AN OUTBREAK OF *PSEUDOMONAS AERUGINOSA* PNEUMONIA AND BLOODSTREAM INFECTION ASSOCIATED WITH INTERMITTENT OTITIS EXTERNA IN A HEALTHCARE WORKER

Anne Zawacki, BSN, MPH; Edward O'Rourke, MD; Gail Potter-Bynoe, BS, CIC; Ann Macone, BS; Stephan Harbarth, MD, MS; Donald Goldmann, MD

ABSTRACT

OBJECTIVES: To investigate an outbreak of *Pseudomonas aeruginosa* pneumonia and bloodstream infection among four neonates, determine risk factors for infection, and implement preventive strategies.

DESIGN: Retrospective case finding; prospective surveillance cultures of patients, personnel, and environmental sites; molecular typing by pulsed-field gel electrophoresis; and a matched case–control study.

PATIENTS AND SETTING: Neonates in the level-III neonatal intensive care unit of a tertiary-care pediatric institution.

INTERVENTIONS: Cohorting of patients with positive results for *P. aeruginosa*, work restrictions for staff with positive results, implementation of an alcohol-based hand product, review of infection control policies and procedures, and closure of the unit until completion of the investigation.

RESULTS: Seven (4%) of 190 environmental cultures and 5 (3%) of 178 cultures of individual healthcare workers' hands grew *P. aeruginosa*. All four outbreak isolates and one previous bloodstream isolate were genotypically identical, as were the *P. aeruginosa* isolates from the hands and external auditory canal of a healthcare worker with intermittent otitis externa. Four of 5 case-patients versus 5 of 15 matched control-patients had been cared for by this healthcare worker ($P = .05$). The healthcare worker was treated and no further cases occurred.

CONCLUSIONS: These findings suggest that a healthcare worker with intermittent otitis externa may have caused this cluster of fatal *P. aeruginosa* infections, adding the external ear to the list of colonized body sites that may serve as a source of potentially pathogenic organisms (*Infect Control Hosp Epidemiol* 2004;25:1083-1089).

Pseudomonas aeruginosa is a well-known nosocomial pathogen but is not commonly associated with neonatal infection except in the outbreak setting.[1,2] Outbreaks have been attributed to a variety of contaminated substances and objects that have direct or indirect contact with newborns. Contaminated medications,[3,4] respiratory equipment,[5] hand lotions,[6] laryngoscopes,[7] blood gas analyzers,[8] and a breast milk pump[9] have all been implicated in common-source neonatal *P. aeruginosa* outbreaks. Indirect contact spread via healthcare workers' (HCWs) hands has also been cited as a possible mechanism for nosocomial transmission of *P. aeruginosa*.[10-12] Reported *P. aeruginosa* outbreaks have been linked to microbiologically documented hand carriage of this organism by HCWs with onychomycosis,[12,13] long natural nails,[10] and artificial nails.[10,12]

Between July 13 and August 30, 1997, four neonates in a neonatal intensive care unit (NICU) developed *P. aeruginosa* bloodstream infections (BSIs) and died within a day of the onset of symptoms. This article summarizes the investigation of this outbreak that ultimately was linked to ear and hand carriage of *P. aeruginosa* by a single HCW who experienced intermittent untreated bouts of otitis externa.

METHODS

Setting

The outbreak occurred in the 18-bed NICU of a tertiary-care pediatric hospital in Massachusetts. Approximately 500 neonates with complex medical and surgical conditions are admitted to this level-III unit each year. All patients are generally transferred from hospitals in the New England region.

Initial Outbreak Presentation

In July 1997, two patients developed nosocomial *P. aeruginosa* BSIs within 7 days of each other and died. In response, general infection control measures, including handwashing practices, were reviewed and reinforced with the NICU staff. An environmental inspection was per-

TABLE 1
CHARACTERISTICS OF THE FIVE NEONATES WITH NOSOCOMIAL *PSEUDOMONAS AERUGINOSA* BACTEREMIA FROM FEBRUARY THROUGH AUGUST 1997

Case-Patient	Admitting Diagnosis	Gestational Age (wk)	Birth Weight (g)	Onset	LOS Prior to *P. aeruginosa* BSI (d)	Death	*P. aeruginosa* Genotype
1	RDS	25	723	2/26/97	15	No	A
2	RDS	27	1,010	7/13/97	15	Yes	A
3	Metabolic disorder	34	1,700	7/20/97	9	Yes	A
4	Esophageal atresia	37	2,390	8/13/97	6	Yes	A
5	RDS	29	1,480	8/30/97	6	Yes	A

