Comparison Study between Using Disposable and Non-Disposable Ventilator Circuits on Ventilator-Associated Pneumonia and Health Care Costs at a Respiratory Care Unit, Siriraj Hospital

Jarunee Songmuang, M.N.S.*, Pachcharat Akatat, R.N.*, Sasithorn Wattanagulanurak, M.N.S.*, Nuttapol Rittayamai, M.D., Siriporn Sripalakit, M.A. (Env.) *****

** Nursing Department, ** Division of Respiratory Disease and Tuberculosis, Department of Medicine, *** Centre for Nosocomial Infection Control, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok 10700, Thailand.*

ABSTRACT

Objective: This research aimed to compare the incidence of ventilator-associated pneumonia (VAP) and ventilator circuit costs among patients using disposable ventilator circuits and patients using non-disposable ventilator circuits.

Materials and Methods: Observational research was performed consisting of the following: A retrospective chart review of a group of patients who used non-disposable circuits (n=193) and a prospective cohort study of a group of patients using disposable circuits (n=166). The sample was purposively selected based on the following inclusion criteria: patients aged 18 years old and over who were admitted to the Respiratory Care Unit, Siriraj Hospital and ventilated >48 h.

Results: VAP incidence in the group non-disposable circuits was 10.41/1,000 ventilator days *(n=27, 13.8%)* and 10.82 /1,000 ventilator days *(n=24, 14.4%)* in the group disposable circuits *(p=0.871)*. According to the data analysis using the U-control chart, no statistically significant differences were found. The unit cost of the non-disposable circuit was lower than that of the disposable circuit (THB 295.94), while the work unit personnel satisfaction toward working with disposable circuits was at a good level *(Mean=3.83)* and medium level *(Mean=3.12)* in non-disposable circuits *(p=0.002)*.

Conclusion: The type of ventilator circuits had no effects on VAP rate. The unit cost of non-disposable circuits was lower than that of disposable circuits, while the work unit personnel had a higher satisfaction working with disposable circuits than non-disposable circuits.

Keywords: Ventilator-associated pneumonia; health care costs; non-disposable ventilator circuits; disposable ventilator circuits (Siriraj Med J 2023; 75: 191-199)

INTRODUCTION

Ventilator-associated pneumonia (VAP) is pneumonia occurring at least 48 h after intubation and ventilation or within 48 h after extubation. The diagnostic criteria and clinical symptoms are used for its diagnosis.[1,2] VAP is well known as a major hospital infection correlated with the time on ventilators, length of stay, mortality rate, and higher costs. One US study reported that treatment expenses were USD 25,000–28,000 higher per patient with VAP[5], while the mortality rate in connection with VAP was 5%–65%, depending on the patients' condition.[3,4] VAP incidence in intensive care units (ICUs), where most patients use ventilators, has been reported to range from 8%–28%[5,6], or 13–51/1,000 ventilator days.[7] The

Corresponding author: Jarunee Songmuang
E-mail: dah_ns@hotmail.com
Received 9 November 2022 Revised 16 December 2022 Accepted 27 December 2022
ORCID ID:http://orcid.org/0000-0001-9354-7694
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Respiratory Care Unit (RCU), Department of Medicine, Siriraj Hospital, provides care for patients with respiratory failure, unstable blood circulation, respiratory infections, air-borne infections, difficulty weaning from ventilators and severe complications from diagnostic procedures and treatment of respiratory illnesses. The VAP incidence rate was 0–16.9/1,000 ventilator days in 2018 and 0–27.2/1,000 ventilator days in 2019.[8] In addition to affecting patients' health and costs, the problem increases hospital and staff workloads, with more complex care and treatment needed for the prevention of infections, which then translates into increased hospital expenses and costs.

