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Contamination of Portable Radiograph Equipment With Resistant Bacteria in the ICU

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Background: **Approximately 15% of nosocomial infections in the ICU result from spread of bacteria on caregivers' hands. The routine chest radiograph provides an unexamined opportunity for bacterial spread: close contact with each patient and sequential examination of ICU patients. This study examined infection control procedures performed during routine chest radiographs, assessed whether resistant bacteria were transferred to the radiograph machine, and determined whether improved infection control practices by radiograph technicians could reduce bacterial transfer.**

Methods: **Radiograph technicians were observed performing chest radiographs on all ICU patients. Culture specimens were taken from the radiograph machine. An educational intervention directed at technicians was instituted, and its effect on infection control and machine contamination was measured.**

Results: **Surveillance of 173, 113, and 120 chest radiographs during observation, intervention, and follow-up periods was performed. Adequate infection control was practiced during the performance of 2 of 173 observation period radiographs (1%), 48 of 113 intervention period radiographs (42%; $p < 0.001$), and 12 of 120 follow-up period radiographs (10%; ($p < 0.001$) [follow-up vs intervention and observation periods]. Radiograph machine surface culture samples yielded resistant Gram-negative bacteria on 12 of 30 occasions (39%), 0 of 29 occasions, and 7 of 14 occasions (50%), respectively, for the observation, intervention, and follow-up periods ($p < 0.001$).**

Conclusion: **Multiresistant bacteria are frequently transferred from patients to the radiograph machine in the presence of poor infection control practices, and may be a source of cross-infection/colonization. Improved infection control practices decrease the occurrence of resistant organisms on the radiograph equipment. Radiograph technicians should be included in efforts to improve infection control measures.** ***(CHEST 2009; 136:426–432)***

Abbreviations: MRSA = methicillin-resistant *Staphylococcus aureus*; PFGE = pulsed-field gel electrophoresis; VRE = vancomycin-resistant enterococcus

Nosocomial infections caused by highly resistant bacteria[1] are a major problem encountered in modern ICUs and affect 20% of ICU patients.[2] They are associated with attributable mortality (up to 44%), prolonged ICU admission,[3] and increased costs.[4,5] Approximately 15% of these infections are thought to originate from patient-to-patient transfer of bacteria,[6] with the primary mechanism beinginadequate hand hygiene by members of the ICU team.

For editorial comment see page 335

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Table 1—*Results of Radiograph Technician Observation Regarding Use of Infection Control Measures Before (Observation), During (Intervention), and After (Follow-up) Institution of the Educational Intervention*

Infection Control Steps	Observation (Phases 1 and 2)	Intervention (Phase 3)	Follow-up (Phase 4)	p Value*		
				1	2	3
Subgroup 1. Before starting patient care						
Put on gloves before touching patient	144 (83)	92 (81)	105 (88)			
Alcohol hand rub before touching patient	19 (11)	39 (35)	16 (13)	1c	2c	
Washed hands before touching patient	4 (2)	18 (16)	12 (10)	1c		3b
Put cassette in plastic bag	83 (48)	112 (99)	113 (94)	1c		3c
Subgroup 2. After inserting cassette and before touching radiograph machine						
Removed gloves before touching machine	25 (14)	55 (49)	61 (51)	1c		3c
Put on new gloves before touching machine	26 (15)	44 (39)	10 (8)	1c	2c	
Alcohol hand rub before touching machine	0 (0)	60 (53)	33 (28)	1c	2c	3c
Washed hands before touching machine	0 (0)	5 (4)	5 (4)	1b		3a
Subgroup 3. After performing radiograph but before removing cassette						
Changed gloves before removing cassette	2 (1)	46 (41)	20 (17)	1c	2c	3c
Alcohol hand rub before removing cassette	10 (6)	43 (38)	11 (9)	1c	2c	
Washed hands before removing cassette	0 (0)	13 (12)	6 (5)	1c		3b
Subgroup 4. After removing cassette and before moving to next patient						
Removed gloves before moving to next patient	120 (69)	98 (87)	51 (43)	1c	2c	3c
Alcohol hand rub before moving to next patient	21 (12)	56 (50)	11 (9)	1c	2c	
Washed hands before moving to next patient	5 (3)	30 (27)	1 (1)	1c	2c	

Data are presented as No. of times radiograph technician performed each infection control step ([No./total number of radiographs performed during relevant study period] × 100).

