JOURNAL OF CLINICAL MICROBIOLOGY, Mar. 1989, p. 495–503
0095-1137/89/030495-09$02.00/0

Vol. 27, No. 3

Microbial Burdens in Disposable and Nondisposable Ventilator Circuits Used for 24 and 48 h in Intensive Care Units

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Received 1 July 1988/Accepted 16 November 1988

One hospital sought to study the differences in using resterilizable permanent versus disposable ventilator circuits and changing the circuits on a 24-h versus a 48-h basis. Over a period of 13 months 656 condensate samples from 92 permanent and 72 disposable circuits were collected and plated by a loop dilution technique. Two samples were collected from the inspiratory limb (humidifier; tubing or nebulizer), and two were collected from the expiratory limb (tubing and trap) of each circuit. Contamination rates were higher for disposable circuits than for permanent circuits and for 48-h changes than for 24-h changes. Results of χ^2 testing by site indicated there was more contamination on the inspiratory and expiratory limbs each with use of disposable circuits than with the use of permanent circuits. The total results (χ^2 analysis) showed significantly greater microbial growth with the use of disposable circuits (permanent versus disposable, $P < 0.001$) and extension of time to 48-h changes (24 h versus 48 h, $P < 0.05$). In the experience of this hospital permanent circuits proved more advantageous from the standpoint of contamination risk and cost.

Critically ill patients in intensive care units (ICUs) have an 18% risk for acquiring nosocomial infections, whereas general medical and surgical patients have a 6% risk (8). Listed among factors causing pulmonary infections is the use of respiratory therapy (15, 23). A possible source of infection is the microbial growth that develops in the warm, moist environment of in-use ventilator circuits (4, 5, 20, 21). Two types of ventilator breathing circuits currently in use are the disposable and the nondisposable, more often called permanent, resterilizable circuits. Depending on patient conditions and therapies, we measured 35% or more condensate formed in disposable circuits than in permanent circuits over a 24-h period. Thus, more frequent emptying of condensate is required, increasing the chances of contamination by additional manipulation of wet equipment.

In the interest of cost containment, there is a trend toward the use of disposable circuits with the extended use of circuits from the conventional 24-h changes (25) to 48-h changes. In one study, the investigators detected no statistically significant differences between 24- and 48-h concentrations of microorganisms found within in-use circuits (4). This report was based on the study of ventilator inspiratory phase gas entrapment, using a tube-broth method of Edmondson and Sanford and Aerotest and Anderson air samplers. In some hospitals that were listed, circuits were changed twice or three times weekly, causing circuits to be left in operation for 72 and even 96 h, but no quantitative cultures were reported for these circuits (4). In two other studies (20, 21) with a direct dilution method, exponential increases of microorganisms were shown to occur up to 72 h. The increased number of bacteria found in the in-use circuits was considered to be a risk factor among the high-risk ICU patients, because it is possible for the contaminated expiratory condensate to be spilled into the inspiratory line by the tilt of the wye connector (Fig. 1). Furthermore, retrograde spillage into the bronchial tree of an intubated patient or a tracheostomy patient occurs when the tubing is accidentally raised (5, 20, 21).

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We have evaluated the differences between quantitative bacterial cultures found in permanent and disposable circuits at 24- and 48-h changes used for ICU patients. From the standpoint of microbial counts, this study demonstrates that disposable circuits were inferior to permanent circuits, because quantitative bacterial counts were significantly higher with time.

To make cost containment feasible, a study of the operational cost of equipment was made to help determine the choice between permanent and disposable ventilator circuits. In this hospital, the cost ratio for permanent versus disposable circuits was 30 to 1, i.e., one permanent circuit must withstand more than 30 cleaning and sterilizing cycles to be more cost effective than a disposable unit. We found that the permanent circuits were able to withstand this number of cleaning-sterilizing cycles. This hospital sought to investigate the possibility of prolongation of permanent and disposable circuit use and the cost of each based on the current volume of ventilator use.

(Some of these results were presented previously [B. Malecka-Griggs, Abstr. Annu. Meet. Am. Soc. Microbiol. 1984, L3, p. 308; Malecka-Griggs, Abstr. Annu. Meet. Am. Soc. Microbiol. 1985, L8, p. 380].)

MATERIALS AND METHODS

Samples. At Georgia Baptist Medical Center (523 beds), Atlanta, 656 fluid samples were obtained on 54 intermittent days over a period of 13 months. Four different sample sites were used on 164 MA-1 (Puritan-Bennett Respiratory Products, Overland Park, Kans.) ventilator circuits. These ventilators were in continuous use on each individual of the current population of 47 patients in medical (19 patients) and surgical (28 patients) ICUs. Two of the 28 surgical patients were placed in a neurological ICU. Of the total samples, 368 were from 92 permanent circuits consisting of silicone tubing (Puritan Bennett); 288 were from disposable circuits consisting of polyvinylchloride tubing (Inspiron from Rancho Cucamonga, Calif.; or tubing from Airlife, Montclair, Calif.). The four sample sites shown in Fig. 1 were as follows: the cascade humidifier, filled approximately every 6 h by stop-

