Effectiveness of Bacterial Disinfectants on Surfaces of Mechanical Ventilator Systems

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BACKGROUND: Pathogens in healthcare settings can be transmitted via skin contact and environmental media. This study investigates bacterial contamination rate on surfaces of mechanical ventilator systems and bedside equipment. An experimental study evaluates the effectiveness of 75% alcohol in killing bacteria on surfaces. METHODS: Surface swab sampling was conducted on ventilator systems and patient bedside equipment for detection of bacterial contamination. Surfaces of ventilator systems, such as faceplates, Y-pieces, and water traps, were swab sampled at 0.5, 8, and 24 hours after initial disinfection using a solution containing 0.5% sodium hypochlorite and pasteurization. The 75% alcohol aerosol was sprayed on the surfaces of faceplates, Y-pieces, and water traps on ventilator systems at 24 hours after initial disinfection, and then bacterial levels on the surfaces were evaluated. RESULTS: Detection rates of *Staphylococcus aureus* were measured on the handrails of mechanical ventilators (64.7%), Y-pieces of breathing circuits (86.7%), and resuscitators (60.0%). *Pseudomonas aeruginosa* was identified on the surfaces of Y-pieces (6.7%) and water traps (13.3%) of breathing circuits, and also on suction systems (6.7%) and resuscitators (13.3%). The positive rate for total bacterial count was clearly increased on the surfaces of faceplates, Y-pieces, and water traps at 8 hour following disinfection by 0.5% sodium hypochlorite solution and pasteurization. Concentrations of *S. aureus* on surfaces decreased following treatment with 75% alcohol. However, considerable *P. aeruginosa* growth on water trap surfaces was observed after treatment with 75% alcohol. CONCLUSIONS: The surfaces of ventilator systems, including faceplates, Y-pieces, and water traps, must be disinfected frequently (at least every 8 h) to control bacterial growth. Disinfection using 75% alcohol spray with air drying effectively decreased *S. aureus* on ventilator system surfaces. *Key words: mechanical ventilator system; breathing circuit; disinfectant effectiveness; bacterial contamination; surface swab sampling.* [Respir Care 2012; 57(2):250–256.

Introduction

Pathogens in hospitals can be transmitted via skin contact, particularly involving the hands[1–3] and environmental media. Medical personnel thus should observe good personal hygiene (including frequent and correct handwashing,[4] as well as glove-changing[5,6]) and environmental health practices (including cleaning the surfaces of medical instruments and equipment[7]) to maximize patient safety and care quality.[8,9] A previous study demonstrated that only 40% of medical workers maintained proper hand hygiene.[2,7] Appropriate use of paper for drying hands after washing is also important in minimizing hand contamination.[4,10]

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The authors have disclosed no conflicts of interest.

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DOI: 10.4187/respcare.01180

Bloodstream infection and ventilator-associated pneumonia are associated with device contamination (for example involving central venous catheters, urinary catheters, and ventilators) in intensive care units.[11] An association was identified between increased numbers of bacterial colonies on environmental surfaces and unfamiliarity with work environments or infection control strategies.[12] In hospitals, pathogenic microorganisms survive and grow on polluted environmental surfaces,[13–15] including faucet handles, computer keyboards,[16] and medical charts.[17] Besides these surfaces, sinks, commodes, bedside tables, toilet handrails, bedrails, telephones, and door knobs are high-risk objects in healthcare settings.[18]

Microorganisms that grow on environmental surfaces include bacteria, such as *Actinobacillus actinomycetemcomitans*, *Bacteroides fragilis*, *Clostridium difficile*, *Escherichia coli*, *Mycobacterium smegmatis*, *Prevotella intermedia*, *Pseudomonas aeruginosa*, *Salmonella thyphimurium*, *Staphylococcus aureus*, *Streptococcus mutans*,[19] methicillin-resistant *S. aureus* and vancomycin-resistant *Enterococcus*,[20] and viruses, such as noroviruses.[21]