*Observation vs intervention: 1a, $p < 0.05$; 1b, $p < 0.01$; 1c, $p < 0.001$. Intervention vs follow-up: 2a, $p < 0.05$; 2b, $p < 0.01$; 2c, $p < 0.001$. Observation vs follow-up: 3a, $p < 0.05$; 3b, $p < 0.01$; 3c, $p < 0.001$.

Radiograph technicians are not generally considered to be part of the "ICU team." They are not exposed to the educational activity of the ICU and thus might not be aware of the problems wrought by resistant bacteria and their spread. However, radiograph technicians come to the ICU daily, moving from patient to patient while performing routine chest and other radiographs. These procedures involve close contact between the radiology technician and the patient, creating situations where bacteria can be transferred to the technicians' hands and subsequently to the radiograph machine, which could serve as a reservoir for spreading these resistant bacteria to other patients. The sequential nature of daily radiograph rounds could thus be a source of patient-to-patient bacterial transfer if adequate infection control precautions are not followed. This study investigated the following: (1) the adequacy of infection control procedures during the performance of chest radiographs in the ICU, (2) whether resistant bacteria are transferred to the radiograph machine and whether similar bacteria were isolated from ICU patients, and (3) whether improved infection control practices could reduce bacterial colonization of the portable radiograph machine.

Materials and Methods

This study was performed in the ICU (20 beds) of the Hadassah-Hebrew University Medical Center at Ein Kerem, a 750-bed urban academic tertiary referral center. The study included four phases.

Phase 1: Covert Observation

For radiographs performed over 2 months, a yes/no notation was recorded for each of 14 predefined infection control measures by a study investigator without the technician's knowledge (first column, Infection Control Steps, Table 1). Broadly, the infection control steps included the possibility of glove use, alcohol hand rub use, and hand washing during the radiograph process. "Adequate practice" was defined as the use of at least one step from each subgroup, considered to be the minimum required to break a potential chain of infection. "Best practice" would have included hand washing prior to patient contact and subsequent alcohol hand rub and glove use at each stage. In addition, radiograph cassettes were placed in nylon bags prior to use and wiped with chlorhexidine/alcohol after exposure and removal from the bag.

Phase 2: Observation and Microbiology

Surface culture samples were obtained from the radiograph machine at the end of the morning radiograph round (and also on some occasions prior to commencing the radiograph round) specifically seeking Gram-negative bacteria resistant to ceftazidime, ceftriaxone, or imipenem; methicillin-resistant *Staphylococcus aureus* (MRSA); or vancomycin-resistant enterococci (VRE), the "resistant" bacteria. Other bacteria were defined as "nonresistant" and classified only according to the Gram stain characteristics.

Using aseptic technique, a 2 × 2 cm sterile gauze was soaked with 3 mL of tryptic soy broth and wiped vigorously over the handle, trigger, aiming device, and other areas touched by the radiograph technician (Fig 1). The gauze was inserted into a sterile container and immediately transported to the microbiology laboratory. Cultures were incubated overnight after the addition of further tryptic soy broth and vortex mixing of the sample. Subcultures were made on Columbia colistin-nalidixic acid agar and MacConkey agar (Novamed; Jerusalem, Israel), and