The etiology of VAP is attributed to obstructions to natural bacteria and mucus disposal mechanisms during intubation, while the formation of bacterial microfilms around the endotracheal tube (ETT) causes choking from secretions that accumulate above the balloon. In addition, the positive pressure from ventilators enables germs to easily enter the lower respiratory tract. This is facilitated by differences in immunity and VAP risk factors in each patient.[9,10] Many factors contribute to VAP, including patient factors and factors related to the examination and treatment procedures, such as the patient's age, disease severity, immunodeficiency, the use of proton-pump inhibitors, the use of narcotics or neuromuscular blocking agents, previous antibiotic exposure, emergency intubation, re-intubation, bronchoscopy, and contaminated medical equipment, such as nebulizers and ventilator circuits.[9,11,12] In the RCU, used ventilator circuits are sterilized before use by the next patient. However, if the cleaning and disinfection processes are performed inadequately, infections can break out among patients. According to a study conducted by Li et al. compared the rates of bacterial contamination in non-disposable and disposable ventilator circuits, and found the bacterial infection rates in the group using non-disposable ventilator circuits were higher than in the group using disposable ventilator circuits, with statistical significance (94.8% and 81.9% $p < 0.01$).[13] In Thailand, Srisan et al. conducted a study to compare the VAP incidence rates among pediatric patients on non-disposable and disposable ventilator circuits, and found the VAP incidence rates were not statistically significantly different (20.53 and 30.77/1,000 ventilator days, $p = 0.24$). Regarding the treatment agency expenses, however, the group using disposable ventilator circuits had higher costs.[14] Apart from the major health issues caused by VAP incidence, hospital costs and expenses, workloads, and infection risks to the staff involved in preparing ventilator circuits are also important. Although trends in the findings from previous studies have shown that the use of disposable or non-disposable ventilator circuits have no effect on VAP incidence, differences in the patients' condition, environment, care standards, and ventilator circuit cleaning guidelines may cause the results to be different. Consequently, the present research was conducted to compare the effects from using non-disposable ventilator circuits to the effects from using disposable ventilator circuits in the RCU in terms of VAP incidence, agency costs, and staff satisfaction with the aim to ensure that the existing resources can be used cost-effectively with the highest benefit. Furthermore, this study was conducted with the aim of creating evidence-based practices that can be used by other institutions.

MATERIALS AND METHODS

This observational study was conducted at Siriraj Hospital in Bangkok, Thailand. The Institutional Review Board of the Faculty of Medicine Siriraj Hospital, approved the study protocol (COA no. Si 136/2020). The research involved a study of the variances of VAP incidence. The population studied was the number of days on ventilators and the incidence of VAP. VAP was diagnozed by using the criteria of the Centers for Disease Control and Prevention.[1] VAP means pneumonia in patients who had been on ventilatures for more than two days. Diagnostic crteria and clinical symptoms consisted of chest x-ray images with new or additional infiltrations and at least two of the following three factors: (1) fever > 38°C or temperature below 36°C; (2) leukopenia (≤ 4,000 WBC/mm^3) or leukocytosis (≥ 12,000 WBC/mm^3); and (3) sputum containing pus or changing characteristics, higher volume or difficulty breathing. The patients who participated in the study had to meet the following inclusion criteria: (1) patients were intubated or on tracheostomy; (2) patients were on ventilators for at least 48 h; (3) patients were aged 18 years old and over; and (4) patients consented to participate in the research project. The exclusion criteria consisted of one of the following criteria: (1) patients were pregnant; and (2) patients were on ventilators for less than 48 h. The sample size calculation criteria of the American Society of Testing and Materials were used. The criteria specified a minimum sample size of more than or equal to 1/U bar and the appropriate sample size was 4/U bar (U bar or average VAP incidence/1,000 ventilator days). In this study, the sample size was calculated by using the VAP incidence rate in the period January 2018 to December 2018 of 10.8/1,000 ventilator days. Therefore, the appropriate sample size per dataset was 1/0.0108–4/0.0108 or 93–370 ventilator days. For the U-control chart to be able to compare and display VAP incidence variances with quality, at least 15 datasets were needed per group. In this study, the sample was divided into the following two groups: (1) A group using non-disposable ventilator circuits (Hamilton). The data of this group were collected retrospectively in the period October 2018 to December 2019 for a total of 15 datasets. In this group, 235 patients used ventilators and 192 patients met the inclusion criteria; (2) A group using disposable ventilator circuits (Fisher & Paykel, model RT 380). Due to the COVID-19 situation, the number of ventilator days was less than 93 days in certain months, causing the data from two months to be merged into one data set. In this group, the data were collected for 17 months between June 2020 and October 2021 (15 datasets). This group had a total of 201 patients who were on ventilators with 166 patients who met the inclusion criteria, 148 patients who were on ventilators and used non-disposable ventilator circuits before changing to use disposable ventilator circuits after joining the research project and 18 patients who began using ventilators in the RCU by using disposable ventilator circuits from the start.