Environmental surfaces can be disinfected with solutions of 70% ethyl alcohol, 1% hypochlorite, 0.2% peracetic acid, and 2.4% glutaraldehyde to inhibit microorganism transmission and growth.[19,22] To our knowledge, no previous study has evaluated bacterial contamination rates on surfaces of mechanical ventilator systems, or the effectiveness of bacterial disinfectants (0.5% sodium hypochlorite solution) and pasteurization on surfaces of mechanical ventilators. This study used swab sampling at a respiratory care center within a medical center in Taipei City to investigate bacterial contamination rates, for example for *S. aureus* and *P. aeruginosa*, on surfaces of mechanical ventilator systems, including Y-pieces and water traps of breathing circuits, and of bedside equipment such as buttons on bedrails and monitors, suction systems, and resuscitators. This experimental study also evaluated the effectiveness of 75% alcohol in killing *S. aureus* and *P. aeruginosa* on the surfaces of mechanical ventilator systems (such as faceplates, Y-pieces, and water traps of breathing circuits) at the same respiratory care center.

QUICK LOOK

Current knowledge

Surfaces of equipment and furniture in patient rooms harbor pathogenic organisms that can be transmitted via skin contact.

What this paper contributes to our knowledge

The surfaces of ventilators and ventilator circuits are commonly colonized with pathogenic bacteria, including *Staphylococcus aureus*. Disinfection of these surfaces with an alcohol spray and air drying 3 times a day decreases colonization.

Methods

Study Location

This study selected a 15-bed respiratory care center at Mackay Memorial Hospital in Taipei City as the sampling location. The study protocol was approved by the institutional review board of the hospital. All sampled patients were intubated on either endotracheal tube or tracheostomy tube in the respiratory care center. All patients in the respiratory care center were stable but could not be disconnected from mechanical ventilators. The respiratory care center was accessible 24/7 to relatives.

The surfaces and breathing circuits of ventilators were disinfected with 0.5% sodium hypochlorite and pasteurization, respectively, when patients were discharged or expired. The breathing circuits of ventilator systems were changed at 2 weekly intervals during use.

Survey of Environmental Surface Contamination

Surface swab sampling was conducted on 17 in-use mechanical ventilators (Servo-i, Siemens, Maquet Critical Care, Solna, Sweden, and Raphael, Hamilton Medical, Raphael Silver, Switzerland) (including faceplates, silence buttons, shuttle buttons, ventilator plates, and handrails), 15 breathing circuits (including Y-pieces and water traps) and 4 kinds of beside equipment (including bedrail buttons, monitor buttons, suction systems, and resuscitators) in the respiratory care center (Fig. 1). All the surface samples were collected during 2 weeks after changing the breathing circuits. Sterile Bacon swabs moistened with 1 mL sterile distilled water were used for environmental surface sampling. The sampling area was 5×5 cm^2 for each sampling site.

Assessment of the Effectiveness of 75% Alcohol in Sterilizing the Ventilator System Surfaces

Nine ventilators were selected and randomly assigned to 3 study groups to evaluate the effectiveness of 75% alcohol in decreasing bacterial counts on the environmental surfaces. The study groups were as follows: control group: no alcohol intervention (no. = 3); experimental group 1 (E1): 75% alcohol aerosol with air drying (no. = 3); and, experimental group 2 (E2): 75% alcohol with tissue drying (no. = 3). To ensure the effectiveness of 75% alcohol in killing *S. aureus* and *P. aeruginosa* on surfaces, this study