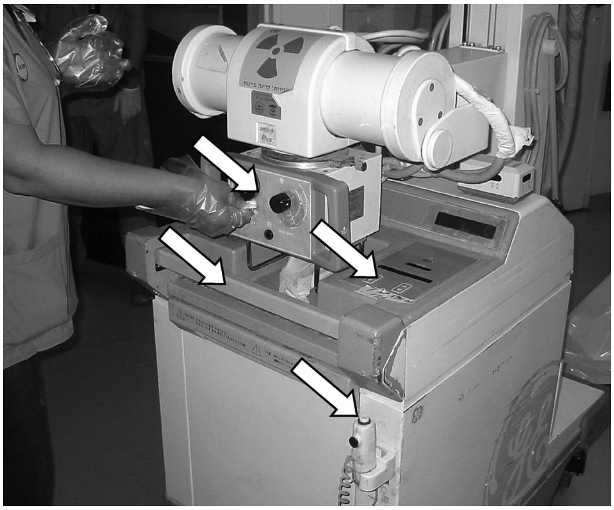

FIGURE 1. Areas of radiograph machine cultured (marked by arrows).

disks of ceftazidime, ceftriaxone, and imipenem were applied. After a further overnight incubation, catalase-positive colonies resembling staphylococci and catalase-negative colonies resembling enterococci (bile-esculin positive, growth in the presence of 6% NaCl) were picked from the colistin-nalidixic acid plates and identified to species level. *S aureus* was tested for methicillin resistance using cefoxitin disks.[7] Vancomycin resistance in enterococci was sought by culture on Mueller-Hinton agar containing 4 mg/L vancomycin and subsequent minimal inhibitory concentration determination using the Etest (AB Biodisk; Solna, Sweden). Any Gram-negative organism showing no inhibition zone or a noticeably small zone around a disk, or growing within a zone demarcated by susceptible organisms in the often mixed cultures, was identified by routine conventional methods and subjected to susceptibility testing according to the Clinical and Laboratory Standards Institute disk diffusion procedure.[7] Extended-spectrum β-lactamase production was confirmed by the disk approximation test.

The ICU care protocol determined that routine nasal, axillary, and perineal surveillance cultures for the resistant organisms defined earlier were obtained on all patients on admission to the ICU and weekly thereafter. In addition, all blood culture isolates were routinely preserved at −80°C in the microbiology laboratory.

Resistant *Acinetobacter baumannii* isolates from the radiograph machine and from blood culture isolates of patients present during the study were examined by pulsed-field gel electrophoresis (PFGE) according to the protocol of the European Commission Concerted Action project Antibiotic Resistance Prevention and Control.[8] Strain relatedness was determined visually according to the criteria of Tenover et al.[9]

Phase 3: Intervention

The radiology technicians were informed in personal discussion every day prior to the radiograph round that infection control practices were not being adhered to, that multiresistant bacteria were being cultured from the radiograph machine, and that this could be detrimental to patient safety. They were requested to improve infection control measures using alcohol hand rub and changing gloves before and after each contact with the patient or radiograph machine. During this period, the collection of radiograph machine cultures was continued and further limited noncovert observations made of infection control practice.

Phase 4: Follow-up

Five months after conclusion of the intervention, an additional month of technician observation and machine cultures was performed. Basic demographic patient data were collected during study phases 2 to 4. The institutional ethics committee approved the performance of this study.

Data Analysis

No record was made of the radiograph technicians' or patients' names. Analyses were performed using statistical software (SAS version 8.02; SAS Institute; Cary, NC). Data from the observation, intervention, and follow-up periods were compared using the Student *t* test, and the χ^2 or Fisher exact tests as appropriate.

In order to simplify interpretation of the technician observation data, a summary measure of glove and alcohol hand rub use was created. There were four occasions when glove change and/or alcohol hand rub could be employed: one in each infection control practice subgroup. The mean number of times each action was employed was calculated and compared across the study periods.

To ensure comparability of the observation, intervention, and follow-up periods, the number of "at-risk" days for transfer of resistant bacteria to the radiograph machine was calculated. An at-risk day was defined as a patient ICU day following detection of resistant bacteria in either surveillance or clinical cultures until ICU discharge. Microbiological records were checked from hospital admission for all ICU patients in order to ascertain whether they had colonization/infection with resistant bacteria prior to ICU admission.

To assess the clinical impact of the intervention, bacteriologic data were used to assess the appearance of the resistant bacteria defined earlier in patients free of them on admission. For this analysis, surveillance and clinical cultures were used.

