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Original Article

An outbreak of methicillin-resistant *Staphylococcus aureus* infection in patients of a pediatric intensive care unit and high carriage rate among health care workers

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Background and Purpose: Methicillin-resistant *Staphylococcus aureus* (MRSA) has been the leading cause of nosocomial infections in many hospitals. To investigate the impact of carriage by health care workers (HCWs) on patient transmission, surveillance culture was performed following an outbreak of MRSA in a pediatric intensive care unit (PICU).

Methods: Isolates from 61 HCWs and 10 environmental sites were collected. Pulsed-field gel electrophoresis (PFGE) and antibiogram analysis were performed to determine the clonal relationship between isolates and potential routes of transmission.

Results: The overall carriage rate of HCWs was 67.2% (41/61) for *S. aureus* and 26.2% (16/61) for MRSA. One MRSA was isolated from the 10 environmental sites sampled. Two major MRSA clusters were identified based on the PFGE patterns. Isolates with indistinguishable PFGE patterns (pulsotype A) were found in all patient isolates from the outbreak, from several HCWs plus the environmental isolate; all were resistant to ciprofloxacin, clindamycin, erythromycin, gentamicin, tetracycline, and trimethoprim-sulfamethoxazole. Interestingly, the isolate from a patient who had prolonged hospitalization in PICU had PFGE patterns (pulsotype B) distinct from the strains involved in the outbreak. This strain was susceptible to ciprofloxacin and trimethoprim-sulfamethoxazole, and was also found in several HCWs. Thus, there appeared to be 2 main MRSA clones circulating in the PICU of our hospital.

Conclusions: Person-to-person and environment-to-person (or vice versa) transmissions are documented in this study. Strict hand washing before and after patient contact must be enforced and closely monitored, as it is the principal preventive measure in containing the spread of MRSA. To prevent the emergence of vancomycin-resistant MRSA and the further transmission of multidrug-resistant organisms, implementation of periodic and routine active surveillance cultures as part of infection control measures may also be evaluated.

Key words: Carrier state; Cross infection; Infection control; *Staphylococcus aureus*

Introduction

Methicillin-resistant *Staphylococcus aureus* (MRSA) is a major cause of morbidity and mortality around the world. It has also been one of the most common causes of nosocomial infections since the late 1970s [1-3]. In the United States, the proportion of nosocomial infections due to MRSA increased from 2% in the 1980s to nearly 50% in 2004 according to the National Nosocomial Infection Surveillance System [4]. In the United Kingdom, 44% of *S. aureus* isolated from the health care system in 2004 was methicillin resistant [5]. In Japan, MRSA comprised 60-70% of *S. aureus* strains isolated from inpatients [6].

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In a multicenter surveillance study in Taiwan, the rate of methicillin resistance among *S. aureus* collected from inpatients and outpatients combined was nearly 60%, and was highest in isolates from the intensive care unit (ICU) [73%], followed by the wards (62%) and outpatient settings (41%) [7]. A study from a major medical center in Taiwan also found a remarkable increase in MRSA prevalence, accounting for 75-84% of *S. aureus* nosocomial infections from 1998-2000, compared to less than 30% in 1990 [8].

MRSA may spread from person-to-person and from one hospital to another, causing outbreaks in different hospitals [9,10]. Although carriage of MRSA by health care workers (HCWs) has been a topic of concern since the 1980s [11-13], the precise role that HCWs play in initiating and maintaining MRSA outbreaks in the hospitals is not well defined. To elucidate the possible transmission of MRSA between HCWs, the hospital environment, and patients, we investigated an outbreak of MRSA in the pediatric ICU (PICU) of a tertiary care hospital in southern Taiwan. Pulsed-field gel electrophoresis (PFGE) and antibiograms were analyzed on isolates obtained from patients, HCWs, and environmental samples to determine their clonal relationship and the potential routes of transmission.