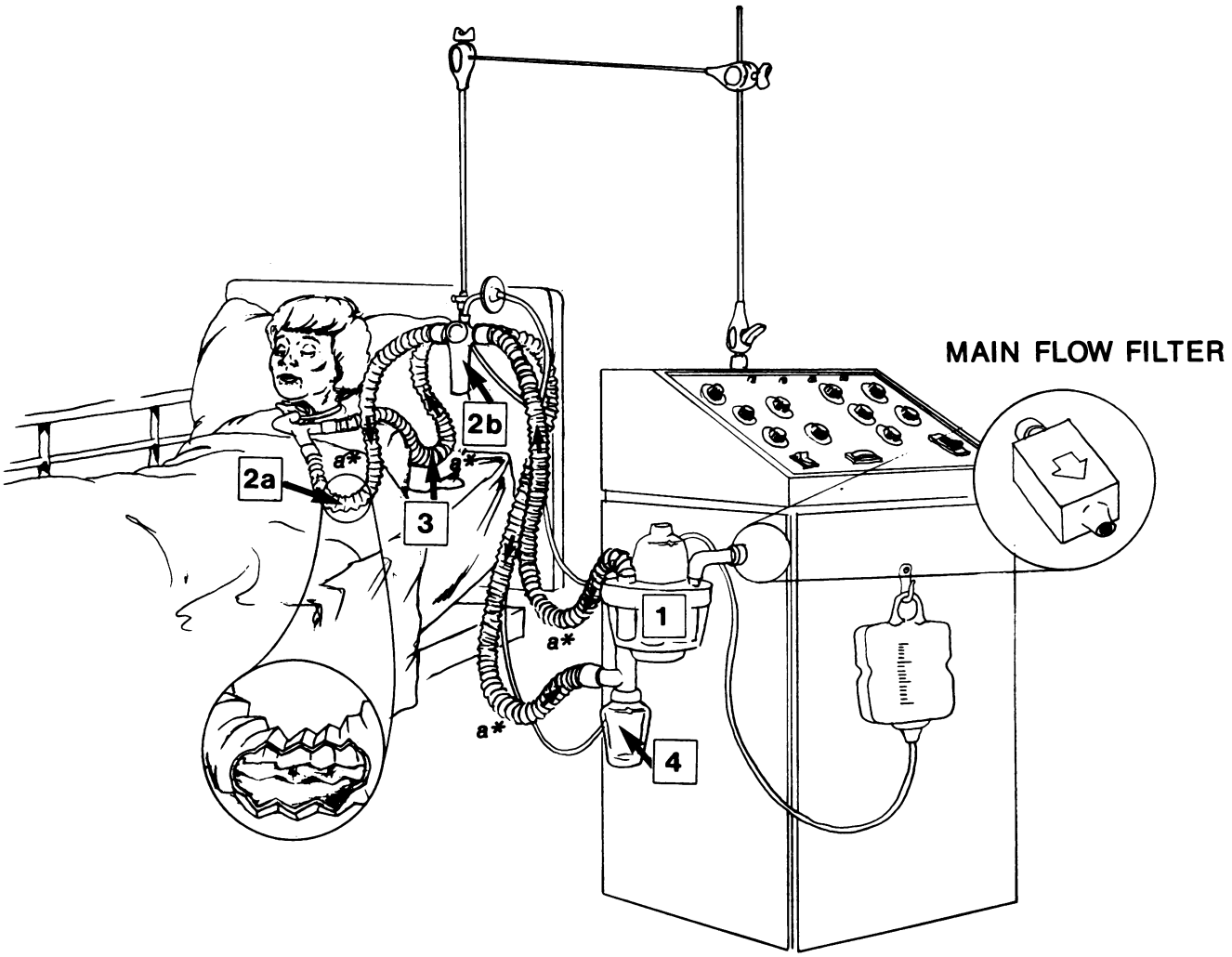

FIG. 1. MA-1 ventilator. Sampling sites: 1, cascade humidifier (H); 2a, inspiratory tubing (distal to wye connector) or nebulizer trap (2b) (I/N); 3, expiratory tubing (distal to wye connector) (E); 4, expiratory trap (ET); *a**, sites where condensate collects in tubing.

cock control from a prefilled 2,000-ml sterile water container (Travenol Laboratories, Chicago, Ill., or Airlife); inspiratory tubing or, occasionally, the nebulizer trap; the expiratory tubing; and the expiratory trap.

Sampling protocol. Samples were randomly collected 54 times over a period of 13 months. Two of the respiratory therapy personnel were trained to collect samples. When their case load allowed, these persons collected the samples from the population of patients on continuous ventilation for that day. Thus, no set pattern of sampling days was maintained. Samples were designed to be obtained from each site just before the circuits were changed at 3:00 p.m. The tubing was disconnected at the usual sites for emptying condensate, and 1 ml of condensate from each site was removed with a sterile pipette (with the aid of a Caulfield Pipettor) and placed into a sterile 18- by 150-mm screw-cap test tube. The tubes were then placed on ice and processed within 1 h after sample collections were made.

Change of circuits. The first group of samples was collected during a 6-week preliminary period to establish a base-line contamination rate (the ratio of positive samples to the total samples of a given group) for the permanent circuits changed every 24 h on the mechanically ventilated ICU patients. Within the following 6 weeks, a new protocol was tried, during which permanent circuits were changed every 24 h on the patients with pneumonia or other bodily infectious disease processes. Permanent circuits were extended to 48 h on newly intubated, noninfectious patients, such as those with cardiac arrest, ruptured aneurism, gastrointestinal bleeding, or gunshot or head injury. Tracheal aspirate reports of these kinds of patients usually read "no growth" or "few organisms" of normal flora, such as *Staphylococcus epidermidis*, *Streptococcus viridans*, *Bacillus* spp., or diphtheroids. Thereafter, each patient's chart was reviewed daily for reports of increased leukocytes or increased kinds and numbers of microorganisms in the sputum or tracheal aspirate, positive microbial cultural reports from other parts of the body, or diagnoses of new infectious processes. In addition, during this study, increases from low to moderate or higher numbers of organisms in the circuits were noted. When these indicators were positive for a given patient, the circuit changes were changed back from a 48-h to a 24-h protocol until extubation or transfer to the general hospital population.