Because this study was not supported by external funding, sample size was determined by observer availability and limited laboratory facilities. All p values are two tailed (except where specified), and significance was defined as $p < 0.05$.

RESULTS

This study was performed over 13 months from February 2007 to March 2008. The initial observation and microbiology periods (phases 1 and 2) lasted 4 months together, the intervention period was 4 months, and the follow-up period was 1 month. Basic demographic data were similar for the observation, intervention, and follow-up phases of the study (Table 2).

Observation of 173, 113, and 120 chest radiographs during the observation, intervention, and follow-up periods were performed (Table 1). A marked improvement in infection control practice occurred from the observation to intervention periods (Table 1). The presence of adequate practice increased from 2 of 173 radiographs (1%) in the observation period to 48 of 113 radiographs (42%) in the intervention period ($p < 0.001$). Individual actions and adequate practice declined during the

Table 2—*Basic Demographics*

Variables	Observation (Phases 1 and 2)	Intervention (Phase 3)	Follow-up (Phase 4)	p Value
Patients admitted, No.	64	46	19	
Age, yr	60 ± 19	63 ± 18	65 ± 16	0.502
APACHE II score	27 ± 12	26 ± 12	26 ± 12	0.947
Length of ICU stay, d	10 ± 13	9 ± 12	7.5 ± 5	0.617
Male gender	41 (64)	26 (56)	10 (53)	0.578
ICU mortality	12 (19)	8 (17)	6 (31)	0.399
Hospital mortality	22 (34)	15 (33)	8 (42)	0.785

Data are presented as mean ± SD or No. (%) unless otherwise indicated.

follow-up period with adequate practice being evident in 12 of 120 radiographs (10%; $p < 0.001$; follow-up vs intervention periods); however, this remained better than at baseline ($p < 0.001$; adequate practice in follow-up vs observation periods).

Gloves were used appropriately on 1.7 ± 0.8, 2.5 ± 1.1, and 1.6 ± 0.9 occasions (maximum of 4 occasions), respectively, for the observation, intervention, and follow-up periods (observation vs intervention, $p < 0.001$; intervention vs follow-up, $p < 0.001$; observation vs follow-up, $p = 0.002$). Alcohol hand rub was used appropriately on 0.3 ± 0.7, 1.7 ± 1.1, and 0.6 ± 0.9 occasions for the three periods (observation vs intervention, $p < 0.001$; intervention vs follow-up, $p < 0.001$; observation vs follow-up, $p = 0.07$).

During the microbiology phase of the observation period, preradiograph round surface culture samples were obtained on 11 occasions. No resistant Gram-negative organisms or VRE were cultured; MRSA was cultured once (1 in 11; 9%). Three of 11 preround cultures (27%) grew no bacteria, 1/11 grew susceptible Gram-positive bacteria (9%), and 5 of 11 grew susceptible Gram-negative bacteria (45%). At the end of the morning radiograph round, resistant Gram-negative bacteria were cultured on 12 of 30 surface culture sets obtained (39%) and VRE on 1 of 30 occasions (3%). Eleven postround cultures (11 of 30; 37%) grew no bacteria, 6 of 30 postround cultures (19%) grew susceptible Gram-positive bacteria, and 6 of 30 postround cultures (19%) grew susceptible Gram-negative bacteria (Table 3). On 10 of 12 days (83%) when a resistant Gram-negative bacterium was cultured from the radiograph machine, the same species was present in surveillance or clinical cultures of at least one ICU patient.

Comparing only paired sets of cultures from the observation periods (sets with preround and postround radiograph sets from the same day), resistant Gram-negative organisms appeared in the postround radiograph sets on 4 of 11 occasions (36%; one-tailed $p = 0.045$). MRSA (found in one preround radiograph culture set) was not found in the matched postround radiograph set.

