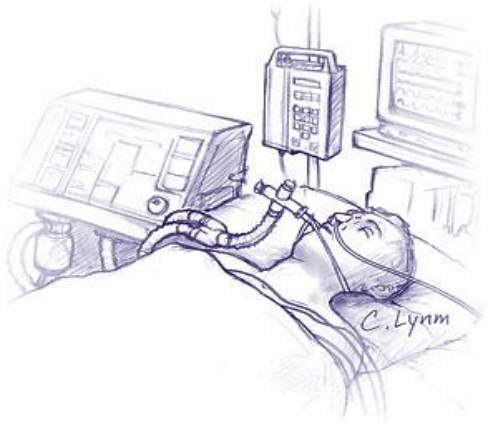
Master of Public Health

Master international de Santé Publique

Economic impact of ventilator-associated pneumonia (VAP) and evaluation of the VAP prevention program



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CDC Centers for Disease Control and prevention

DRG Diagnosis-Related Group

€ Euros

HCUP Healthcare Cost and Utilization Project

ICD-9-CM International Classification of Diseases, ninth revision, Clinical Modification

ICU Intensive Care Unit

IHI Institute for Healthcare Improvement

Log Logarithm

LOS Length Of Stay

MSMC Mount Sinai Medical Center

NIS Nationwide Inpatient Sample

P P-value

SPARCS Statewide Planning and Research Cooperative System

VAP Ventilator-Associated Pneumonia

$ American dollars

1. Topic and context of the study

1.1. Scope of the public health impact of ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) is one of the most common hospital-acquired infections in intensive care units (ICUs) at all ages. It has been estimated that 86% of all nosocomial pneumonias were linked to mechanical ventilation [1, 2]. VAP has been defined by the Centers for Disease Control and prevention (CDC) as «pneumonia in persons who had a device to assist or control respiration continuously through a tracheostomy or by endotracheal intubation within the 48-hour period before the onset of infection, inclusive of the weaning period». In addition, it is specified that "there is no minimum period of time that the ventilator must be in place in order for the pneumonia to be considered ventilator associated" [3].

A patient can get VAP when germs enter his/her lungs through the ventilator. The pathogenesis of this disease is due to two subsequent processes: first, the colonization of the aerodigestive tract by a pathogenic organism and secondly, the aspiration of these contaminated secretions into the lower airway [4]. Major symptoms include fever, pulmonary infiltrate and purulent endotracheal tube secretions [5].

Ventilator-associated pneumonia mainly results from bacterial infections which account for 80% of the cases. Gram-negative bacilli, in particular P.aeruginosa and Enterobacteriaceae, are responsible for 60% to 70% of VAP. However, polymicrobial infections can also occur and 15% of patients develop superinfections [5].

VAP is estimated to affect 10 to 20% of patients under mechanical ventilation. Ventilated patients are at a 3 to 21-fold higher risk of developing nosocomial pneumonia compared to other patients [5, 6]. In 2009, 21,894 VAP cases occurred in the US representing 0.06% of all hospitalizations[1].

[1] Figures obtained using the Nationwide Inpatient Sample database (http://www.hcup-us.ahrq.gov/db/nation/nis/nisdbdocumentation.jsp).

VAP is associated with significant mortality and morbidity among affected patients with a crude death rate between 5 and 65% [6]. However, it is difficult to determine if the patients died of their pneumonia or with their pneumonia. It is estimated that the mortality attributable to VAP is about 30% which means that only one third of patients with the disease actually die directly from it. It is nevertheless one of the highest mortality rates among all nosocomial infections [4, 5].

There is no gold standard for the diagnosis of ventilator-associated pneumonia and a controversy therefore exists about the best diagnostic methods. Several strategies are used such as clinical characteristics, X-rays, histological examination of lung tissues and cultures of secretions collected by noninvasive or invasive techniques [5, 6].

The treatment of VAP relies on an antimicrobial therapy which is adapted to each patient depending on a wide number of factors (identified germ, previous therapy, duration of ventilation and hospitalization, antimicrobial resistance patterns, etc.) [6].

1.2. Estimated economic impact of ventilator-associated pneumonia

Most of the previously published studies estimated costs of VAP to be between 10,000 and 40,000 American dollars ($) per case [7-9]. One study found a cost of up to $ 57,000 per hospitalization in a shock trauma ICU [10]. These additional costs were due to the increased utilization of healthcare resources by affected patients resulting in excess direct medical costs. VAP was found to lead to an increase in the ICU length of stay (LOS), a longer duration of mechanical ventilation, a prolonged duration of the global hospital stay and the use of antibiotics therapy [7-10]. These costs are avoidable and justify the prevention efforts focusing on VAP.

1.3. Prevention of ventilator-associated pneumonia - a key issue

Prevention strategies are most useful in diseases with high prevalence or with modifiable risk factors such as VAP. An effective prevention of ventilator-associated pneumonia would have a significant impact on mortality and morbidity [4, 5]. The reduction of the incidence of VAP is essential as the number of ventilated patients is increasing and antimicrobial resistances are emerging [5]. Ventilator-associated pneumonia has been recognized as an important public health issue and guidelines for prevention have been published by several institutions including the CDC [11].

The figure 1 summarizes the main prevention strategies based on the strength of the recommendations: type A refers to recommendations supported by good evidence, type B refers to recommendations supported by moderate evidence and type C refers to recommendations which are controversial or supported by poor evidence.

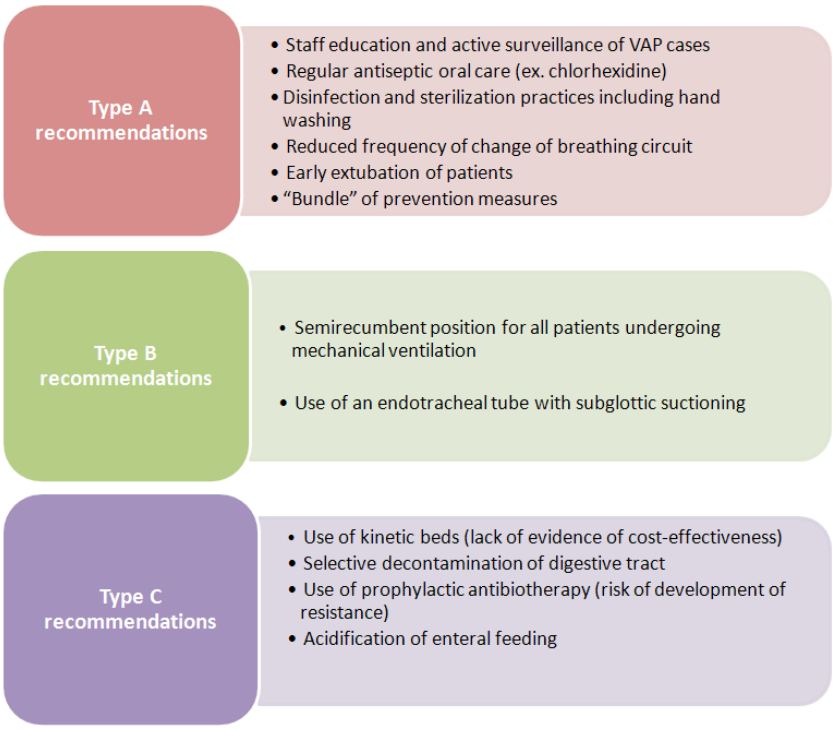

Figure 1. Classification of recommendations for VAP prevention strategies based on the strength of evidence [1, 4, 5, 11, 12].

It is however important to outline that the literature regarding prevention measures against VAP is extensive and sometimes conflicting.