Physicians adhered to a diagnosis of pneumonia when at least one of the following criteria were met. For criterion 1, the patient has rales or dullness to percussion and at least one of the following: (i) new purulent sputum; (ii) positive

blood culture; or (iii) isolation of an etiologic agent from a specimen obtained by transtracheal aspirate, bronchial brushing, or biopsy. For criterion 2, the patient has chest radiographic examination that shows new or progressive infiltrate(s), consolidation, cavitation, or pleural effusion and at least one of the stipulations as i, ii, or iii above. Later, when the hospital changed to disposable circuits for the remaining 10 months of this study, these same guidelines were used for determining either 24- or 48-h usage of circuits.

Tracheal aspirates. Generally, tracheal aspirates were routinely collected by hospital personnel on intubation or tracheotomy and thereafter, every third day until extubation. These specimens were processed in the hospital laboratory by streaking on appropriate plates with an uncalibrated loop. Therefore, reports were not returned as quantitated CFU but as, for example, "few," "scant," or "moderate."

Patients. Among the 47 patients, 36 were male and 11 were female. The age range was 17 to 88 years; the mean was 66 years. Days spent on the ventilator ranged from 1 to 53. The patient characteristics were similar to those of other high-risk ICU patients described in literature (2, 3, 12–14, 18, 21, 27). More specifically, 11 patients had cancer and 8 had coronary bypass grafts (all of these patients received immunodepressant treatments); 11 had tracheostomies; 20 had chronic obstructive pulmonary disease or respiratory or cardiac failure, usually with some additional diagnoses. All were or had been receiving antibiotic therapy.

Plating and identification. Samples were plated onto blood agar plates containing 5% sheep blood in Trypticase soy agar (BBL Microbiology Systems, Cockeysville, Md.) by a direct dilution technique with 0.1-ml pipettes and 0.01- and 0.001-ml calibrated loops (20, 21). These plates were incubated aerobically for 24 to 48 h at 37°C and for 3 to 5 additional days at 25°C for slow growers. The number and characteristics of the resulting colonies were recorded. Representative colonies were tested by the Gram stain and oxidase test (General Diagnostics, Morris Plains, N.J.) and inoculated into triple sugar iron agar (Difco Laboratories, Detroit, Mich.). Oxiferm and Enterotube systems (Roche Diagnostics, Nutley, N.J.) were used for identification of gram-negative rods. Tests for motility (wet mounts or motility test medium; Difco) and growth at 42°C were included when necessary. Staphylococci were grown on mannitol-salt agar slants (Difco) and were tested for resistance to novobiocin disks (Difco). Catalase and coagulase tests were performed. Beta-hemolytic streptococci and *Streptococcus pneumoniae* were tested by A and P disks (BBL), respectively. Heaping white *Candida* sp.-like colonies (diameter, 2 to 3 mm) were Gram stained and observed for single and budding yeast cells, and the organisms were grown on cornmeal–Tween 80 agar plates for observation of pseudomycelia and chlamydospores. When necessary, the *Manual of Clinical Microbiology* (19) was used as a reference for verification of microorganisms.

Environmental control. The hospital used the following protocol for environmental control. The permanent circuits, including nebulizer trap and cascade humidifier, were scrubbed with a solution of Detergent 1-2-2 (M. D. Co., Northbrook, Ill.). The parts were then rinsed, dried, packaged, and sterilized with ethylene oxide. Used circuits from isolation rooms were first packaged and decontaminated in ethylene oxide before the above procedure. The packages were then dated and shelved after aeration. All disposable circuits, except the nondisposable parts (Cascade humidifiers), were placed in biohazard plastic bags, tightly secured, and transported from the ICU for disposal. Quarterly random quality checks (by the hospital and our team) of permanent and disposable circuits (a total of 10 each) were negative when sampled. In our laboratory, the direct dilution technique described was used to sample the washings of 50 ml of sterile water that was gently agitated within the tubing of each of the prepackaged circuits. Thirty 1-ml fluid samples from prefilled water containers were negative when processed by direct dilution and were used as controls for a sterile water supply.

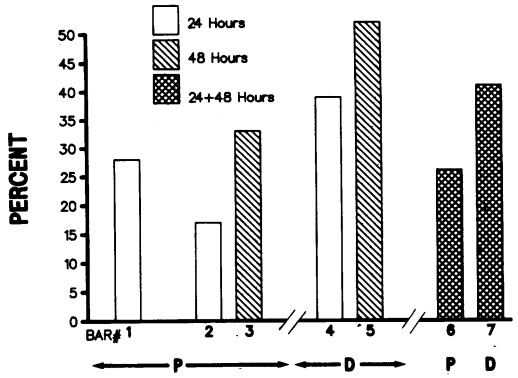

FIG. 2. Contamination rates and results of χ^2 analysis for permanent (P) and disposable (D) circuits: $P < 0.02$ (bar 2 versus bar 3); $P < 0.1$ (bar 4 versus bar 5); $P < 0.05$ (bars 1, 2, and 4 versus bars 3 and 5); $P < 0.001$ (bars 1 and 2 versus bar 4); $P < 0.05$ (bar 3 versus bar 5); $P < 0.001$ (bar 6 versus bar 7).

Statistical methods. Nonparametric statistics were used to analyze the data. The chi-square (χ^2) test (9) was the predominant statistical tool used; however, some data were more appropriately analyzed by the Wilcoxon matched-pair signed-ranks test (7).