Methods

Study population

A patient (patient P1) who had had prolonged hospitalization in the PICU of a tertiary care hospital in southern Taiwan was known to be sputum culture positive for MRSA for a long period of time since January 2001. In October 2001, MRSA was isolated from 3 patients within a period of 15 days (designated as patients P3, P4, and P5). These patients were admitted in 3 adjacent beds (bed numbers 2, 3, and 4, respectively; Fig. 1) in the PICU. Multiple isolates of MRSA were obtained from wound, sputum, and blood specimens of these patients. Another 2 patients (patients P2 and P6) who

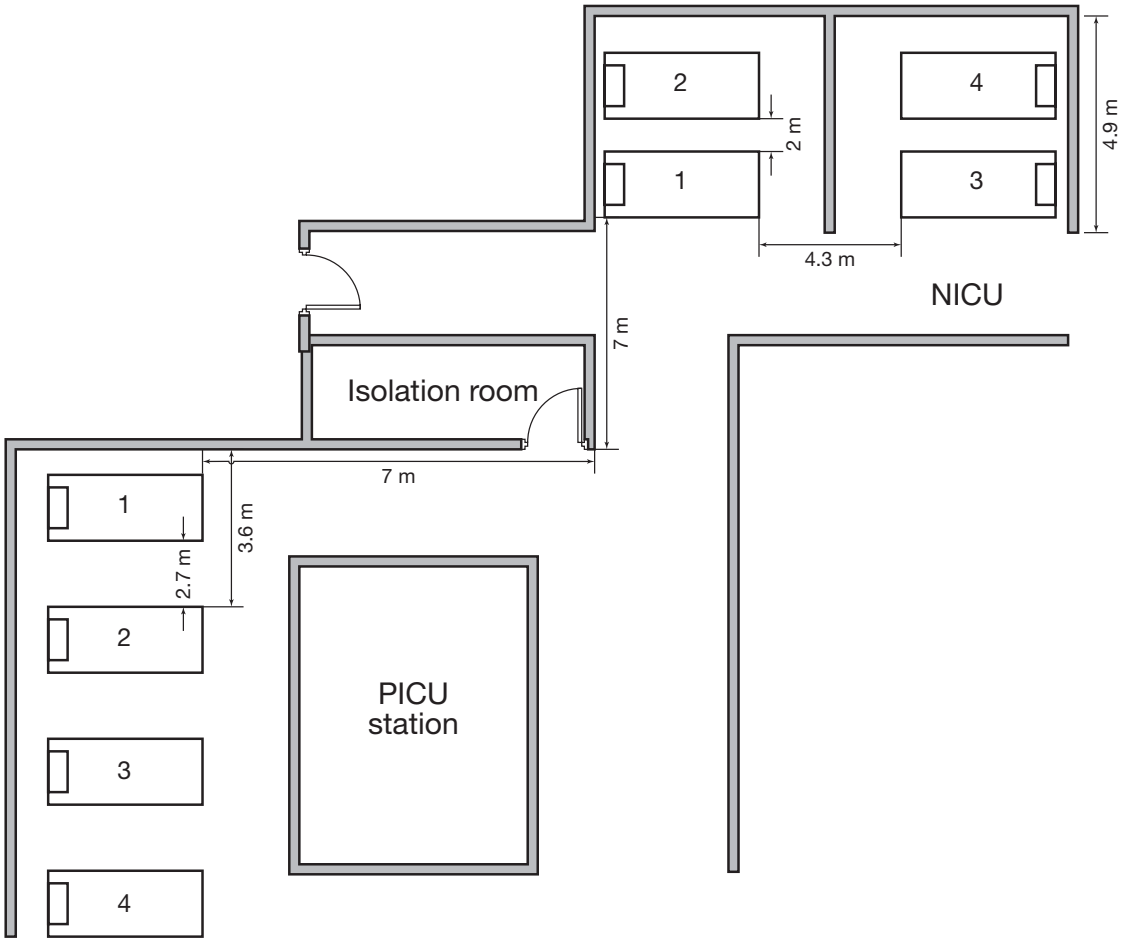


Fig. 1. Layout of the pediatric intensive care unit (PICU) and neonatal intensive care unit (NICU) at the Veterans General Hospital-Kaohsiung. The NICU is a continuation of the PICU with the shortest distance between NICU and PICU being approximately 7 m.

stayed in the neonatal ICU (NICU) adjacent to the PICU, about 18 m from bed 2 (Fig. 1), also had MRSA within that period of time. Despite the fact that there was a long-term MRSA carrier in the PICU, it seemed unusual that 5 patients had cultures positive for MRSA within such a short period of time, and thus, an investigation was conducted.