RDS = respiratory distress syndrome; BSI = bloodstream infection; LOS = length of stay in the neonatal intensive care unit.

formed and samples for surveillance cultures for *P. aeruginosa* were obtained from the remaining patients on three separate occasions during the next 10 days. The two case-patients had been in adjacent beds and in close proximity to a long-term NICU patient known to have respiratory colonization with *P. aeruginosa*. The surveillance cultures of all other patients were negative for *P. aeruginosa*. This led to the working hypothesis that the long-term, colonized patient had served as a reservoir and that the first two case-patients had been infected by indirect contact via the hands of HCWs. The single colonized patient was transferred out of the NICU on July 21, thus removing the hypothesized source-patient. No additional patients were colonized as assessed through biweekly surveillance cultures. However, on August 13, a third fatal case of *P. aeruginosa* BSI occurred. The original hypothesis was rejected and a comprehensive epidemiologic investigation was initiated. Two weeks later, despite ongoing control efforts, a fourth fatal case occurred (Table 1).

Outbreak Investigation

The outbreak investigation included five concurrent areas of inquiry: (1) retrospective case finding and prospective screening cultures of NICU patients to identify additional colonized patients and determine the scope of the outbreak; (2) assessment of infection control procedures to prevent further transmission of *P. aeruginosa*; (3) selected surveillance cultures of the environment and screening cultures of HCWs' hands in search of a possible common source of the outbreak; (4) molecular typing of available isolates to determine whether case-patients were infected or colonized with a single clone of *P. aeruginosa*; and (5) a matched case–control study to elucidate risk factors for *P. aeruginosa* BSI.

Case Finding

Potential case-patients were initially defined as any NICU patient from July 1, 1994, through August 31, 1997, with *P. aeruginosa* colonization or infection at any body site. The computerized microbiology database and infection control surveillance records were reviewed. NICU mortality records for the previous 3 years were reviewed to identi-

fy any cases with possible infectious etiology. The microbiology database and surveillance records were also used to identify additional cases of *P. aeruginosa* BSI in other areas of the hospital. After the outbreak genotype was identified, the preliminary case definition was revised and limited to patients with blood cultures positive for the *P. aeruginosa* outbreak strain from July 1, 1994, through August 31, 1997.

Surveillance Cultures of Patients and the Environment

Patient surveillance cultures for colonization with *P. aeruginosa* were performed from mid-July through September 1997. Cultures were initially performed biweekly but were increased to triweekly after the occurrence of the third case. Samples included stool or perirectal swabs for all NICU patients, and throat cultures were performed for patients who were not receiving ventilation and tracheal aspirate cultures for those who were.

A thorough review of the environment was performed including multiple inspections of the NICU and central respiratory equipment area. To identify a possible inanimate source,[14] cultures were performed of moist areas (eg, sinks, faucets, and water samples), equipment (eg, respirators and bedside monitors), and containers of hand lotions and soaps.

Samples for surveillance cultures were obtained using cotton-tipped swabs (Culturette Collection and Transport Systems, Becton Dickinson Microbiology Systems, Sparks, MD). Samples were immediately transported to the microbiology laboratory and processed within 4 hours of arrival.

Surveillance Cultures of HCWs

All HCWs, including NICU staff as well as personnel from additional support and consultative services caring for NICU patients, had a semiquantitative broth rinse hand culture performed on arrival for work and prior to performing hand hygiene, or on entering the unit.[15,16] Each HCW was screened once; most were screened two or three times during the course of the investigation. HCWs rubbed their hands with 50 mL of broth (10% trypticase soy broth with asolectin and polyethylene glycol

sorbitan monopalmitate)[17] in a sterile basin for 1 minute. Coded vials were stored at 4°C and plated within 8 hours of collection.

HCWs with hand cultures positive for *P. aeruginosa* were referred to the Occupational Health Service, where hand cultures were repeated, a physical examination of skin integrity was performed, and swabs of other body sites (nose, throat, ears, axillae, groin, toe webs, vagina, and rectum) were collected.

Microbiological Methods

Samples for surveillance cultures of patients and the environment and samples from body sites of HCWs with positive results for *P. aeruginosa* were inoculated onto MacConkey and cetrimide agar plates. Semiquantitative cultures were performed of the handwashing samples by inoculating 0.1, 0.5, and 1.0 mL onto three MacConkey plates.