RESULTS

Of the 368 fluid samples obtained from permanent MA-1 circuits, 95 (26%) were positive for microbial growth; 118 (41%) of 288 fluid samples obtained from disposable circuits were positive. Gram-negative rods were the predominant aerobic organisms found among the positive cultures for both types of circuits.

Contamination rates for permanent circuits. The data for the 368 samples were obtained from 92 circuits. The contamination rate of the samples collected during the first 6 weeks of the study was 28% (Fig. 2, bar 1). There was a high incidence (35%) of *Pseudomonas cepacia* (see Fig. 6). During this period, in-service training sessions were conducted for respiratory therapy personnel to explain sampling procedures and to emphasize asepsis and hand washing.

A subsequent 6-week testing or trial period was conducted during which the use of circuits was extended to 48 h on newly intubated, noninfectious cases. Thereafter, charts were reviewed daily for indication of increasing patient or circuit colonization. If patients became colonized or infected as previously indicated, the circuits of these patients were then changed back to a 24-h protocol. Thus, the majority of ICU patients on continuous mechanical ventilation were generally changed on a 24-h basis. The respective contamination rates for the 24- and 48-h samples were 17 and 33% (Fig. 2).

Samples were obtained intermittently. However, there were 10 positive sets of samples that were obtained consec-

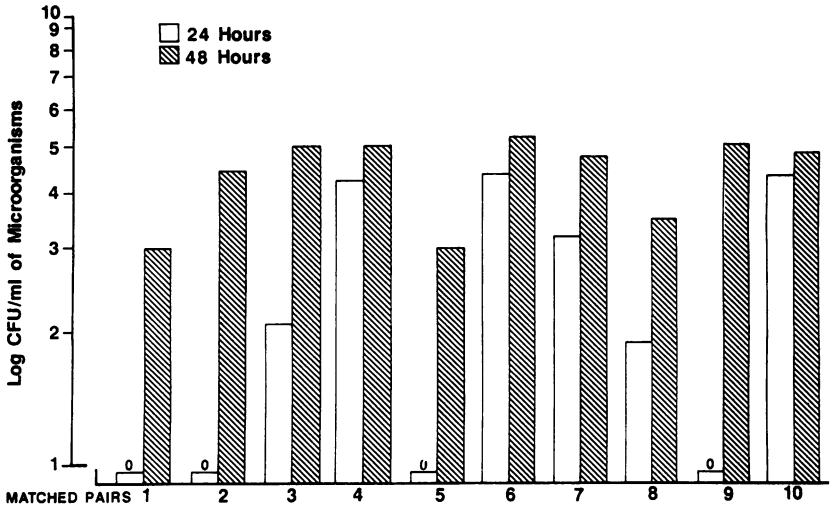

FIG. 3. Differences of microbial concentration for matched pairs of expiratory tubing. Wilcoxon matched-pair signed-ranks test ($P < 0.005$).

utively at 24 h and then at 48 h on a given circuit. Thus, the data of these 10 matched consecutive pairs, when subjected to the Wilcoxon matched-pair signed-ranks test, gave $P < 0.005$. Pairs 1, 2, 3, 5, 8, and 9 of Fig. 3 had 0 or $<10^3$ CFU of organisms per ml at 24 h but yielded $\geq 10^3$ to 10^5 CFU/ml at 48 h. The remaining four pairs had $>10^3$ CFU/ml at 24 h and, with the exception of pair 10, increased 10-fold at 48 h. Pair 6 reached $>10^5$ CFU/ml. These figures are a minimum, since the upper limit of the microbial count does not exceed 10^6 CFU/ml with the loop dilution technique (21).

Contamination rates and χ^2 analysis for 24- versus 48-h changes and permanent versus disposable circuits. The results of the analyses of the data for the contamination rates are summarized and depicted in Fig. 2. The respective contamination rates for 24- and 48-h permanent circuits were 17 and 33%; χ^2 analysis gave $P < 0.02$ (bar 2 versus bar 3). Respective contamination rates for 24- and 48-h disposable circuits were: 39 and 52%; χ^2 analysis gave $P < 0.1$ (bar 4 versus bar 5). When all 24- and 48-h results were pooled, 24-h versus 48-h changes by χ^2 analysis gave $P < 0.05$ (bars 1, 2, and 4 versus bars 3 and 5).

The respective contamination rates for permanent and disposable circuits used 24 h were 24 and 39%; χ^2 analysis gave $P < 0.001$ (bars 1 and 2 versus bar 4). The respective contamination rates for permanent and disposable circuits used 48 h were 33 and 52%; χ^2 analysis gave $P < 0.05$ (bar 3 versus bar 5). When all permanent and all disposable circuit results were pooled, the contamination rates were 26 and 41%, respectively; χ^2 analysis gave $P < 0.001$ (bar 6 versus bar 7).

Contamination rates and microbial counts by site. The logarithmic levels of microbial counts (CFU per milliliter) of each positive sample and the contamination rates by site can be respectively observed for the 92 permanent and 72 disposable circuits in Fig. 4 and 5: 1 and 3% for the humidifier; 4 and 11% for the inspiratory tubing; 14 and 16% for the expiratory tubing; 7 and 11% for the expiratory trap. When the positive and negative samples at each site for the circuits were tested (permanent versus disposable circuits) by χ^2 analysis, there were statistically significant differences only on the inspiratory limb: humidifier ($P < 0.01$) and inspiratory tubing ($P < 0.001$). However, when the data were pooled there was significance on both inspiratory and expiratory limbs (permanent versus disposable circuits): humidifier plus inspiratory tubing ($P < 0.001$) and expiratory tubing plus expiratory trap ($P < 0.02$).

