Controlling an Outbreak of Multidrug-resistant Acinetobacter baumannii in a Pediatric Intensive Care Unit: a Retrospective Analysis

Joung-Hee Byun, Su Eun Park, Minhae Seo, Jeungmi Jang, Mi Sun Hwang, Ju Yeoun Song, Chulhun L. Chang and Young A Kim

1Department of Pediatrics, Pusan National University Children's Hospital, Yangsan, Korea
2Research Institute for Convergence of Biomedical Science and Technology, Pusan National University Yangsan Hospital, Yangsan, Korea
3Infection Prevention and Control Department, Pusan National University Yangsan Hospital, Yangsan, Korea
4Department of Nursing, Pusan National University Yangsan Hospital, Yangsan, Korea
5Department of Laboratory Medicine, Pusan National University Yangsan Hospital, Yangsan, Korea

ABSTRACT

Background: Multidrug-resistant Acinetobacter baumannii (MDRAB) is widespread among intensive care units worldwide, posing a threat to patients and the health system. We describe the successful management of a MDRAB outbreak by implementing an infection-control strategy in a pediatric intensive care unit (PICU).

Methods: This retrospective study investigated the patients admitted to the PICU in periods 1 (8 months) and 2 (7 months), from the index MDRAB case to intervention implementation, and from intervention implementation to cessation of MDRAB spread. An infection-control strategy was designed following six concepts: 1) cohort isolation of colonized patients, 2) enforcement of hand hygiene, 3) universal contact precautions, 4) environmental management, 5) periodic surveillance culture study, and 6) monitoring and feedback.

Results: Of the 427 patients, 29 were confirmed to have MDRAB colonization, of which 18 had MDRAB infections. Overall incidence per 1,000 patient days decreased from 7.8 (period 1) to 5.8 (period 2). The MDRAB outbreak was declared terminated after the 6-month follow-up following period 2. MDRAB was detected on the computer keyboard and in condensed water inside the ventilator circuits. The rate of hand hygiene performance was the lowest in the three months before and after index case admission and increased from 84% (period 1) to 95% (period 2). Patients with higher severity, indicated by a higher Pediatric Risk of Mortality III score, were more likely to develop colonization ($P = 0.030$), because they had invasive devices and required more contact with healthcare workers. MDRAB colonization contributed to an increase in the duration of mechanical ventilation and PICU stay ($P < 0.001$), but did not affect mortality ($P = 0.273$).

Conclusion: The MDRAB outbreak was successfully terminated by the implementation of a comprehensive infection-control strategy focused on the promotion of hand hygiene, universal contact precautions, and environmental management through multidisciplinary teamwork.

Keywords: Acinetobacter baumannii; Outbreak; Intensive Care Unit; Pediatric; Infection-control
INTRODUCTION

Acinetobacter baumannii (A. baumannii), which is well known for its tenacious survival in the environment and its ability to confer antibiotic resistance to other coexisting bacteria, and the antimicrobial resistance are crucial problems that have caused high morbidity and mortality in critically ill patients. The Korean Nosocomial Infections Surveillance System showed that, since 2010, A. baumannii was the most relevant causative organism of ventilator-associated pneumonia (VAP), and its resistance to carbapenem increased from 53% in 2006 to 90% in 2013. In a study conducted in 2012 at 162 intensive care units in 24 countries, A. baumannii was the most significant pathogen and had the highest antibiotic resistance among Gram-negative bacteria in bloodstream infections. These results are in line with a study conducted at 173 hospitals in 2018. The multidrug-resistant A. baumannii (MDRAB) pathogen is posing a serious threat to patient survival, and desperate efforts to manage the spread of MDRAB in intensive care units have been widely documented. However, controlling MDRAB outbreaks remains a clinical challenge.

In our hospital, we experienced an MDRAB outbreak that lasted 15 months after the index case was first admitted to the pediatric intensive care unit (PICU). When an MDRAB outbreak occurs in the intensive care unit (ICU), the most effective and simplest methods to address the outbreak is to close the unit and disinfect the internal environment. However, since this was the only PICU in our region, it was virtually impossible to close the unit even temporarily. Instead of closing the unit, we tried to implement a comprehensive infection-control strategy and finally succeeded in eliminating the pathogen in the PICU.

