REVIEW ARTICLE

Contamination of healthcare environment by carbapenem-resistant *Acinetobacter baumannii*

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ABSTRACT

Acinetobacter baumannii is frequently found on floors, devices, and environmental sites in hospitals and can survive for prolonged periods and accumulate resistance determinants. The infection and presence of carbapenem-resistant *A. baumannii* (CRAB) in patients is associated with increased mortality, severe clinical outcomes, and longer lengths of stay at hospitals. This review addresses contamination by CRAB in corporal surfaces of patients and healthcare workers and environmental sites at healthcare-related settings. We summarized published data during the last decade on potential reservoirs for CRAB, including contamination frequency and the involved resistance mechanisms, and some measures associated with the elimination of CRAB from hospital surfaces.

Key Indexing Terms: Carbapenem-resistant; Acinetobacter baumannii; Healthcare-associated infections; Antimicrobial resistance; Multidrug-resistant microorganism. **[Am J Med Sci 2022;364(6):685–694.]**

INTRODUCTION

Acinetobacter baumannii is a Gram-negative opportunistic pathogen that has emerged as one of the most important causative agents of healthcare-associated infections (HAIs) related to outbreaks worldwide and is considered to be endemic in many hospitals. This microorganism has a significant ability to survive for prolonged periods in the nosocomial environment and is frequently detected on floors, devices, and environmental sites in hospitals.[1,2]

A. baumannii accumulates resistance determinants, leading to the development of multidrug-resistant (MDR) strains.[3] Carbapenems have been used to treat MDR A. baumannii infections.[4] Nonetheless, the incidence of carbapenem-resistant *A. baumannii* (CRAB) has increased over time, leading to limited therapeutic options. This event is considered a sentinel event for emerging antimicrobial resistance.[3]

Carbapenem resistance is associated with multiple mechanisms including the production of carbapenemases.[5] The following classes of enzymes involved in carbapenem resistance have been reported: class A, *Klebsiella pneumoniae* carbapenemase (KPC) and Guiana extended-spectrum β-lactamase (GES); class B, New Delhi metallo-β-lactamase (NDM), Imipenem-hydrolyzing beta-lactamases (IMP), and Verona integron-encoded metallo- β-lactamase (VIM); and class D, oxacillinases (OXA), including OXA-23, OXA-24, OXA-51, and OXA-58.[6,7] The ability for GES to expand their spectrum to hydrolyze carbapenems is notabe, as a result of a single or double amino acid substitutions[8,9]; the presence of GES enzyme is frequently reported in *A. baumannii* isolates (5 to 26%).[10–13]

Tigecycline and colistin are considered last resort treatment options for CRAB infections. However, these antimicrobial agents have adverse effects, including high toxicity and reduced efficacy in some tissues.[14,15] Ceftazidime/avibactam has been proposed to manage CRAB infections, with *in vitro* resistance reported.[16]

Due to the antimicrobial resistance implications in *A. baumannii,* the understanding of contamination by CRAB in the hospital environment is essential for HAI control. Despite reported evidence, the importance of hospital environmental contamination by pathogens and the subsequent colonization process is still debated. Healthcare workers (HCWs) are important for dissemination in clinical settings.[17] In this review, we addressed colonization by CRAB on the corporal surfaces of patients and contamination of environmental sites in healthcare-related settings, and the role of HCWs in its dissemination. Data from the literature, related to potential CRAB reservoirs in healthcare settings and patients during the last decade, is summarized. Additionally, the involved carbapenem resistance mechanisms and measures associated with the elimination of CRAB from hospital surfaces are described.

INCIDENCE OF *A. baumannii* INFECTIONS AND THE IMPACT OF CARBAPENEM RESISTANCE

The incidence of HAIs caused by *A. baumannii* is reported as 25.1 cases per 1000 patients according to 18 healthcare centers studied in Europe, Eastern Mediterranean, and Africa.[18] In intensive care units (ICU), *A. baumannii* infections are as high as 56.5 cases per 1000 patients, accounting for 20.9% of all HAIs.[18] The Centers for Disease Control and Prevention estimates 8,500 infections in hospitalized patients and 700 deaths caused by carbapenem-resistant *Acinetobacter* in the United States.[19]

During recent years, CRAB prevalence has increased worldwide, and the indiscriminate use of carbapenem is a factor that contributes to the appearance of CRAB and other drug-resistant pathogens.[20] In the US between 2014 and 2018, up to 78% of *A. baumannii* isolates were resistant to carbapenems, as reported by the SENTRY Antimicrobial Surveillance Program.[21] In 2017, *Acinetobacter* spp. was included on the WHO list of antibiotic-resistant bacteria for research, discovery, and development of new antibiotics.[22]