Surveillance cultures were performed on the HCWs including all of the nursing personnel of both PICU and NICU, and some of the physicians (14/38, 36.8%) during November 2001. In addition to the medical personnel, environmental cultures were also performed on samples obtained within PICU at the same time. The nine isolates obtained from the 6 patients (patients P1-P6) including the patient who was known to be a MRSA carrier before this outbreak (patient P1), and all isolates obtained from the surveillance cultures were eligible for the study.

Specimen collection and processing for surveillance culture

Specimens for surveillance culture were obtained from HCWs and the environment by a single investigator. A single sterile cotton swab was used to sample both nares, which was then plated immediately onto 5% sheep blood agar (SBA) plate (Becton Dickinson Microbiology System, Cockeysville, MD, USA). The right and left hand specimens of HCWs were obtained by placing their hands onto 2 separate SBA plates directly without washing their hands before culture. The environmental samples were taken before the regular daily cleaning. Sterile cotton swabs moistened with sterile saline were rolled several times over a surface area of approximately 5×5 cm^2 and then inoculated onto the SBA plates. The environmental sites cultured included the patients' charts, bed rails, faucets, monitors, oxygen adapters on the wall, suction switches, and ventilator buttons. These surveillance cultures were performed during November 2001.

Identification and antimicrobial susceptibility testing

Identification of *S. aureus* was performed according to standard bacteriological procedures. Gram stain reactions, colony morphology, catalase, slide (Staphaurex Plus; Remel Europe Ltd., Dartford, England) and tube coagulase (coagulase plasma, rabbit with ethylenediamine tetra-acetic acid; Becton Dickinson Microbiology Systems, Sparks, MD, USA) were used for identification. MRSA strains from clinical samples were defined as those *S. aureus* isolates resistant to methicillin based on the disk diffusion testing of 10 μg oxacillin disk on Columbia agar supplemented with 5% sodium chloride at 37°C after 24-48 h incubation. Methicillin resistance was checked by the ability of the isolate to grow on Columbia agar supplemented with 5% salt and 4 mg/L methicillin. All isolates were stored in a blood glycerol broth at –70°C. Methicillin resistance was subsequently confirmed by minimal inhibitory concentration (MIC) testing as described below.

Susceptibilities to 13 antimicrobials were determined based on results of the MICs obtained from the broth microdilution method in accordance with the guidelines of the Clinical and Laboratory Standards Institute [14], using Sensititre custom designed plates (Trek Diagnostics, East Essex, England). Antimicrobials tested included chloramphenicol, ciprofloxacin, clindamycin, erythromycin, gentamicin, oxacillin, penicillin, quinupristin/dalfopristin, rifampin, tetracycline, trimethoprim-sulfamethoxazole (SXT), vancomycin, and teicoplanin.

PFGE

Clonal relationship of all MRSA isolates was determined by PFGE using *Sma*I digested genomic DNA. DNA plugs were prepared by following manufacturer's instructions for the GenePath Group 6 Reagent kit (Bio-Rad Laboratories, Hercules, CA, USA). After restriction enzyme digestion with 50 U of *Sma*I, gels were electrophoresed for 24 h at 14°C at a constant voltage of 6 V/cm, with starting and ending pulse time of 2.2 and 37.3 s, respectively, using the CHEF Mapper (Bio-Rad). PFGE patterns were analyzed using the CHEF Mapper XA Interactive Software (Version 1.2, Bio-Rad). Cluster analysis was performed by unweighted pair-group method with arithmetic mean with Jaccard's coefficient and the dendrograms prepared. The assignment of PFGE patterns followed published guidelines [15]. Isolates with ≥80% similarity were considered to belong to the same pulsotype and subtypes were assigned to isolates having ≤3 DNA band differences within the same pulsotype.

