




# Detection of Carbapenemase Genes in *Acinetobacter baumannii* Isolates from Al-Azizya Hospital, Wasit, Iraq

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## Abstract

**Background:** *Acinetobacter baumannii* is a critical nosocomial pathogen notorious for its multidrug resistance (MDR) and ability to cause severe infections, particularly in intensive care units (ICUs). Carbapenem-resistant *A. baumannii* (CRAB) poses a significant public health threat due to limited treatment options and high mortality rates.

**Objectives:** This study aimed to detect carbapenemase genes (*bla*<sub>OXA-23</sub>, *bla*<sub>OXA-48</sub>, *bla*<sub>NDM</sub>, and *bla*<sub>VIM</sub>) and evaluate antibiotic resistance patterns in *A. baumannii* isolates from Al-Azizya Hospital, Wasit, Iraq.

**Methods:** Fifty-eight *A. baumannii* isolates were collected from clinical samples and identified using phenotypic and biochemical tests. Antibiotic susceptibility was assessed via the disk diffusion method, and carbapenemase genes were detected using PCR.

**Results:** All isolates harbored the intrinsic *bla*<sub>OXA-51</sub> gene, confirming their identity as *A. baumannii*. The prevalence of carbapenemase genes was as follows: *bla*<sub>OXA-23</sub> (26%), *bla*<sub>VIM</sub> (24%), *bla*<sub>OXA-48</sub> (22%), and *bla*<sub>NDM</sub> (21%). High resistance rates were observed against ceftazidime (100%), meropenem (96%), and imipenem (95%), with aztreonam showing the lowest resistance (59%).

**Conclusions:** These findings highlight the genetic diversity of carbapenem resistance mechanisms in this region and underscore the urgent need for stringent infection control measures, including enhanced surveillance, strict antibiotic stewardship, and the development of novel therapeutic strategies to combat CRAB infections. This study contributes to a better understanding of CRAB's molecular epidemiology in Iraq and informs strategies to mitigate the spread of MDR *A. baumannii* in healthcare settings.

**Keywords:** *Acinetobacter baumannii*, Carbapenems, Multidrug Resistance, Infection Control, Antimicrobial Stewardship

## 1. Background

*Acinetobacter baumannii* is a gram-negative, non-fermenting coccobacillus that has emerged as a significant nosocomial pathogen, particularly in intensive care units (ICUs) and burn wards. Its ability to cause severe, hard-to-treat infections and its remarkable capacity to develop multidrug resistance (MDR) has made it a formidable challenge for healthcare systems worldwide. The World Health Organization (WHO) has classified *A. baumannii* as a "critical priority" pathogen, emphasizing the urgent need for new therapeutic

strategies to combat its spread (1). The pathogenicity of *A. baumannii* is driven by several virulence factors, including biofilm formation and capsular polysaccharide production. Biofilms enable the bacterium to adhere to surfaces, such as medical devices, and protect it from both host immune responses and antibiotics (2). Capsular polysaccharides further enhance its virulence by shielding it from phagocytosis and other immune defenses (3). These traits and its ability to survive in harsh environments make *A. baumannii* a persistent threat in healthcare settings. Studies have shown that the bacterium can survive on dry surfaces for up to 30 days, with survival

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prolonged in moist conditions, complicating infection control efforts (4).

One of the most alarming features of *A. baumannii* is its capacity to develop MDR, especially to carbapenems, which are often regarded as last-resort treatments. The rise of carbapenem-resistant *A. baumannii* (CRAB) has severely limited therapeutic options, leaving clinicians with few effective antibiotics (5). Resistance to carbapenems is primarily mediated by the production of carbapenem-hydrolyzing class D  $\beta$ -lactamases (CHDLs), such as OXA-23 and OXA-24, which degrade carbapenems and other  $\beta$ -lactam antibiotics (6). Additionally, efflux pump overexpression and alterations in outer membrane permeability contribute to its resistance profile (7). As a result, treatment often relies on polymyxins and combination therapies, which are associated with higher toxicity and limited efficacy (8).

Carbapenem resistance in *A. baumannii* is primarily driven by carbapenemase enzymes encoded by genes such as *bla*<sub>OXA-23</sub>, *bla*<sub>OXA-48</sub>, *bla*<sub>NDM</sub>, and *bla*<sub>VIM</sub>. These enzymes hydrolyze carbapenems, rendering them ineffective. For example, *bla*<sub>OXA-48</sub>, frequently found in *Enterobacteriaceae*, can transfer between bacterial species, spreading resistance (9). Similarly, *bla*<sub>NDM</sub> and *bla*<sub>VIM</sub> significantly contribute to resistance in *Pseudomonas aeruginosa* and *A. baumannii* (10). These genes are often linked to high rates of MDR, complicating treatment and infection control efforts (11).