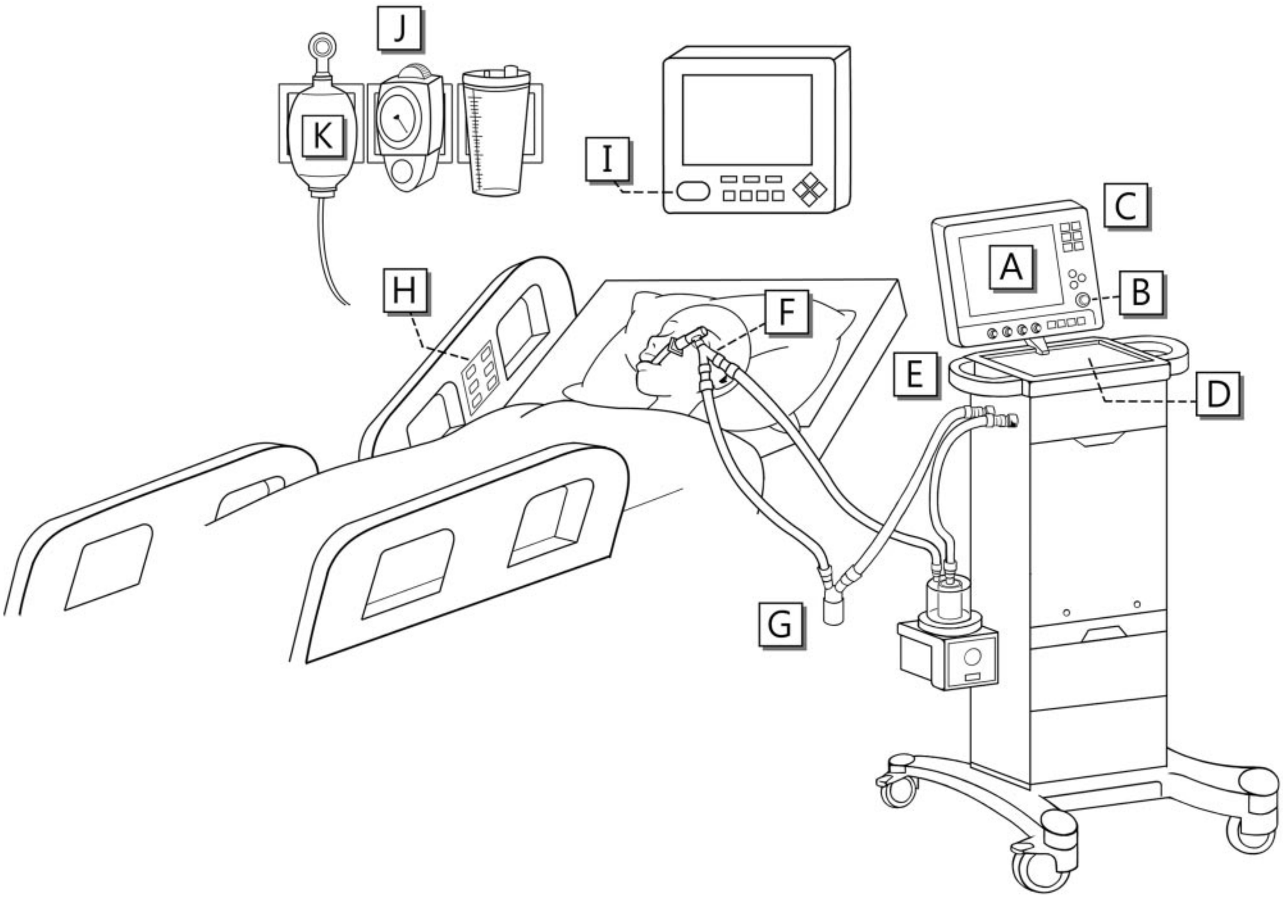

Fig. 1. Diagram of surface swab sampling points. A: faceplate, (B) shuttle button, (C) silence button, (D) ventilator plate, (E) handrail, (F) Y-piece, (G) water trap, (H) bedrail buttons, (I) monitor buttons, (J) suction system switch, (K) resuscitator.

selected 3 sampling points, including ventilator faceplates, Y-pieces, and water traps on breathing circuits, based on the results of previous ventilator surveys showing higher bacterial contamination rates in these areas.

Ventilator faceplates were first disinfected with 0.5% sodium hypochlorite, while Y pieces-and water traps of breathing circuits were pasteurized before patient use. Swab sampling was performed at 0.5, 8, and 24 hours following initial disinfection of ventilator system surfaces. The 75% alcohol aerosol was applied after swab sampling at 24 hours, and bacterial growth on the surfaces was assessed at 0.5, 8, and 24 hours following intervention in the form of disinfection with 75% alcohol (Fig. 2).

Bacterial Culture and Analysis

The solution extracted from the sampling swabs was cultured on different agar plates for total bacteria, *S. aureus*, and *P. aeruginosa* analysis, respectively. All agar plates were incubated at 30°C for 1–2 days. The bacterial concentration was expressed in terms of colony forming units (CFU) on surfaces.

