Original Article
Mechanical cleaning of ventilator pipe reduces ventilator-associated pneumonia compared with manual immersion disinfection

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Abstract: Objective: To investigate the effects of mechanical cleaning or manual immersion disinfection of ventilator pipe cleaning on ventilator-associated pneumonia (VAP). Methods: 140 patients who received mechanical ventilation (MV) in the intensive care unit (ICU) were divided into groups A and B, with 70 in each group. Group A received mechanical cleaning disinfection, whereas group B received manual immersion disinfection. Bacterial culture and adenosine triphosphate (ATP) were detected in the eluate of the breathing tube wall in the study and control groups. The incidences of VAP within 2 weeks of group A and group B who received mechanical ventilation (MV) were compared. The qualified rate of respiratory tube cleaning, hospitalization time, blood laboratory indicators, and sputum culture results before and after respiratory tube cleaning were also observed in group A and group B. Results: The qualified rates by bacterial culture and ATP test were significantly higher for the study group than that for the control group (P < 0.05). Hospital stay in group A was significantly shorter than that in group B (P < 0.05). white blood cell count, neutrophil ratio, and mononuclear cell ratio in group A were significantly lower than those in group B (P < 0.05). After use, the sputum culture positivity rate after breathing tube cleaning disinfection was significantly lower in group A than that in group B (P < 0.05). The incidence of VAP was significantly lower in group A than that in group B (P < 0.05). Conclusion: Compared with manual immersion disinfection, mechanical cleaning disinfection reduced the pollution rate of the breathing pipe, controlled the quality of cleaning and disinfection, and improved the ventilator pipeline cleaning pass rate.

Keywords: Mechanical cleaning disinfecting, manual immersion disinfection, ventilator pipe cleaning, associated pneumonia, mechanical ventilation

Introduction

Mechanical ventilation (MV) is an important rescue method for respiratory failure in critically ill patients. With the extension of ventilation time, patients often develop ventilator-associated pneumonia (VAP) after receiving MV therapy. VAP is an important nosocomial infection and one of the most common complications of MV ventilation [1, 2]. Studies have shown that the incidence of VAP can reach 10% to 20% in patients receiving MV therapy for > 48 h [3]. The occurrence of VAP not only increases medical costs, but also affects the patient's physical rehabilitation [4]. With the widespread use of ventilators, the incidence of VAP has increased year after year, which has become a difficult and hot topic in clinical work [5].

The pathogenic factors of VAP are more complicated, including invasive examination, long-term bed confinement, and improper use of antibiotics in the clinic, which result in low immune function and other factors [6]. Bacterial contamination of the ventilator pipe is an important exogenous cause of VAP [7]. In addition to the improper use of the ventilator, uncompleted cleaning and disinfection of the ventilator pipe is an important cause of bacterial contamination [8]. If the ventilator is not completely sterilized, bacteria can multiply in the wet and warm environment of the pipe and invade the patient's respiratory tract by breathing and positive pressure ventilation, eventually causing VAP [9]. VAP

is an important cause of prolonged use of ventilators, prolonged hospital stay, increased medical costs, and increased complications and mortality in critically ill patients [10]. Therefore, control of the quality of ventilator pipe cleaning and disinfection is of great significance to prevention of VAP.

From the perspective of the disinfection supply center, cleaning and disinfection of the ventilator pipe is completed by the disinfection supply center, and the ventilator pipe cleaned using the mechanical cleaning and manual immersion disinfection methods is applied to patients in the clinical intensive care unit (ICU). This study compared the effects of the two disinfection methods on the incidence of VAP to improve efficiency of the disinfection supply center and reduce the probability of VAP after ventilator application.

Materials and methods

General data

140 sets of ventilator pipes were collected from the disinfection supply center and divided into two groups (70 sets in each). The study group was treated with mechanical cleaning disinfection, and the control group was treated with manual immersion disinfection. The ventilator pipes were reclaimed from the respective ICUs. Each set included a water collector, 1 Y-joint, and 6 breathing pipelines. The 140 patients who were receiving MV in the ICU were divided into groups A and B, with 70 cases in each group. In group A, the breathing tubes and accessories of the study group were used, and in group B, those of the control group were used. Group A included 47 men and 23 women, aged 21-66 years (mean ± SD, 41.63 ± 12.67 years). Group B included 42 men and 28 women, aged 24 65 years (mean ± SD, 42.63 ± 11.25 years).