The media were incubated at 35°C and examined for growth at 24 and 48 hours. Non–lactose-fermenting, gram-negative rods were identified by oxidase and characteristic green pigment on cetrimide agar. Pigment negative strains were identified by VITEK GNI+ card (bioMérieux, Hazelwood, MO).

Susceptibility testing was performed on all available *P. aeruginosa* isolates using the MicroScan Autoscan System (Dade Behring, Inc., Sacramento, CA).

Molecular Typing

All available clinical *P. aeruginosa* isolates from patients in the NICU from 1996 to 1997 (n = 6), all available *P. aeruginosa* blood culture isolates from any hospital unit from July 1994 through August 1997 (n = 13), and all isolates from positive surveillance cultures (n = 16) were typed and characterized by pulsed-field gel electrophoresis (PFGE) at the Centers for Disease Control and Prevention using previously validated methods.[18]

Epidemiologic Methods and Statistical Analysis

A matched case–control study was performed including the five definitive case-patients with genotypically identical *P. aeruginosa* bloodstream isolates. With the use of the 1997 NICU admission log and a random numbers table, three control-patients were selected for each case-patient and matched for birth weight and duration of hospitalization. A control-patient was defined as a neonate with a birth weight within 250 g of that of the case-patient, who was hospitalized in the NICU for at least as long as the time until the onset of *P. aeruginosa* infection in the case-patient. All case-patients and control-patients were admitted between February 8 and August 23, 1997. Seven of the 15 control-patients had overlapping NICU admissions, and 5 were hospitalized within 7 days of the matched case-patient. The other three control-patients were hospitalized within 1 to 3 months of the matched case-patient. Risk factors assessed included patient demographics, gestational age, admitting diagnosis, underlying diseases, type and duration of ventilation,
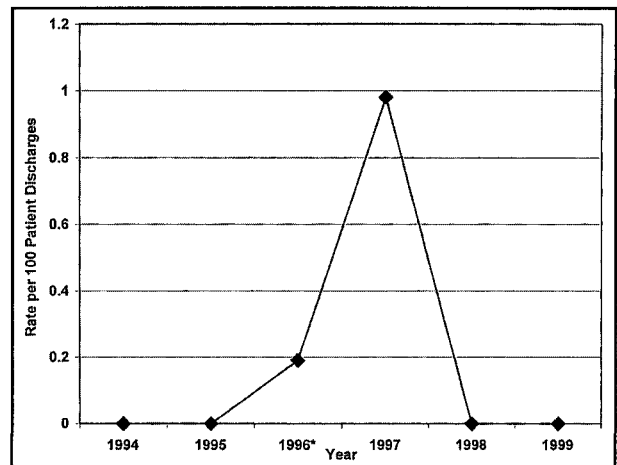

FIGURE 1. Rate of *Pseudomonas aeruginosa* bloodstream infections among patients in the neonatal intensive care unit according to year. *Isolate not available for genotyping.

type of venous or arterial access, antimicrobial use, nutrition, medical interventions, and exposure to individual HCWs. Case-patients were considered exposed to a potential risk factor if the exposure occurred prior to the onset of infection and matched control-patients were considered exposed to a potential risk factor if exposed during a comparable number of ICU-days.

Data were collected retrospectively by review of patient charts and patient care assignment records using standardized forms and were transferred to Epi-Info software (version 6.04; Centers for Disease Control and Prevention, Atlanta, GA). Risk factors for *P. aeruginosa* BSI were determined by Mantel–Haenszel summary chi-square tests for matched set analysis and univariable conditional logistic regression analysis using STATA software (version 6.0; STATA Corp., College Station, TX).

RESULTS

Outbreak Description and Case Finding

During a 6-week period in July and August 1997, four patients in the NICU died of *P. aeruginosa* infection. All four experienced *P. aeruginosa* pneumonia with secondary BSI. Only two cases of *P. aeruginosa* BSI had occurred in the NICU during the 3 years prior to July 1997 (Fig. 1). Based on the lack of positive *P. aeruginosa* BSI prior to July 1996, the analysis was limited to July 1996 through September 1997.