1.4. Environment of the study

The study was conducted at Mount Sinai Medical Center (MSMC) which is a non-profit academic hospital based in New York City. It is a highly competitive institution ranked 16th out of 5,000 American hospitals in the US News & World Report Honor Roll of elite hospitals [13].
VAP incidence is increasingly considered as an indicator of quality of care and it is therefore important to compare it with MSMC main competitors.

2. Objectives of the project

The main aim of the study was to assess the economic impact of ventilator-associated pneumonia and to evaluate the prevention program at Mount Sinai Medical Center.

We therefore had four objectives:

1) To analyze the incidence and risk factors of ventilator-associated pneumonia at the national and state level as well as within Mount Sinai Medical Center;
2) To compare VAP incidence between MSMC and the other main academic hospitals of New York City;
3) To assess the costs of VAP within MSMC;
4) To estimate the costs of the prevention program and to compare them to the costs of VAP.

3. Materials and methods

3.1. Data sources

Several data sources were used to carry out the analysis.

To estimate the national incidence of VAP, we used the de-identified Nationwide Inpatient Sample (NIS) database[2] which is part of the Healthcare Cost and Utilization Project (HCUP). This initiative is financed by state-industry partnerships in collaboration with the Agency for healthcare research and quality [14]. The NIS is the largest administrative database of hospital inpatient stays in the US with yearly weighted data on around a thousand hospitals. The different hospitals were first stratified based on their location (urban or rural), their geographic region, their teaching status[3], their ownership (non-federal, private not-for-profit or private investor-owned) as well as their bed size (small, medium or large). Finally, a random sample of hospitals which approximated all US community hospitals was selected and their data was collected [15].

In addition, we used the de-identified New York State Statewide Planning and Research Cooperative System (SPARCS) which is a discharge database providing data for all the hospitalizations in New York State [16].

Finally, we obtained a third dataset with detailed demographics and clinical information for Mount Sinai patients from the hospital in-house data.

The three databases provided information regarding patients' demographics *(*age, sex, race), patients' medical information (primary and secondary diagnoses and procedures, admission and discharge status, length of stay) and payment data. In addition, information on hospital characteristics such as teaching status and location were obtained from the NIS database.

[2] http://www.hcup-us.ahrq.gov/db/nation/nis/nisdbdocumentation.jsp
[3] A hospital was considered to be a teaching hospital if it had a residency program approved by the American medical association, was a member of the Council of Teaching Hospitals or had a ratio of full-time equivalent interns and residents to beds of 0.25 or higher.

Data from the six main academic hospitals, competitors of MSMC in New York City, were obtained from SPARCS database. Those hospitals were Lenox Hill Hospital, Saint Lukes Roosevelt Hospital, NYU Hospital Center, NY Presbyterian Hospital-Columbia, NY Presbyterian Hospital-New York Weill-Cornell and Montefiore Medical Center.

Detailed costs data were available in Mount Sinai database (total costs of stay and total direct costs of stay per patient as well as their subcategories such as diagnostic or respiratory therapy direct costs).

Patients' comorbidities[4] were assessed and added to SPARCS and MSMC databases. They were computed through the Elixhauser comorbidity measure which relies separately on 30 comorbidities identified by the International classification of diseases, ninth revision, clinical modification (ICD-9-CM)[5] codes [17]. We used the HCUP comorbidity software version 3.7 after adapting the databases to the requirement of the software [18]. We only considered comorbidities which were present on admission and computed a weighted Elixhauser comorbidity score using van Walraven *et al.* method to facilitate comparison of hospitals [19].

Procedure classes were also added to MSMC database in order to match patients according to the type of procedures they underwent. For that purpose, we used the HCUP software tool which classifies procedures into 4 groups: minor diagnostic (non-operating room diagnostic procedures), minor therapeutic (non-operating room therapeutic procedures), major diagnostic (all diagnostic operating room procedures identified through the Diagnosis-Related Groups (DRGs)[6]) and major therapeutic (all therapeutic operating room procedures identified through DRGs) [20].

[4] Comorbidities are serious conditions that a patient may suffer from in addition to a primary diagnosis.
[5] ICD-9-CM code is a standardized diagnostic classification endorsed by the World Health Organization.
[6] DRGs represent a classification of US hospitals patients into homogenous groups based on their principal and secondary diagnoses, surgical procedures, sex, age and discharge status.

3.2. Study design

Firstly, cross-sectional studies were carried out on NIS, SPARCS and MSMC databases to determine incidence and predictors of ventilator-associated pneumonia.
Secondly, a retrospective case-control study was conducted on MSMC database to determine the costs of VAP. Patients undergoing mechanical ventilation and suffering from VAP were matched with similar ventilated patients who did not develop VAP.

3.3. Study inclusion criteria

Inclusion:
Patients who had been undergoing mechanical ventilation during hospitalization
Exclusion:
Patients who had not been undergoing mechanical ventilation during hospitalization

Patients undergoing mechanical ventilation were identified through ICD-9-CM codes: 96.70 (continuous mechanical ventilation of unspecified duration, 96.71 (continuous invasive mechanical ventilation for less than 96 continuous hours) and 96.72 (continuous invasive mechanical ventilation for 96 consecutive hours or more). We also used the version 26 of DRGs and added patients classified in the following categories: respiratory system diagnosis with ventilator support superior or equal to 96 hours (DRGs 207 and 208), extracorporeal membrane oxygenation or tracheostomy with mechanical ventilation superior or equal to 96 hours with principal diagnosis except face, mouth, and neck diagnoses with and without major operating room procedure (DRGs 003 and 004) , septicemia with mechanical ventilation superior or equal to 96 hours (DRG 870), extensive burns or full thickness burns with mechanical ventilation superior or equal to 96 hours with or without skin draft (DRGs 927 and 933) [21].

In the 2009 version of the ICD-9-CM classification, available since October 2008, the code 997.31 was issued for the diagnosis of ventilator-associated pneumonia as part of the respiratory complications of medical care not elsewhere classified [22]. This code was used for the identification of VAP cases in NIS and SPARCS databases.

For MSMC cohort of patients, additional clinical information was available. We excluded hospitalizations which were not associated with ventilators orders or positive x-rays as well as hospitalizations of patients who had pneumonia prior to admission or before ventilation.
For the case-control study, outliers with a very long or very short length of stay were also excluded as they were likely to bias the results. As the LOS was not normally distributed, the logarithm (log) of this variable was computed. Hospitalizations included in the analysis had a length of stay within an interval represented by the mean of the log(LOS) ± 1.96 times the standard deviation of log(LOS). The extreme values outside of this interval were excluded. In addition, pediatric patients, aged less than 12 years old, were dropped as they were lost after the matching.

The figure 2 sums up the process of selection of patients for MSMC VAP cohort.