CRAB RESERVOIRS

The colonization by CRAB in patients is associated with increased mortality,[23,24] severe clinical outcomes,[22] and a higher length of stay at hospitals.[25] Furthermore, healthcare settings are reservoirs of drug-resistant microorganisms, including methicillin-resistant *Staphylococcus aureus*, extended-spectrum β-lactamase–producing Enterobacteriaceae, and CRAB, among others.[26]

Corporal surfaces from HCWs and patients (skin and mucosal surfaces from patients and HCWs, such as palmar surfaces, retroauricular and antecubital creases, nostril, rectum, etc.)[27] with predisposing factors (long period hospitalization, catheter insertion, and wounds) are also sites prone to contamination and/or colonization by CRAB, which may contribute to its dissemination (Tables 1 and 2).[26,28–32]

The CRAB contamination rate is higher among hospitalized patients (up to 80% of CRAB detection), as shown by rectal and nasal swab cultures. CRAB recovery from hands and gloves of HCWs, and from skin and mucosa of patients (pharynx, nasal, rectum, groin, axilla, and mouth) has been previously reported.[26,28]

Additionally, diverse studies have shown that *A. baumannii* is one of the most abundant pathogens across workplaces, devices, and floors in hospitals.[2,69] Up to 93% of hospital environmental surfaces are contaminated by CRAB.[31,32] Hospital environments, medical equipment, and medical devices have been reported as sites contaminated by CRAB, so they are all considered potential reservoirs for this pathogen.[26,28–32] CRAB isolates have also been recovered from bed headboard, monitor screens, bedrails, bedside tables, infusion pumps, medical ventilators, bed sheets, pillows, sinks, floors, and another high touch contact nosocomial environmental spots (Table 2).[28,29,31]

Transient presence of CRAB has been found to last from 6 days to 5 weeks in patients and on environmental surfaces, which could represent a risk for HAI development and/or contamination to other patients, HCWs, and other hospital areas.[47,70]

MEASURES FOR PREVENTING OR REDUCING COLONIZATION BY *A. baumannii* IN HEALTHCARE SETTINGS

Different strategies to reduce *A. baumannii* infections have been described, including the implementation of antimicrobial stewardship programs. In a study by Cheon et al. nosocomial MDR *A. baumannii* was reduced 10-fold after decreasing carbapenem use.[20] Thus, a coordinated effort between healthcare facilities authorities, HCWs, and laboratory surveillance programs is needed to reduce CRAB's impact.

Diverse protocols have been applied as preventive measures for the presence of antimicrobial-resistant microorganisms, including CRAB. Among them, active surveillance cultures (ASCs) have been used to identify and monitor contamination in patients, HCWs[55,71] and environmental sites.[29,31,53,63,72]

Different conditions can be used for ASCs. For example, culture media used and sampling sites can be standardized to improve infection control or spread prevention. Additionally, the utility of ASCs for carriage detection should be determined for specific processes, such as during patient admission or ward transference. Other aspects to consider for ASCs include sampling frequency, patients with medical devices and catheters, HCW monitoring frequency, and the subjects that should be included in the surveillance.[29,31,50,57,59,62,63,72–74]

ASCs, contact precautions, and preventive isolation can be applied to avoid pathogen dissemination from patients colonized with CRAB.[75] Nevertheless, the success of these methods strongly depends on the cohort and the adherence to precautions.[55,76]

Prevention measures for dissemination of antimicrobial-resistant pathogens include cleaning techniques for environmental surfaces and antiseptic baths. The effectiveness of cleaning techniques is associated with diverse aspects, including disinfectant products (chlorhexidine,

TABLE 1. Reports of colonization by CRAB in patients.