Data collection

In the data collection, the patients' medical records were used to collect the data retrospectively in the group using non-disposable ventilators, while letters were prepared for the patients or their representatives to sign and grant consent to participate in the study before collecting data from the group using disposable ventilators. The researcher then began using the case record form to collect data on the patients' demographics, co-morbidities, APACHE II scores, ventilator indications, VAP risk factors, number of ventilator days, length of hospitalization, ICU mortality, 30-day mortality, survival past one month after transfer from the ICU, hospital charges, and use of antibiotics. Data on the ventilator circuit costs were collected by calculating the equipment prices, depreciation, expendable equipment costs, gassing costs, infected waste disposal costs, and staff wages throughout the process to summarize the average cost per ventilator circuit. Data on staff satisfaction were collected by using the satisfaction assessment form to compare their satisfaction between working with disposable ventilators and non-disposable ventilators. Data were collected for comparison at the same time point at the end of the research project.

Statistics

Fisher's exact test was applied for the data analysis, with the data analyzed using the Minitab (U-control chart) program to assess the variances in VAP incidence. The SPSS program was used for the descriptive and comparison statistics, with $p < 0.05$ indicating statistical significance. The data analysis was as follows: (1) sample characteristics were reported by the mean scores, percentages, and standard deviation; differences were compared using t-test statistics in the case of quantitative data, while chi-square statistics were used for the qualitative data; (2) clinical outcomes were reported as median scores and differences were compared using the Mann–Whitney U-test. Data on the length of hospitalization, length of stay in the ICU, number of ventilator days, expenses from the hospitalization and antibiotics, clinical outcomes in terms of the number of patients with VAP and the treatment outcomes before transfer from the ICU were reported using percentages, while the differences were compared using chi-square test statistics, Kaplan-Meier survival rate analysis by using the log-rank test, analysis of factors with effects on the hazard ratio according to the Cox Regression Model and the VAP incidence fluctuation assessment control graph; (3) staff satisfaction was reported by percentages, mean scores, and standard deviation, while differences were compared using paired sample test statistics and Fisher's exact test.

RESULTS

In this study, 358 participants were enrolled divided into two groups: the non-disposable ventilator circuits group, comprising 192 patients who used non-disposable ventilator circuits (53.6%) for a combined 2,527 ventilator days, and the disposable ventilator circuits group, comprising 166 patients who used disposable ventilator circuits (46.4%) for a combined 2,354 ventilator days. The demographic data of both groups were similar. Most of the study cohort were males, aged over 60 years old and had co-morbidities. The illness severity was assessed based on APACHE II scores. The patients in the disposable ventilator circuits group had lower scores than the patients in the non-disposable ventilator circuits group *($p = 0.007$)*. As a co-morbidity, chronic lung disease was higher in the group using disposable circuits than the group using non-disposable circuits *($p = 0.02$)*. The other co-morbidities showed no statistically significant difference. The main cause of respiratory failure was pneumonia. The risk of VAP from receiving proton-pump inhibitors was the only risk factor in the group using disposable ventilator circuits that was lower than in the group using non-disposable ventilator circuits *($p = 0.001$)*. Other aspects, such as antibiotics, sedatives and re-intubation, were not statistically significantly different (Table 1).