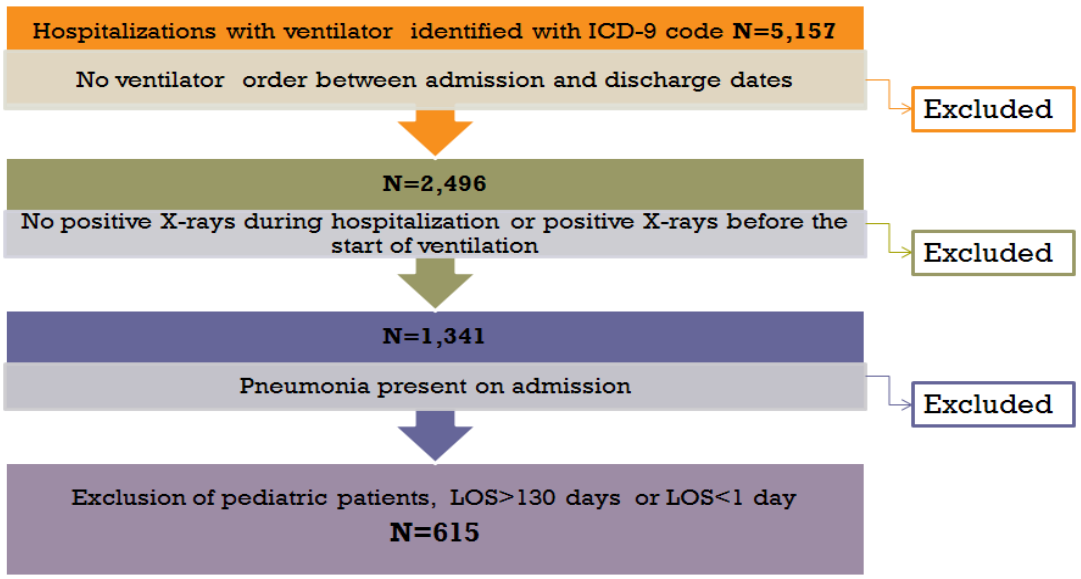

Figure 2. Selection of Mount Sinai VAP cohort

Patients were then classified by their type of DRG, either medical or surgical as the costs of hospitalizations are often much higher in surgical DRGs [23].

3.4. Ethical considerations

The only possible risk to subjects was related to breach of confidentiality as a retrospective study was carried out. Appropriate measures were therefore taken in order to ensure the respect of patients' privacy such as firewall, softwares to encrypt sensitive data and password protected desktops.
The study was approved by the Institutional review board of Mount Sinai School of Medicine and data use agreements were obtained for all databases.

3.5. Statistical analysis

3.5.1. Identification of factors influencing the probability to develop VAP

First, we used the three databases to determine VAP incidence at the national, state and hospital level. We then identified patients' demographics and hospitals characteristics which were associated with VAP. For NIS database, the weight and the strata of the data were taken into account for each calculation to account for database design.

Chi-square tests were computed for categorical variables and t-tests for continuous variables to assess differences between ventilated patients with VAP and those without VAP. A logistic regression was then carried out to predict risk factors associated with VAP as the health outcome was a dichotomous variable. All factors significant at the 0.1 level in the univariate analysis were included in the multivariate analyses. The final models included variables with a p-value (p) less than 0.05.
For MSMC database, the logistic regression was also used to output the probability of developing VAP for each patient.

3.5.2. Matching of cases and controls to assess differences in outcomes

A propensity matching with a ratio of one case per one control was carried out using the SAS code from *Lori S. Parsons* [24]. The propensity score for each patient was his/her conditional probability to develop VAP given his/her risk factors for this infection computed through the logistic regression. We chose propensity score for matching as it reduces bias by balancing covariates between VAP and non VAP cases and has been found to be more robust than simple multivariate regressions [25, 26].

Quality of the matching was assessed by determining covariate balance between VAP patients and non VAP patients through the computation of standardized differences.
Two different formulas were used as follows depending on the nature of the variables:

-for the categorical variables: $\frac{\%(cases)-\%(controls)}{\sqrt{\%(cases)*\left(1-\%(cases)\right)+\%(controls)*(1-\%controls)}}$;

-for the continuous variables: $\frac{\text{mean(cases)}-\text{mean(controls)}}{\sqrt{(\text{standard deviation(cases)}^2+\text{standard deviation (controls)}^2}}$ [25].

Finally, the means of the different outcomes (lengths of stay, costs and mortality rates) were compared between cases and controls by conducting paired t-tests.

All statistical analyses were performed using SAS Software version 9.2 [27].

3.6. Estimation of the costs of the prevention program

Costs of the different preventive measures used against VAP in MSMC were determined through a literature review. We searched 4 bibliographic databases (PUBMED, EMBASE, EBSCO and SCIENCEDIRECT) using keywords relating to costs and names of the different prevention measures. Several costs were only assessed in European countries. To convert them into $, we applied the conversion rate used at the time of the publication.

To compare the costs of the prevention program with the extra costs of VAP, we assumed 100% effectiveness and 100% compliance with guidelines.

We first determined the annual incremental costs of prevention (ΔCp) by comparing the annual extra costs of VAP (ECvap) to the annual total costs of prevention (TCp):

$$\Delta Cp = TCp - ECvap$$

When ΔCp was negative, we computed the minimal reduction (MinRN) in the annual number of VAP cases (Nvap) for the prevention program to be cost-neutral:

$$MinRN = \frac{TCp}{ECvap/Nvap}$$

We then computed the minimal percent reduction (Min%) in the annual incidence of VAP (Ivap) for the prevention program to be cost-neutral:

$$Min\% = Ivap - \frac{(Nvap - MinRN)}{Annual\ number\ of\ hospitalizations\ with\ ventilation}$$

Finally, we constructed a three-dimensional table, using SigmaPlot software, to show expected savings based on different values of the effectiveness of prevention and of the compliance with guidelines [28].

4. Results

4.1. Predictors of ventilator-associated pneumonia

The rate of VAP (i.e. the number of hospitalizations with VAP over the number of hospitalizations with mechanical ventilation) was 1.95% at the national level and 1.72% in New York State hospitals.

4.1.1. Risk factors associated with VAP: patients' demographics and comorbidities

At the national level as well as in New York state, patients with ventilator-associated pneumonia were found to be significantly older ($p<0.0001$) and more likely to be male ($p<0.001$) than ventilated patients without VAP. Patients with numerous comorbidities were also more likely to develop VAP especially if they suffered from hypertension ($p<0.0001$), paralysis ($p<0.0001$), neurological disorders ($p=0.0246$ at the national level and $p<0.0001$ at the state level), chronic pulmonary disease ($p=0.0186$ and 0.0002), hypothyroidism ($p=0.0120$ and 0.0001), depression ($p=0.017$ and 0.0027), metastatic cancer ($p<0.0001$), weight loss ($p<0.0001$) and psychoses ($p=0.043$ and 0.0002).
The median household income[7], used as a socioeconomic status indicator and available for the national level estimate, was not associated with VAP ($p=0.6184$).

4.1.2. Risk factors associated with VAP: Hospitals characteristics

In NIS database, urban teaching hospitals had higher rates of VAP than rural or urban non-teaching hospitals. However, these differences were only found to be significant at the univariate level and not in the multivariate analysis after controlling for patients' age, sex, race, comorbidities as well as for other hospitals characteristics ($p=0.0724$ for rural hospitals and $p=0.1932$ for urban non-teaching hospitals).
The mean number of registered nurses per 1,000 adjusted inpatient days was higher for VAP cases than for ventilated patients without VAP ($p=0.0434$).

[7] This variable provided a quartile classification of the estimated median household income of residents in the patient's ZIP Code going from 1 (for the most deprived populations) to 4 (for the richest populations).

In addition, there were more VAP patients in public hospitals than in private ones but this difference was not statistically significant in the multivariate analysis (p=0.3461).
Finally, large hospitals had higher VAP rates than small and medium hospitals (p=0.0014 and p=0.0003 respectively).

The detailed results for patients' demographics, comorbidities and hospitals characteristics are presented in *the annex 1*.

4.2. Comparison of the main academic hospitals of New York City

In SPARCS database, the rate of patients suffering from VAP compared to all patients undergoing mechanical ventilation was found to be equal to 4.79% for MSMC. This rate was significantly higher than in other major academic hospitals of New York City except New York Presbyterian Hospital-Columbia Presbyterian Center. The results are presented in the table 1.