Infection control measures

A series of infection control measures were implented after this outbreak in addition to the surveillance culture. HCWs were required to wear a surgical mask, a cap, and gloves during contact with MRSA-positive patients. Hand washing with chlorhexidine surgical scrub before and after contact with patients was also implemented. Antibiotic control was monitored discreetly by the infection control team.

Table 1. Demographic and clinical data of patients from whom methicillin-resistant *Staphylococcus aureus* was isolated

Patient no.	Age/gender	Ward bed	Underlying disease	Date		Specimen	PFGE pattern
				Admission	Culture		
P1	10 months/M	PICU-10	Recurrent pneumonia with respiratory failure	September 29, 2000	August 14, 2001	Sputum	B1
P2	8 days/M	NICU-01	Prematurity	October 16, 2001	October 24, 2001	Sputum	A1
P3-1	4 years/M	PICU-03	Head injury	August 18, 2001	October 25, 2001	Sputum	A2
P3-2					November 3, 2001	Sputum	A2
P3-3					November 8, 2001	Pus	A2
P4-1	2 months/M	PICU-05	Congenital heart disease	October 12, 2001	October 26, 2001	Blood	A3
P4-2					November 7, 2001	Pus	A3
P5	22 days/F	PICU-02	Prematurity	October 7, 2001	October 29, 2001	Sputum	A1
P6	25 days/F	NICU-05	Prematurity	October 13, 2001	November 7, 2001	Eye discharge	A1

Abbreviations: PFGE = pulsed-field gel electrophoresis; M = male; F = female; PICU = pediatric intensive care unit; NICU = neonatal intensive care unit

Nosocomial infection rate of MRSA

Nosocomial infection rate of MRSA was defined as the number of infections divided by patient-days spent at the hospital in a month. This method was considered to be more appropriate than the method of simply dividing the number of infections acquired during a month by the number of patients discharged during that month so that differences over time could be tested [16].

Results

Demographic and clinical data of patients

Demographic and clinical data of the 6 patients are listed in Table 1. Patient P1 was admitted in September 2000, and the MRSA isolate used in this study was obtained from his sputum culture in August 2001. Between October 24 and 26, 2001, MRSA was cultured from the sputum of patients P2 and P3, and from the blood culture of patient P4. Within a few days, patients P5 and P6 also had MRSA isolated from their sputum and eye discharge, respectively. MRSA was also isolated from follow-up cultures of the sputum and wound samples of P3, and the wound sample of P4 in early November. P2 to P6 were hospitalized for periods of 8 days to more than 2 months before MRSA was first isolated from the samples. These isolates are identified using the patient number throughout the manuscript (P1, P2, P3-1, P3-2, P3-3, P4-1, P4-2, P5, and P6).

S. aureus and MRSA carriage among HCWs

A total of 61 HCWs, including 47 nursing staff (100.0%) and 14 physicians (36.8%), and 10 environmental sites were studied. The detailed results for carriage are shown in Table 2. Of the 61 HCWs studied, 41 (67.2%) had *S. aureus* colonized in nares and/or hands, among whom 16 (26.2%, 16/61) carried MRSA. A total of 24 MRSA isolates were recovered from these 16 HCWs, among whom MRSA was isolated from the nares and both hands in 2 HCWs (2/61, 3.3%), from the nares and one hand in 4 HCWs (4/61, 6.6%), from the nares only in 5 HCWs (5/61, 8.2%), and from the hands only in 5 HCWs (5/61, 8.2%). These results indicated that had we only sampled the nares, some MRSA carriage would have been missed. The HCW MRSA isolates are identified with a prefix M and S in Table 3 and Fig. 2. Of the 10 environmental sites cultured from the PICU, MRSA was isolated from the button of the ventilator (isolate V1).

Nosocomial infection rate of MRSA

Before this outbreak, the average nosocomial infection rate of MRSA in the PICU was 1.15 per 1000 patient-days between January and September 2001. The nosocomial infection rate of MRSA in the PICU declined from 8.03 per 1000 patient-days in October 2001 to 4.05 per 1000 patient-days in November 2001.

