serious health care–associated infection (HAI), as the leading cause of morbidity and mortality for device-associated infections (DAIs), particularly in the intensive care unit (ICU) setting [1-4]. The mortality attributable to VAP has been shown to exceed 10% [5].

Furthermore, VAPs have long been considered among the commonest type of HAI, resulting in a substantial increase in hospital costs and length of stay (LOS) [2,5]. Patients with VAP require prolonged periods of mechanical ventilation, excess use of antimicrobial medications, and increased direct medical costs [5].

Ventilator-associated pneumonia occurs when there is bacterial invasion of the pulmonary parenchyma in a patient receiving mechanical ventilation. Risk factors for VAP include prolonged intubation, enteral feeding, witnessed aspiration, paralytic agents, underlying illness, and extremes of age [6]. In early studies, it was reported that between 10% and 20% of patients undergoing ventilation developed VAP [7]. More recently, publications report rates of VAP that range from 1 to 4 cases per 1000 ventilator-days in industrialized countries [8] and around 13 cases per 1000 ventilator-days in the developing world, as reported by the International Nosocomial Infection Control Consortium (INICC) [9].

Surveillance has proven an effective tool for the reduction of DA-HAI in the developed world, and leading US agencies and professional societies have endorsed the recommendations of the Institute of Healthcare Improvement that a ventilator bundle be implemented at every ICU to reduce the incidence of VAP to zero [10]. However, in limited-resource countries, the importance of measuring the ICU patient infection risks, outcomes, and processes remains underrecognized many times [2,11], and very few analyses have been performed to show the impact of interventions on the VAP rate, which would serve as guidance for tackling this problem [2]. Likewise, study heterogeneity in developing countries may hinder the underlying causes of excessive variation in the reported rates [2,4].

As a countervailing strategy, in 2002, the INICC developed an outcome and process surveillance program specifically designed for ICUs in developing countries [12]. Through the implementation of the INICC program, it was demonstrated that there was a notable difference in the DA-HAI rates between the ICUs of hospitals from the industrialized world and those from limited-resource health care settings, with rates ranging from 3 to 5 times higher [3,4,13,14].

Within the context of developing countries, outcome and process surveillance, integrated in an intervention bundle with performance feedback of infection control practices, has been shown to successfully reduce and control DA-HAIs in different studies conducted in INICC member hospitals [15]. The multidimensional infection control approach for VAP reduction implemented in this study was based on the guidelines published by the Society for Health Care and Epidemiology of America and the Infectious Diseases Society of America, which describe evidence-based interventions and recommendations for VAP prevention in the ICU [6]. Their core recommendations are designed to interrupt the 3 most common mechanisms by which VAP develops: aspiration of secretions, colonization of the aerodigestive tract, and use of contaminated equipment. Our approach included those interventions that are associated with the reduction of the aspiration of secretions, such as maintaining patients in a semirecumbent position (30°-45° elevation of the head of the bed) unless there are contraindications and the reduction of the colonization of aerodigestive tract, such as oral care with chlorhexidine and hand-hygiene procedures.

This study analyzed the impact of a multidimensional approach on VAP rates adopted in 3 ICUs of a university hospital in Shanghai, which included the following measures for VAP reduction: (1) bundle of infection control interventions, (2) education, (3) outcome surveillance, (4) process surveillance, (5) feedback of VAP rates, and (6) performance feedback of infection control practices.

2. Methods

2.1. Setting and study design

The study was performed in 3 ICUs (surgical ICU, cardiothoracic ICU, and medical ICU) of Zhongshan Hospital, a university hospital located in Shanghai, China. It was divided into 2 phases: phase 1 (baseline period, consisting in the first 12 months of participation in the INICC program, from January to December 2005), and phase 2 (intervention period, from January 2006 to July 2009). During phase 1, we performed active, prospective DAI surveillance, and during phase 2, we implemented a multidimensional approach.

The hospital participates actively in the INICC surveillance program with an infection control team that comprised a medical and infection control professionals and has a microbiology laboratory where pathogens isolated from clinical samples are analyzed in vitro drug sensitivity tests are provided.

2.2. Intervention period

The intervention period started after 12 months of surveillance. The multidimensional infection control approach includes the following practices: (1) outcome surveillance, (2) education, (3) a bundle of infection control interventions, (4) process surveillance, (5) feedback of VAP rates, and (6) performance feedback of infection control practices.

2.3. International Nosocomial Infection Control Consortium methodology

The INICC Surveillance Program includes 2 components: outcome surveillance (VAP rates and consequences) and process surveillance (adherence to hand hygiene and other basic preventive infection control practices). Surveillance was conducted by completing standardized forms, which were then sent for their monthly analysis to the INICC headquarters office in Buenos Aires [12].