Percentages of kinds of organisms found in circuits. Predominating organisms were similar for both types of circuits, with 138 organisms for the permanent circuits and 144 organisms for the disposable circuits. The representative organisms found in this study are summarized in Fig. 6. The results for permanent circuits were as follows: gram-negative rods (22.5% fermenters and 60% nonfermenters, with *P. cepacia* predominating at 35%); gram-positive rods and cocci, 14.5%; and yeasts, 3%. The results for disposable circuits were as follows: gram-negative rods (31% fermenters and 50% nonfermenters, with *Pseudomonas aeruginosa* predominating at 30%); gram-positive rods and cocci, 10%; and yeasts, 9%.

Patient demographics. A study was made to find the similarities of the population of patients sampled with permanent circuits and those sampled with disposable circuits. Since the patients were intermittently sampled over two different periods (permanent circuits during the first 3

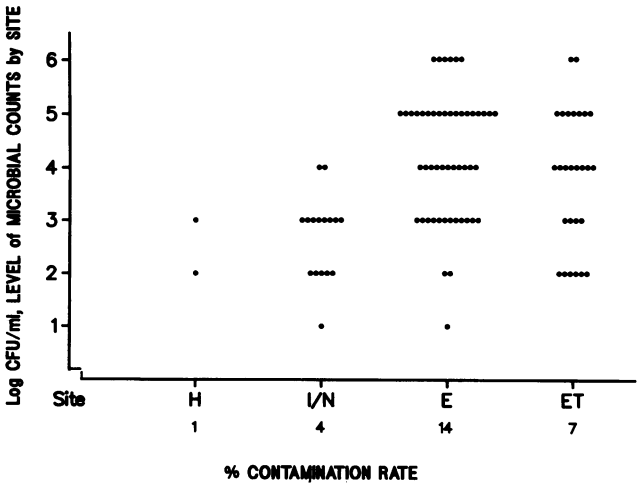

FIG. 4. Contamination rates and logarithmic levels of microbial counts by site for permanent circuits. See Fig. 1 for sites.

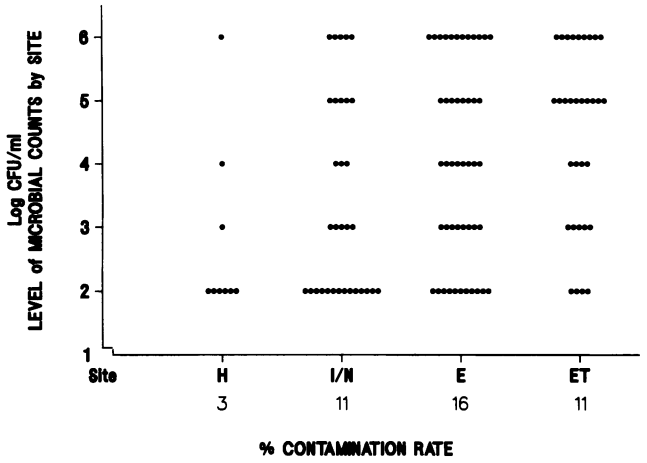

FIG. 5. Contamination rates and logarithmic levels of microbial counts by site for disposable circuits. See Fig. 1 for sites.

months; disposable circuits during the remaining 10 months), an underlying comparison was made to ensure that the population of patients was basically equal in severity of disease. The patients in the population, as described in this study, were predominantly multisystem organ failure-type patients. In general, the patients were either surgically septic or nonseptic on admission; the medical patients were all chronically diseased (chronic obstructive pulmonary disease) or organ failure-type patients. When compared by age, sex, service, primary diagnosis, and discharge status, the results show a similar group of patients. The 22 patients using disposable circuits were thus compared with 22 of the 25 patients using permanent circuits. Three of the latter were short-term patients and were not used in this comparison to keep the numbers equal. They were included in the final percentages to make a total of 47 patients. The comparison (permanent versus disposable circuits) resulted as follows: male surgical patients who died, 10 versus 9; male surgical patients who were discharged (or transferred), 4 versus 3; male medical patients who died, 2 versus 4; male medical patients who were discharged, 2 versus 2; female surgical patients who died, 0 versus 2; female medical patients who died, 2 versus 0; female medical patients who were discharged (or transferred), 2 versus 2. There were no female surgical patients who were discharged. There was one male terminal cancer patient who died at age 35, whereas all other male cancer patients died at age 64 or above.

Of the 47 patients ventilated for 4 to 5 days, 10 had uncolonized circuits; 12 of the 37 remaining colonized patients had circuits predominantly colonized with *P. cepacia*, 12 had circuits colonized with *P. aeruginosa*, and 20 had circuits colonized with various organisms belonging to the family *Enterobacteriaceae*. Sixty-eight percent (25 of 37) of the patients became colonized with one to four organisms on an average of 4.5 days. The circuits of two of four patients (patients 3 and 41, Table 1) became progressively colonized with an average of six organisms by days 21 to 27 of ventilation. Of the colonized patients, 56.8% (21 of 37) were surgical; 43.2% (16 of 37) were medical.