Table 3—*Bacteriologic Results of Radiograph Machine Culture Samples Obtained at the End of the Daily Radiograph Round*

Variables	Observation (Phases 1 and 2)	Intervention (Phase 3)	Follow-up (Phase 4)	p Value*		
				1	2	3
Culture samples, No.	30	29	14			
Culture result						
Resistant organisms						
A baumannii	5 (17)	0 (0)	4 (29)		2b	
K pneumoniae	6 (20)	0 (0)	4 (29)	1a	2b	
Pseudomonas aeruginosa	1 (3)	0 (0)	0 (0)			
Stenotrophomonas maltophilia	1 (3)	0 (0)	0 (0)			
Resistant Gram negatives†	12 (39)	0 (0)	6 (43)	1c	2c	
VRE	1 (3)	0 (0)	1 (7)			
Nonresistant organisms						
Gram positives	6 (19)	6 (21)	11 (79)		2c	3c
Gram negatives	6 (19)	5 (17)	8 (57)		2c	3b
Culture negative	11 (37)	22 (67)	1 (7)	1b	2c	

Data are presented as No. of isolates cultured (%) unless otherwise indicated.
*Observation vs intervention: 1a, $p < 0.05$; 1b, $p < 0.01$; 1c, $p < 0.001$. Intervention vs follow-up: 2a, $p < 0.05$; 2b, $p < 0.01$; 2c, $p < 0.001$. Observation vs follow-up: 3a, $p < 0.05$; 3b, $p < 0.01$; 3c, $p < 0.001$.
†Total No. of cultures with resistant Gram-negative organism; exceeds number of individual cultures as multiple bacteria grew in single cultures.

During the intervention phase, 29 postround radiograph machine surface culture samples were obtained. The presence of resistant Gram-negative organisms decreased to zero (vs 12 of 31 [39%] during the observation period; $p < 0.001$) [Table 3]. No culture findings were positive for VRE or MRSA. The proportion of cultures without bacterial growth increased from 11 of 30, or 37% (observation period) to 22 of 29, or 67%; $p = 0.002$. The presence of susceptible Gram-positive and Gram-negative organisms did not change. Twelve paired preround and postround radiograph culture sets were obtained during this period. No resistant organisms were cultured in any of these sets.

During the follow-up period, 14 paired (preround and postround) machine cultures were obtained. Resistant bacteria were isolated from 7 of 14 postround machine cultures (50%), an increase to levels not significantly different from the observation period (Table 3). The occurrence of nonresistant bacteria was higher in the follow-up period than both the observation and intervention periods (Table 3). In contrast to the other study periods, more resistant bacteria were present in the preround machine cultures during the follow-up period (*A baumannii* on 1 of 14 occasions [7%], *Klebsiella pneumoniae* on 2 of 14 occasions [14%], and VRE on 1 of 15 occasions [7%].

PFGE was performed on eight multidrug resistant *A baumannii* isolates obtained from the radiograph machine during the observation phase (Fig 2). Of these, three (lanes 4, 8, and 9) showed band patterns that were identical to each other and to *A baumannii* isolates obtained from a patient (lanes 5, 6, and 7) who was present in the unit at the time that these radiograph machine cultures were taken. Other *A baumannii* isolates obtained from clinical cultures, the radiograph machine, and other sites in the hospital during the study period showed a wide range of band patterns. The number of at-risk days for bacterial transfer and the number of new patient colonizations/infections are shown in Table 4.

Discussion

Radiograph technicians and their equipment were identified by the present study as a likely important additional focus to be considered when attempting to reduce bacterial cross-infection between ICU patients. This study showed that infection control measures are practiced poorly by radiograph technicians, that over the short-term infection control practices can be significantly improved, but that the improvement is not maintained over time. In parallel, the study demonstrated that the radiograph equipment is frequently colonized by highly resistant bacteria, in some cases bacteria identical to those found in patient cultures; that improved infection control technique reduces contamination to zero; but that with a regression of infection control practices, resistant bacteria appear again. The incidence of new patient infection/colonization also decreased