2.4. Outcome surveillance

It includes rates of VAP per 1000 mechanical ventilator (MV)-days, microorganism profile, bacterial resistance, and LOS in the participating ICUs per each type of DAI.

2.5. Process surveillance

It includes the surveillance of compliance rates for hand-hygiene practices and some specific infection control measures for the prevention of VAP [12].

Hand-hygiene compliance by health care workers (HCWs) is determined by measuring the frequency with which hand hygiene is performed when clearly indicated. Health care workers' practices are observed by the hospital infection control practitioner during randomly selected 1-hour observation periods, 3 times a week. Although the HCWs are aware that their practices are regularly observed, they do not actually know the exact moment in which their practices are being monitored [12]. Direct observation comprises the "Five Moments for Hand Hygiene" as recommended by the World Health Organization [16].

2.6. Performance feedback

Surveillance data are processed by the INICC headquarters team, which prepares and sends to the hospital a final report on its monthly rates of outcome and process surveillance of DA-HAIs. The investigators at the participating ICUs receive feedback on their performances at monthly meetings, where charts showing a running record of the analyzed data are reviewed and then posted in a prominent location in the ICUs.

2.7. Components of the multidimensional approach

The multidimensional infection control approach for VAP prevention included the sequential implementation of the following interventions:

2005

1. Performance of active outcome surveillance for VAP [6]
2. Education regarding epidemiology of VAP, risk factors, and interventions [6]
3. Performance of regular oral care with an antiseptic solution (chlorhexidine 2 times daily for patients with mechanical ventilation) [17,18]

2006

4. Promotion of adherence to hand-hygiene guidelines. This included the use of ethanol solution towels and alcohol hand rub. Alcohol hand rub bottles were available bedside. Alcohol hand rub was requested before and after patient and patient's fluid contact [19,20].

2008

5. Maintenance of patients in a semirecumbent position (30°-45° elevation of the head of the bed), unless there are contraindications [18,21]
6. Feedback of VAP rates
7. Process surveillance: direct observation of hand-hygiene compliance, duration of the ventilation, and ventilation ratio use, using structured observation tools at regularly scheduled intervals [12]
8. Performance feedback of infection control practices.

2.8. Definition criteria for VAP

We applied the Centers for Disease Control and Prevention/National Health Safety Network (NHSN) definitions and criteria for VAP [22]. Ventilator-associated

Table 1 Overall characteristics of study population and features of VAP

Surveillance period	January 2005 to June 2009
Total no. of patients	16 429
Total ICU bed days	74 116
Male (%)	60.8
Average age (y)	54.7 ± 16.9
Utilization rate of ventilator (%)	60
Intubation days per patient (d)	1.77 ± 11.5
Patients with VAP (cases)	365
VAP rate (case per 1000 MV-days)	12.57 (95% CI, 11.3-14.9)

Table 2 Incidence of VAP at Zhongshan Hospital by ICU type (2005-2009)

Type of ICU	VAP, n	MV-days	MV duration (d), mean (range)	VAP rate	95% CI
Surgical ICU	196	12 028	1.83 (0-708)	16.3	14.1-18.7
Medical ICU	22	2207	2.69 (0-639)	10.0	6.3-15.1
Cardiothoracic ICU	147	14 806	1.64 (0-126)	9.3	14.1-18.7

pneumonia is indicated in a mechanically ventilated patient with a chest radiograph that shows new or progressive infiltrates, consolidation, cavitation, or pleural effusion. The patient must also meet at least 1 of the following criteria: new onset of purulent sputum or change in character of sputum, organism cultured from blood, or isolation of an etiologic agent from a specimen obtained by tracheal aspirate, bronchial brushing, or bronchoalveolar lavage, or biopsy [23].

2.9. Samples and cultures

Culture samples were obtained from the endotracheal tube in patients with deep aspiration or from bronchoalveolar lavage fluid. We performed gram staining and aerobic cultures.

2.10. Statistical methods

Patients' characteristics during baseline and during intervention period in each ICU were compared using Fisher exact test for dichotomous variables and unmatched Student *t* test for continuous variables. Relative risk (RR) ratios with 95% confidence intervals (CI) were calculated for comparison of rates at baseline and subsequent intervention period.

Data analysis was performed with SPSS16.0 (SPSS Inc [an IBM company], Chicago, Ill).

Ventilator use ratio is the total number of MV-days divided by the total number of patient days. Ventilator-associated pneumonia rate per 1000 MV-days of patients with VAP indicates the total number of VAP divided by the total number of MV-days × 1000.