Inclusion and exclusion criteria

Inclusion criteria were patients who had undergone a major surgery and those who were expected to receive MV for ≥2 days. This study was approved by the ethics committee of the hospital. The subjects and family members were identified and signed a full informed consent form. Exclusion criteria were patients with severe lung disease, pre-operative pneumonia, pneumonia prior to mechanical ventilation and those developing pneumonia within 48 h [11]; patients with severe liver, kidney, and hematopoietic dysfunctions; postoperative patients with cachexia tumor; patients with mental illness or family history of mental illness; and patients with ventilator leaks or improper use of ventilators.

Cleaning scheme

The disassembly, recovery, packaging, and delivery of the breathing tubes and accessories were completed by the professional staff arranged by the ICU staff. After being sent to the disinfection supply center, the breathing tubes and accessories were registered, double-checked, and counted in the ward. The mechanical cleaning disinfection method was adopted as the study treatment. The specific method was as follows: The ventilator pipe was disassembled to its minimized form, and visible dirt was initially washed with running water. Then, the pipe was installed in accordance with the thickness and length of each component to the corresponding mechanical cleaning interface of the cleaning machine. The pipeline program for automatic disinfection and pipeline program settings were selected as follows: pre-rinse with cold water for 150 s, set the main wash program water temperature to 40°C, wash with 1:100 alkaline multi-enzyme solution for 350 s, rinse once or twice with pure water for 350 s, sterilize at 93°C with pure water, apply wet heat disinfection for 350 s, and dry at 90°C for 2,000 s. The cleaning process took about 1 h. The manual immersion disinfection method was treated as the control group. The specific method was as follows: The ventilator pipe was disassembled to its minimized form, and visible and inner wall dirt was initially washed with running water. Then, the pipe was soaked with 1:100 alkaline multi-enzyme solution for 20 min, rinsed with flow water, immersed and disinfected for 30 min with 500-mg/L chlorine disinfectant, rinsed with pure water, and air dried. The process took 1.5 to 3.0 days. After disinfection with mechanical cleaning and manual immersion, the ventilator pipes and fittings were placed in a sterilized sealed bag after drying; affixed with corresponding labels, signatures, and marks; placed in a sealed box; and sent to the ICU by professional staff.

Table 1. Baseline data for groups A and B [n(%)]/($\bar{x} \pm$ sd)

Category	Group A (n = 70)	Group B (n = 70)	t/χ^2	P
Gender			0.771	0.483
Male	47 (67.14)	42 (60.00)		
Female	23 (32.86)	28 (40.00)		
Age	41.63 ± 12.67	42.63 ± 11.25	0.493	0.622
Glu (mmol/L)	5.81 ± 0.79	5.73 ± 0.91	0.555	0.579
ALT (U/L)	59.56 ± 11.53	61.63 ± 12.63	1.013	0.313
AST (U/L)	18.63 ± 6.58	19.25 ± 7.26	0.529	0.597
APACHEII score (points)	14.13 ± 3.58	13.82 ± 3.15	0.543	0.587
Body weight (kg)	62.58 ± 11.63	63.58 ± 11.58	0.509	0.611
Basic diseases and treatment methods			1.626	0.897
Chronic bronchitis	17 (24.29)	15 (21.43)		
Cerebrovascular disease	19 (27.14)	23 (32.86)		
Serious trauma	13 (18.57)	16 (22.86)		
Severe pancreatitis	4 (5.71)	3 (4.29)		
After CPR	8 (11.43)	7 (10.00)		
After surgery	9 (12.86)	6 (8.57)		
Tracheotomy			0.622	0.431
Yes	19 (27.14)	15 (21.43)		
No	51 (72.86)	55 (78.57)		
Operation time (min)	58.72 ± 6.91	60.15 ± 7.13	0.230	1.205
Intraoperative blood loss (mL)	197.13 ± 41.15	201.46 ± 55.94	0.603	0.522
Application of acid suppressant			0.471	0.493
Yes	31 (44.29)	27 (38.57)		
No	39 (55.71)	43 (61.43)		