Table 2. *Staphylococcus aureus* (inclusive of methicillin-susceptible *S. aureus* and methicillin-resistant *S. aureus* [MRSA]) and MRSA carriage state of 61 health care workers

Specimen positive in	No. of health care workers positive (%)	
	S. aureus	MRSA
Nares only	18 (29.5)	5 (8.2)
One hand only	5 (8.2)	5 (8.2)
Both hands only	0 (0.0)	0 (0.0)
Nares and one hand	11 (18.0)	4 (6.6)
Nares and both hands	7 (11.5)	2 (3.3)
Any specimen	41 (67.2)	16 (26.2)

Table 3. Antimicrobial susceptibility and pulsed-field gel electrophoresis (PFGE) patterns of the methicillin-resistant *Staphylococcus aureus* isolates from patients, health care workers, and the hospital environment

Isolate[a]	Specimen	PFGE pattern[b]	MIC and interpretation[c]													
			CHL		CIP		CLI		ERY		GEN		SXT		TCY	
M1	Left hand	A1	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
M12	Nares	A1	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
M13	Nares	A1	R	32	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
S2	Right hand	A1	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
P2	Sputum	A1	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
P5	Sputum	A1	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
P6	Eye	A1	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
P3	Sputum	A2	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
V1	Ventilator button	A2	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
P4	Blood	A3	I	16	R	>4	R	>4	R	>4	R	>16	R	>4	R	>8
M10	Nares	B1	R	>32	S	0.25	R	>4	R	>4	S	≤1.0	S	≤0.5	R	>8
M16	Nares	B1	R	32	S	0.5	R	>4	R	>4	S	≤1.0	S	≤0.5	S	≤1.0
M25	Nares	B1	R	>32	S	0.5	R	>4	R	>4	S	≤1.0	S	≤0.5	R	>8
P1	Sputum	B1	R	>32	S	0.25	R	>4	R	>4	R	>16	S	≤0.5	R	>8
M15	Nares	B2	R	>32	S	≤0.06	R	>4	R	>4	R	>16	S	≤0.5	R	>8
M22	Right hand	B2	R	>32	S	0.5	R	>4	R	>4	R	>16	S	≤0.5	R	>8
M3	Left hand	B3	I	16	S	0.25	S	≤0.25	I	1	S	≤1.0	S	≤0.5	R	>8
S3	Right hand	B3	R	32	S	0.25	S	≤0.25	S	0.5	S	≤1.0	S	≤0.5	R	>8
M23	Nares	B4	I	16	S	0.12	R	>4	R	>4	R	>16	S	≤0.5	R	>8
M9	Left hand	B4	I	16	S	0.25	R	>4	R	>4	R	>16	S	≤0.5	S	≤1.0
M6	Left hand		R	>32	S	0.5	R	>4	R	>4	R	>16	S	≤0.5	S	≤1.0
S9	Nares		R	>32	S	0.12	R	>4	R	>4	R	>16	S	≤0.5	S	≤1.0
M19	Nares		I	16	S	0.25	S	≤0.25	S	0.5	S	≤1.0	S	≤0.5	R	>8

Abbreviations: MIC = minimal inhibitory concentration; CHL = chloramphenicol; CIP = ciprofloxacin; CLI = clindamycin; ERY = erythromycin; GEN = gentamicin; SXT = trimethoprim-sulfamethoxazole; TCY = tetracycline; I = intermediate; R = resistant; S = susceptible

[a]Isolates with the prefix P were obtained from patients; isolates with the prefixes M and S were obtained from health care workers.

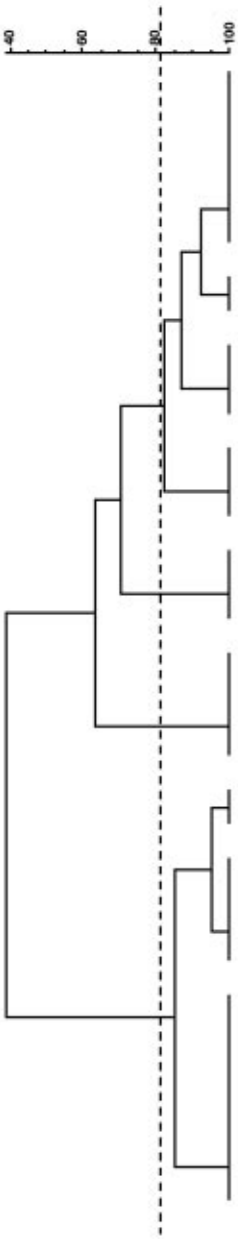
[b]For PFGE patterns, see Fig. 2. Single isolates with PFGE patterns distinct from patterns in A and B clusters were not assigned a pattern name.