For measurement data, according to the normal distribution, *t* test or nonparametric statistical methods were used to test the difference between comparison groups.

For segment information, the Pearson χ^2 test was used to compare differences between groups. Linear regression was used to find the best-fitting curve for the incidence trend line; the test level used was .05 (bilateral test).

We present crude VAP rates and 95% CI stratified by a 3-month period since the start of the surveillance (Fig. 2), and because there were more than 300 events during the study period, we then used Poisson regression, with the number of days of device use as an exposure with the coefficient constrained to zero to calculate rate ratios, considering each 3-month period separately, compared with the baseline year of surveillance.

3. Results

For 4 years and 7 months, data from 16 429 patients hospitalized in the 3 ICUs (surgical ICU, cardiothoracic ICU, and medical ICU), for a total of 74 116 ICU bed days, were collected by prospective surveillance (Table 1).

The average age of the study population was 54.7 ± 16.9 years, 61.2% of which were male. The intubation period per patient was 1.77 ± 11.5 days. The ventilator use ratio was 0.38. We recorded 365 cases of VAP; there were 157 cases of clinical diagnosis of VAP (Pneumonia1) and 208 cases of laboratory diagnosis (Pneumonia2). The overall VAP rate was 12.57 (95% CI, 11.3-14.9) cases per 1000 ventilator-days. (Table 1).

The highest VAP rate was found in the surgical ICU, with 16.3 per 1000 ventilator-days, followed by the medical ICU, with 10.0 per 1000 ventilator-days, and the cardiothoracic ICU, with 9.9 per 1000 ventilator-days. (Table 2).

The microorganism profile is shown in Table 3.

The VAP baseline rate in 2005 (phase 1) was 24.1 per 1000 ventilator-days. During phase 2, the VAP rate was significantly reduced: in 2006, the VAP rate was 16.6 per 1000 ventilator-days (2006 vs 2005: RR, 0.69; 95% CI, 0.53-0.90; P = .0001); in 2007, the VAP rate was 9.5 per 1000 ventilator-days (2007 vs 2005: RR, 0.39; 95% CI, 0.29-0.53; P = .0001); in 2008, the VAP rate was 7.5 per 1000 ventilator-days (2008 vs 2005: RR, 0.31; 95% CI, 0.23-0.44; P = .0001); and in 2009, the VAP rate was 5.7 per 1000 ventilator-days (2009 vs 2005: RR, 0.31; 95% CI, 0.16-0.36;

Table 3 Microorganism profile of VAP in the participating ICUs by number of isolated pathogens and distribution percentage

Isolated microorganisms	No. of isolated pathogens	Percentage of isolated pathogens
A baumannii	60	29
Pseudomonas aeruginosa	34	16
S aureus	38	18
Stenotrophomonas maltophilia	19	9
Candida spp.	18	9
Escherichia coli	17	8
Klebsiella pneumoniae	11	5
Burkholderia cepacia	7	3
Enterobacter cloacae	4	2
Total	208	100.00

P = .0001), amounting to a 79% cumulative VAP rate reduction. (Table 4 and Fig. 1).

We present crude VAP rates and 95% CI stratified by a 3-month period since the start of the surveillance. After the first 3 months after the start of the intervention, there is a dramatic drop in VAP rates, which is maintained for the following 3 years (Fig. 2). The regression results comparing of rates during the 3-month period with the intervention at baseline found no significant reduction in rates in the first 9 months after intervention (although rates are falling), and for all further periods, the rates were significantly lower.

There was a significant reduction in the average LOS. The results are shown in Table 5.

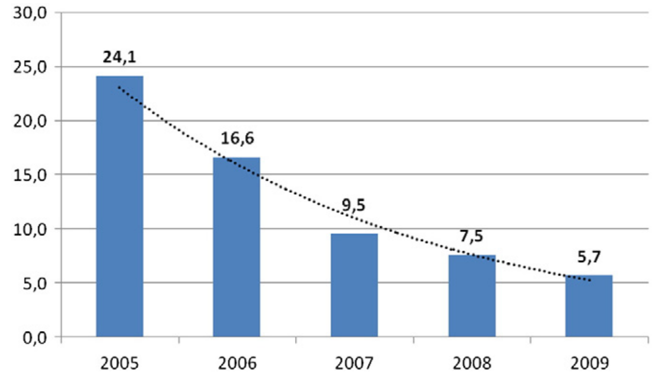


Fig. 1 Trend of the VAP rate from January 2005 to July 2009 in the participating ICUs of Zhongshan Hospital.