The review of microbiological records from the latter period revealed a total of 16 patients in the NICU with any culture positive for *P. aeruginosa*. Excluding the four case-patients, there were two neonates with BSI, two with eye infection, one with wound infection, and seven with respiratory or gastrointestinal colonization. The microbiology laboratory routinely saves only organisms isolated from sterile body fluids, so the isolates from the patients with eye, wound, respiratory, or gastrointestinal sources were not available for PFGE. However, the *P. aeruginosa*
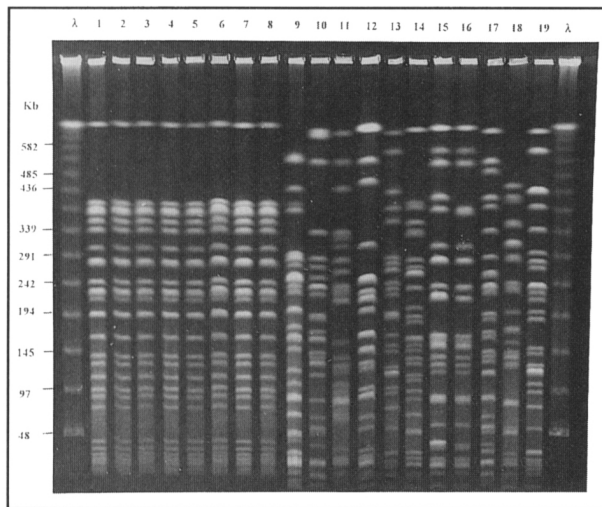
FIGURE 2. Results of pulsed-field gel electrophoresis of *Pseudomonas aeruginosa* strains isolated from neonates, healthcare workers (HCWs), and environmental samples. Lane λ = molecular-size ladder; lane 1 = blood from case-patient 4; lane 2 = blood from case-patient 3; lane 3 = blood from case-patient 2; lane 4 = blood from case-patient 1; lane 5 = blood from case-patient 5; lane 6 = handwash from HCW 2; lane 7 = ear swab from HCW 2; lane 8 = ventilator flow sensor; lane 9 = sink drain 1; lane 10 = faucet blades from sink 2; lane 11 = sink drain 3; lane 12 = faucet sink 4; lane 13 = handwash from HCW 5; lane 14 = handwash from HCW 3; lane 15 = handwash from HCW 1; lane 16 = sputum from patient initially hypothesized to be the source of the *P. aeruginosa;* lane 17 = rectal isolate from surveillance culture of neonatal intensive care unit (NICU) patient 1; lane 18 = rectal isolate from surveillance culture of NICU patient 2; and lane 19 = rectal isolate from surveillance culture of NICU patient 3.

isolate from the colonized, long-term patient hypothesized to be the reservoir for the first two cases of the outbreak was available and was submitted for PFGE.

The two additional cases of *P. aeruginosa* BSI that were identified by case finding occurred in July 1996 and February 1997. The patient from July 1996 underwent autopsy and had extensive necrotizing pneumonia with a blood culture positive for *P. aeruginosa*; however, this isolate was not available for genotyping. The patient from February 1997 had a blood culture positive for *P. aeruginosa* without evidence of pneumonia and was included as a case-patient in our analysis because the isolate was identical to the outbreak genotype. No other cases were identified by review of unit mortality records. Information regarding the five definitive case-patients is summarized in Table 1.

Microbiological Investigation of Patients and the Environment

The five available case isolates had the same antibiotic susceptibility profile, typical of a community isolate (none was resistant to tobramycin, piperacillin, ceftazadime, or imipenem). By PFGE, the five case isolates were identical (Fig. 2). The clinical isolate from the colonized patient originally thought to be the source of the outbreak (n = 1), the isolates obtained from patient surveillance cultures (n = 3), and the bloodstream isolates

from patients in other parts of the hospital (n = 13) were not related to the outbreak strain or to each other.

Seven (4%) of 190 environmental cultures were positive for *P. aeruginosa*. Genotypically unrelated *P. aeruginosa* isolates were obtained from sink handles (n = 2) and sink drains (n = 4). A single culture sample from a wet ventilator flow sensor obtained during reprocessing, which had been cleaned but not disinfected, was positive for the outbreak genotype (Fig. 2).

Microbiological Investigation of HCWs

A total of 327 hand cultures were performed for 178 individual HCWs. Hand cultures of 5 (3%) of the 178 HCWs were repeatedly positive for *P. aeruginosa*, with colony counts ranging from 4 to more than 3,000 colonies per milliliter. Genotyping by PFGE was performed simultaneously on all *P. aeruginosa* isolates of HCWs and the isolates from the five case-patients. The specimens from the hands of HCWs 1, 3, 4, and 5 were unrelated to the outbreak strain or to each other (Fig. 2). Samples for cultures collected from other body sites of HCWs 1, 3, 4, and 5 during the physical examination were negative for *P. aeruginosa*.