As for clinical outcomes, VAP incidence was reported at 51 episodes divided into 27 episodes in the group

TABLE 1. Patient characteristics.

Patient data (n = 358)	Non-disposable (n = 192)	Disposable (n = 166)	P
Male, *n (%)*	120 (62.5)	100 (60.2)	.661
Age *(years) (mean ± SD)*	65.01 ± 17.16	65.83 ± 16.03	.642
BMI *(mean ± SD)*	21.95 ± 6.09	22.97 ± 6.70	.130
APACHE II Score *(mean ± SD)*	24.13 ± 7.16	22.01 ± 7.50	.007*
Co-morbidities, *n (%)*	178 (92.7)	157 (94.6)	.472
Hypertension	94 (49.0)	92 (55.4)	
Chronic Lung Disease	67 (34.9)	78 (47.0)	
Cardiovascular Disease	52 (27.1)	46 (27.7)	
Chronic Renal Failure	46 (24.0)	33 (19.9)	
Diabetes	44 (22.9)	52 (31.3)	
Cancer	44 (22.9)	32 (19.3)	
Stroke	27 (14.1)	20 (12.0)	
Connective Tissue	21 (10.9)	12 (7.2)	
Other	27 (14.1)	23 (13.8)	
Cause of Intubation, *n (%)*			
Pneumonia	81 (42.2)	82 (49.4)	.172
Obstructive Airway Disease	23 (12.0)	13 (7.8)	.193
ARDS	20 (10.4)	13 (7.8)	.399
Heart Failure	10 (5.2)	9 (5.4)	.928
Alteration of Consciousness	8 (4.2)	11 (6.6)	.301
Cardiac Arrest	8 (4.2)	5 (3.0)	.560
Aspiration	7 (3.6)	8 (4.8)	.581
Septicemia	7 (3.6)	4 (2.4)	.499
Risk of VAP Incidence[9,11,12], *n (%)*			
Proton-pump Inhibitors	190 (99.0)	152 (91.6)	.001*
Previous Antibiotic Exposure	183 (95.3)	157 (94.6)	.751
Sedative	148 (77.1)	126 (75.9)	.793
Re-intubation	37 (19.3)	24 (14.5)	.227

*Statistical significance

Abbreviations: BMI = Body mass index, APACHE II = Acute physiology and chronic health evaluation II, ARDS = acute respiratory distress syndrome

using non-disposable ventilator circuits (13.8%) with a VAP incidence rate of 10.68/1,000 ventilator days versus 24 episodes in the group using disposable ventilator circuits (14.4%) with a VAP incidence rate of 10.19/1,000 ventilator days, which showed no statistically significant difference *(p=0.87)*. A survival rate analysis by Kaplan-Meier using the log-rank test found the time to a VAP event of non-disposable ventilator circuits to be 52 days *(95%CI: 35.91-68.09)*, while the time for patients with disposable ventilator circuits was 85 days *(95%CI: 57.37-112.63)*, which had no statistical significance *(p=0.256)*. An analysis of factors with effects on the Hazard ratio according to the Cox Regression Model found disposable ventilator circuits to reduce VAP incidence by 0.72 times *(HR 0.72, 95%CI: 0.407-1.274)*, which similarly had no statistical significance *(p=0.259)*. Other outcome aspects, such as the length of hospitalization, length of stay in the ICU, and number of ventilator days, were also not statistically significantly different. In addition, the outcomes before transfer from the ICU to other wards, discharge, deaths, referrals to other hospitals, and survival at one month after leaving the ICU were also not statistically significantly different (Table 2). According to the culturing results, the main causes of VAP were Carbapenem-resistant *Acinetobacter baumannii* (47%), Carbapenem-susceptible *Pseudomonas aeruginosa* (13.7%), Carbapenem-susceptible *Acinetobacter baumannii* (9.8%) and Gram-negative bacteria (9.8%).