[c]All isolates were susceptible to quinupristin/dalfopristin (MIC, 0.25-1.00 μg/mL), rifampin (MIC, ≤0.5 μg/mL), teicoplanin (MIC, ≤1 μg/mL), and vancomycin (MIC, 1 μg/mL).

The overall nosocomial infection rate of ICUs in this tertiary care hospital was 5.31 per 1000 patient-days through 2001.

Antimicrobial susceptibility and PFGE patterns of MRSA isolates

All 9 MRSA isolates from the 6 patients and all 24 MRSA isolates from the 16 HCWs were tested for antimicrobial susceptibility and subjected to molecular typing by PFGE. All MRSA isolates were susceptible to quinupristin/dalfopristin (MIC, 0.25-1 μg/mL), rifampin (MIC, ≤0.5 μg/mL), teicoplanin (MIC, ≤1 μg/mL), and vancomycin (MIC, 1 μg/mL). The susceptibility profiles of the other 7 antimicrobials and the dendrogram generated from the PFGE results of the MRSA isolates from 6 patients and 16 HCWs are presented in Table 3 and Fig. 2. Because isolates from the same patient and HCWs had similar antibiograms and indistinguishable PFGE patterns (Fig. 2), only one isolate per patient and HCW is presented in Table 3.



Isolate no.	Specimen	PFGE pattern	Same person as
M25	Nares	B1	
M26	Right hand	B1	M25
P1	Sputum	B1	
M10	Nares	B1	
M11	Left hand	B1	M10
M16	Nares	B1	
M22	Right hand	B2	
M15	Nares	B2	
M3	Left hand	B3	
M4	Nares	B3	M3
S3	Right hand	B3	
M23	Nares	B4	
M24	Left hand	B4	M23
M9	Left hand	B4	
M19	Nares		
M20	Right hand		M19
M21	Left hand		M19
M6	Right hand		
M7	Left hand		M6
M8	Nares		M6
S9	Nares		
P4-1	Blood	A3	
P4-2	Wound	A3	P4-1
V1	Ventilator	A2	
P3-1	Sputum	A2	
P3-2	Sputum	A2	P3-1
P3-3	Wound	A2	P3-1
P2	Sputum	A1	
P6	Eye	A1	
P5	Sputum	A1	
M1	Left hand	A1	
M12	Nares	A1	
M13	Nares	A1	
S2	Right hand	A1	

Fig. 2. Dendrogram of methicillin-resistant *Staphylococcus aureus* isolates based on pulsed-field gel electrophoresis (PFGE) results of *SmaI* (restriction enzyme from *Serratia marcescens*) digested genomic DNA. Isolates with the prefix P were obtained from patients; isolates with the prefixes M and S were obtained from health care workers (HCWs); and the isolate with the prefix V1 was from the ventilator button. Isolates from the same patients or HCWs are noted in the last column. Isolates that share 80% or greater similarity were assigned a PFGE pattern starting with the same letter (A or B), while those with identical patterns were assigned the same subtype. Single isolates with PFGE patterns distinct from patterns in A and B clusters were not assigned a pattern name.

Based on the PFGE patterns, the MRSA isolates could be divided into 2 distinct clusters (patterns A and B). All PFGE pattern A (pulsotype A) isolates were resistant to ciprofloxacin, clindamycin, erythromycin, gentamicin, SXT, and tetracycline. Isolates obtained from patients P2, P5, and P6 were indistinguishable from each other and were designated PFGE pattern A1. Four isolates obtained from HCWs also had A1 PFGE pattern indistinguishable from patient isolates, indicating that these isolates were all part of the outbreak. All 3 isolates obtained from patient P3 demonstrated pattern A2, which was indistinguishable from that of

the environmental isolate (V1). Of note is the fact that the environmental isolate was obtained from the ventilator button more than 2 weeks after the isolation of MRSA from patient P3. The isolate from patient P4 (pattern A3) was closely related to A2 isolates with just 2 band difference; thus, the A2 and A3 isolates were probably involved in the outbreak along with isolates with PFGE pattern A1.