The initial hand culture from HCW 2 yielded 4 colonies per milliliter of *P. aeruginosa*. Three hand cultures performed during a 7-day period for HCW 2 yielded a range of 4 to 14 colonies per milliliter of *P. aeruginosa*. In addition, an external ear culture sample, obtained during the physical examination, yielded a moderate amount of *P. aeruginosa* with no clinical evidence of infection. Subsequent ear cultures were negative for *P. aeruginosa*. All case-patient isolates were identical to the *P. aeruginosa* isolates from the hand and external ear cultures of HCW 2 by PFGE (Fig. 2). Samples collected from other body sites of HCW 2 were negative for *P. aeruginosa*.

Epidemiologic Methods and Statistical Analysis

The case–control study of five case-patients with *P. aeruginosa* BSI and 15 control-patients matched on birth weight and duration of NICU exposure revealed no significant associations except a likely association with HCW 2. Four of 5 case-patients versus 5 of 15 matched control-patients had been cared for by HCW 2 (*P* = .05; Table 2). In addition, the mean days of exposure to ventilator flow sensors tended to be higher (*P* = .08) in case-patients than in control-patients (Table 2).

Infection Control Measures

Infection control measures included cohorting of staff and colonized or infected patients, reassignment of HCWs with positive results for *P. aeruginosa* (n = 5) to non-clinical activities, and implementation of contact precautions for all patients infected or colonized with *P. aeruginosa*. Empiric antibiotic coverage of patients with sepsis of unknown origin was changed from ampicillin and gentamicin to piperacillin and tobramycin for optimal coverage of *P. aeruginosa*. In addition to a thorough review of patient care practices, handwashing compliance

TABLE 2

EPIDEMIOLOGIC CHARACTERISTICS OF PATIENTS WITH AND WITHOUT PSEUDOMONAS AERUGINOSA BACTEREMIA*

Characteristic	Case-Patients (n = 5)	Control-Patients (n = 15)	OR‡ (CI$_{95}$)	P§
Mean birth weight, g (± SD)†	1,460 (± 290)	1,530 (± 160)	0.99 (0.98 to 1.01)	> .2
Mean gestational age, wk (± SD)	30.4 (± 2.2)	31.5 (± 1.1)	0.65 (0.31 to 1.36)	> .2
Exposure factors‖				
Surgery	2	7	0.79 (0.11 to 5.43)	> .2
Umbilical catheter	4	7	4.57 (0.34 to 60.86)	> .2
Peripheral catheter	2	4	1.83 (0.20 to 16.49)	> .2
Central venous catheter	0	3	Undefined	> .2
Arterial catheter	2	8	0.58 (0.07 to 4.88)	> .2
Nasogastric tube	5	12	Undefined	> .2
Mechanical ventilation	5	12	Undefined	> .2
Mean days exposed to ventilator flow sensors (± SD)	5.0 (± 1.6)	1.8 (± 0.7)	1.77 (0.93 to 3.37)	.08
Breastfeeding	2	10	0.23 (0.1 to 2.68)	> .2
Chest tube	2	2	4.37 (0.37 to 51.24)	> .2
Ampicillin and gentamicin	4	15	0.33 (∞ to 12.99)	> .2
Cefazolin	1	1	3.0 (0.19 to 47.97)	> .2
Vancomycin	2	3	3.56 (0.27 to 47.27)	> .2
Clindamycin	1	2	1.73 (0.1 to 30.76)	> .2
Exposure to HCW 2	4	5	Undefined	.05

OR = odds ratio; CI$_{95}$ = 95% confidence interval; SD = standard deviation; HCW = healthcare worker.
*Matched case–control study, univariable analysis.
†This variable was used for the matching process.
‡For continuous variables, the OR represents the odds of acquiring P. aeruginosa bacteremia for each 1-unit (age or days exposed to a flow sensor) or 100-unit (weight) increment in the exposure variable of interest. An undefined OR is due to insufficient strata to calculate the effect estimate.
§Calculated by Mantel-Haenszel summary chi-square tests.
‖Exposure factors for cases prior to bacteremia due to P. aeruginosa.

was observed and an alcohol-based handrub was introduced. Wall-mounted, previously opened soaps and lotions were removed and replaced with new, previously unopened stock. Personal hand lotions were removed from the unit. Pharmacy admixing and dosing practices were reviewed, but no changes were necessary. Discrepancies with recommended high-level disinfection policies for ventilator flow sensors were addressed. After the occurrence of the fourth case of fatal P. aeruginosa BSI, the NICU was closed to new admissions until completion of the investigation.