Table 1 shows the progressive increase in the kinds and numbers of organisms found in the circuits with extension of days on the ventilator. The table includes a listing of 11 patients who had one or two similar kinds of organisms in the circuits and in their tracheal aspirates or sputum or other

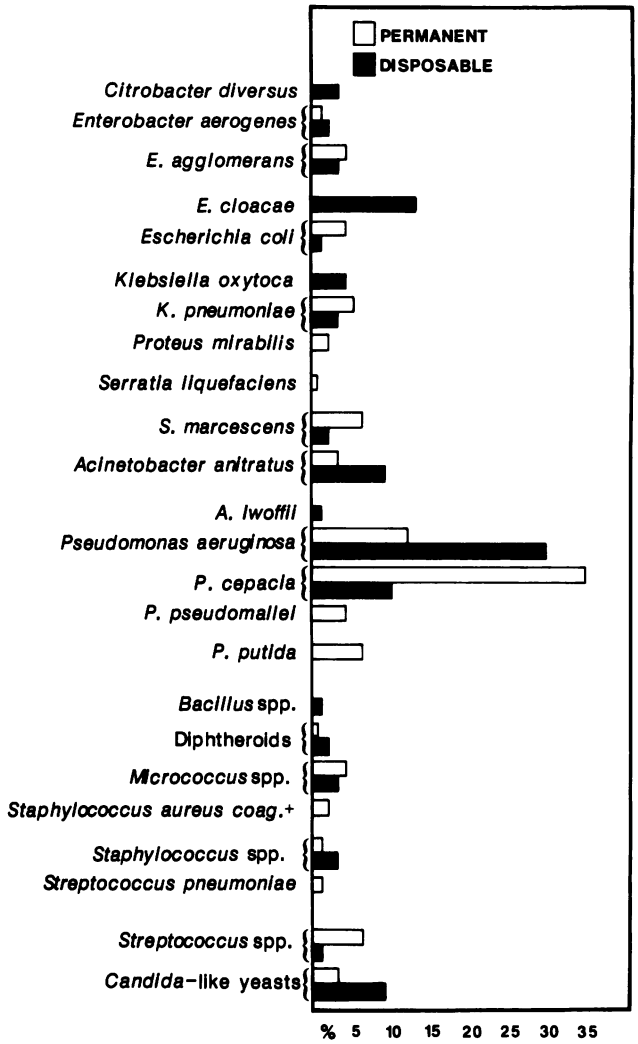

FIG. 6. Percentages of organisms occurring in samples (138 organisms from permanent circuits and 144 organisms from disposable circuits).

(wound or urinary tract infection) microbiological culture reports.

In other instances colonization was notable in eight newly admitted patients where "no growth" was reported in the tracheal aspirate or sputum on intubation or instrumentation for tracheostomy, but the circuits became colonized within the stated average of 4.5 days. On subsequent days the tracheal aspirate or sputum also became positive for the same kind of organism in six of eight of the newly colonized patients. The organisms in these particular circuits became markers for colonization of the patient and indicated a possible exogenous source for the colonization of the circuits.

Percentage of fatalities and acquired pneumonias. During the hospital confinement of the ICU patients, 61.7% (29 of 47) died, 13 (27.6%) were discharged to home care, and 5 (10.6%) were transferred to other institutions. According to the records, 12.7% (6 of 47) developed known cases of pneumonia 48 h or more after admission. Of these known pneumonia cases, 8% (2 of 25) occurred during the use of permanent circuits and 18% (4 of 22) occurred during the use of disposable circuits. Additionally, 12.7% (6 of 47) had

TABLE 1. Individual case studies

Patient no.	Diagnosis	Hospital		Days vented	Organism(s) isolated	Log_{10} CFU/ml at site[b]:				Laboratory reports, tracheal aspirate, etc.
		Dismissal	Service[a]			H	I/N	E	ET	
1 (male, age 73 yr)	Lung cancer, lobectomy, pneumonia	Died	SICU	21	*P. cepacia*, *P. aeruginosa*, *Pseudomonas putida*	3	3	6	6	Heavy *Pseudomonas* species
				27	*P. cepacia*		2	4	2	
				28	*P. cepacia*, *P. aeruginosa*		2	6	5	
				29	*P. cepacia*		3	4	4	
				32	*P. cepacia*			4	3	
2 (male age 71 yr)	Hematoma, pneumonia	Home	SICU	15	*P. cepacia*, *P. aeruginosa*			4		95% *Pseudomonas* species
				16	*P. cepacia*, *P. aeruginosa*			3	4	
3 (male, age 66 yr)	Laryngeal, cancer	Died	SICU	2	*Enterobacter agglomerans*, *Serratia marcescens*, coagulase-positive *Staphylococcus* sp.			6	3	Neck wound: 50% nonhemolytic streptococci, 30% *Escherichia coli*
				6	*S. liquificans*			3		
				7	*E. agglomerans*, *S. marcescens*, coagulase-positive *Staphylococcus* sp. nonhemolytic streptococci			4	3	
				9	*E. coli*			6	2	
				13						Patient isolated
				19	*P. aeruginosa*, *P. putida*		2	6	6	
				20	*P. aeruginosa*		2	6	6	*P. aeruginosa*, *E. coli*
				21	*P. aeruginosa*, *P. putida*			6	6	
6 (male, age 69 yr)	Lung cancer, lobectomy	Died	SICU	7	No growth					80% yeasts, 15% hemolytic streptococci
				10	*Candida*-like yeast			3		
				11	*E. aerogenes*, beta-streptococci			3		
8 (male, age 50 yr)	Head injury	Died	SICU	4	Beta-streptococci		3			100% *P. mirabilis*
				5	*P. mirabilis*			2		100% *Proteus* species from CNS[c]
				7	*P. mirabilis*, *P. cepacia*			4		UTI[d]; 100% *P. mirabilis*
15 (female, age 83 yr)	Bronchitis, respiratory failure, pneumonia	Died	MICU	17						*S. marcescens*
				19	*P. cepacia*		3	4		UTI: *Pseudomonas* sp. (10^5 CFU/ml); blood: *S. marcescens*
				20	*P. cepacia*, *S. marcescens*		3	3		
21 (female, age 67 yr)	Cardiac	Died	MICU	2	*P. cepacia*, nonhemolytic streptococci			4		UTI: *E. coli*
				8	*P. cepacia*, nonhemolytid streptococci, *Candida*-like yeast		2	4	3	*Candida albicans*
22 (female, age 51 yr)	Respiratory failure, pneumonia	Trans-ferred	MICU	1	*Acinetobacter anitratus*			2		Blood: *S. pneumoniae*, *S. epidermidis*
				2	*A. anitratus*			4	3	100% *A. anitratus*; UTI: *E. coli*
34 (male, age 79 yr)	Respiratory failure	Died	SICU	11	*E. coli*			3		*E. coli*; UTI: *E. coli*