In the Middle East, including Iraq, the prevalence of CRAB is rising, posing significant challenges to healthcare systems already strained by limited resources and high rates of hospital-acquired infections. Globally, CRAB has been reported with high prevalence in regions such as Europe (e.g., Greece and Italy) and Asia (e.g., China and India), reflecting a widespread challenge to infection control (12, 13). A study from Jordan reported 98.1% resistance to meropenem and 87.7% resistance to imipenem among CRAB isolates, highlighting the severity of the issue (14). In Iran, genomic analyses have revealed the presence of multiple antibiotic resistance genes in CRAB strains, underscoring the ongoing evolution and spread of these pathogens (11). The increasing rates of CRAB infections are particularly concerning in resource-limited settings, where infection control measures and access to effective antibiotics are often inadequate (12).

In Iraq, particularly in the Wasit region, data on the molecular epidemiology of carbapenemase genes in *A. baumannii* isolates are limited. However, studies in Erbil

have identified *bla*<sub>OXA-23</sub> and *bla*<sub>OXA-51</sub> as the most prevalent carbapenemase genes among isolates, with ST 556 and ST 218 being the most common sequence types (15). Another study in Iraq found that all tested isolates carried *bla*<sub>OXA-23</sub> and *bla*<sub>OXA-51</sub>, with some also harboring *bla*<sub>OXA-58</sub> (16). These findings highlight a concerning level of carbapenem resistance in Iraq, though data from the Wasit region remain scarce. Understanding the prevalence and distribution of carbapenemase genes is crucial for developing effective infection control strategies and guiding empirical antibiotic therapy. The genetic adaptability of *A. baumannii*, combined with its ability to thrive in hospital environments and disseminate resistance genes via mobile genetic elements (MGEs), has made CRAB a major public health threat (17). Global travel further facilitates the spread of resistant strains into new environments, underscoring the need for coordinated international efforts to address this growing crisis (18).

## 2. Objectives

This study aimed to: (1) Detect the presence of carbapenemase genes (*bla*<sub>OXA-23</sub>, *bla*<sub>OXA-48</sub>, *bla*<sub>NDM</sub>, and *bla*<sub>VIM</sub>) in *A. baumannii* isolates from Al-Azizya Hospital, Wasit, Iraq; (2) assess their antibiotic resistance patterns; and (3) analyze the distribution of these genes and resistance profiles to enhance understanding of CRAB's molecular epidemiology in Iraq and guide local infection control and antibiotic stewardship strategies.

## 3. Methods

### 3.1. Sample Collection

Clinical specimens, including urine, wound swabs, blood, and respiratory secretions, were collected from 112 patients (49 in the ICU and 63 in non-ICU wards) at Al-Azizya Hospital, Wasit, Iraq (Figure 1), from May to November 2023, following standard microbiological protocols (19).

### 3.2. Phenotypic Characterization of the Isolates

Clinical specimens were cultured on MacConkey and blood agar at 37°C for 24 - 48 hours to isolate *A. baumannii* (19). Suspected colonies, identified by their non-lactose-fermenting, smooth, and mucoid appearance, were subjected to Gram staining to confirm gram-negative coccobacilli morphology. Phenotypic identification was performed using standard biochemical tests, including oxidase (negative), catalase



**Figure 1.** Map of Iraq highlighting Wasit province, where the study was conducted

(positive), citrate utilization (positive), motility (non-motile), and growth at 44°C (positive). The API 20NE system (bioMérieux, France) was used to confirm identification, following the manufacturer's instructions.

### 3.3. Antibiotic Susceptibility Testing

Antibiotic susceptibility was assessed using the disk diffusion method according to Clinical and Laboratory Standards Institute (CLSI) guidelines (M100, 33rd edition, 2023) (20). The following antibiotics were tested: Ceftazidime, cefotaxime, ciprofloxacin, ceftriaxone, gentamicin, amikacin, aztreonam, imipenem, and meropenem.

### 3.4. Molecular Detection of Carbapenemase Genes

DNA was extracted from bacterial isolates using a simple boiling method (21). PCR was performed to

detect the presence of *bla*<sub>OXA-23</sub>, *bla*<sub>OXA-48</sub>, *bla*<sub>NDM</sub>, and *bla*<sub>VIM</sub> genes using specific primers listed in Table 1. The *bla*<sub>OXA-51</sub> gene, intrinsic to *A. baumannii*, was used as a confirmatory marker for species identification (22). *Acinetobacter baumannii* (ATCC 19606) was used as the positive control, and molecular-grade water was used as the negative control in all PCR assays. PCR products were visualized on 1.5% agarose gels stained with ethidium bromide and compared against a DNA 100 bp size marker for identification (22).