4. Discussion

An analysis on our baseline data in phase 1 showed that the rate of MV use was similar to NHSN's rates in the United States (0.38), but the VAP incidence rate (12.5 per 1000 ventilator-days) was significantly higher than that of NHSN (3.1 per 1000 ventilator-days) [24]. The stratified analysis also showed that the VAP incidence rates in the different ICUs in 2005 were higher than those in NHSN: in the surgical ICU, the rate was 16.3 per 1000 ventilator-days (vs 3.8 per 1000 ventilator-days in NHSN's report); in the medical ICU, the rate was 10.0 per 1000 ventilator-days (vs 1.9 per 1000 ventilator-days in NHSN's report); and in the cardiothoracic ICU, the rate was 9.9 per 1000 ventilator-days (vs 2.1 per 1000 ventilator-days in NHSN's report) [24].

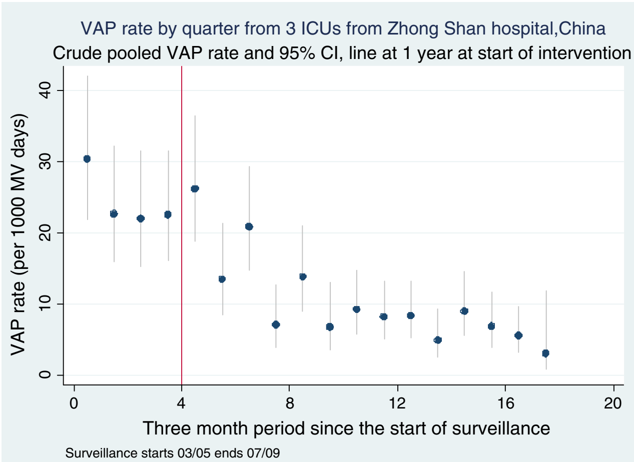
During phase 2 (from January 2006 to July 2009), the ICU days and device utilization ratio increased (ventilator utilization rate, central vascular catheter, and urinary catheter utilization rates); however, the VAP annual incidence rate decreased to 5.34 per 1000 ventilator-days. This decrease is mainly explained by the effect of the implementation of our multidimensional infection control approach. That the VAP incidence decreased when the MV use increased means that infection control interventions were effective.

Regarding the microorganism profile, we found that the most common VAP pathogens in the ICUs were gram-negative bacteria: 77.8%, which is similar to the results of the United States and Europe [8,24]. According to the data reported in 24 international research studies, gram-negative bacilli accounted for 58% of VAP pathogens, *Staphylococcus aureus* accounted for 20%, and other gram-positive bacteria accounted for 14% [2]. Methicillin-resistant Staphylococcus aureus (MRSA) has become a worldwide issue of concern because it was reported for the first time in 1961 in the United Kingdom and is now one of the most seriously regarded pathogens in HAIs [2]. As described in the INICC report, there was a high incidence of MRSA in the ICU from 2003 to 2008, and the MRSA isolated from VAP accounted for 84.1% of *S aureus* in ICUs. Likewise, in our study, we found data similar to INICC, with 82.5% of MRSA [9]. In addition, the second most common pathogen was *Acinetobacter baumanni*, which is possibly increasing because ICU patients are administered with a variety of broad-spectrum antibiotics and as a consequence of inadequate resistant control measures [4].

The data associated to the VAP incidence rate reported in this study mainly reflect the average level of infection control in developing countries during a certain period. From 2003 to 2008, the average VAP incidence rate was 13.6 per 1000 ventilator-days in 173 INICC ICUs [9]. The average VAP incidence rate at Zhongshan Hospital was similar to the data reported by INICC [9]. Although the VAP incidence rate achieved in phase 2 is much lower than the one presented in last INICC's report, it is still higher than the rates reported by the NHSN [8]. We consider that this higher VAP incidence rate is related to limitations associated with socioeconomic factors: the ICU equipment is less advanced than in developed countries, medical resources are relatively insufficient, there are crowded wards, patient-nurse ratio is low, and there is low compliance with preventive measures.

Table 4 Ventilator-associated pneumonia annual rate in surgical, cardiothoracic, and medical ICUs

Year	No of patients	% Patients with MV	VAP cases	MV-days	VAP per rate 1000 bed days	Comparison	RR (95% CI)	*P*
2005	3250	61.5	130	5399	24.1			
2006	4112	56.4	97	5850	16.6	2005 vs 2006	0.69 (0.53-0.90)	.0051
2007	4405	51.9	62	6513	9.5	2005 vs 2007	0.39 (0.29-0.53)	.0000
2008	3992	58.4	49	6555	7.5	2005 vs 2008	0.31 (0.23-0.44)	.0000
2009	3330	52.4	27	4771	5.7	2005 vs 2009	0.24 (0.16-0.36)	.0000



VAP, ventilator-associated pneumonia; MV, mechanical ventilator;

Fig. 2 Ventilator-associated pneumonia rate during a 3-month period in the participating ICUs of Zhongshan Hospital.