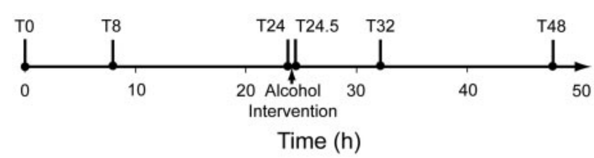

Fig. 2. Timing of swab sampling on the ventilator system surfaces. At time zero (T0) the surfaces were disinfected with 0.5% sodium hypochlorite or pasteurization. At 24 hours (T24) the surfaces were disinfected with 75% alcohol. Swab samples were taken at T0, T8, T24, T24.5, T32, and T48.

Data Analysis

SPSS version 13.0 (SPSS, Chicago, Illinois) was used for the statistical analyses. The level of significance was set to $P < .05$. The chi-square test was used to assess the association between the detection rates and sampling points/sampling time points/intervention strategy using 75% alcohol. The nonparametric Wilcoxon rank sum test was used to compare bacterial concentrations among the different sampling time points and study groups. For purposes of analysis, 500 CFU/mL was set as the level of important bacterial contamination.

Table 1. Detection Rates of Total Bacteria, *Staphylococcus aureus*, and *Pseudomonas aeruginosa* on the Surfaces of Mechanical Ventilator Systems and Bedside Equipment

Sampling Point	no.	Total Bacteria			*Staphylococcus aureus*			*Pseudomonas aeruginosa*		
		Rate (%)	Median (range)	P*	Rate (%)	Median (range)	P*	Rate (%)	Median (range)	P*
Mechanical Ventilators				.38			.87			NA
Faceplates	17	94.1	122 (0–500)		56.3	2 (0–500)		0	0 (0–0)	
Silence buttons	17	88.2	8 (0–500)		56.3	2 (0–86)		0	0 (0–0)	
Shuttle buttons	17	88.2	8 (0–500)		47.1	0 (0–156)		0	0 (0–0)	
Ventilator plates	17	70.6	32 (0–500)		52.9	2 (0–26)		0	0 (0–0)	
Handrails	17	82.4	22 (0–500)		64.7	2 (0–290)		0	0 (0–0)	
Breathing Circuits				NA			.02			.54
Y-pieces	15	100	500 (24–500)		86.7	6 (0–500)		6.7	0 (0–500)	
Water traps	15	100	500 (22–500)		46.7	0 (0–500)		13.3	0 (0–500)	
Bedside Equipment				.28			.54			.28
Bedrail buttons	15	86.7	12 (0–500)		46.7	0 (0–12)		0	0 (0–0)	
Monitor buttons	15	100	100 (2–500)		33.3	0 (0–56)		0	0 (0–0)	
Suction system switches	15	93.3	150 (0–500)		46.7	0 (0–500)		6.7	0 (0–500)	
Resuscitators	15	100	500 (16–500)		60.0	2 (0–500)		13.3	0 (0–210)	

* Chi-square test.

Results

Subject patients were on ventilators in the respiratory care center for 10–34 days (average, 19.75 d). Bacteria were detected at a 100% rate on Y-pieces and water traps of breathing circuits, bedside monitor buttons, and resuscitators (Table 1). Bacteria were detected at other swab sampling points on surfaces at rates of 70.6–94.1%. No significant differences in detection rates of total bacterial counts among sampling points were observed in the ventilators systems and bedside equipment. Higher positive rates of *S. aureus* were identified on handrails of mechanical ventilators (64.7%), Y-pieces in breathing circuits (86.7%), and resuscitators (60.0%). *S. aureus* was more prevalent on Y-pieces than on water traps ($P = .02$). Besides Y-pieces (6.7%) and water traps (13.3%) in breathing circuits, suction systems (6.7%), and resuscitators (13.3%) (bedside equipment), *P. aeruginosa* was not detected on other environmental surfaces. Detection rates of *P. aeruginosa* did not differ significantly among sampling points in the ventilator systems and bedside equipment.