Population characteristics	Sampled sites	CRAB recovery (n/N)*	Associated resistance determinant	Study length (weeks)	Country, year	Refs.
Patients from a spinal cord injury unit	Stool	3/20	OXA-23 and OXA-69	4	USA, 2015	33
Patients from a medical ICU and a surgical ICU of a tertiary care hospital	Tracheal aspirates (intubated) or throat (non-intubated); groin	9/10	OXA-23	4	Germany, 2015	34
Injured adult patients from 3 hospitals	Groin, pharynx, nasal, perianal, and hairline	18/21[a]	OXA-48	52	Germany, 2016	35
Patients from an adult ICU during a CRAB outbreak	Rectum	2/7[a]	NDM-1	35	France, 2013	36
Patients from an ICU or other wards (NS)	Respiratory tract and skin	8/21[a]	OXA-23	36	Italy, 2012	30
Patients from two ICUs of a large general hospital	NS	74/391[a]	OXA-23	24	Italy, 2013	37
Patients from a medical-surgical ICU	Tracheal/oropharyngeal secretions and rectum	52/234[a]	OXA-23	52	Brazil, 2013	38
Colonized or infected adult patients from a medical ICU	Skin, mucous membranes, open wounds, and secretions	38/867	OXA-23 and OXA-143	48	Brazil, 2016	39
Patients and environmental surfaces from a medical ICU	Nares, axillae, groin, rectum, wounds, exit sites of drains, and endotracheal tube aspirates	3/7	OXA-23	4	Singapore, 2018	40
Patients from the CCC, ICU, emergency room, operating room, and other tertiary care hospital wards	Sputum, throat swabs, and stool	12/15[a]	OXA-23 and ISAba-1	40	Japan, 2016	41
Patients from an adult ICU or an emergency room ICU	Throat and rectum or stools	158/412	OXA-23, OXA-24, OXA-58, OXA-66, OXA-68, and NDM-1	40	Indonesia, 2018	42
Patients from a neurological ICU of an adult hospital	Urine, throat, groin, axilla, and rectum	12/32[a]	OXA-23, VIM, and IMP	24	Turkey, 2019	43
Newborns from a neonatal ICU	Rectum	17/762	OXA-23 and NDM-1	32	Turkey, 2016	44
Patients from 32 adult ICUs	Rectum	117/493	OXA-23, OXA-24/40, IMP, and GES	64	Kuwait, 2020	45
Patients from a medical and a surgical ICU	Mouth, rectum, and groin	32/83	OXA-23, OXA-24, and NDM-1.	24	Morocco, 2017	46
Patients from an ICU	Rectum	9/63	OXA-23 and NDM-1	12	Tunisia, 2018	47
Environmental surfaces from an ICU, two medical wards and two surgical wards of a general hospital.	Wound	1/21	OXA-69, ISAba1, and GES-11	4	Saudi Arabia, 2020	48

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TABLE 1. (*continued*)

Population characteristics	Sampled sites	CRAB recovery (n/N)*	Associated resistance determinant	Study length (weeks)	Country, year	Refs.
Patients from 6 adult ICUs (trauma, surgical, medical, and neurosurgical units) of a hospital	Rectum and respiratory tract from patients	17/25 (respiratory tract 8/25 (rectum)	ND	20	USA, 2016	49
Mechanically ventilated patients from 30 acute care facilities and 10 LTC facilities	Sputum and perianal region	76/358	ND	2	USA, 2012	50
Mechanically ventilated patients from an ICU	Rectum and respiratory	45/360	ND	92	USA, 2016	51
Liver transplant patients from a tertiary hospital	Inguinal-rectal area, axilla, and throat	83/181	ND	8	Brazil, 2017	52
Mechanically ventilated patients from a medical center	Mouth, rectum, and skin	32/34	ND	36	Israel, 2016	53
Adult patients who had a CRAB clinical culture during a prior hospitalization	Mouth, rectum, and skin	12/38	N.D.	120	Israel, 2019	54
Patients from a medical ICU	Throat or trachea, skin, and urine	98/1115[a]	N.D.	176	Korea, 2017	55
Residents from 28 nursing homes	Rectum, axilla, and nasal fossae	92/1408	ND	8	Hong Kong, 2016	32
Patients from an ICU	NS	22/40[a]	N.D.	20	Taiwan, 2014	56
Patients from two general wards of a general hospital	NS	6/12	ND	24	Taiwan, 2017	57
Neonate patients from a NICU	Trachea	257/3,367[a]	N.D.	28	Thailand, 2020	58
Patients with CRAB positive cultures from an adult ICU	Tracheal aspirate, rectum, sternal skin, and urine	129/160	ND	280	Thailand, 2013	59

Abbreviations: CCC, critical care center; CCU, coronary care unit; CRAB, carbapenem-resistant *A. baumannii*; GES: Guiana extended-spectrum-lactamase; ICU, intensive care unit; IMP, imipenem; ISAba, insertion sequence in *A. baumannii*; LTC, long-term care; MDRO: multidrug-resistant microorganisms; ND, not determined; NDM, New Delhi metallo-beta-lactamase; NICU, neonatal intensive care unit; NIU, neonatal intermediate unit; NS, not specified; OXA, oxacillinase, VIM, Verona integron encoded-metallo-beta-lactamase.

[a] A proportion of the study population showed clinical evidence of CRAB infection (cases not considered colonization).