No cases occurred following reassignment of the HCWs with positive results for P. aeruginosa to non-clinical duties. HCWs with positive results for P. aeruginosa performed a handwashing regimen of a 1-minute wash with a 2% chlorhexidine gluconate antimicrobial product hourly during waking hours for a 5-day period. HCWs 3, 4, and 5 had no evidence of nail infection and returned to clinical duties approximately 1 month after their initial positive handwashing culture, when it was determined that their isolates did not match the outbreak strain and repeat hand cultures were negative for P. aeruginosa. Eradication of P. aeruginosa was confirmed by two negative hand cultures performed after completion of the handwashing regimen.

The P. aeruginosa isolate from HCW 1 was not related to the outbreak strain (Fig. 2). During the physical examination in Occupational Health Services, HCW 1 noted that treatment for onychomycosis had recently been completed as prescribed by a personal dermatologist. HCW 1 was treated with a 14-day course of ciprofloxacin, performed the handwashing regimen and follow-up testing described above, and returned to clinical duties 7 weeks after the initial positive culture.

After identification of the probable source of the outbreak, the otitis externa of the implicated HCW (HCW 2) was treated with a 5-day course of combination steroid and antibiotic otic solution (hydrocortisone, neomycin sulfate, and polymyxin B). Clearance of P. aeruginosa from the hands was documented by three negative handwashing cultures performed during a 1-month period, following completion of the previously described handwashing regimen. To verify eradication of P. aeruginosa ear colonization, cultures of both ears were performed every 2 weeks for a 2-month period, followed by two additional sets 2 and 6 months later. HCW 2 resumed clinical duties 3 months after the initial positive handwashing culture was identified, when 3 negative hand cultures and 2 negative ear cultures were performed after the completion of treatment.

DISCUSSION

The identification of a cluster of four patients with rapidly fatal *P. aeruginosa* infection prompted this outbreak investigation. The third and fourth cases occurred despite comprehensive traditional outbreak control measures, so the unit was closed for new admissions while the investigation continued. Using a combination of microbiological and epidemiologic methods, we identified a HCW with intermittent otitis externa as the most likely source for this cluster of infections. Although clinical evidence of otitis externa was absent during the initial physical examination, the HCW was a swimmer and recalled bouts of intermittent otitis externa prior to and during the outbreak. Although the mechanism of transmission cannot be definitively ascertained, it is plausible that *P. aeruginosa* could have been spread from ear to hand to patient. The outbreak terminated after the implicated HCW was removed from clinical duties, treated, and cleared of *P. aeruginosa* carriage. No further cases of *P. aeruginosa* infection or colonization with the implicated genotype have occurred.

An alternative hypothesis focused on contaminated respiratory care equipment as the potential source of infection. Although a problematic disinfection practice was identified, the appropriate high-level disinfection process was reimplemented 2 weeks prior to the occurrence of the fourth case. In addition, of five flow sensors cultured during various stages of the discrepant disinfection process, only one sensor was positive for the outbreak strain and no cases occurred in two other ICUs that used the same ventilator sensors.

Neonatal infections due to *P. aeruginosa* include pneumonia, BSI, meningitis, conjunctivitis, and surgical-site, urinary tract, and gastrointestinal infection.[1,2,19] Although less common than some other causes of neonatal infection,[20] *P. aeruginosa* sepsis is particularly virulent in this patient population, with case-fatality rates exceeding 50%.[2] Although sporadic cases do occur, most published reports have focused on outbreaks of *P. aeruginosa*.[21] However, *P. aeruginosa* outbreaks have rarely been attributed to hand carriage of HCWs. Recently, two NICU outbreak investigations have associated nosocomial *P. aeruginosa* infection with hand carriage of HCWs.[10,12] Moolenaar et al.[10] described an outbreak of *P. aeruginosa* BSI and endotracheal tube colonization in a NICU and determined that exposure to two particular nurses was associated with acquiring *P. aeruginosa*. Interestingly, the genetic and environmental evidence found in this investigation suggested a possible role for long natural or artificial fingernails in the colonization of the implicated HCWs' hands with *P. aeruginosa*. Foca et al.[12] conducted an epidemiologic and molecular investigation of *P. aeruginosa* infection or colonization in their NICU. Cultures performed from environmental sources were negative, but cultures of the hands of 10 (6%) of 165 HCWs were positive for *P. aeruginosa*. Significant risk factors for colonization included the use of artificial nails or nail wraps. However, only one HCW with *Candida* species ony-

chomycosis was persistently colonized with a *P. aeruginosa* strain that was identical to the predominant clone. All other *P. aeruginosa* isolates of HCWs were unrelated to the predominant clone or to other patient clones identified.