The median bacterial level on the faceplate surfaces (122 CFU) exceeded that on the handrails (22 CFU) of ventilator systems (see Table 1). Total bacterial counts on the surfaces of Y-pieces and water traps in breathing circuits exceeded 500 CFU. Moreover, resuscitators had higher bacterial levels (median > 500 CFU) than suction systems (150 CFU) and monitor buttons (100 CFU). *S. aureus* was detected on all surfaces of ventilator systems and bedside equipment. Maximal counts (> 500 CFU) for *S. aureus* and *P. aeruginosa* occurred on surfaces of Y-pieces and water traps of ventilator systems and suction systems.

To estimate the effectiveness of initial disinfection with 0.5% sodium hypochlorite and pasteurization, this investigation selected 9 in-use mechanical ventilators for collecting surface samples from faceplates, Y-pieces, and water traps for bacterial analysis. Bacterial detection rates were 44.4% for ventilator faceplates at 0.5 hours after disinfection with 0.5% sodium hypochlorite, 55.6% for Y-pieces, and 66.7% for water traps in breathing circuits at 0.5 hours after pasteurization (Table 2). Considerable bacterial contamination (median > 500 CFU) existed on surfaces of Y-pieces at 8 hours after use. Significant bacterial growth was observed on surfaces of water traps at 24 hours after pasteurization. Total bacterial counts on the surfaces of faceplates ($P = .05$), Y-pieces ($P < .001$), and water traps ($P = .03$) in ventilator systems varied significantly with sampling time. The total bacterial concentrations measured at 8 hours (faceplates: $P = .012$; Y-pieces: $P = .007$; water traps: $P = .018$) and 24 hours (faceplates: $P = .033$; Y-pieces: $P = .008$; water traps: $P = .011$), respectively, significantly exceeded those measured at 0.5 hours following initial disinfection.

Detection rates for *S. aureus* on the surfaces of faceplates, Y-pieces, and water traps in ventilator systems were 11.1%, 66.7%, and 88.9%, respectively, at 0.5 hours after initial disinfection with a solution containing 0.5% sodium hypochlorite and pasteurization (see Table 2). No significant differences among different sampling time points were observed in the detection rates of *S. aureus* on the surfaces. Additionally, *P. aeruginosa* growth was not de-

Table 2. Comparison of Detection Rates and Bacterial Concentrations on the Ventilators' Surfaces Among Different Sampling Time Points

Sampling Time Point	no.	Total Bacteria			*Staphylococcus aureus*			*Pseudomonas aeruginosa*		
		Rate (%)	Median (range)	*P**	Rate (%)	Median (range)	*P**	Rate (%)	Median (range)	*P**
Faceplates				.05			.22			NA
$T_{0.5}$	9	44.4	0 (0–8)		11.1	0 (0–8)		0	0 (0–0)	
T_8	9	88.9	22 (0 to > 500)†		44.4	0 (0–26)		0	0 (0–0)	
T_{24}	9	88.9	12 (0–414)‡		44.4	0 (0–24)		0	0 (0–0)	
Y-pieces				< .001			.38			.31
$T_{0.5}$	9	55.6	2 (0–62)		66.7	2 (0–48)		0	0 (0–0)	
T_8	9	100	> 500 (24 to > 500)†		88.9	4 (0 to > 500)		22.2	0 (0 to > 500)	
T_{24}	9	100	> 500 (26 to > 500)‡		88.9	30 (0 to > 500)		22.2	0 (0–200)	
Water Traps				.03			.75			.15
$T_{0.5}$	9	66.7	6 (0 to > 500)		88.9	4 (0–130)		0	0 (0–0)	
T_8	9	100	68 (2 to > 500)†		88.9	12 (0 to > 500)		33.3	0 (0–14)	
T_{24}	9	100	> 500 (8 to > 500)‡		77.8	4 (0–64)		33.3	0 (0 to < 500)	

* Chi-square test.
† Comparison of bacterial concentrations between $T_{0.5}$ (0.5 hour after disinfection) and T_8 (8 hours after disinfection) on the surfaces of faceplates (P = .012), Y-pieces (P = .007), and water traps (P = .018) by Wilcoxon rank sum test.
‡ Comparison of bacterial concentrations between $T_{0.5}$ and T_{24} (24 hours after disinfection) on the surfaces of faceplates (P = .033), Y-pieces (P = .008), and water traps (P = .011) by Wilcoxon rank sum test.