TABLE 2. CRAB contamination reports in the environment of healthcare settings and healthcare workers.

Population/surface characteristics	Sampled sites	CRAB recovery in environmental samples or HCWs (n/N)	Associated resistance determinant	Study length (weeks)	Country, year	Refs.
Nurses and environmental surfaces from a spinal cord injury unit	Nurses' hands Sinks, high touch surfaces, ice machine drain, water outlet, ice outlet, ice, and water	1/15 nurses 2/10 samples	OXA-23 and OXA-69	4	USA, 2015	33
Environmental surfaces near patients from an ICU and semi-intensive therapy/care of a tertiary hospital	Bed headboard, drug carts, crash carts, ventilator monitors, manifolds, floors, patient call buttons, and telephones	2/45	OXA-23	4	Italy, 2014	60
Environmental surfaces from an adult ICU	Nurse gloves, floor, bedrails, bedside tables, Ambu bags, monitors, valves, pumps, door handles, ventilators, stethoscopes, nursing tables, equipment, and medical carts	70/886	OXA-23	36	Brazil, 2017	61
CCC, ICU, emergency room, operating room, and other wards (NS) of a tertiary care hospital	Stainless steel sinks, bedrails, locker handles, stethoscopes, mobile medical carts, mobile carts with a suction bottle, and pulse oximetry	17/82	OXA-23 and ISAba-1	40	Japan, 2016	41
Environmental surfaces and HCWs from an ICU of a tertiary care hospital	Computer keyboards, bedrails, nurse supply carts, ventilator panels, ventilator airflow sensors, bedside cabinets, curtains, and mattresses. Nurses, doctors, and cleaning staff hands and/or gloves.	32/1550 samples 4/15 HCWs	OXA-23 and ISAba-1	12 (non-continuous)	China, 2015	62
Environmental surfaces from an adult ICU or an emergency room ICU	Washbasins, bedrails, bedside cabinet tables, ventilators, monitor screens, infusion pumps, and mattresses	6/400	OXA-23, OXA-24, OXA-58, OXA-66, OXA-68, and NDM-1	40 (non-continuous)	Indonesia, 2018	42
Environmental surfaces from a medical ICU of a hospital	Physiological monitor terminals, bedside rails, automatic door buttons, infusion pumps, resuscitation bags, ventilator panels, suction bottles, stethoscopes, tables, and sinks	11/233	OXA-23	4	Singapore, 2018	40
Environmental surfaces near patients infected by *A baumannii* from trauma, surgery, and neurosurgical ICUs	Ventilators, bedrails, bedside curtains, monitors, and tables	18/22	OXA-23	48	Taiwan, 2013	63
Isolates from HCWs and environmental surfaces of ICUs wards (surgery, medical, cardiovascular surgery, and CCU)	IV catheters, IV solutions, ventilators, laryngoscopy knives, incubators, taps, sinks, drug containers, monitors, tables, feeding pumps, MVE, intubation tubes, resuscitation equipment, and blood gas devices HCW hands	42/233 samples 3/18 HCWs	OXA-23	68	Turkey, 2014	64

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TABLE 2. (*continued*)

Population/surface characteristics	Sampled sites	CRAB recovery in environmental samples or HCWs (n/N)	Associated resistance determinant	Study length (weeks)	Country, year	Refs.
Isolates of environmental surfaces from 2 ICUs, neurosurgery, neurology, and orthopedic of a hospital	Bedcovers, ventilators, doorknobs, patient clothes, blood pressure cuffs, bedrails, and pillows	18/22	OXA-23	28	Iran, 2018	[65]
Environmental surfaces from a medical and a surgical ICU	Floors, bed sheets, medical ventilators, pillows, monitors, patient trolleys, and IV solution stands	36/72	OXA-23, OXA-24, and NDM-1	24	Morocco, 2017	[46]
Environmental surfaces from the ICU, infectious disease, medical, and pediatric wards of 2 teaching hospitals	Handles, bed sheets, medical equipment, and bedrails	61/67	NDM-1 and OXA-23	200	Algeria, 2015	[66]
Environmental surfaces from an ICU, two medical wards and two surgical wards of a general hospital.	Alcohol dispenser, nurse desk, and computer keyboard	3/30	OXA-69, ISAba1, and GES-11	4	Saudi Arabia, 2020	[48]
Environmental surfaces from 6 adult ICUs (trauma, surgical, medical, and neurosurgical units) of a hospital	Bedrails, bedside tables, ventilator panels, IV pumps, and unit air samples	758/1690	ND	20	USA, 2016	[49]
Mattresses from an adult ICU, a CCU, and other clinical units (NS)	Mattresses	19/51	ND	12	Brazil, 2016	[67]
Air from two ICUs of a medical center	Air samples	24/186	ND	32	Turkey, 2016	[68]
Environmental surfaces from two general wards of a general hospital	Oxygen humidifiers, bedrails, and table surfaces	8/60	ND	24	Taiwan, 2017	[57]
Environmental surfaces from an ICU	Bedrails, bedside sinks, bedside tables, and monitors	12/22	ND	20	Taiwan, 2014	[56]