In this study, we describe the successful strategy implemented to terminate the MDRAB in the PICU of our institution. In addition, we analyze the clinical impact of the MDRAB outbreak and share the process that led us to implement the infection-control strategy.

METHODS

This study was conducted in a tertiary-care teaching hospital by retrospectively reviewing the medical records of patients admitted to the PICU from June 2017 to August 2018. Subsequently, the results of microbiological tests conducted at the PICU were investigated through February 2019.

Hospital setting

The PICU at our institution has ten open beds and three isolation rooms (Fig. 1), and approximately 400 medical-surgical critically ill children (age < 19 years) are admitted to the unit every year. During the outbreak, four physicians worked exclusively at the PICU, and four sporadically provided care at the unit. There were 26 nurses assigned to the PICU, and the nurse-to-patient ratio was 1:2, with one nurse caring for two to three patients. In our hospital, the regular infection-control policy for MDRAB is based on the infection-control guidelines of the Korea Disease Control and Prevention Agency for multidrug-resistant microorganisms in healthcare facilities (Table 1).

Definitions

Throughout this study, specific parameters were defined as follows: colonization refers to the presence of the pathogen on the skin or body fluids, including sputum and urine, without causing
disease. Infection indicates any of the following three MDRAB-caused diseases: bloodstream infection, pneumonia, and urinary tract infection. When MDRAB was detected in blood culture, it was diagnosed as a bloodstream infection. Pneumonia, particularly VAP, which develops after more than 48 hours of mechanical ventilation, was defined as new or progressive pulmonary infiltration that was detected on chest radiography with supportive clinical findings. A urinary tract infection was diagnosed when MDRAB was detected in the urine of patients with a fever, leukocytosis, and pyuria. The term “MDRAB group” refers to patients with either MDRAB colonization or infection, whereas the other participants are referred to as the control group.

The incidence density rate was used to report the results of this study and refers to the number of cases of newly detected MDRAB in 1,000 patient days. Cases were determined after the detection of MDRAB in any type of specimen. The patient days and new incidence number per month were investigated.

**Table 1.** Summary of the infection-control strategy for MDRAB outbreaks and comparisons with infection-control policies for MDRAB in our hospital

| Concepts                        | Implemented interventions                                      | Details                                      | Policies of our hospital            |
|---------------------------------|---------------------------------------------------------------|----------------------------------------------|-------------------------------------|
| Cohort isolation                | Cohort isolation of colonized patients                        | Mandatory                                    | Recommended                         |
| Enforcement of hand hygiene     | Regular education programs on hand hygiene                   | Including circulating staff                   | Not regular                         |
|                                 | Monitoring of hand hygiene performance                       | Daily for the first month; then three times per week | Twice a month                      |
| Universal contact precautions   | Wearing gloves and plastic gowns during contact in the patient zone | For all patients                             | For affected patients only         |
| Environmental cleaning and disinfection | Extensive management using checklists | Under the supervision of the unit manager | None                               |
|                                 | Patient zone                                                | Three times a day                            | Once a day                          |
|                                 | Environment except the patient zone                          | Twice a day                                  | Once a day                          |
| Surveillance cultures           | Initial and periodic cultures for all patients               | Once a week                                  | None                                |
|                                 | Environmental surveillance cultures                          | Once a week                                  | None                                |
|                                 | Assessment of bacterial colonization for staff               | Including circulating staff                   | None                                |
| Monitoring and feedback         | Discussions on the performance of the infection-control strategy | Monthly                                     | None                                |

MDRAB = multidrug-resistant A. baumannii.
Index case and bacterial spread

A female patient was born at another hospital and underwent congenital diaphragmatic hernia repair surgery at our hospital’s neonatal ICU on her first day of life. On day 7, the patient was transferred to the PICU for extracorporeal membrane oxygenation due to septic shock that was diagnosed on June 6, 2017, and eventually died from multiorgan failure on day 20. Throughout her stay at the PICU, MDRAB was consistently detected in blood cultures (Table 2).