Table 1. Comparison of VAP rates for patients undergoing mechanical ventilation in the main academic hospitals of New York City

Hospitals of interest	Number of patients suffering from VAP	Total number of patients under ventilators	Rate VAP/Ventilators (%)	P-value (in comparison with Mount Sinai)
New York Presbyterian Hospital-Columbia Presbyterian Center	403	6,370	6.33	0.0004
Mount Sinai Hospital	*250*	*5,218*	*4.79*	
St Lukes Roosevelt Hospital Center- Roosevelt Hospital Division	35	1,363	2.57	0.0003
Montefiore Medical Center-Henry and Lucy Moses Div	96	3,976	2.41	<0.0001
New York Presbyterian Hospital-New York Weill Cornell Center	103	4,567	2.26	<0.0001
NYU Hospitals Center	25	2,066	1.21	<0.0001
Lenox Hill Hospital	3	1,733	0.17	<0.0001

However, patients' severity of illness, measured by the mean Elixhauser comorbidities score, was found to be significantly higher in Mount Sinai Medical Center compared to patients from the other hospitals of interest.

Table 2. Comparison of the mean Elixhauser score for patients undergoing mechanical ventilation in the main academic hospitals of New York City

Hospitals of interest	Mean Elixhauser score	95% Confidence Interval	P-value (in comparison with Mount Sinai)
New York Presbyterian Hospital-Columbia Presbyterian Center	3.10	[2.99-3.21]	<0.0001
Mount Sinai Hospital	*6.03*	[*5.87-6.19*]	
St Lukes Roosevelt Hospital Center-Roosevelt Hospital Division	3.14	[2.90-3.38]	<0.0001
Montefiore Medical Center- Henry and Lucy Moses Div	3.30	[3.15-3.44]	<0.0001
New York Presbyterian Hospital-New York Weill Cornell Center	3.44	[3.30-3.58]	<0.0001
NYU Hospitals Center	3.77	[3.55-3.98]	<0.0001
Lenox Hill Hospital	3.16	[2.95-3.38]	<0.0001

4.3. Evaluation of the economic impact of ventilator-associated pneumonia within Mount Sinai Medical Center

Over the period going from the last quarter of 2008 to the third quarter of 2011, 15.5% of ventilated patients from medical DRGs and 29.2% of ventilated patients from surgical DRGs were estimated to develop VAP. Those rates, estimated based on the algorithm shown in the figure 2, corresponded to 19 cases per 1,000 ventilator days in the medical group and to 16 cases per 1,000 ventilator days in the surgical group.

The probability to develop VAP (propensity score) was estimated using logistic regression analysis. The differences between VAP and non VAP patients for the variables used to output the probability to develop VAP are presented in the *annex 2*.

After the propensity score matching, 128 VAP cases out of 129 were matched with controls for patients from medical DRGs while 484 out of 486 cases were matched with controls for patients from surgical DRGs. The standardized differences for patients' probability to develop VAP before and after matching are presented in the table 3.

Table 3. Standardized differences between VAP and non VAP patients before and after matching for the probability of developing VAP

	Standardized difference between VAP and non VAP patients before matching	Standardized difference between VAP and non VAP patients after matching
Probability of developing VAP in the medical DRGs group	66.1%	2.0%
Probability of developing VAP in the surgical DRGs group	49.1%	1.2%

An important reduction in the standardized differences of the probability to develop VAP between cases and controls for both medical (from 66.1% to 2%) and surgical (from 49.1% to 1.2%) group of patients was achieved after matching.

In addition, the standardized differences between VAP and non VAP cases were less than 10% for the great majority of variables included as recommended for a successful propensity score matching [25]. The full results for both DRGs groups (rates for VAP and non VAP patients, standardized differences after matching and p-values) are presented in the *annex 3*.

4.3.1. Differences in hospital stays between VAP and non VAP patients

The differences in the hospital lengths of stays after matching between cases and controls are presented in the table 4.

Table 4. Differences in hospital stays between VAP and non VAP patients from October 2008 to September 2011

	Surgical DRGs group				Medical DRGs group			
Variable	**Mean value (days) VAP**	**Mean value (days) Non VAP**	**Difference VAP-Non VAP**	**P-value**	**Mean value (days) VAP**	**Mean value (days) Non VAP**	**Difference VAP-non VAP**	**P-value**
Length of stay	37.3	32.6	4.7	0.0036	18.4	17.7	0.7	0.2014
Length of stay after start of ventilation	33.9	26.2	7.7	<0.0001	15.8	13.9	1.9	0.0774
Length of ICU stay	22.0	19.4	2.6	0.0455	9.4	8.1	1.3	0.4328

A significantly higher LOS was observed for VAP patients in the surgical DRG group (37 days versus 34 days for non VAP patients).
To reduce the time-dependent bias and the risks of improperly estimating the effect of VAP, we considered the length of stay after the start of ventilation [29]. This variable was also found to be significantly higher for VAP patients in the surgical DRG group. Similarly, the length of ICU stay was higher for surgical patients suffering from VAP.
There were no significant differences in overall LOS, LOS after start of ventilation and ICU stay for medical patients with and without VAP.

Very high mortality rates were observed for cases and controls. However, the differences were not statistically significant: 46.6% of cases against 53.4% of controls in the surgical DRGs group (p=0.194) and 46.5% of cases against 53.5% of controls in the medical DRGs group (p=0.261).

4.3.2. Differences in extra hospital costs between VAP and non VAP patients

The annual extra hospital costs of VAP were estimated at $5,905,939 when considering all VAP cases. Detailed differences in costs between cases and controls after matching are presented in the table 5, both for surgical and medical DRGs groups.

Table 5. Differences in hospital costs between VAP and non VAP patients from October 2008 to September 2011

	Surgical DRGs group				Medical DRGs group			
Variable	**Mean costs per VAP patients (in $)**	**Mean costs per non VAP patients (in $)**	**VAP-non VAP**	**P-value**	**Mean costs per VAP patients (in $)**	**Mean costs per non VAP patients (in $)**	**VAP-non VAP**	**P-value**
Total costs	157,116	122,176	34,940	<0.0001	53,004	47,291	5,713	0.0815
Direct costs	92,381	69,929	22,452	<0.0001	28,586	25,070	3,516	0.0654
ICU direct cost	32,610	22,298	10,312	<0.0001	10,098	7,411	2,687	0.0056
Diagnostic direct cost	301	249	53	0.0026	194	130	64	0.0003
Imaging direct cost	3,975	2,782	1,193	<0.0001	1,351	1,017	334	0.0075
Laboratory direct cost	2,844	2,388	456	<0.0001	1,412	1,291	121	0.1856
Blood bank direct cost	4,750	3,089	1,661	<0.0001	2,003	1,419	584	0.2288
Rehabilitation therapy direct cost	591	393	197	<0.0001	399	461	-62	0.2500
Respiratory therapy direct cost	3,562	3,106	456	0.0445	1,648	1,885	-237	0.4814
Surgery direct cost	16,678	8,450	8,228	<0.0001	308	248	59	0.2007
Pharmacy direct cost	8,354	8,121	233	0.0489	3,506	3,104	402	0.1647

As hypothesized, costs were higher for patients from surgical DRGs than for patients from medical DRGs. In the surgical DRGs group, the total costs of hospital stays per patient were found to be significantly higher for VAP cases than for controls with a difference of $34,940. This is mainly explained by higher ICU, imaging, blood bank and surgery direct costs.

In the medical DRGs group, the total costs and total direct costs of hospital stays per patient were higher for VAP cases than for controls but these differences were not found to be statistically significant. However, ICU, diagnostic and imaging direct costs were significantly higher for VAP patients.