When the U-control chart was used to assess variances in VAP incidence, the data for both the upper control limit (UCL) and the lower control limit (LCL) had normal distributions within a common cause variable, meaning the infections were considered to have been continual without special causes. Therefore, the VAP incidence in patients using non-disposable and disposable ventilator circuits were not statistically significantly different (Fig 1).

In terms of the average cost of the ventilator circuits

TABLE 2. Ventilator-related and Clinical outcomes.

Outcome	Non-disposable *(n = 192)*	Disposable *(n = 166)*	*P*
VAP case, *n (%)*	27 (13.8)	24 (14.4)	.871
Length of Hospitalization *(days)**	32 (16.5–49)	37 (15–59)	.240
Length of Stay in ICU *(days)**	13 (7–23)	14 (8–31)	.121
Ventilator Days *(days)**	8 (4–13)	9 (5–18)	.208
Discharge Status, *n (%)*			
Transfer	111 (57.8)	82 (49.4)	.330
Death	56 (29.2)	53 (31.9)	.330
Discharge	18 (9.4)	24 (14.5)	.330
Transferred Hospital	7 (3.6)	7 (4.2)	.330
Alive at 1 month after leaving the ICU, *n (%)*	104 (55.6)	98 (59.4)	.474

* Median (interquartile range)
Abbreviation: VAP = Ventilator-associated pneumonia

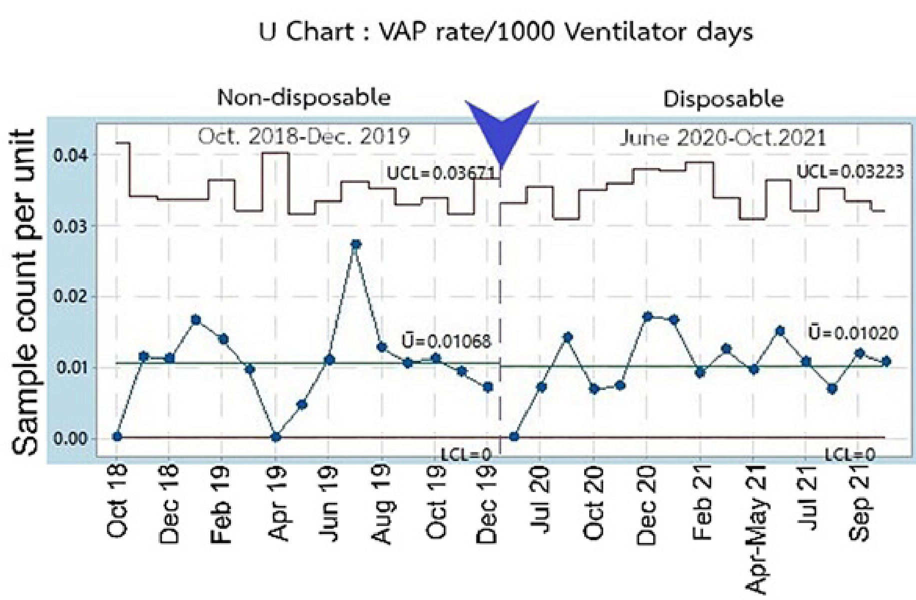

Fig 1. U-control chart of VAP incidence in patients using non-disposable ventilator circuits and patients using disposable ventilator circuits. The arrow indicates the change in patient group.

in one round of change for one month, after calculations based on the activity and time, the non-disposable ventilator circuits were found to have an average cost of THB 1,863.56, while the disposable ventilator circuits were found to have an average cost of THB 2,159.5, meaning the average cost of the non-disposable ventilator circuits was on average THB 295.94 lower (Table 3). In terms of the overall expenses from the hospitalization and antibiotics use in patients who had VAP and patients who did not have VAP, the patients who had VAP had higher overall hospitalization and antibiotic expenses than the patients who did not have VAP *($p < 0.00$)*.