Pulsotype B isolates were all susceptible to ciprofloxacin and SXT. However, pulsotype B isolates had varied susceptibilities to clindamycin, erythromycin, gentamicin, and tetracycline. The isolate from patient P1, who had been admitted to PICU for a long time and had cultured positive for MRSA multiple times, showed a totally different PFGE pattern (B1) from that of the other patients. The susceptibility profile of this isolate was also quite different from those of patients 2 to 6, indicating that the MRSA isolate from P1 was not involved in the outbreak. However, several HCWs carried MRSA indistinguishable from P1. In addition, several other HCWs carried MRSA with 80% or higher similarity to B1 isolates (patterns B2 to B4, Fig. 2) despite the fact that the P1 isolate and HCW isolates were obtained over 3 months apart, indicating that this closely related clone may be evolving in our hospital and is being transmitted between HCWs.

Discussion

Our study documented the transmission of MRSA between HCWs and patients. MRSA strains frequently colonize the anterior nares, throat, or perineum of the host, particularly in immunocompromised patients, such as preterm infants [17]. Medical staff can be a vehicle in the spread of MRSA within a hospital, as direct person-to-person contact contributes to the transmission of MRSA. It is generally believed that MRSA may spread from colonized HCWs to patients and vice versa. However, reports documenting such transmission are scarce [18,19].

The PFGE and antibiogram results of our study prove beyond doubt the transmission of infection between patients and HCWs. In our study, the PFGE patterns of patients P2-P6 were either indistinguishable or closely related according to the Tenover criteria [15]. There were also HCWs whose isolates demonstrated the same PFGE patterns as those of isolates from patients P2, P5, P6 (pulsotype A1), and P1 (pulsotype B), thereby establishing the transmission of MRSA between patients and HCWs.

Environment may serve as a reservoir for *S. aureus*, in addition to the person-to-person transmission observed, as *S. aureus* can survive for relatively long survival periods on inanimate surfaces. *S. aureus* is stable in dry environments with a median survival time of 12 days (1 to >60 days) on inanimate surfaces in ICUs [20,21]. In comparison, the median survival time of other important pathogens, such as *Pseudomonas aeruginosa*, is around 1.5 days in ICU. The finding of a PICU environmental sample MRSA isolate with a PFGE pattern indistinguishable from that of a patient isolate involved in an outbreak 2 weeks earlier confirmed the role of the environment in maintaining MRSA and thus facilitating its transmission. Similar results have also been reported from patients in a geriatric long-term ward and in isolation rooms [22,23].

It is biologically plausible that MRSA from patients can contaminate the environment, with MRSA from the environment being transmitted back to other patients through HCWs due to unsatisfactory infection control measures. It has been reported that the longer a patient stays in the ICU, the higher the likelihood of his colonization with MRSA, as indicated by the higher MRSA colonization rates seen in patients during weeks 3 and 4 of hospitalization than in weeks 1 and 2 [23]. Long hospital stays may also contribute to transmission of MRSA from the environment to patients.

The antibiograms of the MRSA isolates from the 5 patients (P2 to P6) involved in the outbreak were virtually identical. These isolates showed multidrug resistance. A previous study of MRSA isolates collected between 1986 and 2001 from a university hospital in northern Taiwan revealed that multidrug-resistant MRSA accounted for 95% of all MRSA isolates causing nosocomial infections [24]. It appears that multidrug-resistant MRSA is a common problem in the hospitals in Taiwan. It is alarming to find several HCWs carrying the same pulsotype of MRSA, i.e., pulsotype A, as the patients — they were all resistant to ciprofloxacin, gentamicin, and SXT, in addition to clindamycin, erythromycin, and tetracycline.