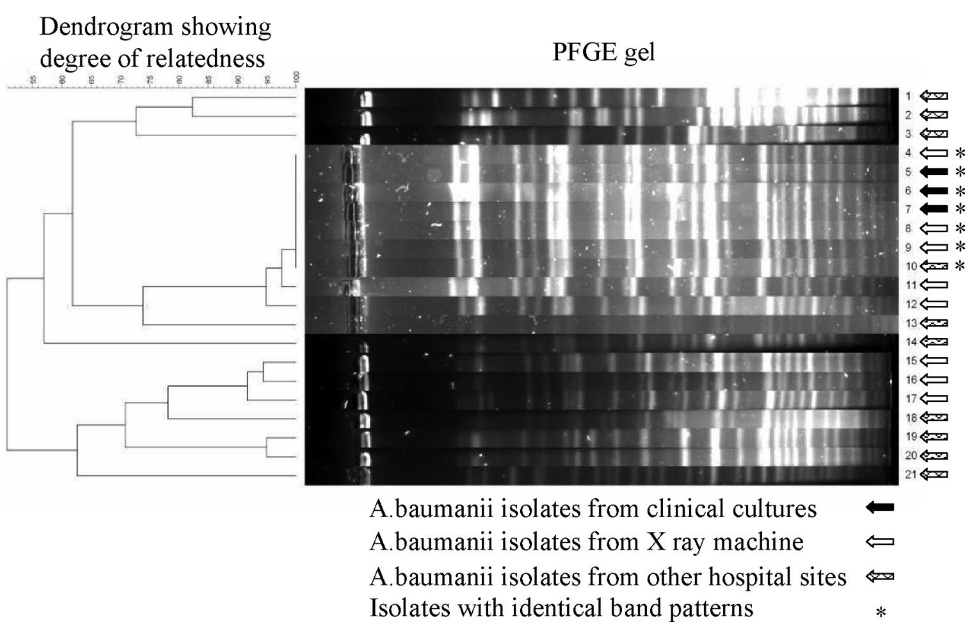

Figure 2. Results of PFGE analysis of *A baumannii* isolates showing clonal similarity between cultures taken from radiograph machine and patient.

Table 4—*At-Risk Days for Transmission of Resistant Bacteria Found on Radiograph Machine, and Incidence of New Patient Infection/Colonization During the Study Periods*

Variables	Observation (Phases 1 and 2)	Intervention (Phase 3)	Follow-up (Phase 4)	p Value* 1	p Value* 2	p Value* 3
Patient days with risk of bacterial transmission						
Total patient days	740	389	221			
K pneumoniae	162 (22)	111 (29)	36 (16)	1a	2c	
Pseudomonas aeruginosa	135 (18)	91 (23)	0 (0)	1a	2c	3c
A baumannii	155 (21)	25 (6)	2 (1)	1c	2b	3c
VRE	140 (19)	66 (17)	41 (19)			
MRSA	191 (26)	81 (21)	24 (11)		2b	3c
Patients free of resistant bacteria on admission but with new infection/colonization in the ICU						
Total patients	70	65	27			
K pneumoniae	12 (17)	3 (5)	1 (4)	1a		
P aeruginosa	4 (6)	5 (8)	0 (0)			
A baumannii	8 (11)	1(2)	1 (4)		2a	
VRE	9 (13)	5 (8)	1 (4)			
MRSA	7 (10)	6 (9)	1 (4)			
Total new infection/colonization	40 (57)	20 (31)	4 (15)	1b		3c

Data are presented as No. or No. (%). At-risk days for bacterial transmission = total No. of patient days after discovery of a resistant bacteria in clinical or surveillance cultures.

*Observation vs intervention: 1a, $p < 0.05$; 1b, $p < 0.01$; 1c, $p < 0.001$. Intervention vs follow-up: 2a, $p < 0.05$; 2b, $p < 0.01$; 2c, $p < 0.001$. Observation vs follow-up: 3a, $p < 0.05$; 3b, $p < 0.01$; 3c, $p < 0.001$.

from the observation to intervention periods (there were too few events in the follow-up period for comment).