Next, we assessed the satisfaction among the 42 staff members in the hospital work unit toward the ventilator circuits. The work unit personnel consisted of 34 nurses (81%) and 8 nurse assistants (19%) with a mean age *(mean ±SD)* of 37 ± 10 years old, and work experience of <5 years (5 personnel or 11.9%), 5–10 years (14 personnel or 33.3%), or >10 years (23 personnel or 54.8%). In terms of their satisfaction toward ventilator circuits, they expressed a medium level of satisfaction toward non-disposable ventilator circuits in every question item, but a good level of satisfaction toward disposable ventilator circuits in most questions, with only the question on the amount of fluids remaining in the ventilator circuits showing a medium level of satisfaction (Table 4). However, when the work unit personnel were asked for their opinions regarding "if the work unit were to implement a policy to change disposable ventilator circuits", most of the personnel approved (33 personnel or 78.6%) while a minority disapproved (9 personnel or 21.4%), but without a statistically significant difference *($p = 0.168$)*. However, when the opinions of the nurses were separated from the nurse assistants, it was found that 25 nurses (73.5%) approved and 9 nurses disapproved (26.5%) with this change scenario, while every nurse assistant approved (8 personnel or 100%).

TABLE 3. Ventilator circuits related cost per set.

Cost/set (THB)	Non-disposable	Disposable
Cost per set	694.44	2,124
Labor cost	250.69	35.5
Maintenance cost	918.43	0
Total Cost per set	**1,863.56**	**2,159.5**

calculated from the costs in 1 month

TABLE 4. Satisfaction of the personnel with non-disposable and disposable ventilator circuits.

	Level of satisfaction (Mean)		
Question topics	**Non-disposable**	**Disposable**	***P-value***
Convenience in assembling	Medium (2.88)	Good (4.41)	<.000*
Time spent assembling	Medium (2.88)	Good (4.07)	<.000*
Preparatory testing before use	Medium (3.46)	Good (3.98)	.001*
Flexibility during nursing care	Medium (3.50)	Good (3.90)	.061
Circuit weight, tension	Medium (2.98)	Good (3.81)	.005*
Condensate fluids in the ventilator circuits	Medium (3.43)	Medium (3.14)	.279
Removal of the ventilator circuits after use	Medium (2.86)	Good (4.33)	<.000*
Total satisfaction	Medium (3.12)	Good (3.83)	.002*

*Statistically significant

DISCUSSION

The findings indicated that use of non-disposable versus disposable ventilator circuits had no effect on VAP incidence. This was consistent with a study conducted by Srisan among pediatric children.[14] Furthermore, another study found the bacterial contamination of used ventilator circuits to not be correlated with VAP incidence.[13,15] The findings support the evidence-based practice whereby ventilator circuits should not be frequently replaced without appropriate indicators.[16]

The VAP incidence rates in the group using non-disposable ventilator circuits and the group using disposable ventilator circuits were 10.68 and 10.19 per 1,000 ventilator days, respectively. This finding corresponded with the mean VAP incidence rate of the RCU in 2018, which was 10 per 1,000 ventilator days.[8] The findings from this study are also consistent with the findings of most previous studies, which found hospitalization expenses and antibiotic expenses in patients who had VAP to be higher than in patients without VAP.[17,18] Therefore, finding preventive measures is important. VAP prevention guidelines consist of the following three main guidelines: (1) guidelines for preventing and controlling hospital infections, such as providing instructions for staff on infection prevention, proper hand washing, and on the appropriate number of personnel; (2) guidelines for reducing bacterial growth, such as washing hands before contact with patients and keeping the environment clean, proper antibiotic use, the provision of proton-pump inhibitors based on necessity, oral cavity cleaning, In addition to reducing complications from mechanical ventilation, weaning from ventilators as soon as possible also reduces expenses in other areas[19]; and (3) guidelines for reducing aspiration, such as by positioning patients' heads to be at a 30–45 degree angle, controlling the intra-cuff pressure of ETT at 25–30 cmH_2O, suctioning saliva before suctioning in ETT, assessing the amount of gastric content, preventing condensate fluids from entering patients, and not changing the ventilator circuits more than every seven days.[9,12] Many institutions have developed guidelines from evidence-based practices and found the aforementioned practices to be able to reduce the incidence of VAP. The researcher's own agency implemented "guidelines for preventing ventilator-associated pneumonia in adults" from Siriraj Hospital or the WHAP-C Bundle in every patient who was on a ventilator. The guidelines covered the topics: (1) weaning patients off ventilators; (2) hygienic hand washing; (3) aspiration precautions; (4) contamination prevention; and (5) chest physiotherapy. Furthermore, discipline was constantly monitored in terms of compliance with the guidelines. Thus, both the study groups in the present research received care under the same standards. However, because VAP occurs due to multiple causes, including external and personal factors, including accuracy and consistency of compliance with preventive guidelines, VAP remains a major problem requiring further study and correction.[20-22]