In our study, a total of five HCWs were at least transiently colonized with *P. aeruginosa* strains, a finding previously described.[22] Because the initial outbreak control measures included reinforcement of good hand hygiene practices, our primary intention in requesting hand cultures of a variety of HCWs was to focus attention on the hands as a possible means of patient-to-patient indirect transmission. Although we knew from previous studies performed in our NICU that HCWs' hands may be colonized with gram-negative bacteria,[23] we were surprised to find five HCWs with hand cultures positive for *P. aeruginosa*. Of these five HCWs, the implicated HCW (HCW 2) had the lowest colony count from the initial hand culture (4 colonies per milliliter), with a moderate amount of *P. aeruginosa* from the culture of the external ear, supporting the theory of transient hand carriage with transmission by indirect contact from the ear to hand to patient. The range of colony counts for the remaining four HCWs with positive results for *P. aeruginosa* was 930 to more than 3,000 colonies per milliliter. Of note, one HCW had previously received treatment for onychomycosis and was colonized with a non-outbreak strain. This particular strain differed by one band from the strain from the long-term, ventilator-dependent, colonized patient initially hypothesized to be the reservoir for the initial two cases in July (Fig. 2).

Although culturing of HCWs is generally not performed in the early stages of an outbreak investigation, we elected to initiate hand cultures prior to the case–control study. In our experience, hand cultures may have provided a more rapid identification of a possible source of the outbreak, and reassignment of staff with positive results for *P. aeruginosa* to non-clinical duties may have avoided additional cases while the investigation continued. Early HCW screening may also identify individuals with onychomycosis, dermatitis, or other conditions that might increase the risk of chronic hand colonization. However, it is not unusual for HCWs to have transient hand colonization with nosocomial pathogens, and aggressive culturing could lead to unnecessary exclusion of HCWs from clinical care and considerable anxiety.

Our investigation had limitations. First, case-patients may have been missed. Although the retrospective review of the microbiological database from July 1996 through September 1997 revealed 16 patients with clinical cultures positive for *P. aeruginosa*, the laboratory routinely saved only isolates from sterile body sites. The bloodstream isolates were available, but isolates from 10 patients with *P. aeruginosa* from the eyes, wounds, and respiratory or gastrointestinal tracts were unavailable for molecular typing. In addition, the patient from July 1996 had a clinical course similar to those of the four case-patients who died, but the blood culture positive for *P.*

aeruginosa was of an autopsy specimen. Autopsy samples also were not routinely saved in the laboratory, so an additional case-patient may have been missed.

Second, we must acknowledge that the small sample size of the case–control study limited the precision of the matched set analysis, yielding large 95% confidence intervals. However, despite the limitations of such a small data set, the disappearance of the epidemic strain from the unit after removal and treatment of the implicated HCW strongly suggests that this HCW may have been the primary source of the epidemic.

Finally, although a significant association was demonstrated between the exposure of 4 of the 5 case-patients and 5 of the 15 control-patients to HCW 2 ($P = .05$), the relationship may have been attenuated by our definition of exposure. For our investigation, exposure was defined as being assigned the primary care of the patient, or participating in the initial transport of the patient to our facility. Although HCW 2 was not assigned the primary care or the transport of one of the five case-patients, HCW 2 had been assigned to a patient in the bed adjacent to the nonexposed case-patient. It is plausible that exposure may have occurred during cross-coverage, or when assistance with patient care was provided.

We investigated an outbreak of fatal neonatal pneumonia and BSI caused by a single strain of *P. aeruginosa*. With the help of hand cultures and molecular and epidemiologic analyses, we linked one HCW with intermittent otitis externa to the outbreak. Treatment and removal of the implicated HCW ended the outbreak. These findings demonstrate the hazards of infected or colonized HCWs in the NICU setting and the challenges related to rapid detection of asymptomatic carriage of potential pathogens. Detecting and eradicating HCWs' infection or colonization with potential pathogens may reduce the risk of life-threatening cross-infections.