The seriousness of bacterial spread was not perceived until sporadic MDRAB colonization and infection were detected about 2 months after the index case admission. As the number of cases continued to increase, measures were implemented to strengthen hand hygiene, undertake active surveillance culture tests, and to clean the PICU environment; however, these efforts could not contain the bacterial spread. In mid-January 2018, a comprehensive infection-control strategy focusing on preventing new MDRAB colonization was implemented by a multidisciplinary team consisting of the PICU staff, a pediatric infectious disease specialist, the Infection Prevention and Control Department, and the Department of Laboratory Medicine.

Study period and patients

The study duration was divided into two periods. Period 1 comprised the first eight months from the MDRAB introduction to the implementation of the infection-control strategy. Period 2 consisted of the seven months from intervention implementation to the month of discharge of the last MDRAB-colonized patient. The follow-up period for monitoring the incidence of MDRAB colonization or infection in the PICU lasted six months. All patients admitted to the PICU during periods 1 and 2 were included in this study. Patient demographics, results of the microbiologic study, PICU stay, mechanical ventilation days, the Pediatric Risk of Mortality III (PRISM III) score, and mortality were investigated.

Interventions

The infection-control intervention comprised six concepts and is shown in Table 1. The strategy of these interventions is described in greater detail in the following list.

1) MDRAB-colonized patients were isolated in isolation rooms. A clean zone was designated, and in the absence of isolation rooms, patients were quarantined in areas other than the

---

**Table 2.** In vitro activities of antimicrobial agents against *A. baumannii* isolated from the index case

| Antimicrobial agents                  | MIC       | Activities |
|---------------------------------------|-----------|------------|
| Ampicillin/sulbactam                  | 16 or ≥ 32| I or R     |
| Cefotaxime                            | ≥ 64      | R          |
| Cefepime                              | ≥ 64      | R          |
| Ceftazidime                           | ≥ 64      | R          |
| Ciprofloxacin                         | ≥ 4       | R          |
| Gentamicin                            | ≥ 16      | R          |
| Imipenem                              | ≥ 16      | R          |
| Meropenem                             | ≥ 16      | R          |
| Minocycline                           | ≤ 1       | S          |
| Piperacillin/tazobactam               | ≥ 128     | R          |
| Tigecycline                           | 4         | I          |
| Trimethoprim/sulfamethoxazole         | ≥ 160 or ≥ 320 | R |
| Colistin                              | ≤ 0.5     | S          |

Four types of profiles were found depending on the minimal inhibitory concentration difference of ampicillin/sulbactam and trimethoprim/sulfamethoxazole.

MIC = minimal inhibitory concentration, I = intermediate, R = resistance, S = susceptible.
clean zone. Patient isolation ended only when three consecutive surveillance bacterial culture tests conducted on alternate days yielded MDRAB-negative results. Medical equipment was used exclusively for one patient if feasible, and shared equipment, such as echocardiogram and electrocardiogram machines, were thoroughly disinfected before and after use. To prevent cross-contact, nurses were separately designated to provide care for either the MDRAB-colonized or non-colonized patients.

2) A pediatric infectious disease specialist and nurses of the Infection Prevention and Control Department imparted regular education programs on hand hygiene for healthcare workers at the PICU and operation rooms; healthcare workers included monthly rotation staff, radiographers, and rehabilitation therapists. The Infection Prevention and Control Department monitored the hand hygiene performance of healthcare workers during work and provided immediate feedback daily for the first month, then three times a week. In addition, aseptic techniques were reinforced for all invasive procedures performed at the PICU and operating room.

3) Regardless of the MDRAB colonization status, universal contact precautions were applied by wearing gloves and plastic gowns during contact with all PICU patients. Contact precautions should be ensured when entering the patient zone, which includes both a patient and his or her surroundings. Healthcare workers received monitoring and feedback from the Infection Prevention and Control Department on appropriate contact precautions, including the donning and removal of personal protective equipment. For patients receiving mechanical ventilation, only a closed suction protective equipment. For patients receiving mechanical ventilation, only a closed suction system was used, and the disconnection of the ventilator circuit was minimized.