Table 3. Comparison of Detection Rates and Bacterial Concentrations on the Ventilators' Surfaces Among Different Study Groups

Sampling Group	no.	Total Bacteria			*Staphylococcus aureus*			*Pseudomonas aeruginosa*		
		Rate (%)	Median (range)	*P**	Rate (%)	Median (range)	*P**	Rate (%)	Median (range)	*P**
Faceplates				.31			< .001			NA
Control group	9	100	36 (6 to > 500)		66.7	16 (0–140)		0	0 (0–0)	
E1 group	9	77.8	10 (0–168)		22.2	0 (0–12)†		0	0 (0–0)	
E2 group	9	77.8	12 (0 to > 500)		100.0	4 (2–24)‡		0	0 (0–0)	
Y-pieces				.35			.01			.38
Control group	9	100	> 500 (24 to > 500)		88.9	12 (0 to > 500)		11.1	0 (0–16)	
E1 group	9	88.9	146 (0 to > 500)		44.4	0 (0–104)†		11.1	0 (0 to > 500)	
E2 group	9	100	> 500 (10 to > 500)		100.0	20 (12 to > 500)‡		33.3	0 (0 to > 500)	
Water Traps				.35			.03			.03
Control group	9	100	> 500 (106 to > 500)		100.0	30 (2–380)		0	0 (0–0)	
E1 group	9	88.9	> 500 (0 to > 500)		44.4	0 (0–184)		55.6	24 (0 to > 500)†	
E2 group	9	100	> 500 (226 to > 500)		66.7	6 (0–66)		22.2	0 (0 to > 500)	

* Chi-square test.
† Comparison of bacterial concentrations between control group and experimental group 1 (E1 group) on the surfaces of faceplates (P = .05), Y-pieces (P = .03), and water traps (P = .04) by Wilcoxon rank sum test.
‡ Comparison of bacterial concentrations between E1 group and E2 group on the surfaces of faceplates (P = .05) and Y-pieces (P = .02) by Wilcoxon rank sum test.

tected on the surfaces at 0.5 hours after initial disinfection. The detection rates of *P. aeruginosa* on the ventilator faceplates were 0% at different sampling time points. However, *P. aeruginosa* was detected on the surfaces of Y-pieces and water traps at 8 hours and 24 hours after initial disinfection with pasteurization.

To estimate the effectiveness of treatment with 75% alcohol to decrease bacterial growth on the ventilator surfaces, this study selected 9 in-use mechanical ventilators for swab sampling. This study reported that 75% alcohol aerosol did not decrease total bacterial concentrations on the material surfaces (Table 3). Detection rates and concentrations for *S. aureus* on the surfaces of faceplates ($P < .001$) and Y-pieces ($P = .01$) in ventilator systems were significantly decreased after spraying with 75% alcohol. The concentrations of *S. aureus* on the surfaces of faceplates (4 CFU) and Y-pieces (20 CFU) in the E2 group were significantly higher than for the E1 group (faceplates:

0 CFU: $P = .05$; Y-pieces: 0 CFU, $P = .02$). Moreover, detection of *P. aeruginosa* clearly differed on the surfaces of water traps among study groups ($P = .03$). Concentrations of *P. aeruginosa* on the surfaces of water traps differed significantly between the E1 group (24 CFU) and the control group (0 CFU) ($P = .04$).

Discussion

This study detected bacteria, particularly *S. aureus*, on surfaces of mechanical ventilators (detection rates 47.1–64.7%). The surfaces of Y-pieces and water traps on breathing circuits tested positive for *S. aureus* (46.7–86.7%) and *P. aeruginosa* (6.7–13.3%). Furthermore, 33.3–60.0% of surfaces on bedside equipment tested positive for *S. aureus*, and 6.7–13.3% tested positive for *P. aeruginosa* (with the exceptions of buttons on bedrails and monitors). Thus, environmental contamination on ventilator system surfaces and bedside equipment requires closer attention from medical personnel in hospitals. The relationship between patient infection and contamination of environmental surfaces remains unknown and warrants further investigation.