4.4. Evaluation of the costs of VAP prevention measures

Several prevention measures against VAP were implemented within MSMC based on the 'ventilator bundle' recommended by the Institute for Healthcare Improvement (IHI) [30]. A specific checklist was also created in January 2012 to encourage compliance with the prevention measures. It consists of an online form that ICU physicians have to fill out for all ventilated patients to indicate whether VAP prevention was applied.

The prevention measures used in MSMC are an elevation of the head of patients' bed superior to 30° unless medically contraindicated, daily sedation vacation and oral care every four hours and whenever necessary. In addition, deep venous thrombosis and peptic ulcer disease prophylaxes were applied as recommended in the guidelines for the 'ventilator bundle'. However, all patients in ICUs are subjected to these measures and not only the ventilated ones. The costs of these prophylaxes were therefore not included in the specific costs of VAP prevention.

The estimated costs for the prevention measures are presented in the table 6.

Table 6. Costs of the prevention measures implemented within Mount Sinai Medical Center [31, 32]

Prevention measures	Costs per patient
Elevation of the head of the bed	No extra costs, no extra nursing time: automatic elevation of the head of the bed
Oral care every four hours and when necessary	Mean length of stay for ventilated patients without VAP in MSMC=24.54 days $ 21.35 per day 21.35*24.54 =$ 523.9 per case [31]
Sedation vacation	Conversion rate in 2010: $1=0.76 € 19.06 € per day (administration) + 3.18 € per day (wake-up) (19.06+3.18)/0.76*24.54=$ 718.1 per case [32]
Total costs per hospitalization	$ 1,242

In MSMC, the total costs of prevention per patient were estimated at $1,242.
The results of the comparison of the annual costs of VAP and the costs of prevention assuming 100% effectiveness as well as 100% compliance are presented in the table 7.

Table 7. Annual costs of VAP versus costs of prevention assuming 100% effectiveness and 100% compliance with guidelines from October 2008 to September 2011

	All VAP cases	Medical DRGs	Surgical DRGs
Number of VAP cases per year	205	43	162
Annual number of hospitalizations with mechanical ventilation	832	277	555
VAP incidence	24.6%	15.5%	29.2%
Annual extra costs of VAP	$ 5,905,845	$245,659	$ 5,660,280
Annual costs of prevention	$ 1,033,344	$ 344,034	$ 689,310
Annual incremental costs of prevention	-$ 4,872,595	**$98,375**	**-$ 4,970,970**
Minimal reduction in the number of VAP cases for the prevention program to be cost-neutral	36	-	20
Minimal % reduction in VAP incidence to be achieved for the prevention program to be cost-neutral	**4.3%**	-	**3.6%**

Assuming 100% compliance with guidelines and 100% effectiveness of measures, VAP prevention would generate annual savings of $4,872,595 for MSMC. Prevention would result in additional costs of $98,375 in the medical DRG group while in the surgical group it would result in savings of $4,970,970. In this group, an annual reduction of the VAP incidence of only 3.6% would be enough to reach cost-neutrality of the prevention program.

The relationship between savings, adherence to the guidelines and effectiveness of the prevention measures considering all VAP cases are shown in the figure 3.

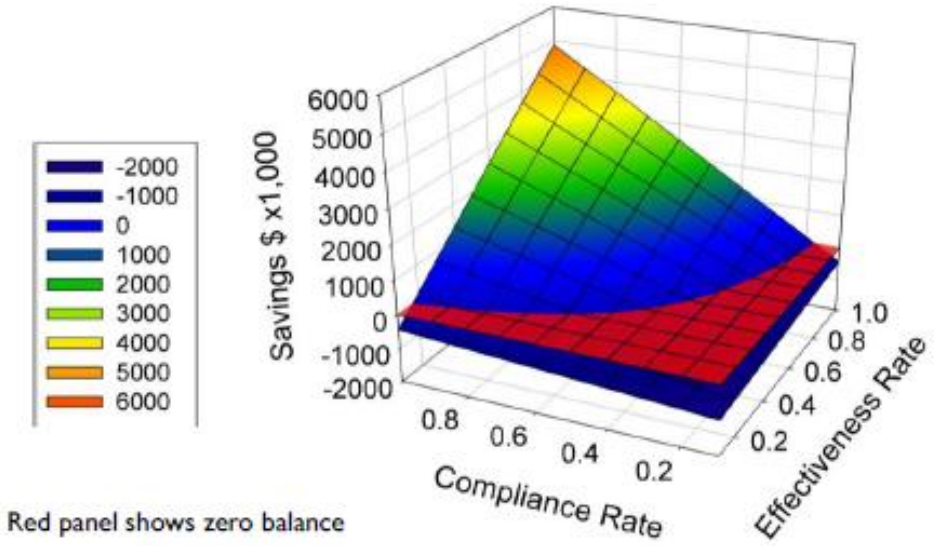

Figure 3. Relationship between savings, adherence to guidelines and effectiveness of the prevention measures against VAP

The part of the three-dimensional plot highlighted in red corresponds to the combination of compliance and effectiveness rates for which the costs of the prevention measures equal the excess costs of VAP. Above this zone, prevention measures generate savings while below this zone, they generate spending. The impact of VAP prevention on hospitals costs depends therefore on both compliance and effectiveness rates.

5. Discussion

In Mount Sinai Medical Center, surgical patients with VAP had significantly higher length of stays than controls. For those patients, excess costs of VAP were estimated at $34,940 per hospitalization. Differences in length of stay and costs were not statistically significant for medical patients. Mortality rates were similar between VAP cases and controls in both medical and surgical groups of patients.

Comparison of these results with the literature is complicated by differences in definitions of VAP used by various authors. Several articles took into account only patients who had been on ventilators for at least 24 hours [9, 10]. Others defined VAP as a pneumonia occurring in the course of a hospitalization more than 48 hours after the initiation of endotracheal intubation and mechanical ventilation [33]. Those definitions are not consistent with the CDC definition used in our study which specifies that there is no minimum period of ventilation for a pneumonia to be considered ventilator-associated [3].

Due to the ambiguity of VAP definition, the major constraint of our research was encountered in the identification of VAP cases. We used ICD-9-CM classification to determine VAP incidence in NIS and SPARCS database since it was the only available method. But this classification is prone to reporting bias and different doctors can use different definitions of VAP.
To avoid this limitation for MSMC data, we performed additional analysis and created a new VAP cohort based on clinical information (ventilator orders, X-rays results and presence of pneumonia on admission). However, this method might overestimate VAP incidence as cases were not reviewed by epidemiologists or infection control physicians and patients' symptoms as well as microbiology results were not available.

Different interpretations of VAP definition therefore result in very different estimated incidences.
The incidence of VAP can be expressed in two ways, either in percent of ventilated patients or per 1,000 ventilator days. This creates a problem for comparison when the number of ventilator days is not available. Studies found incidence of VAP of 2.5% to 20% when expressed in percent of ventilated patients [6, 7]. The CDC estimated that there were 0.0 to 5.8 cases of VAP per 1,000 ventilator days in American hospitals while other studies found much higher rates [3].

For example, Cocanour *et al.* found 25 cases of VAP per 1,000 ventilator days while Lai *et al*. found 45.1 and 22.4 cases per 1,000 ventilators days respectively in surgical and medical ICUs [10, 34]. In MSMC, the incidence of VAP was estimated at 29.2% (16 cases per 1,000 ventilator days) in the surgical DRGs group and at 15.5% (19 cases per 1,000 ventilator days) in the medical DRGs group. Patients from medical DRGs had higher lengths of mechanical ventilation than surgical patients.

In addition to the use of different definitions of VAP, populations of patients can be very different. In SPARCS database, MSMC was estimated to have significantly higher incidence of VAP than most of its competitors. However, the fact that Mount Sinai hosted very sick patients could be a possible explanation for the relatively high number of VAP cases observed in this hospital. It is therefore important to take into account those differences while comparing data.