Sample collection and culture

On the 1st to 7th day after the patient was applied to the ventilator, the eluates from the ventilator inner wall of the ventilator was taken daily for cell culture and the rate of disinfection was examined. In the breathing tube wall culture method, 50 mL of physiological saline was used to continuously wash the inner wall of the breathing tube [6]. After the elution, the tube was washed again, mixing the solution thoroughly, and 10 mL of saline solution was placed into the sterile tube and centrifuged at 2000 r/min for 20 min. The liquid supernatant was discarded and then mixed thoroughly. A 0.5-mL sediment sample was collected and poured into a blood agar plate. The specimen was spread evenly and placed in a 35°C bacterial incubator for 48 h for counting of viable bacteria. Qualification disinfection: The total number of colonies was < 20 cfu/piece, without pathogenic bacteria, and the rest were unqualified. An adenosine triphosphate (ATP) detector was used to determine the qualification rate of the

eluent, which reads < 50 RLU as qualified. On the 1st, 3rd, and 6th day of the ventilator, the patient's lower respiratory secretions were taken for bacterial culture. Collection method for the lower respiratory tract: If the ventilator had not been removed, specimens should be collected by a specialized medical staff directly through the catheter. If the ventilator was removed, the patient was asked to gargle with a boric acid solution, naturally cough in deeply, and spit into a sterile jar, with its lid closed thereafter. Bacterial culture of lower respiratory tract secretions: The samples were sent to the laboratory within 2 h after collection. Samples were routinely inoculated on Chinese blue agar plates, chocolate-colored blood agar plates, blood agar plates, and sand-protected agar plates, and then incubated in a 35°C bacterial incubator for 48 h [12].

Diagnostic criteria and evaluation methods

We mainly observed the incidence of VAP within two weeks in group A and group B who received

Table 2. Comparison of the cleaning effect between the study group and the control group

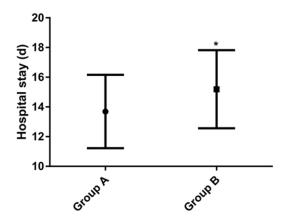| Category	Study Group (number = 480)	Control group (pieces = 480)	χ^2	P
Bacterial culture monitoring				
Qualified pieces	470	452	8.878	0.004
Pass rate (%)	97.92	94.17		
ATP monitoring				
Qualified pieces	478	464	11.097	0.001
Pass rate (%)	99.58	96.67		

Figure 1. Comparison of length of hospital stay between groups A and B. *P < 0.05, compared with group A.

mechanical ventilation. The VAP diagnostic criteria included the following factors: The ventilator was removed after 48 h of use [13]. Chest radiography revealed cough, sputum, and obvious effusion within 48 h after the removal. The body temperature was > 37.5°C. The lungs showed wet rales, and white blood cell count increased. Etiological cultures of the lower respiratory tract secretions were positive. Hospitalization time, blood laboratory parameters, and sputum culture results before and after breathing tube cleaning were observed in groups A and B for 2 weeks.

Statistical methods

SPSS20.0 (Beijing Strong-Vinda Information Technology Co., Ltd.) was used for statistical analysis. Measurement data are expressed as mean ± standard deviation ($\bar{x}$ ± SD). Count data is represented by [n (%)]. The independent *t* test was used to compare measurement data between the groups. The chi-square test was used to compare enumeration data between the groups. When *P* value was < 0.05, the dif-

ference was considered statistically significant.

Results

Baseline data in groups A and B

No statistically significant differences in clinical baseline data such as sex, age, blood glucose (Glu) level, alanine aminotransferase (ALT) level, aspartate aminotransferase (AST) level, APACHE II score, body weight, underlying disease, and treatment methods were found between groups A and B (all P > 0.05; **Table 1**).
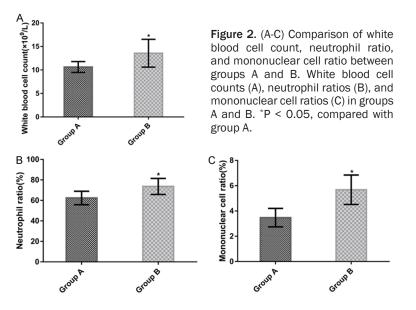
Cleaning effect in the study and control groups

The results of bacterial culture showed that after cleaning and disinfection, 470 (97.92%) and 452 pipes (94.17%) were qualified in the study and control groups, respectively. The qualification rate by bacterial culture after cleaning and disinfection was significantly higher for the study group than for the control group (χ^2 = 8.878, P = 0.004). The ATP test results showed that 478 (99.58%) and 464 pipes (96.67%) were qualified after cleaning and disinfection in the study and control groups, respectively. The qualification rate in the ATP test after cleaning and disinfection was significantly higher for the study group than for the control group (χ^2 = 11.097, P = 0.001; **Table 2**).