REFERENCES

1. Gaynes RP, Edwards JR, Jarvis WR, et al. Nosocomial infections among neonates in high-risk nurseries in the United States: National Nosocomial Infections Surveillance System. *Pediatrics* 1996;98:357-361.
2. Leigh L, Stoll BJ, Rahman M, et al. *Pseudomonas aeruginosa* infection in very low birth weight infants: a case-control study. *Pediatr Infect Dis J* 1995;14:367-371.
3. Baird RM, Shooter RA. *Pseudomonas aeruginosa* infections associated with use of contaminated medicaments. *Br Med J* 1976;2:349-350.
4. Archibald LK, Ramos M, Arduino MJ, et al. *Enterobacter cloacae* and *Pseudomonas aeruginosa* polymicrobial bloodstream infections traced to extrinsic contamination of a dextrose multidose vial. *J Pediatr* 1998;133:640-644.
5. Cobben NA, Drent M, Jonkers M, et al. Outbreak of severe *Pseudomonas aeruginosa* respiratory infections due to contaminated nebulizers. *J Hosp Infect* 1996;33:63-70.
6. Becks VE, Lorenzoni NM. *Pseudomonas aeruginosa* outbreak in a neonatal intensive care unit: a possible link to contaminated hand lotion. *Am J Infect Control* 1995;23:396-398.
7. Neal TJ, Hughes CR, Rothburn MM, et al. The neonatal laryngoscope as a potential source of cross-infection. *J Hosp Infect* 1995;30:315-317.
8. Garland SM, Mackay S, Tabrizi S, et al. *Pseudomonas aeruginosa* outbreak associated with a contaminated blood-gas analyser in a neonatal intensive care unit. *J Hosp Infect* 1996;33:145-151.
9. Thom AR, Cole AP, Watrasiewicz K. *Pseudomonas aeruginosa* infection in a neonatal nursery, possibly transmitted by a breast-milk pump. *Lancet* 1970;1:560-561.
10. Moolenaar RL, Crutcher JM, San Joaquin VH, et al. A prolonged outbreak of *Pseudomonas aeruginosa* in a neonatal intensive care unit: did staff fingernails play a role in disease transmission? *Infect Control Hosp Epidemiol* 2000;21:80-85.
11. Widmer AF, Wenzel RP, Trilla A, et al. Outbreak of *Pseudomonas aeruginosa* infections in a surgical intensive care unit: probable transmission via hands of a health care worker. *Clin Infect Dis* 1993;16:372-376.
12. Foca M, Jakob K, Whittier S, et al. Endemic *Pseudomonas aeruginosa* infection in a neonatal intensive care unit. *N Engl J Med* 2000;343:695-700.
13. Mermel LA, McKay M, Dempsey J, et al. *Pseudomonas* surgical-site infections linked to a healthcare worker with onychomycosis. *Infect Control Hosp Epidemiol* 2003;24:749-752.
14. Grundmann H, Kropec A, Hartung D, et al. *Pseudomonas aeruginosa* in a neonatal intensive care unit: reservoirs and ecology of the nosocomial pathogen. *J Infect Dis* 1993;168:943-947.
15. Larson EL, Strom MS, Evans CA. Analysis of three variables in sampling solutions used to assay bacteria of hands: type of solution, use of antiseptic neutralizers, and solution temperature. *J Clin Microbiol* 1980;12:355-360.
16. Larson EL, Hughes CA, Pyrek JD, et al. Changes in bacterial flora associated with skin damage on hands of health care personnel. *Am J Infect Control* 1998;26:513-521.
17. Isenberg HD. Epidemiologic and infection control microbiology. In: Gilchrist MJR, ed. *Clinical Microbiology Procedures Handbook*, vol. 2. Washington, DC: American Society for Microbiology; 1992.
18. Talon D, Cailleaux V, Thouverez M, et al. Discriminatory power and usefulness of pulsed-field gel electrophoresis in epidemiological studies of *Pseudomonas aeruginosa*. *J Hosp Infect* 1996;32:135-145.
19. Richards MJ, Edwards JR, Culver DH, et al. Nosocomial infections in pediatric intensive care units in the United States: National Nosocomial Infections Surveillance System. *Pediatrics* 1999;103:e39.
20. Holzel H, de Saxe M. Septicaemia in paediatric intensive-care patients at the Hospital for Sick Children, Great Ormond Street. *J Hosp Infect* 1992;22:185-195.
21. Damjanovic V, van Saene HK. Outbreaks of infection in neonatal intensive care units (NICUs). *J Hosp Infect* 1997;35:237-244.
22. Knittle MA, Eitzman DV, Baer H. Role of hand contamination of personnel in the epidemiology of gram-negative nosocomial infections. *J Pediatr* 1975;86:433-437.
23. Goldmann DA, Leclair J, Macone A. Bacterial colonization of neonates admitted to an intensive care environment. *J Pediatr* 1978;93:288-293.