Abbreviations: CCC, critical care center; CCU, coronary care unit; CRAB, carbapenem-resistant A. baumannii; GES: Guiana extended-spectrum-lactamase; GNB, Gram-negative bacilli; HCW, healthcare workers; ICU, intensive care unit; ISAba, insertion sequence in A. baumannii; IV, intravenous; LTC, long-term care; MDRO, multidrug-resistant microorganisms; MVE, mechanical ventilator equipment; ND, not determined; NDM, New Delhi metallo-β-lactamase; NS, not specified; OXA, oxacillinase.

chlorine solution, aerosolized hydrogen peroxide (aHP), etc.), concentration, and action time.[77–81]

An 85% reduction of CRAB contamination was observed after sodium hypochlorite disinfection (24/59 sampled objects were contaminated before disinfection with sodium hypochlorite, and contamination persisted in 3/52 sampled objects after disinfection process); and a 78% reduction after aHP disinfection (59/74 sampled objects were contaminated before disinfection, and 12/68 objects remained contaminated after disinfection).[82]

Daily chlorhexidine baths reduced CRAB acquisition rates by 52% at the ICU (44 cases per 1000 at-risk patient days before chlorhexidine baths and 21.2 cases per 1000 at-risk patient-days after baths introduction, $p < 0.001$).[83]

It has been suggested that cleaning does not reduce the contamination rates in environments, possibly by insufficient frequency of disinfection; however, favorable results are obtained by training HCWs and cleaning staff.[78,82,84]

A study reported a significant reduction ($p < 0.0001$) of CRAB recovery from environmental objects after a training of intensive cleaning manual procedure with sodium hypochlorite. Before training, 78% of sampled objects (62/82) were contaminated by CRAB, while 39% of sampled objects were contaminated (75/191) after training.[82]

Effective actions for control of dissemination and development of infections by CRAB have been reported, including the assignment of specific units or beds for CRAB-colonized patients, closure of contaminated units, contact precautions, environmental contamination surveillance, environmental disinfection, and evaluation of hygiene protocol adherence.[76,85–88]

Apisarnthanarak et el reported the effectiveness of an intervention strategy on ICU included: strict contact isolation of patients colonized or infected by pandrug-resistant *A. baumannii* (including carbapenem resistance), ASCs (rectal swabs and tracheal aspirates), hand hygiene adherence, environmental disinfection with sodium hypochlorite, and antimicrobial stewardship program previously established for carbapenem, third-generation cephalosporins, β-lactam inhibitors, and glycopeptides. In the study, the rate of colonization/infection by pandrug-resistant *A. baumannii* was 3.6 cases per 1000 patient-days before intervention and 1.2 cases per 1000 patient-days after intervention ($p < 0.001$).[88]

CONCLUSIONS

Several studies have suggested the potential role of the healthcare environments as CRAB reservoirs and the probable dissemination of this and other MDR pathogens by HCWs and patients. The presence of microorganisms in corporal surfaces is considered a preceding step for HAI development; thus, eradicating environmental reservoirs could break transmission routes and control infection development. However, CRAB contamination rates in the environment and/or among HCWs is probably higher than originally thought because the search for reservoirs has not been routinely established. Reinforced measures are necessary to prevent nosocomial environment contamination by CRAB. These measures should be based on the knowledge of favorable conditions for this pathogen, the material of colonized surfaces, and hygiene and disinfection protocols. Education for HCWs should not be limited to disinfection techniques but also the knowledge of the role of surfaces and objects as reservoirs for pathogens and their contribution to dissemination in the hospital environment.

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CONFLICTS OF INTEREST

The authors report no conflicts of interest.

CRediT authorship contribution statement

Flora Cruz-López: Conceptualization, Formal analysis, Data curation, Writing – original draft. **Adrián Martínez-Meléndez:** Conceptualization, Data curation, Writing – original draft. **Licet Villarreal-Treviño:** Writing – review & editing. **Rayo Morfín-Otero:** Writing – review & editing. **Héctor Maldonado-Garza:** Writing – review & editing. **Elvira Garza-González:** Writing – review & editing.

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