Hospital stay in groups A and B

Hospital stay was 13.69 ± 1.58 days in group A and 15.58 ± 2.69) days in group B. Hospital stay in group A was significantly shorter than that in group B (*t* = 3.478, P = 0.001; **Figure 1**).

Blood laboratory indicators in groups A and B

White blood cell count, neutrophil ratio, and monocyte ratio were respectively 10.63 ± 1.16 × 10^9/L, 62.37% ± 6.58%, and 3.47% ± 0.73% in group A and 13.56 ± 2.96 × 10^9/L, 73.63% ± 7.83%, and 5.68% ± 1.16% in group B. White blood cell count, neutrophil ratio, and monocyte ratio in group A were significantly lower than those in group B (*t* = 7.711, P = 0.001; *t* = 3.478, P = 0.001; *t* = 3.478, P = 0.001; **Figure 2A-C**).

Figure 2. (A-C) Comparison of white blood cell count, neutrophil ratio, and mononuclear cell ratio between groups A and B. White blood cell counts (A), neutrophil ratios (B), and mononuclear cell ratios (C) in groups A and B. *$P < 0.05$, compared with group A.

Table 3. Comparison of sputum culture results before and after cleaning and disinfection between groups A and B

Category	Group A (n = 70)	Group B (n = 70)	χ^2	P
Before use				
Positive number of cases	1	3	1.029	0.620
Positive rate (%)	1.43	4.29		
After use				
Positive number of cases	4	13	5.423	0.036
Positive rate (%)	5.71	18.57		

Table 4. Comparison of VAP incidence between Groups A and B [n(%)]

Groups	n	VAP	
		Occur	Yet to happen
Group A	70	9 (12.86)	61 (87.14)
Group B	70	20 (28.57)	50 (71.43)
χ^2	5.236	-	-
P	0.036		

Sputum culture results before and after use, and after breathing tube cleaning in groups A and B

In group A, before use and after breathing tube cleaning and disinfection, the sputum culture result was positive in 1 case (1.43%); after use, it was positive in 4 cases (5.71%). In group B, the sputum culture result was positive in 3 cases (4.29%) before use and after breathing tube cleaning and disinfection, and in 13 cases (18.57%) after use. No significant differences in the positivity rates of the sputum culture before use and after cleaning and disinfection of the breathing tube were found between groups A and B ($\chi^2 = 1.029$, P = 0.620). After use, the sputum culture positivity rate after cleaning and disinfection was significantly lower in group A than in group B ($\chi^2 = 5.423$, P = 0.036; Table 3).

Incidence of VAP in groups A and B

In group A, VAP occurred in 9 (12.86%) but not in 61 patients (87.14%). In group B, VAP occurred in 20 (28.57%) but not in 50 patients (71.43%). The incidence of VAP in group A was significantly lower than that in group B ($t = 5.263$, P = 0.036; Table 4).

Discussion

MV is one of the most commonly used rescue methods for respiratory dysfunction in critically ill patients. It can effectively maintain blood oxygen saturation and prevent acidosis and hypoxemia caused by decreased respiratory function [14]. However, prolonged ventilator use makes the patient susceptible to bacterial contamination that causes VAP, which aggravates the condition and affects prognosis of the patient [15]. VAP is a serious nosocomial infection in critically ill patients. The pathogens are mostly multidrug resistant bacteria, which are closely related to ventilator tube contamination, pathogen resistance, disease, and age, and bacterial contamination in the ventilator pipe is an important exogenous causative factor of VAP [16]. Therefore, choosing a ventilator pipe that has been properly cleaned and disinfected is of great significance to prevent the occurrence of VAP.