Conflicting results also appear in the literature regarding the differences in mortality rates between patients suffering from VAP and other ventilated patients. However, the non-significant differences that we observed between the mortality rates of VAP cases and controls are consistent with findings from other studies. Rello *et al.* found a mortality rate of 30.5% for VAP patients against 30.4% for non VAP patients in North American ICUs (p=0.713) [9]. Similarly, Cocanour *et al.* did not find any differences in mortality between cases and controls in a shock trauma ICU [10]. The study conducted by Heyland *et al.* concluded that the attributable risk of mortality due to VAP varied with the type of organism responsible for the disease as well as with the patient population [35].
Particularly high mortality rates were found in our study both for cases and controls. Those findings are coherent with the severity of illness of patients treated in MSMC.

We used propensity score matching to account for patients' severity of illness and other baseline characteristics. We matched patients suffering from VAP with ventilated patients free from the disease based on 25 comorbidities as well as several other factors (age, race, sex and procedures classes). This method provided more robust results than multivariate regressions and adjusted for observed confounders. This is an advantage of our research. Other studies either did not include propensity matching or conducted it with very few variables while it is recommended to include as many relevant criteria as possible to obtain a good matching [26].

Cocanour *et al.* matched patients based only on age and injury severity score while Rello *et al.* matched patients on duration of ventilation which is a health outcome and should be compared between cases and controls after matching [9, 10].
It is however important to note that while propensity score matching has a better performance than multivariate regression, it also presents some limitations as it does not adjust for unobserved confounders.

After carrying the propensity score matching, we were able to assess the extra costs of VAP which were estimated at $34,940 per hospitalization for surgical patients. Our results are consistent with the findings from other studies assessing the economic impact of VAP. They all concluded that the excess costs of VAP were superior to $10,000 per stay [7-10]. Several studies found mean costs of VAP per patient very similar to ours with costs estimated at $39,828 by Kollef *et al.* and at $30,000 by Bird *et al.* in a surgical intensive care unit [7, 36].
In our study, analyses of data for patients from surgical and medical DRGs were carried out separately. It enabled us to avoid bias linked to higher costs of stays for surgical patients compared to medical patients.

We then compared the costs of VAP with the costs of prevention measures. For the surgical DRGs group, it has been estimated that prevention has the potential to save costs. Several other studies concluded that applying prevention measures against VAP could generate cost savings [32, 34, 36]. A study carried out in an American surgical intensive care unit found a reduction of 3.4 cases of VAP per 1,000 ventilator days after implementation of the IHI ventilator bundle. This was estimated to reduce hospital spending by $1.08 million over a 38-month period. However, the costs of prevention measures were not taken into account and savings were therefore overestimated [36].
In our study, the costs of prevention were determined through a literature review as data were not available in MSMC. We were not able to take into account potential variations due to the specific context of our research.
Similarly, generalization of our findings is limited to equivalent contexts. Results are likely to be different given potentially different patient populations and hospitals characteristics.

Finally, an additional field of research was identified. All studies assessing the economic impact of VAP were conducted from the perspective of hospitals which are third-party payers.
Costs for patients after hospitalization, as well as societal costs, were not taken into account. Further research should therefore be conducted in that regard.

6. Conclusion and recommendations

Ventilator-associated pneumonia generates significantly higher hospital costs for patients from surgical DRGs in Mount Sinai Medical Center. In addition, VAP has important consequences for patients' health and is an important indicator of quality of care more and more taken into account in comparison of hospitals. It is therefore of key importance to act towards a reduction of the incidence of this preventable disease, especially as the costs of the prevention measures are relatively low and can generate savings if the compliance is high.

Strong evidence indicates that a stringent implementation of the preventive 'ventilator bundle' and a systematic use of the prevention checklist should be enforced. A focus on staff awareness and education is also essential in parallel with sufficient allocation of resources for infection control.

Finally, the rate of VAP as well as the compliance with the 'ventilator bundle' should be monitored long enough after the implementation of the checklist to assess effectiveness of the prevention program. If no amelioration is observed, adjustments should be made such as the development of strategies to improve compliance and integration with other programs to enhance quality of care in the ICUs.

On a broader scale, a consensus regarding VAP definition should be adopted.

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List of annexes

Annex 1. Differences between VAP and non VAP patients at the national and New York State level

	National estimates				New York State estimates			
Variable	**VAP**	**Non VAP**	**P-value univariate analysis**	**P-value multivariate analysis**	**VAP**	**Non VAP**	**P-value univariate analysis**	**P-value multivariate analysis**
Patients' characteristics								
Mean age	58.57	55.09	<0.0001	<0.0001	62.26	59.64	<0.0001	<0.0001
Sex			<0.0001				<0.0001	
Female	38.20%	45.69%	comparator		42.29%	46.74%	comparator	comparator
Male	61.77%	54.27%	<0.0001	<0.0001	57.71%	53.26%	0.0001	0.001
Race				0.2333			0.0088	
White	50.68%	56.10%	comparator		44.79%	47.36%	comparator	comparator
Black	14.54%	13.44%	0.0762		25.37%	26.04%	0.6053	0.0158
Hispanic	8.57%	9.02%	0.6548		NA	NA		
Asian or Pacific Islander	2.55%	2.41%	0.6494		2.98%	3.24%	0.7117	0.7208
Native American	0.85%	0.67%	0.1826		0.11%	0.20%	0.4176	0.5189
Other	3.15%	3.71%	0.672		26.44%	22.74%	0.0003	<0.0001
Missing	19.66%	14.65%	0.1272		0.32%	0.41%	0.6501	0.6749
Comorbidities								
Congestive heart failure	21.10%	19.52%	0.2008		22.13%	22.37%	0.8031	
Valvular disease	4.25%	4.75%	0.2094		2.82%	3.87%	0.0195	0.0132
Pulmonary circulation disease	7.83%	5.68%	<0.0001	<0.0001	5.59%	4.95%	0.21	
Perivascular disease	6.68%	7.04%	0.4059		3.78%	4.46%	0.1551	
Hypertension	40.10%	44.12%	0.0226	<0.0001	31.22%	40.55%	<0.0001	<0.0001
Paralysis	12.91%	5.84%	<0.0001	<0.0001	12.50%	6.88%	<0.0001	<0.0001
Other neurological disorders	14.55%	12.20%	0.0044	0.0246	17.77%	13.30%	<0.0001	<0.0001
Chronic pulmonary disease	22.93%	26.84%	0.0189	0.0186	17.45%	22.05%	<0.0001	0.0002
Diabetes without complications	19.15%	20.04%	0.4892		14.26%	18.60%	<0.0001	0.0004
Diabetes with complications	3.87%	4.61%	0.0743	0.0633	2.87%	3.69%	0.0633	0.075
Hypothyroidism	6.10%	7.92%	0.0047	0.012	3.09%	5.68%	<0.0001	0.0001
Renal failure	16.30%	16.00%	0.7856		16.54%	17.03%	0.5819	
Liver disease	3.83%	4.21%	0.2505		4.15%	5.35%	0.0217	0.0155
Peptic ulcer disease	0.07%	0.04%	0.4017		0.05%	0.09%	0.6332	
Obesity	9.74%	9.85%	0.8497		3.83%	4.62%	0.1067	
Deficiency anemia	25.23%	21.99%	0.0385	0.0545	13.46%	14.38%	0.2616	