4) Environmental management checklists were created to ensure the cleaning and disinfection of the environment. In accordance with the checklist, nursing and cleaning staff thoroughly recorded the site and time of cleaning and disinfection under the supervision of the unit manager. Nursing staff cleaned the environment of the patient zone and the medical equipment during their duty hours three times a day, and the cleaning staff cleaned the walls surrounding patients, computer supplies, tables, washbasins, and doors, twice a day. Computer keyboards were covered with fresh plastic wrap every day after cleaning and wiped with alcohol every hour. Alcohol and various dilutions and concentrations of hypochlorous acid-based disinfectants were used for their intended use in medical equipment and the environment.

5) The initial surveillance culture test was mandated for all patients admitted to the PICU, and periodic cultures were conducted once a week. Culture specimens were collected from tracheal aspirates from intubated or tracheostomized patients and nasopharyngeal swabs from non-intubated patients. Surveillance culture tests for the PICU environment and operating room, including mechanical ventilators, ventilator circuits, suctioning equipment, bedsrails, infusion pumps, medication carts, washbasins, and cardiovascular bypass equipment, were performed initially and then followed-up weekly. Nasopharyngeal swab cultures of all related medical staff of the PICU and operating room were performed to assess MDRAB colonization. A specific laboratory code for culture detection of MDRAB was developed to accelerate the detection process and reduce the workload of laboratory technicians.

6) Monthly meetings were held to discuss the performance of the control strategy, results of hand hygiene monitoring, and incidence rate of MDRAB colonization and infection.

In addition, access to the PICU was restricted to permit only visits related to patient care, and one of the two entrances was closed. All patients older than two months of age received a 2% chlorohexidine bath every day.
**Microbiology**

Antimicrobial susceptibility tests were conducted to identify antimicrobial agents using VITEK-2 (BioMerieux, Marcy L’Etoile, France) following the recommendations of the Clinical and Laboratory Standards Institute (CLSI) 2015. Susceptibility testing for colistin is not routinely performed in our hospital; however, the broth microdilution method was used to analyze some patient specimens. For the broth microdilution method, the cation-adjusted Mueller–Hinton Broth (BBL; Becton Dickinson, Franklin Lakes, NJ, USA) was used according to CLSI recommendations. The breakpoint for colistin resistance was ≥ 4 μg/mL.

**Statistical analysis**

Statistical analysis was performed using the SPSS version 21 (IBM, Armonk, NY, USA). The normality test was performed on continuous variables with the Shapiro-Wilk test. The difference in clinical variables between the MDRAB and the control groups was analyzed to infer the mechanism of bacterial spread. MDRAB colonization and infection groups were compared to determine the clinical impact of MDRAB infection. The χ² and Fisher’s exact tests were used for comparisons of categorical variables. Between-group differences for continuous variables were compared using an independent t-test and the Mann-Whitney U test as appropriate. Logistic regression analysis was conducted to identify factors significantly related to colonization. A P value of less than 0.05 was considered statistically significant.

**Ethics statement**

This study was approved by the Institutional Review Board of Pusan National University Yangsan Hospital, Korea, with waived informed consent owing to the retrospective nature of the analyses (No. 05-2020-098).

**RESULTS**

**Incidence and surveillance**

Of the 427 patients treated during the outbreak, a total of 29 were confirmed to have MDRAB colonization (18 and 11 patients during periods 1 and 2, respectively). The antibiotic susceptibility test profile of *A. baumannii* detected in colonized patients was identical to that of the four types of MDRAB found in the index case. MDRAB was detected in the aspirated sputum of all patients in the MDRAB group. The mean interval from the day of PICU admission to the first identification of MDRAB was 7.3 ± 5.4 days (median, 5; range, 2–20).

As shown in Fig. 2, the cumulative incidence of MDRAB cases increased steadily during period 1, reaching the highest number of cases (n = 8) in December 2017. In this month, MDRAB patients occupied 7 of 13 beds per day. The rate of hand hygiene performance was the lowest (72%) in the three months before and after index case admission and increased from 84% (period 1) to 95% (period 2). The highest incidence density rate was 17.0, and was observed in September 2017. The overall incidence density rate decreased from 7.8 in period 1 to 5.8 in period 2. New colonization did not occur during the follow-up period of six months. The MDRAB outbreak was declared terminated and the infection-control intervention was discontinued. Thereafter, we reinstated the regular infection-control policy of our hospital, but with continued hand hygiene education and monitoring.