The ventilator pipeline can be sterilized with a chlorine-containing disinfectant to achieve acceptable levels, but it may be contaminated with pathogenic microorganisms during pro-

longed drying [17]. Natural drying of the ventilator pipeline requires 1 to 2 days for vertical drying in dry seasons and 3 to 4 days for complete drying in the wet seasons. Natural exposure of the ventilator pipeline to air for more than 1 day allows bacterial growth and contamination [18]. As chlorine-containing disinfectants have a chemical composition, when used as soaking agent for too long, the ventilator tubes will age and their service life will be shortened [19]. Chlorine-containing disinfectants are prone to pollute the environment. Inhaling the odor components of the disinfectant for a long period will bring damage to the body of workers. The ventilator pipeline is susceptible to human factors, and the quality of cleaning and disinfection is difficult to guarantee [20]. Mechanical cleaning and disinfection are controlled by the internal program of the machine and can be adjusted according to the type of articles to be cleaned and disinfected, without being affected by human factors. Centralized use of mechanical cleaning and disinfection for the ventilator pipeline can improve quality of cleaning, facilitate quality control, and reduce damage to workers and environmental pollution [21]. The results of this study show that after cleaning and disinfection, the bacterial culture and ATP test qualification rates of the study group were significantly higher than those of the control group, which suggests that compared with manual immersion disinfection, mechanical cleaning disinfection can reduce the pollution probability of the ventilator tubes and accessories, improve the qualification rate, and enhance the quality of work, similar to findings of the study by Gurevich et al. [22]. The use of mechanical cleaning and disinfection for ventilator tubes can improve the qualification rate of disinfection and reduce the number of colonies in the tube.

Studies have shown that ventilator tubes in ventilator devices are more susceptible to being infected by pathogenic microorganisms, and bacterial contamination of ventilator tubes is an important inducing factor of VAP [23]. The ventilator humidification device and threaded tube are connected to the patient's mouth and nose with a closed cycle. The exudates and bacteria in the body during exhalation can contaminate the ventilator pipeline [24]. The humidified and heated air in the ventilator tube can form a moist, warm, and airtight environment, and can form condensed water under the interaction with the cold air outside the tube, providing an environment for the bacteria to multiply [25]. Bacteria in the ventilator pipeline can form aerosols with inhaled gases, enter the respiratory tract, and cause repeated lung infections, inducing an inflammatory reaction to the patient's body. It often requires further anti-infective treatment, which prolongs hospital stay and increase the treatment costs of the patient [26]. Joseph et al. reported that exogenously contaminated respiratory devices increase the incidence of VAP [27]. The results of this study show that length of hospital stay, peripheral white blood cell count, neutrophil ratio, and the mononuclear cell ratio in group A were significantly lower than those in group B. After use, the sputum culture positivity rate after cleaning and disinfection of the breathing tube was significantly lower in group A than in group B. The incidence of VAP in group A was significantly lower than that in group B. The results suggest that mechanical cleaning disinfection can effectively control the quality of cleaning and disinfection by cleaning the breathing pipeline. This method can be applied after cleaning and disinfecting the breathing tube, which can effectively reduce the incidence of VAP.

In this study, subjects were screened strictly in accordance with the inclusion and exclusion criteria. No significant differences in sex, age, Glu level, ALT level, AST level, APACHE II score, body weight, underlying disease, and treatment methods were found between groups A and B, which ensured the rigor and reliability of the study. VAP has many pathogenic factors, and its pathogenesis is complex. Fewer cases of VAP occurred in the study group. Therefore, the specific pathogenesis of VAP was not discussed, and this study has some limitations. VAP is a common nosocomial infection associated with ventilated patients. The mortality associated with VAP is also high. The associated organisms and their resistance patterns vary with the different patient groups and hospital settings. Since the diagnostic method available for VAP is not universal, a proper infection control policy with appropriate antibiotic usage can reduce the mortality among ventilated patients. In the future research, more research subjects should be included to discuss the pathogenesis of VAP.

In summary, compared with manual immersion disinfection, mechanical cleaning disinfection reduced the risk of contamination of the breathing pipeline, controlled the quality of the cleaning and disinfection, improved the ventilator line cleaning pass rate. Use of breathing pipelines that have been cleaned and disinfected by mechanical cleaning disinfection can effectively reduce the incidence of VAP.

Disclosure of conflict of interest

None.

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