American Journal of Infection Control 44 (2016) 898-904

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Hospital air: A potential route for transmission of infections caused by β-lactam–resistant bacteria

Seyed Hamed Mirhoseini PhD [a,b,c], Mahnaz Nikaeen PhD [a,*], Zahra Shamsizadeh MS [a,b], Hossein Khanahmad PhD [d]

[a] Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran
[b] Student Research Center, Isfahan University of Medical Sciences, Isfahan, Iran
[c] Department of Environmental Health Engineering, School of Health, Arak University of Medical Sciences, Arak, Iran
[d] Department of Genetics and Molecular Biology, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran

Key Words:
Airborne
hospital
antibiotic-resistant bacteria
nosocomial infection
β-lactam

Background: The emergence of bacterial resistance to β-lactam antibiotics seriously challenges the treatment of various nosocomial infections. This study was designed to investigate the presence of β-lactam–resistant bacteria (BLRB) in hospital air.

Methods: A total of 64 air samples were collected in 4 hospital wards. Detection of airborne bacteria was carried out using culture plates with and without β-lactams. BLRB isolates were screened for the presence of 5 common β-lactamase–encoding genes. Sequence analysis of predominant BLRB was also performed.

Results: The prevalence of BLRB ranged between 3% and 34%. Oxacillin-resistant bacteria had the highest prevalence, followed by ceftazidime- and cefazolin-resistant bacteria. The frequency of β-lactamase–encoding genes in isolated BLRB ranged between 0% and 47%, with the highest and lowest detection for OXA-23 and CTX-m-32, respectively. *Mec*A had a relatively high frequency in surgery wards and operating theaters, whereas the frequency of *bla*TEM was higher in intensive care units and internal medicine wards. OXA-51 was detected in 4 wards. *Acinetobacter* spp, *Acinetobacter baumannii*, and *Staphylococcus* spp were the most predominant BLRB.

Conclusions: The results revealed that hospital air is a potential route of transmission of BLRB, such as *Acinetobacter* and *Staphylococcus*, 2 important causative agents of nosocomial infections. Therefore, improvement of control measures against the spreading of airborne bacteria in hospital environments is warranted.

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Nosocomial infections represent a significant health concern, with approximately 1.4 million people affected worldwide.[1] Approximately 60% of some these infections involve antimicrobial-resistant bacteria[2] and account for about 99,000 deaths per year in the United States.[3] Resistance to antibiotics has been a particular problem over the last decades, increasingly hampering the treatment of hospital-acquired infections.[4] Vulnerable groups of inpatients are especially at high risk of developing antibiotic-resistant infections. Such infections pose a serious threat to immunocompromised patients, causing increased morbidity, mortality, and medical costs.[2,3,5] Because of evolution and emergence of bacterial resistance to antibiotics and an increase in the number of immunosuppressed individuals worldwide because of HIV infection, chemotherapy, drug therapies, and genetic disorders, hospitals are now more often facing the problem of antibiotic-resistant nosocomial infections.[6] Several bacterial pathogens involved in epidemics of human disease have evolved into multidrug-resistant strains after antibiotic use.[5] Multidrug-resistant bacteria, specifically *Mycobacterium tuberculosis*, *Enterococcus faecium*, *Enterobacter cloacae*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Acinetobacter baumannii*, and *Pseudomonas aeruginosa*, are becoming common in hospitals.[5,7] Although contact spread is the main route of transmission for most infections, there is increasing evidence that *P aeruginosa*, methicillin-resistant *S aureus* (MRSA), *M tuberculosis*, and *A baumannii* could be transmitted via the airborne route.[4,8] Airborne microorganisms are spread from numerous sources, including air conditioning systems and respiratory droplets produced by patient coughing or sneezing. Ward activities, such as those generated by

* Address correspondence to Mahnaz Nikaeen, PhD, Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Hezar Jerib Ave, Isfahan, Iran 8174673461.
E-mail address: nikaeen@hlth.mui.ac.ir (M. Nikaeen).

Conflicts of Interest: None to report.
Funding/Support: Supported with funding from the vice chancellery for research of Isfahan University of Medical Sciences (research project no. 392542) as a PhD dissertation thesis.