In the initial environmental culture tests, MDRAB was detected on the computer keyboard and in condensed water inside ventilator circuits in the PICU in 2 of the 24 swab samples.
However, MDRAB was not detected in follow-up weekly tests that were conducted until August 2018. The nasopharyngeal swab cultures of 48 healthcare workers were performed to assess MDRAB colonization, and the results were all negative.

**Clinical characteristics of patients**

Table 3 shows the clinical characteristics of the MDRAB group and the control group during the outbreak. All patients in the MDRAB group received mechanical ventilation support, and the duration of mechanical ventilation and PICU stay was significantly longer than in patients in the control group. All four mortality cases in the MDRAB group occurred because of the exacerbation of the underlying disease and were unrelated to MDRAB infection. There was no statistical difference in the characteristics of MDRAB-colonized patients in periods 1 and 2.

To determine the route of bacterial transmission, logistic regression analysis was performed, including the variables that showed significant between-group differences: open-heart surgery (odds ratio [OR], 3.02; 95% confidence interval [CI], 1.26–7.23; \( P = 0.013 \)) and PRISM III score (OR, 1.06; 95% CI, 1.01–1.12; \( P = 0.030 \)) were significantly correlated with the MDRAB colonization. We investigated possible transmission routes related to open-heart surgery, including cardiopulmonary bypass equipment, environment- and healthcare worker-related transmission in the operating room, and the patient's transport path. We also monitored the implementation of aseptic techniques, but the transmission route was not identified.

Among the 29 patients with MDRAB colonization, 18 were diagnosed with infection, from which 13 had VAP, four bloodstream infection accompanied by VAP, and one urinary tract infection. As few antibiotics were effective against this pathogen, ampicillin/sulbactam, colistin, tigecyclin, and minocycline were used alone or in combination. The treatment
succeeded in all MDRAB-infected patients. The median duration of mechanical ventilation (42 days [interquartile range {IQR}: 73.2] vs. 8 days [IQR: 8], \(P = 0.002\)) and PICU stay (50 days [IQR: 6]) vs. 8 days [IQR: 25], \(P = 0.001\) was significantly longer in the MDRAB-infection group than in the MDRAB-colonization group.

**DISCUSSION**

In this study, we described the successful management of an MDRAB outbreak for 15 months through the implementation of an infection-control strategy in the PICU. The outbreak in question was caused by MDRAB from the index case, as evidenced by the identical antibiotic susceptibility profiles of MDRAB isolates from all affected patients. The mean interval from PICU admission to colonization in our patients was much shorter than the reported average of approximately more than a month.

The outbreak caused by the major MDRAB strain seemed to spread rapidly through environmental contamination. The presence of MDRAB on the surface of the computer keyboard and in condensed water in the ventilator circuit led us to infer that the outbreak presumably initiated through pathogens in the MDRAB colonized patient’s respiratory droplets, contaminated environment, and decidedly poor hand hygiene of healthcare workers, who facilitated bacterial dissemination. As seen in several reports of *Acinetobacter* species outbreaks, environmental contamination is very diverse and extensive,\(^4,13,20,21\) and some *A. baumannii* strains can live for several months on dry surfaces and survive even in anaerobic nutrient-depleted water for over 14 days.\(^1,22\) Therefore, our infection-control strategy relied on six concepts where the most crucial ones were hand hygiene promotion, universal contact precautions, and environment management.