According to the present study, the use of disposable ventilator circuits may be unable to reduce VAP incidence and the costs were higher than for non-disposable ventilator circuits. Therefore, in changing from using non-disposable ventilator circuits to using disposable ventilator circuits, treatment agencies must consider cost-efficiency in every area. In the present study, the job descriptions of the assistant nurses included preparing ventilators. From monitoring the work unit personnel, it was found that the ventilator preparation process took 3–4 h. In addition to the risk of personnel infection from contaminated ventilator circuits, during this time, the work unit lost one nurse assistant who provided care for patients. This was evident in the findings reflecting the opinions of the nurse assistants, all of whom approved changing to disposable ventilator circuits. Furthermore, most nursing personnel and nurse assistants were more satisfied with working with disposable ventilator circuits than non-disposable ventilator circuits, with statistical significance, except on the question of flexibility during nursing care and the issue of condensate fluids remaining in the circuits, which were not statistically significantly different. This can be explained by understanding that even though the disposable dual heated-wire circuits had properties that reduced the fluids remaining in the circuits, poor temperature control in patient wards and the nurses connecting unheated flexible lines from the Y-piece of the ventilators before connecting to the ventilator tubes for convenience when working with patients who had a tracheostomy or were in a prone position caused the temperature control efficiency to be poor, leading to more condensate fluids remaining in the circuits. Moreover, the type of circuit used by our patients had no water trap, causing difficulties in pouring water from the ventilator circuit and inflexibility during nursing care, which represented disadvantages of the circuits and change recommendations from the main personnel. However, disposable ventilator circuits are widely used in developed countries and private hospitals due to their convenience, reduced likelihood of infection among personnel, and higher cost tolerance, such as for higher personnel wages, when compared with developing countries or state-owned hospitals.[14] However, recently, Siriraj Hospital started to use disposable ventilator circuits with COVID-19 patients to prevent personnel infections. Many different types of disposable ventilator circuits are available with differences in terms of the price and their properties. The circuits used in the present study were disposable dual heated-wire circuits with the ability to control temperature, provide humidity during inhalation and exhalation, prevent secretion obstructions and condensate fluids collecting in the circuits. However, according to the present study, the average cost of the disposable ventilator circuits used in the study was higher than for the non-disposable ventilator circuits. Changing to other less expensive ventilator circuits with similar properties would reduce the costs of disposable ventilator circuits, which would benefit reducing the work unit's costs without having a negative effect on patients while preventing infections among personnel during ventilator circuit preparation. The RCU of Siriraj Hospital recently changed to the use of disposable dual heated-wire ventilator circuits under the decision of the work unit's leader, who recognizes the benefits, including the cost-efficiency and prevention of infection among personnel, e.g., during the COVID-19 pandemic. However, the work unit is currently procuring disposable ventilator circuits of other types at lower prices with similar efficiency as replacements to achieve higher cost-efficiency in the future.

CONCLUSION

Using non-disposable versus disposable ventilator circuits had no effects on VAP incidence. Although non-disposable ventilator circuits had lower costs than disposable ventilator circuits, most our work unit personnel were more satisfied with disposable circuits than non-disposable circuits.

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