0196-6553/© 2016 Published by Elsevier Inc. on behalf of Association for Professionals in Infection Control and Epidemiology, Inc.
http://dx.doi.org/10.1016/j.ajic.2016.01.041

bed making and mechanical floor cleaning, have been shown to release large numbers of bacteria into the air.[4,8] Therefore, control and effective prevention of antibiotic-resistant nosocomial infections require a better identification of airborne bacteria that are potentially harmful to patients. This information is critical to implementing more appropriate control measures against the spread of airborne hospital-acquired infections. It is clear that the potential hazards posed by airborne bacteria depend on the pathogenicity of a specific strain, environmental factors, and bacterial gene pool, including antibiotic resistance genes. Beta-lactam antibiotics are generally used to treat inpatients, accounting for approximately 50%-70% of the total antibiotic use; of these, subgroups of penicillins, cephalosporins, and carbapenems comprise the largest share of antibiotics used for human use in most countries.[9] However, the emergence of bacterial resistance to β-lactam antibiotics seriously challenges the control and treatment of some nosocomial infections. The main nosocomial pathogens in the group for which hospital air has been implicated in the transmission include MRSA and *A baumannii*.[10] There are several studies describing the presence and transmission routes of these pathogens in hospital environments, especially in intensive care units (ICU) and burn units.[2,10] However, to our knowledge, no studies have described the levels of β-lactamase–producing bacteria and their resistance genes in hospital environments.

Therefore, this study was carried out (1) to determine the prevalence of airborne β-lactam–resistant bacteria (BLRB) in different wards of 4 educational hospitals, (2) to evaluate the frequency of 5 common β-lactamase–encoding genes in isolated resistant bacteria, and (3) to identify the most predominant BLRB by 16s rRNA gene sequencing.

MATERIALS AND METHODS

Sampling sites and strategies

The study was carried out from March to December 2014 in 4 educational hospitals of Isfahan University of Medical Sciences, Isfahan, Iran. Sampling locations in each hospital included operating theatres (OTs), ICUs, surgery wards (SWs), and internal medicine wards (IMs). For detection of airborne culturable bacteria, each hospital was visited 4 times, and a total of 64 samples were collected using an all-glass impinger, containing 10 mL of phosphate buffer solution. Approximately 2,500 L of air were collected using portable pumps at a flow rate of 12.5 L/min from each site. Air sampling was performed at a height of 1.5 m above the ground level to simulate the breathing zone. At each hospital, air samples from 4 locations were taken on 1 single day from 9 AM to 12 PM after routine cleaning. During the study period, patients, staff, and patient attendants were present, but visitors were limited. Windows were kept closed during sampling, and air exchange between indoor and outdoor environments was restricted. Furthermore, a similar disinfection procedure was used for all hospitals. The characteristics of hospitals and wards are presented in Table 1.

Temperature and relative humidity were recorded by use of a portable weather station (KIMO, France) throughout the sampling periods and were approximately 26°C ± 2.3°C and 28% ± 5.6%, respectively.

All samples were transferred to the laboratory in an insulated box with cooling packs and processed immediately on arrival in the laboratory.

Table 1
Characteristics of investigated hospitals and wards

Type of ward	Construction or renovation age (y)	No. of rooms*	No. of Beds	No. of People†	Area (m^2)	Ventilation system	Sampling location
Hospital A	22						
ICU		4	8	10-15	120	Central operation HVAC‡	Inside ICU, near staff counter
OT		4	4	20-30	240	Central operation HVAC with HEPA filter	Corridor of ward
SW		12	28	40-50	360	Central operation HVAC	Corridor of ward
IM		12	28	40-50	360	Central operation HVAC	Corridor of ward
Hospital B	24						
ICU		1	6	5-10	90	Central operation HVAC	Inside ICU, between patient beds
OT		2	2	4-8	180	Central operation HVAC with HEPA filter	Corridor of ward
SW		9	20	15-30	225	Central operation HVAC	Corridor of ward
IM		6	14	15-30	150	Central operation HVAC	Corridor of ward
Hospital C	15						
ICU		1	4	6-8	70	Central operation HVAC	Inside ICU, near staff counter
OT		3	3	5-8	150	Central operation HVAC with HEPA filter	Corridor of ward
SW		11	20	8-12	220	Central operation HVAC	Corridor of ward
IM		8	18	10-15	160	Central operation HVAC	Corridor of ward
Hospital D	50						
ICU		1	8	6-10	80	Central operation HVAC	Inside ICU, near staff counter
OT		2	2	4-8	120	Central operation HVAC with HEPA filter	Corridor of ward
SW		8	22	20-35	180	Central operation HVAC	Corridor of ward
IM		8	24	20-35	180	Central operation HVAC	Corridor of ward

HEPA, high efficiency particulate air; *HVAC*, heating, ventilating, and air conditioning systems; *ICU*, intensive care unit; *IM*, internal medicine ward; *OT*, operating theatre; *SW*, surgery ward.
*Number of active rooms in the operating theater during the sampling period.
†Including patients, staff, and patient attendants.
‡Heating, ventilating, and air conditioning systems contain 65% efficiency filters.

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