Many inanimate objects in the ICUs (such as computer equipment, sink faucets, beds, and chairs[10–12]) are reservoirs of resistant bacteria, bacteria with genetic profiles identical to those bacteria found in patients.[13] Indeed, these inanimate objects (fomites) may remain colonized by bacteria for prolonged periods of time (up to several weeks).[14–16] To our knowledge, this is the first description of the portable radiograph machine as a fomite for resistant organisms in the ICU. Because transfer of resistant bacteria to the radiograph machine occurs so frequently, and the radiograph machine is often moved sequentially from ICU patient to ICU patient, performing the routine chest radiograph has the potential to spread resistant bacteria in the ICU. The portable chest radiograph could also have a role in the spread of infection beyond the ICU because during the follow-up period in this study, 4 of 14 of machine cultures (29%) were positive for resistant organisms before starting the radiograph round, suggesting the import of resistant organisms to the ICU from other hospital areas.

Bacteria are transferred very rapidly from patients to caregivers' hands in the ICU, at a rate estimated to be up to 24.5 cfu/min on ungloved hands for a range of ICU care procedures,[17,18] and 16.7 cfu/min on gloved hands during respiratory care.[17] So, although contact between the radiograph technician and the patient was limited to inserting the radiograph cassette behind the patient's back and later removing it, this could have been sufficient for the transfer of bacteria. Alternatively, bacteria could have originated from other fomites within the ICU.

It is notoriously difficult to improve hand hygiene compliance in the hospital environment. Much research has been directed to quantifying and improving hand hygiene implementation, it has been widely reviewed, and guidelines have been formulated.[19] Although physicians and nurses' practices have been repeatedly found to be inadequate (particularly physicians),[18] to date, radiograph technicians have not been examined. Unfortunately, as has been found in many other studies[19] of hand hygiene, although the intervention was successful, its maintenance was difficult.

This study was not intended to demonstrate a chain of infection from one patient to the next via the radiograph machine. To design such a study would be virtually impossible because it would require isolation of the chest radiograph process from all other aspects of ICU care. Despite this, there was a significant decrease in the incidence of new colonizations/infections with resistant bacteria during the intervention period, and this with a similar number of at-risk days.

The study was limited because it was based on observations from only one hospital. Also, although there was a parallel improvement in the infection control measures employed by the radiograph technicians and decrease in the occurrence of radiograph machine colonization, it is possible that this effect was due to a general increase in infection control awareness resulting from the study intervention that might have been expressed in ways not measured in the study. Further, the interpretation of the PFGE analysis was limited by the following: (1) the clonal nature of all carbapenem-resistant *K pneumoniae* isolates in the hospital, and (2) the limited availability of *A baumannii* from clinical cultures for comparison with radiograph machine cultures.

Despite the only transient improvement in technician hand hygiene procedures, this study serves two purposes. First it should raise awareness that radiology equipment is a possible source of cross-contamination, a finding previously undescribed. Radiology departments represent a major crossroads in modern hospitals with almost all hospitalized patients undergoing some imaging procedure. Although the study was performed in an ICU, its results are probably applicable to equipment such as a CT scanner or MRI tables. Patient contact with this equipment is considerably longer than with the chest radiograph cassette. Indeed, based on this research, positive surface culture results were obtained from CT scanner beds in our hospital, and subsequently the use of antiseptic wipes instituted between patients. Secondly, the study should lead to further investigation into the effect of radiograph technician hand hygiene on the occurrence of nosocomial infections in ICU patients, for which our study population was too small to assess. In conclusion, this unique study showed that radiograph technicians and their equipment are likely an important link in ICU cross-infection and should be included in efforts to improve infection control practices.

Acknowledgments

Author contributions: Dr. Levin: study initiator and coordinator; contributed to data collection, entry, and analysis, and manuscript preparation. Drs. Shatz and Or-Barbash, and Ms. Moriah: collected observational data and machine cultures. Dr. Sviri: collected demographic data on ICU patients. Dr. Sprung: contributed to study design, data analysis, and manuscript preparation. Drs. Moses and Block: contributed microbiological data.
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Contamination of Portable Radiograph Equipment With Resistant Bacteria in the ICU

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