The VAP incidence was decreased in our hospital through the implementation of the multidimensional approach, including performance of active outcome surveillance for VAP, education regarding epidemiology of VAP, risk factors and interventions, performance of regular oral care with an antiseptic solution, promotion of adherence to hand-hygiene guidelines, maintenance of patients in a semirecumbent position, feedback of VAP rates, process surveillance, use of a structured observation tools at regularly scheduled intervals, and performance feedback of infection control practices.

A limitation of our study lies on the fact that VAP is considered a good quality indicator, and this may have influenced trained infection control professionals to achieve improved VAP rates. Therefore, we are aware that there is a risk that HCWs may involuntary construe the VAP definition, so as to attenuate manifest rates of VAP rates [6]. Despite this difficulty, we consider that the multidimensional nature of our approach is effective in promoting real feedback and communication, so as to be able to obtain successful prevention of VAP.

The effectiveness of the implementation of an integrated infection control program focused on DA-HAI surveillance was demonstrated around 30 years ago, as shown in many studies conducted in the United States, whose results reported that the incidence of DA-HAI can be reduced by as much as 30% and that a related reduction in health care costs is feasible as well [8]. However, within the scope of developing countries, many health care institutions lack basic infection control programs, and most caregivers are unaware of VAP rates at their health care facilities [3,9,11].

Table 5 Length of stay by year in surgical, cardiothoracic, and medical ICUs

Year	Total bed days, n	Average LOS (d), mean ± SD	Comparison	*P*
2005	16 538	6.11 ± 22.9		
2006	16 894	4.79 ± 11.6	2005 vs 2006	.006
2007	16 345	4.59 ± 16.1	2005 vs 2007	.004
2008	13 674	3.93 ± 9.2	2005 vs 2008	.001
2009	10 665	3.67 ± 7.8	2005 vs 2009	.001

To reduce VAP, infection control professionals must implement a strategy based on the accurate knowledge of VAP rates at their health care setting, so as to approach the interventions with cost-effective preventive measures. As reported in several studies, the VAP incidence can be substantially prevented by implementing basic VAP interventions such as hand hygiene [20], semirecumbent positioning [21], and daily rinsing of the mouth with chlorhexidine [18]. To improve compliance, we will continue to strengthen education and training, and communication and monitoring. Nevertheless, it is noteworthy that these data reflect the VAP incidence trend at Zhongshan Hospital and may not represent the general situation in other hospitals.

Educational efforts are derived in benefits that may be short lived without regular reinforcement. Likewise, surveillance of DA-HAI rates should not be expected to lead to a reduction in rates of selected DA-HAIs, unless the collection of these data is used for improvement of patient care practices [15,25]. As a result, buttressing educational efforts with regular feedback in the form of monthly incidence rates of DA-HAIs may provide maximal benefit [3].

5. Conclusions

This is the first study in China that, in the context of ICUs in the developing countries, documents a reduction in rates of VAP in these settings associated with the implementation of this kind of infection control approach. Our findings allow us conclude that applying one infection control measure only, such as 30° head elevation or hand hygiene, is not enough to prevent VAP, but it requires a culture change involving the entire ICU team (doctors, nurses, and respiratory therapists) [6]. Therefore, we aimed at reducing VAP rates through the implementation of the multidimensional approach, which include the adoption of multifaceted measures such as education and training, oral care with chlorhexidine, strict hand-hygiene compliance, and head elevation methods. After our intervention period, we obtained the reported positive results.

Our goals are to sustain a nearly perfect compliance with the multidimensional infection control approach and to keep HCWs highly motivated for VAP prevention. In addition, we expect that the reported improvements result in wider adherence of infection control programs in all hospitals worldwide because it will lead to significant DA-HAI reductions, particularly in the ICU setting. To achieve this, any hospital, from any part of the world, may freely participate in the INICC network, which was created to fulfill a critical and compelling need in limited-resource countries, that is, to achieve significant prevention, control, and reduction of DA-HAI and their adverse effects. Through the INICC surveillance program, investigators are furnished with training and scientific-based methods to conduct outcome and process surveillance for free, and through the publication of these confidentially collected data, relevant scientific information is fostered and disseminated as well.

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