	National estimates				New York State estimates			
Variable	**VAP**	**Non VAP**	**P-value univariate analysis**	**P-value multivariate analysis**	**VAP**	**Non VAP**	**P-value univariate analysis**	**P-value multivariate analysis**
Depression	5.57%	7.57%	0.0004	0.017	2.13%	3.96%	<0.0001	0.0027
Chronic blood loss	1.87%	1.64%	0.4035		1.22%	1.11%	0.645	
AIDS	0.35%	0.32%	0.8079		1.70%	1.52%	0.5186	
Lymphoma	1.18%	1.02%	0.2998		1.12%	1.45%	0.2377	
Metastatic cancer	2.30%	3.28%	0.0002	<0.0001	2.45%	4.83%	<0.0001	<0.0001
Solid tumor without metastasis	2.05%	2.65%	0.0127		1.97%	3.29%	0.0014	0.0002
Rheumatoid arthritis	1.86%	2.02%	0.4783		0.59%	1.37%	0.0036	0.0148
Coagulopathy	15.96%	12.67%	<0.0001	0.2775	14.57%	14.61%	0.9686	
Weight loss	33.48%	14.19%	<0.0001	<0.0001	21.01%	11.55%	<0.0001	<0.0001
Fluid and electrolytes disorders	55.90%	48.36%	<0.0001	0.0149	51.70%	47.64%	0.0005	0.2908
Alcohol abuse	6.97%	7.99%	0.0443	0.0686	6.17%	5.80%	0.4951	
Drug abuse	3.98%	4.96%	0.0047	0.9914	4.26%	5.48%	0.0211	0.1821
Psychoses	4.42%	5.81%	0.001	0.043	2.18%	4.20%	<0.0001	0.0002
Median household income	2.33	2.31	0.6184					
Hospitals characteristics								
Mean number of nurses	4.53	4.32	<0.0001	0.0434				
Hospital size			<0.0001					
Small	15.52%	8.96%	0.007	0.0014				
Medium	13.76%	22.72%	0.0034	0.0003				
Large	68.21%	66.30%	comparator	comparator				
Hospital ownership			0.0026					
Public	72.66%	69.59%	0.0163	0.3461				
Private	24.84%	12.32%	comparator	comparator				
Hospital location and teaching status			0.0035					
Rural	3.28%	6.84%	0.0039	0.0724				
Urban non teaching	31.14%	37.82%	0.0228	0.1932				
Urban teaching	63.08%	53.32%	comparator	comparator				

Annex 2. Differences between VAP and non VAP cohorts in MSMC before matching

	Surgical DRGs group				Medical DRGs group			
Variable	**No VAP (N=1179)**	**VAP (N=486)**	**P-value**	**Standardized difference**	**No VAP (N= 701)**	**VAP (N=129)**	**P-value**	**Standardized difference**
Age	65.6	66.4	0.417	4.8%	64.6	65.3	0.873	4.2%
Female	43.3%	43.8%	0.831	1.1%	45.1%	48.8%	0.431	7.5%
Male	56.7%	56.2%	0.831	-1.1%	54.9%	51.2%	0.431	-7.5%
Caucasian (White)	43.7%	47.3%	0.174	7.3%	33.8%	36.4%	0.564	5.5%
Hispanic/Latino	16.5%	13.2%	0.092	-9.3%	22.0%	16.3%	0.146	-14.5%
African American	19.9%	17.1%	0.178	-7.4%	25.5%	13.2%	0.002	-31.7%
Asian	4.6%	4.3%	0.817	-1.3%	3.9%	7.8%	0.049	16.7%
Pacific Islander	0.3%	0.0%	0.199	-8.3%	0.1%	0.0%	0.668	-5.3%
Native American	0.1%	0.2%	0.517	3.2%	0.0%	0.0%	-	-
Other race	8.4%	8.0%	0.802	-1.4%	9.1%	10.9%	0.538	5.7%
Unknown race	6.5%	9.9%	0.019	12.2%	5.6%	15.5%	<0.0001	32.8%
Congestive heart failure	26.1%	29.0%	0.227	6.5%	29.5%	22.5%	0.103	-16.1%
Valvular disease	11.2%	10.1%	0.507	-3.6%	8.7%	7.8%	0.723	-3.5%
Pulmonary circulation disease	8.4%	7.4%	0.501	-3.7%	9.8%	7.8%	0.457	-7.4%
Hypertension	20.9%	20.2%	0.748	-1.7%	28.5%	24.0%	0.295	-10.2%
Paralysis	4.5%	6.0%	0.207	6.6%	8.6%	8.5%	0.991	-0.1%
Other neurological disorders	11.0%	10.5%	0.751	-1.7%	14.4%	11.6%	0.403	-8.3%
Chronic pulmonary disease	10.4%	7.4%	0.056	-10.6%	16.8%	12.4%	0.209	-12.6%
Diabetes without complications	9.8%	8.2%	0.331	-5.3%	13.4%	11.6%	0.582	-5.4%
Diabetes with complications	4.5%	2.5%	0.052	-11.1%	3.3%	3.1%	0.916	-1.0%
Hypothyroidism	4.7%	3.5%	0.287	-5.9%	7.4%	6.2%	0.624	-4.8%
Renal Failure	14.6%	12.8%	0.328	-5.3%	21.3%	13.2%	0.035	-21.5%
Liver disease	6.6%	5.1%	0.257	-6.3%	13.1%	20.9%	0.020	20.9%
Obesity	4.5%	1.9%	0.010	-15.1%	6.6%	2.3%	0.061	-20.7%
Deficiency anemia	12.5%	9.5%	0.082	-9.6%	19.5%	21.7%	0.572	5.3%
Depression	3.1%	2.1%	0.226	-6.8%	5.6%	4.7%	0.674	-4.1%
Chronic blood loss anemia	0.3%	0.4%	0.595	2.7%	1.1%	1.6%	0.696	3.6%
AIDS	2.8%	0.2%	0.001	-21.4%	7.7%	6.2%	0.551	-5.9%
Lymphoma	1.1%	0.6%	0.356	-5.3%	1.7%	2.3%	0.631	4.4%
Solid tumor without metastasis	3.2%	1.9%	0.125	-8.7%	3.7%	3.1%	0.734	-3.4%
Rheumatoid arthritis	2.2%	0.4%	0.010	-15.8%	2.0%	1.6%	0.735	-3.4%
Coagulopathy	12.9%	13.4%	0.791	1.4%	15.5%	14.7%	0.813	-2.3%
Fluid and electrolytes disorders	3.5	39.3%	0.638	-2.5%	47.6%	55.0%	0.123	14.8%
Alcohol abuse	1.8%	2.3%	0.515	3.4%	3.6%	5.4%	0.314	9.0%
Drug abuse	2.3%	1.0%	0.088	-9.9%	7.1%	5.4%	0.482	-7.0%
Psychoses	1.4%	0.8%	0.304	-5.9%	3.9%	3.9%	0.990	0.1%
Procedure class	3.5	3.6	0.003	20.2%	2.0	2.0	0.467	8.1%