All isolates in pulsotype B were uniformly susceptible to ciprofloxacin and SXT. The molecular basis for the varied susceptibilities to gentamicin for isolates within patterns B1 and to tetracycline for isolates within B1 and B4 is unknown at the present time. Horizontal gene transfer may play a role as resistance genes for these 2 classes of antibiotics are often carried on transferable genetic elements. The fact that several

HCWs also carried MRSA with indistinguishable PFGE patterns from that of the P1 isolate is a great concern — how and when the HCWs and P1 acquired this MRSA strain is not known. However, this finding further emphasizes the need for routine surveillance of HCWs and patients at risk for MRSA carriage. Furthermore, the antibiograms of P1 isolate and the several other MRSA strains carried by some HCWs showed that they might be closer to the community-acquired MRSA reported in other countries [25,26]. Community-acquired MRSA infections in Taiwanese children have been reported recently [27]. All isolates in that report were also susceptible to ciprofloxacin and SXT.

Another recent study of MRSA from Taiwan also revealed that in addition to the predominance of the multidrug-resistant MRSA clones with resistance profile similar to our pulsotype A isolates, another closely related clone with less resistance and distinct genetic profiles is also common in Taiwanese hospitals [28]. Further molecular characterization of the pulsotype B isolates in this study and circulating strains of community-acquired MRSA in Taiwan may clarify its origin and identify factors allowing its persistence in the hospital environment.

The most effective control measure for the prevention of nosocomial transmission of MRSA is contact precautions, including the frequent washing of hands, wearing of gloves and gowns, and cohorting of patients, as MRSA is transmitted by direct contact. However, in most facilities, most colonized patients are still undetected and not kept apart even with the implementation of contact precautions.

In 2003, the Society for Healthcare Epidemiology of America (SHEA) emphasized the importance of active surveillance culture of patients and HCWs, in addition to contact precaution and antibiotic usage control, since most colonized patients are never recognized using clinical microbiology cultures [29]. SHEA recommends the following measures for the control of the spread of MRSA:

- active surveillance cultures to identify the reservoir of spread
- hand hygiene of medical staff
- barrier precautions for patients known or suspected to be colonized or infected with MRSA, such as gloves, gowns, and masks
- antibiotic stewardship — avoid inappropriate or excessive antibiotic use
- decolonization or suppression of colonized patients
- others, such as educational programs, environmental disinfection, etc.

Although we did not have such a policy in our hospital at the time of the outbreak and only identified the MRSA infections from clinical cultures, it is worth noting that the nosocomial infection rate of MRSA did decrease after surveillance culture for HCWs was performed in the PICU. Increased awareness of hand hygiene and strict contact precautions also reduced the transmission, hence lowering the MRSA nosocomial infection rate.

It is not well established whether all patients hospitalized in the same ward should be screened in an outbreak setting [29], especially in view of the fact that HCWs have been implicated in the transmission of MRSA between patients. Further, because we also wanted to identify the potential environmental reservoirs of MRSA, we only performed environmental sampling and screening of the HCWs. Because the physicians who cared for ICU patients were always on rotation, not all of them were available for surveillance culture. It is possible that some of these HCWs carried the same MRSA strain as the patients, and so there may have been more transmission of infection between HCWs and patients. However, the nasal carriage rate of the HCWs surveyed (18%) was already quite high compared to the rates (less than 10%) reported in other countries [13,30]. This study also provided ample evidence of an MRSA outbreak in a PICU and the transmission of MRSA between HCWs and patients.

In summary, there were 2 main clusters of MRSA circulating in the PICU. In this study, person-to-person and environment-to-person (or vice versa) transmission have been documented. The high MRSA carriage rate of the PICU medical staff indicated that the infection control program needs much strengthening. Currently, the increasing prevalence of nosocomial MRSA infections and colonization remains a critical problem to be solved. Strict hand washing before and after patient contact must be enforced and monitored, as it remains the key infection control measure for controlling the spread of MRSA. To prevent the emergence of vancomycin-resistant MRSA and the transmission of multidrug-resistant organisms, implementation of periodic or routine active surveillance cultures may also be considered as part of the infection control measures.

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