Hand hygiene is the most important and powerful defense to prevent the transmission of nosocomial pathogens. However, hand hygiene alone is not effective against pathogens such as MDRAB, which can live for extended periods in the environment. Mousa et al.\(^23\) measured air samples from around ventilated patients and reported that *A. baumannii* disseminated as
a form of aerosol during treatment, and activities such as endotracheal suctioning, changing
bedsheets, and diapers were most likely to be associated with air contamination. The nature
of patient care in intensive units is such that healthcare workers come into close contact with
the patient and the patient’s environment, and therefore wearing a plastic gown helps prevent
pathogen spread through the clothes of healthcare-workers. In universal contact precautions,
hand hygiene promotion and lowering healthcare worker-patient contact rates achieved
remarkable results. In endemic situations, we suggest that universal contact precautions
is more effective in controlling an outbreak than contact precautions that are implemented
only for the affected patients. However, some studies conducted in non-endemic intensive
care units and focused on the acquisition rate of antibiotic resistance have questioned the
effectiveness of universal contact precautions. Given the staff burden and medical costs,
it should be noted that these strategies should be strictly implemented in a short period.

With regard to the host factor for bacterial transmission, we found that an open-heart surgery
and a higher PRISM III score were associated with MDRAB colonization. The transmission
route related to open-heart surgery was not identified, although the association can be
deduced from the higher PRISM III score in the MDRAB group. Patients with higher PRISM III
scores were more vulnerable to MDRAB colonization because they had invasive devices, such
as central venous catheters, a urinary catheter, arterial lines, and multiple chest tubes, and
required more contact with healthcare workers. In this regard, we believe that hand hygiene
promotion and universal contact precautions played a key role in our infection-control strategy.

In this study, MDRAB colonization contributed to increased morbidity but did not affect
mortality. The MDRAB-associated mortality rate exceeds 25%, and even reaches 75%
depending on several factors. Importantly, antibiotic susceptibility is the most
fundamental factor when treating MRDAB infections. Fortunately, the MDRAB strain was
susceptible to colistin and intermediate susceptible to amoxicillin/sulbactam; otherwise,
the outbreak would have resulted in several fatal cases due to the MDRAB infection. In
the early period of the outbreak, PICU staff tried to prevent further spread but were very
ineffective until the infection-control strategy devised by the multidisciplinary team was
applied. Had the outbreak been recognized as a serious situation early and responded quickly
to at this point, the affected patients and their morbidity would have been considerably lower.
We demonstrated that early recognition of an outbreak and prompt intervention measures
are the most important and effective control strategies to improve patient outcomes
following environmental contamination with long-lived bacteria, such as A. baumannii.

Many factors are involved in developing MDRAB outbreaks, including the acquisition rate of
antibiotic resistance. However, we speculate that the outbreak we experienced was caused
by environmental contamination with the major MDRAB strain derived from the index
case and MDRAB transmission due to the poor hand hygiene among healthcare workers.
Therefore, in this study, we focused on controlling the MDRAB outbreak, and the acquisition
rate of antibiotic resistance is beyond the scope of our study.

This study has some limitations. We tried to statistically infer the association between
patient characteristics and MDRAB colonization to identify risk factors for bacterial spread.
However, statistical approaches may be inappropriate because the investigation began long
after the outbreak had occurred. Furthermore, the reliability of the results is limited because
of the small number of patients. In addition, due to the nature of the retrospective descriptive
study design, unrecognized factors might have mediated the development of the outbreak.
In conclusion, we experienced an MDRAB outbreak that caused a significant morbidity increase, probably due to a contaminated environment and poor hand hygiene. The MDRAB outbreak was successfully controlled at our PICU by implementing a comprehensive infection-control strategy involving a multidisciplinary team. We believe that hand hygiene promotion, universal contact precautions, and environmental cleaning and disinfection are vital to control an MDRAB outbreak.

ACKNOWLEDGMENTS

We thank all the members of the multidisciplinary team for their dedication to implementing the infection-control strategy.

REFERENCES

1. Weber DJ, Rutala WA, Miller MB, Hudlage K, Sickbert-Bennett E. Role of hospital surfaces in the transmission of emerging health care-associated pathogens: norovirus, Clostridium difficile, and Acinetobacter species. Am J Infect Control 2010;38(S Suppl 1):S25-33. [PUBMED] [CROSSREF]

2. Choi IS, Choi JA, Jang SJ, Park G, Jeong SH, Kim CM, et al. Distribution of adeG, adeE, adeY, abeM, and adel efflux pump genes in clinical isolates of Acinetobacter species from Korea. Lab Med Online 2019;9(4):201-9. [CROSSREF]