Annex 3. Detailed results of the propensity score matching

	Surgical DRGs group				Medical DRGs group			
Variable	**No VAP (N=484)**	**VAP (N=484)**	**P-value**	**Standardized difference**	**No VAP (N= 128)**	**VAP (N=128)**	**P-value**	**Standardized difference**
Age	66.7	66.4	0.7391	-2.0%	65.5	65.3	0.7887	-1.6%
Female	46.3%	44.0%	0.4332	-4.6%	46.1%	48.4%	0.6911	4.7%
Male	53.7%	56.0%	0.4332	4.6%	53.9%	51.6%	0.6911	-4.7%
Caucasian (White)	50.2%	47.5%	0.3775	-5.4%	33.6%	36.7%	0.6056	6.5%
Hispanic/Latino	13.4%	13.2%	0.9199	-0.6%	14.8%	16.4%	0.7055	4.3%
African American	15.7%	17.1%	0.5377	3.9%	15.6%	13.3%	0.5485	-6.7%
Asian	4.5%	4.3%	0.8694	-1.0%	8.6%	7.0%	0.5930	-5.8%
Pacific Islander	0.0%	0.0%	-	-	0.0%	0.0%	-	-
Native American	0.2%	0.2%	1.0000	0.0%	0.0%	0.0%	-	-
Other race	7.4%	8.1%	0.7098	2.3%	9.4%	10.9%	0.6949	5.2%
Unknown race	8.5%	9.5%	0.5351	3.6%	18.0%	15.6%	0.5316	-6.3%
Congestive heart failure	28.1%	28.7%	0.8185	1.4%	23.4%	21.9%	0.7681	-3.7%
Valvular disease	9.1%	10.1%	0.5831	3.5%	7.0%	7.8%	0.7963	3.0%
Pulmonary circulation disease	6.2%	7.4%	0.4461	4.9%	9.4%	7.8%	0.6547	-5.6%
Hypertension	17.8%	19.8%	0.4014	5.3%	24.2%	24.2%	1.0000	0.0%
Paralysis	6.2%	6.0%	0.8886	-0.9%	7.8%	8.6%	0.8185	2.8%
Other neurological disorders	10.7%	10.5%	0.9156	-0.7%	14.1%	11.7%	0.5775	-7.0%
Chronic pulmonary disease	7.2%	7.4%	0.9013	0.8%	10.9%	12.5%	0.6698	4.9%
Diabetes without complications	7.0%	8.3%	0.4533	4.7%	13.3%	11.7%	0.7150	-4.7%
Diabetes with complications	2.1%	2.5%	0.6547	2.8%	3.9%	3.1%	0.7389	-4.2%
Hypothyroidism	4.3%	3.5%	0.4795	-4.3%	4.7%	6.3%	0.5930	6.9%
Renal Failure	13.0%	12.8%	0.9215	-0.6%	10.2%	13.3%	0.4142	9.7%
Liver disease	5.2%	5.2%	1.0000	0.0%	19.5%	20.3%	0.8694	2.0%
Obesity	2.5%	1.9%	0.4669	-4.3%	3.1%	2.3%	0.7055	-4.8%
Deficiency anemias	9.9%	9.5%	0.8208	-1.4%	21.9%	21.1%	0.8788	-1.9%
Depression	2.1%	2.1%	1.0000	0.0%	5.5%	4.7%	0.7815	-3.6%
Chronic blood loss anemia	0.4%	0.4%	1.0000	0.0%	0.8%	1.6%	0.5637	7.3%
AIDS	0.4%	0.2%	0.3173	-3.7%	5.5%	6.3%	0.7815	3.3%
Lymphoma	0.6%	0.6%	1.0000	0.0%	3.9%	2.3%	0.4142	-9.0%
Solid tumor without metastasis	1.5%	1.9%	0.6171	3.2%	3.9%	3.1%	0.7389	-4.2%
Rheumatoid arthritis	0.6%	0.4%	0.6547	-2.9%	0.8%	1.6%	0.5637	7.3%
Coagulopathy	11.0%	13.0%	0.3268	6.4%	14.8%	14.8%	1.0000	0.0%
Fluid and electrolytes disorders	38.6%	39.0%	0.8981	0.8%	52.3%	54.7%	0.7180	4.7%
Alcohol abuse	2.3%	2.3%	1.0000	0.0%	3.9%	5.5%	0.5637	7.4%
Drug abuse	0.6%	1.0%	0.4142	4.6%	4.7%	5.5%	0.7630	3.5%
Psychoses	0.6%	0.8%	0.7055	2.4%	2.3%	3.9%	0.4795	9.0%
Procedure class	3.7	3.6	0.3498	-4.7%	2.1	2.0	0.8726	-4.8%

Abstract

Economic impact of ventilator-associated pneumonia (VAP) and evaluation of the VAP prevention program

Background: Ventilator-associated pneumonia (VAP) is one of the most common nosocomial infections in intensive care units. This infection is associated with significant mortality and is estimated to result in excess direct costs. Prevention of VAP is of key importance in response to the evolving environment (development of antibiotics resistance and limited resources).

Objectives: The goal of this study was to assess the economic impact of VAP within Mount Sinai Medical Center, a highly competitive non-for-profit American hospital, and to evaluate the costs of the prevention program after determining predictors as well as incidence of VAP and comparing those data with major academic hospitals in New York City.

Methods: We analyzed hospital inpatient stays databases at the national and state level to measure associations between VAP incidence, patients' demographics and hospitals characteristics as well as to compare Mount Sinai Medical Center with its main competitors. In addition, a retrospective case-control study was carried out on Mount Sinai patients from 2008 to 2011 to assess the economic impact of VAP. The costs of the prevention program were evaluated through a literature review.

Results: Mount Sinai Medical Center had a higher incidence rate of VAP than most of its competitors but treated significantly sicker patients. The mean excess hospital costs of VAP per case were found to be respectively $34,940 ($p<0.0001$) and $5,713 ($p=0.0815$) for surgical and medical Diagnosis related groups. The prevention program represented costs of $1,242 per ventilated patient.

Conclusions: VAP generates excess costs for Mount Sinai Medical Center and is an important indicator of quality of care. Prevention measures against this infection have low costs and should therefore be implemented stringently.

Keywords: ventilator-associated pneumonia, nosocomial infection, costs, prevention, quality of care.

Abstract in French

Impact économique des pneumonies acquises sous ventilateur (PAV) et évaluation du programme de prévention

Contexte : Les pneumonies acquises sous ventilateur (PAV) représentent l'une des plus fréquentes maladies nosocomiales dans les unités de soins intensifs. Cette infection est associée à une mortalité importante ainsi qu'à des coûts estimés être excédentaires. La prévention des PAV est par ailleurs primordiale dans le contexte d'un environnement en évolution (développement de résistances aux antibiotiques et ressources limitées).

Objectifs : Cette étude analyse l'impact économique des PAV au sein du *Mount Sinai Medical Center* et évalue les coûts du programme de prévention après avoir déterminé les facteurs de risque ainsi que l'incidence de cette maladie et avoir comparé ces données à celles des autres principaux centres hospitaliers universitaires de la ville de New York.

Méthodes : Des bases de données hospitalières au niveau national et fédéral ont été analysées afin de déterminer l'association entre l'incidence des PAV et les caractéristiques des différents patients et hôpitaux ainsi que pour comparer le *Mount Sinai Medical Center* avec ses principaux compétiteurs. Une analyse rétrospective de cas témoins a été réalisée sur des patients de *Mount Sinai* pour déterminer l'impact économique des PAV. Enfin, la rentabilité du programme de prévention a été évaluée au moyen d'une revue de la littérature.

Résultats : Le taux d'incidence des PAV au sein du Mount Sinai Medical Center est plus élevé que chez la majorité de ses compétiteurs mais cet hôpital traite des patients significativement plus sévères. Le coût moyen additionnel par cas de PAV a été estimé respectivement à \$34,940 ($p<0.001$) et \$5,713 ($p=0.0815$) pour les groupes homogènes de séjours chirurgicaux et médicaux. Le programme de prévention représente des coûts de \$1,242 par patient ventilé.

Conclusion : Les PAV génèrent des coûts additionnels et sont un important indicateur de la qualité des soins. Les mesures de prévention contre cette infection représentent des coûts faibles et doivent être implémentées avec rigueur.

Mots-clés : pneumonies acquises sous ventilateur, infections nosocomiales, coûts, prévention, qualité des soins