40 (female, age 59 yr)	Lung cancer, respiratory failure	Died	SICU	26	*Klebsiella oxytoca*; *A. anitratus*, coagulase-positive *Staphylococcus* sp.	4	4	3	90% *A. nitratus*, *S. aureus*
				27	*K. oxytoca*, *A. anitratus*		2	2	
				34	*A. anitratus*			2	99% *K. oxytoca*
				40	*K. oxytoca*, *A. anitratus*		2	2	50% gram-negative rods, 50% mixed organisms
				42	*K. oxytoca*, *A. anitratus*		4		
				43	*K. oxytoca*, *A. anitratus*	2	3	4	3
41 (male, age 66 yr)	Coronary bypass, septicemia pneumonia	Died	SICU	18	*E. coli*, *Candida*-like yeast, diphtheroids, *Bacillus* spp.			4	4	*E. coli*; blood: *S. epidermidis*
				19	*Candida*-like yeast, *Streptococcus* spp., coagulase-negative *Staphylococcus* sp.	2	4	6	6	
				26	*E. aerogenes*			4	6	
				27	*P. aeruginosa*		3			Gram-positive cocci, chains
				32	*P. aeruginosa*		6	6	6	100% *Pseudomonas* species
				33	*P. aeruginosa*		6	6		
				34	*P. aeruginosa*		5	5	4	
				35	*P. aeruginosa*		5	5		Gram-negative rods
				39	*P. aeruginosa*			6	6	
				41	*P. aeruginosa*		2			*P. aeruginosa*; *Pseudomonas* septicemia
				46	*P. aeruginosa*		5	5	5	*Pseudomonas* pneumonia
				47	*P. aeruginosa*		6	6	6	

[a] SICU, Surgical ICU; MICU, medical ICU.
[b] See Fig. 1 for sites.
[c] CNS, Central nervous system.
[d] UTI, Urinary tract infection.

pneumonia on admission and were not counted in these percentages. These latter patients were those from previous admissions from other hospitals who had recurring problems with pneumonia; the etiology of their original pneumonia could not be determined. Neither serological typing nor determination of antimicrobial resistance patterns was feasible during this study, because not all organisms in the tracheal aspirate or sputum specimens were identified to genus and species. The percentage of cases of pneumonia occurring among those using circuits for 24 or 48 h was not calculated because of the selective process of using a circuit on a given patient for either 24 or 48 h, according to the presence of infection or colonization of tracheal aspirate and circuits. Furthermore, under the conditions of this study, a correlation between the incidence of pneumonia and the contamination rates of the circuits is by implication.

DISCUSSION

A review of the statistical analyses shows a marked difference between permanent and disposable use of circuits and between 24-h versus 48-h use of circuits. There were significantly greater microbial numbers in the disposable circuits than in the permanent ones, there were increased numbers of bacteria when use of the circuits was extended to 48 h, and there were significantly greater microbial numbers in the inspiratory and expiratory limbs with the use of disposable circuits than with the use of permanent ones.

During two different periods of sampling, *P. cepacia* (permanent circuits) and *P. aeruginosa* (disposable circuits) became the predominating organisms present in the circuits. No patients were reported with *P. cepacia* in their cultures during the time of this study. The preponderence of *P. aeruginosa* during the latter part of the study may be attributed partially to the overwhelming colonization and infectious state of patient 41 (Table 1). The presence of the high numbers of these organisms in the circuits was a source of danger among the high-risk patients. Both organisms were equally distributed among surgical and medical patients, indicating a possible transferrence by personnel assigned to both medical and surgical units. The technique used during airway care and handwashing became suspect. To address the situation, an in-service training period was instituted stressing handwashing and airway care procedures. Thereafter, these procedures were periodically reinforced by the supervising respiratory therapists.

When deciding to extend the use of circuits to 48 h, a given set of criteria was used to determine which circuits should be extended. Thus, patient charts were reviewed daily to determine the status of patient colonization or infection according to sputum or tracheal aspirate reports, other microbiological laboratory reports, or new diagnoses of infectious disease processes. During this study, increases in circuit colonization were also considered. Ordinarily, in this hospital, a chief determinant for length of circuit usage would be the routine bi- or triweekly tracheal aspirate report in lieu of the microbiological surveillance of circuits. The rationale for extending the circuits according to a set of criteria was to proceed cautiously into the practice of extending the use of circuits on critically ill patients. After the change-of-circuit protocol was initiated for permanent circuits, there was a 94% higher contamination rate when time was extended to 48 h (Fig. 2).