3. Wendt C, Dietze B, Dietz E, Rüden H. Survival of Acinetobacter baumannii on dry surfaces. J Clin Microbiol 1997;35(6):1394-7. [PUBMED] [CROSSREF]

4. Hong KB, Oh HS, Song JS, Lim JH, Kang DK, Son IS, et al. Investigation and control of an outbreak of imipenem-resistant Acinetobacter baumannii infection in a pediatric intensive care unit. Pediatr Infect Dis J 2012;31(7):685-90. [PUBMED] [CROSSREF]

5. Lee H, Lee H. Clinical and economic evaluation of multidrug-resistant Acinetobacter baumannii colonization in the intensive care unit. Infect Chemother 2016;48(3):174-80. [PUBMED] [CROSSREF]

6. Kim YJ, Kim SI, Hong KW, Kim YR, Park YJ, Kang MW. Risk factors for mortality in patients with carbapenem-resistant Acinetobacter baumannii bacteremia: impact of appropriate antimicrobial therapy. J Korean Med Sci 2012;27(5):471-5. [PUBMED] [CROSSREF]

7. Choi JY, Kwak YG, Yoo H, Lee SO, Kim HB, Han SH, et al. Trends in the distribution and antimicrobial susceptibility of causative pathogens of device-associated infection in Korean intensive care units from 2006 to 2013: results from the Korean Nosocomial Infections Surveillance System (KONIS). J Hosp Infect 2016;92(4):363-71. [PUBMED] [CROSSREF]

8. Tabah A, Koulenti D, Laupland K, Misset B, Valles J, Bruzzi de Carvalho F, et al. Characteristics and determinants of outcome of hospital-acquired bloodstream infections in intensive care units: the EUROBACT International Cohort Study. Intensive Care Med 2012;38(12):1930-45. [PUBMED] [CROSSREF]

9. Kadri SS, Adjemian J, Lai YL, Spaulding AB, Ricotta E, Prevots DR, et al. Difficult-to-treat resistance in Gram-negative bacteremia at 173 US hospitals: retrospective cohort analysis of prevalence, predictors, and outcome of resistance to all first-line agents. Clin Infect Dis 2018;67(12):1803-14. [PUBMED] [CROSSREF]

10. Teerawattanapong N, Panich P, Kulpokin D, Na Ranong S, Kongpakkawattana K, Saksinanon A, et al. A systematic review of the burden of multidrug-resistant healthcare-associated infections among intensive care unit patients in Southeast Asia: the rise of multidrug-resistant Acinetobacter baumannii. Infect Control Hosp Epidemiol 2018;39(5):525-33. [PUBMED] [CROSSREF]
11. Cheon S, Kim MJ, Yun SJ, Moon JY, Kim YS. Controlling endemic multidrug-resistant *Acinetobacter baumannii* in intensive care units using antimicrobial stewardship and infection control. *Korean J Intern Med* 2016;31(2):367-74. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

12. Warde E, Davies E, Ward A. Control of a multidrug-resistant *Acinetobacter baumannii* outbreak. *Br J Nurs* 2019;28(4):242-8. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

13. Shi HJ, Kim JH, Kim NY, Lee JB, Eom JS. Environmental culture of bacteria at the intensive care unit of a tertiary hospital in Korea: a consideration for improving medical environmental safety and healthcare-associated infection. *Korean J Healthc Assoc Infect Control Prev* 2020;25(2):105-14. [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

14. Ray A, Perez F, Beltramini AM, Jakubowycz M, Dimick P, Jacobs MR, et al. Use of vaporized hydrogen peroxide decontamination during an outbreak of multidrug-resistant *Acinetobacter baumannii* infection at a long-term acute care hospital. *Infect Control Hosp Epidemiol* 2010;31(12):1236-41. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

15. Gramatniece A, Silamikelis I, Zahare I, Urtans V, Zahare I, Dimina E, et al. Control of *Acinetobacter baumannii* outbreak in the neonatal intensive care unit in Latvia: whole-genome sequencing powered investigation and closure of the ward. *Antimicrob Resist Infect Control* 2019;8(1):84. [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

16. Korea Centers for Disease Control and Prevention. Infection control guidelines for multidrug resistant microorganisms in healthcare facilities (Korean). http://www.kdca.go.kr/board/board.es?mid=a20507020000&bid=0019&act=view&list_no=138310&tag=&nPage=1. Updated August 20, 2021.