Nosocomial infection is a global medical problem. Such infections can cause illness and death, contribute to increased hospitalization rates and treatment costs.[23] Patients in intensive care units frequently become infected via invasive therapy and open wounds.[17] In Taiwan, the predominant microbial species involved in nosocomial respiratory-tract infection in intensive care units are *S. aureus*, *Klebsiella pneumoniae*, *Stenotrophomonas maltophilia*, *P. aeruginosa*, and *Acinetobacter baumannii*, according to the Center for Disease Control and Prevention in Taiwan (http://www.cdc.gov.tw/ct.asp). Griffith et al found that *S. aureus* is common on skin, and identified a strong correlation between *S. aureus* contamination on environmental surfaces and skin.[24] A suitable disinfection strategy for caregiver hands, medical equipment, and environmental surfaces will help prevent microorganism transmission.[25]

The World Health Organization indicated that severe acute respiratory syndrome coronavirus was susceptible to both 10% sodium hypochlorite and 75% alcohol, and thus recommended that these be used to disinfect medical instrument surfaces (http://www.who.int/csr/sars). Barker et al demonstrated that 5,000 ppm sodium hypochlorite disinfectant eliminated surface norovirus contamination.[8] To our knowledge, to date no study has assessed the effectiveness of 0.5% sodium hypochlorite, pasteurization, and 75% alcohol in killing bacteria on the surfaces of mechanical ventilators. This study found that some sampling swabs were positive for *S. aureus* and other bacteria following initial disinfection with 0.5% sodium hypochlorite on ventilator faceplates and pasteurization of Y-pieces and water traps of breathing circuits, indicating that 0.5% sodium hypochlorite and pasteurization did not kill all *S. aureus* and other bacteria. Further investigations should be conducted with larger sample sizes to assess the effectiveness of various sodium hypochlorite concentrations and pasteurizations in killing bacteria on the surfaces of ventilator faceplates, Y-pieces, and water traps. Inspection of packing procedures for Y-pieces and water traps in breathing circuit systems is also essential. Moreover, large bacterial populations existed on the surfaces of Y-pieces at 8 hours and water traps at 24 hours after initial disinfection by pasteurization. Thus, periodically cleaning the surfaces of Y-pieces and water traps in breathing circuits during usage is important.

Conclusions

Disinfecting surfaces of faceplates and Y-pieces in ventilator systems with 75% alcohol decreased *S. aureus* levels. However, 75% alcohol did not significantly affect *S. aureus* concentrations on water trap surfaces. Likely reasons for this finding are that respiratory therapists did not wear gloves or thoroughly wash their hands before touching water traps, and water traps contacted the ground. This study thus suggests workers wash their hands before contacting water traps, and water traps be positioned a suitable distance from the ground. Additionally, levels of *S. aureus* on the material surfaces were higher in the E2 group than in the E1 group. This phenomenon possibly resulted from tissue papers being used to dry the surfaces after treatment with 75% alcohol spray. The tissue papers tested positive for bacteria (67%), including *S. aureus* (100%), but not *P. aeruginosa* (0%) (data not shown). One possible suggestion is to wipe 75% alcohol on material surfaces with sterile gauze rather than tissue paper, to reduce bacterial contamination.

Besides faceplates on ventilator systems, the positive rates of *P. aeruginosa* on the surfaces of Y-pieces and water traps increased at 8 hours and 24 hours following initial disinfection with pasteurization. Notably, this result demonstrated that 75% alcohol was ineffective in reducing *P. aeruginosa* concentrations on water trap surfaces in breathing circuits. Moreover, only 3 swab samples were collected at different sampling times for the 3 study groups examined. Attempting to reproduce the above data using larger numbers of mechanical ventilators would be worthwhile.

Until recently, no disinfection guidelines existed for surfaces of mechanical ventilator systems. Preliminary findings demonstrate that total bacterial levels on ventilator surfaces were raised after 8 hours use, suggesting that ventilator surfaces (including faceplates, Y-pieces, and water traps) should be disinfected at least every 8 hours to control bacterial growth. Future studies could evaluate the effectiveness of other disinfectants in killing bacteria on ventilator system surfaces. Finally, healthcare workers should keep their hands clean to promote healthcare quality and protect patients.

ACKNOWLEDGMENT

We thank the Chang Gung University, Taiwan, for financially supporting this research. Ted Knoy is appreciated for his editorial assistance.

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