The Wilcoxon matched-paired signed-ranks test, used on the 10 matched pairs of expiratory-tubing data, proved highly significant. Whether this represented a gross contam-

ination or a growth of microorganisms is not known, but either or both were possible. As pointed out, exponential increases of microorganisms are documented when circuits were used for 24, 48, and 72 h (4, 5, 20, 21), and there is evidence that *P. cepacia* and other pseudomonads may grow exponentially in 24 h (10, 11). Moreover, these increased numbers of organisms represent not only the patient's individual flora but apparently hospital-acquired flora as well. The danger of retrograde flow of these kinds of microbe-laden condensates into the bronchial tree has been indicated. More consecutive matched-paired samples are needed on a greater number of patients to see whether the increased contamination correlates with an increased incidence of pneumonia.

Figures 4 and 5 and the reported χ^2 analyses bear out the fact that fewer organisms were found in the inspiratory and expiratory limbs of the permanent circuits than in the disposable ones. This finding becomes an important factor, since we found there was 35% more condensate in the disposable circuits when compared with the permanent circuits. There is more concern over high microbial counts in the inspiratory limb than in the expiratory limb. The inspiratory limb is the one that most intimately communicates with the patient's airway, especially with the constant-flow modes of ventilation. Furthermore, this study indicated a greater and more equal distribution of organisms throughout the entire disposable circuits used for 24 or 48 h compared with that in the permanent circuits used for 24 and 48 h (Fig. 2, 4, and 5). The finding of no statistical significance ($P < 0.1$ by χ^2 analysis, disposable circuit used 24 h versus 48 h) is consistent with that of Craven and associates in their study of disposable circuits (4).

Studies are needed to determine why there was more contamination especially in the inspiratory limb of the disposable circuits than in the permanent ones and why there was 35% more condensate in disposable circuits plus higher microbial counts throughout the entire disposable circuits compared with counts in the permanent ones. Some contributing factors may be the chemical nature of the materials used to make the corrugated tubing of the circuits (silicone for permanent circuits; polyvinylchloride for disposable ones), the thickness and sturdiness of the tubing walls, and the bore size (inner diameter) of the tubing. Adherence of various organisms to one type of tubing material as opposed to another type may play a role in the differences in bacterial counts as shown in this study. Differences in adherence factors have been noted. Sheth and colleagues reported that polyvinylchloride intraveneous catheters were more frequently colonized by bacteria, such as coagulase-negative staphylococci, than were Teflon catheters, which, in turn, were colonized by a greater variety of microorganisms (24). Investigation of microbial adherence factors regarding the tubing of ventilator circuits made of various kinds and grades of materials may prove fruitful.

The lower percentage of organisms in the expiratory trap than in the expiratory tubing for both types of circuits could be due to the warmer temperatures and fresher nutrients in the expiratory tubing than in the compact trap distally removed from the warmth of the tubing (Fig. 1). Personnel expected the opposite and were more careful with the expiratory trap than with the expiratory tubing.

Rapid colonization, as we found, in the first 4 to 5 days of confinement, particularly among the very ill patients has been documented (6, 16, 17, 21). Johanson et al. (17) found a leveling-off process after 4 days of confinement; however, on a long-term basis, we found a progressive pattern of circuit colonization with the extension of time (Table 1). Additionally, it is known that the risk of hospital-associated pneumonia increases significantly after the fifth day of therapy with respiratory assistance devices (6). Further studies of circuit-changes at 48 h and exceeding 48 h are warranted, if hospitals such as those listed (4) and others have extended the use of circuits beyond 48 h.

The high death rate (61.7%) among this population of patients is attributed chiefly to the designation of this hospital as a trauma unit. The hospital receives critical patients from the southeastern states. Similar high death rates in ICUs have been noted in the literature. Manship and associates (22), Department of Surgery, University of South Carolina School of Medicine, report that 58% of 77 patients they studied died of multisystem and organ failure in a surgical ICU. In a 5-year study, Bryan and Reynolds (1), Department of Medicine, Richland Memorial Hospital in South Carolina, report that their 58% death rate was attributed directly to nosocomial pneumonia. These deaths occurred almost exclusively in patients with serious and largely irreversible underlying diseases.

From this preliminary study, the following recommendations for ICU high-risk patients are offered: use 24-h changes of the entire circuit on ICU patients who are on continuous mechanical ventilation; perform tracheal aspirate cultures at least twice a week; check laboratory reports and charts daily when establishing the day's routine to determine state of colonization and infection; use aspectic technique and thorough handwashing procedures consistently.

Suggestions for further investigation include the following: study means of cost containment without sacrificing microbiological principles; study ways to improve performance of disposable and permanent circuits from a microbiological standpoint; develop experimental research designs to provide safer alternatives for delivery of respiratory care; and test new protocols for specific hospital settings and disseminate these findings to hospital personnel through in-service training.

Respiratory care departments use either disposable or permanent ventilator tubing depending on their volume and cost parameters. The cost determination can be predicted by appropriate formulas (26). This institution experienced a sudden rise in ventilator days when it received its trauma designation causing respiratory therapy personnel to review the protocol for ventilator circuit changes. Prior use of disposable circuits with lower fixed costs (at the previous lower usage volume) became questionable in light of the increased volume of ventilator days and with concern for contamination risk. Based on the outcome of this study, the hospital is pursuing the purchase and use of permanent circuitry, since this is clearly more advantageous in terms of contamination risk and cost.

ACKNOWLEDGMENTS

We gratefully acknowledge Barry Coalson, Stephen Welch, Murray Odrezin, and Angell Green for excellent technical assistance.

This study was supported by funds from the Departments of Biology and Respiratory Therapy, Georgia State University.

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