17. Kim YA, Kim H, Kim YM, Park SE. A successful application of adult polymyxin B-immobilized fiber column hemoperfusion to a neonate with septic shock. *Acute Crit Care* 2019;34(4):284-8. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

18. Clinical and Laboratory Standards Institute. *Performance Standards for Antimicrobial Susceptibility Testing, Twenty-fifth Informational Supplement, M100-S25*. Wayne, PA, USA: CLSI; 2015.

19. Park HJ, Kim JM, Kim KH, Kim DS. Current analysis of *Acintobacter baumannii* infection among pediatric patients in a single-centered study. *Korean J Pediatr Infect Dis* 2011;18(1):23-30. [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

20. Nutman A, Lerner A, Schwartz D, Carmeli Y. Evaluation of carriage and environmental contamination by carbapenem-resistant *Acinetobacter baumannii*. *Clin Microbiol Infect* 2016;22(11):949.e5-7. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

21. Ng DH, Marimuthu K, Lee JJ, Khong WX, Ng OT, Zhang W, et al. Environmental colonization and onward clonal transmission of carbapenem-resistant *Acinetobacter baumannii* (CRAB) in a medical intensive care unit: the case for environmental hygiene. *Antimicrob Resist Infect Control* 2018;7(1):51. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

22. Dekic S, Hrenovic J, van Wilpe E, Venter C, Goic-Barisic I. Survival of emerging pathogen *Acinetobacter baumannii* in water environment exposed to different oxygen conditions. *Water Sci Technol* 2019;80(8):1581-90. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

23. Mousa M, Schwartz D, Carmeli Y, Nutman A. Droplet aerosol dissemination of carbapenem-resistant *Acinetobacter baumannii* surrounding ventilated patients. *Infect Control Hosp Epidemiol* 2019;40(3):365-7. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

24. Harris AD, Morgan DJ, Pineles L, Perencevich EN, Barnes SL. Deconstructing the relative benefits of a universal glove and gown intervention on MRSA acquisition. *J Hosp Infect* 2017;96(1):49-53. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

25. Harris AD, Morgan DJ, Pineles L, Magder L, O’Hara LM, Johnson JK. Acquisition of antibiotic-resistant Gram-negative bacteria in the Benefits of Universal Glove and Gown (BUGG) cluster randomized trial. *Clin Infect Dis* 2021;72(4):431-7. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

26. Harris AD, Pineles L, Belton B, Johnson JK, Shardell M, Loeb M, et al. Universal glove and gown use and acquisition of antibiotic-resistant bacteria in the ICU: a randomized trial. *JAMA* 2013;310(15):1571-80. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)

27. Tawney A, Sempoche L, Lephart P, Valentine K, Thomas R, Asmar BL, et al. Impact of contact isolation precautions on multi-drug resistant *Acinetobacter baumannii* in the pediatric intensive care unit. *Infect Control Hosp Epidemiol* 2015;36(9):1108-10. [PUBMED](https://pubmed.ncbi.nlm.nih.gov/) | [CROSSREF](https://doi.org/10.3346/jkms.2021.36.e307)
28. Park SY, Lee EJ, Kim T, Yu SN, Park KH, Lee MS, et al. Early administration of appropriate antimicrobial agents to improve the outcome of carbapenem-resistant Acinetobacter baumannii complex bacteraemic pneumonia. *Int J Antimicrob Agents* 2018;51(3):407-12.

29. Kim B, Kim K, Yoon JS. Nosocomial Acinetobacter baumannii infection in children in adult versus pediatric intensive care units. *Pediatr Int* 2020;62(4):451-8.

30. Shi J, Sun T, Cui Y, Wang C, Wang F, Zhou Y, et al. Multidrug resistant and extensively drug resistant Acinetobacter baumannii hospital infection associated with high mortality: a retrospective study in the pediatric intensive care unit. *BMC Infect Dis* 2020;20(1):597.