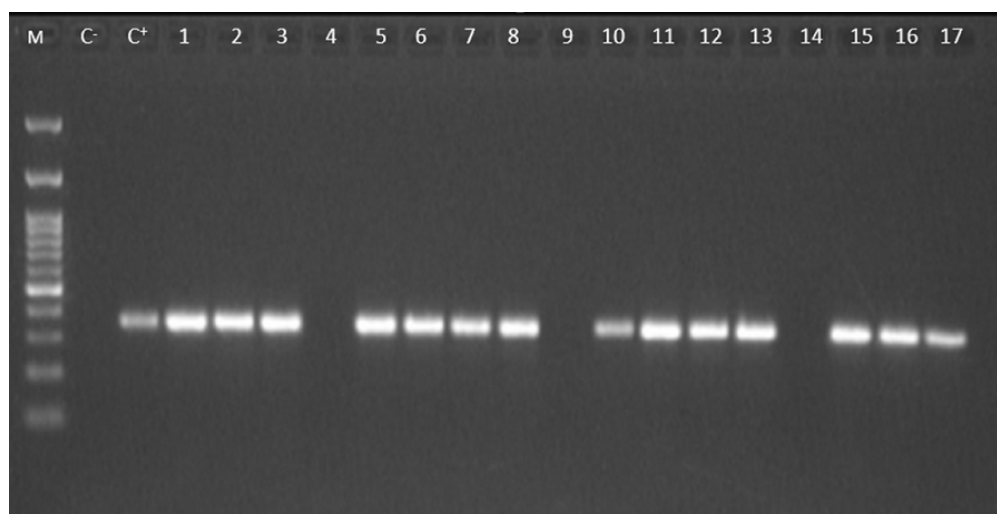
## 4. Results

### 4.1. Phenotypic and Genotypic Characterization of Strains

Based on the biochemical and Gram staining results, 63 isolates were identified as *A. baumannii*. However, using PCR of the species-specific marker *bla*<sub>OXA-51</sub> gene,

**Table 1.** The List of Oligonucleotide Primers Used in This Study

Target Genes and Primer Sequence (5'→3')	PCR Product Size (bp)	Reference
<b><i>bla</i><sub>OXA-51</sub></b>	353	(23)
F: TAATGCTTTGATCGGCCTTG		
R: TGGATTGCACTTCATCTTGG		
<b><i>bla</i><sub>VIM</sub></b>	390	(23)
F: GATGGTGTGTCGCGATA		
R: CGAATGCGCAGCACCAG		
<b><i>bla</i><sub>NDM</sub></b>	621	(23)
F: GGTTTGCGGATCTGTTTTC		
R: CGGAATGGCTCATCAGATC		
<b><i>bla</i><sub>OXA-23</sub></b>	300	(23)
F: GATGTGCATAGTATTCGTCG		
R: TCACAACAATAAAGCACTG		
<b><i>bla</i><sub>OXA-48</sub></b>	597	(23)
F: AACGGGCGAACCAAGCATTTT		
R: TGAGCACTTCCTTTGTGATGGCT		

**Figure 2.** Agarose gel electrophoresis of PCR-amplified *bla*<sub>OXA-51</sub> gene in *Acinetobacter baumannii* isolates. Lanes: (M) DNA size marker (100 - 1500 bp), (C-) negative control, (C+) positive control, 1-17, PCR products from *A. baumannii* isolates, displaying expected bands (353 bp).

58 (92%) isolates were confirmed to be *A. baumannii* (Figure 2).

#### 4.2. Frequency of Isolates Based on the Type of Patient Wards and Gender

As shown in Table 2, out of 58 isolates, 32 were recovered from 49 patients hospitalized in the ICU, while 26 isolates were collected from 63 patients in the

non-ICU wards. Of these, 38 strains (65.5%) were isolated from women, and 20 strains (34.5%) were recovered from men.

#### 4.3. Frequency of Strains Based on the Type of Patient Specimens

As indicated in Table 3, out of 58 *A. baumannii* strains, the highest number was related to urine samples (43.1%),

**Table 2.** Frequency of *Acinetobacter baumannii* Isolates Based on the Type of Patient Wards and Gender

Categories	ICU Wards	Non-ICU Wards	Total
<b>Number of patients</b>	49	63	112
Female	36	51	87
Male	13	12	25
<b>Number of isolates</b>	32	26	58
<b>Gender distribution of isolates; No. (%)</b>			
Female	-	-	38 (65.5)
Male	-	-	20 (34.5)

**Table 3.** Frequency of Strains According to the Type of Patient Specimens <sup>a</sup>

Variables	Values
<b>Type of specimens</b>	
Urine	25 (43.1)
Blood	14 (24.2)
Wound	9 (15.5)
Respiratory secretions	6 (10.3)
<b>Catheter</b>	4 (6.9)
<b>Total</b>	58 (100)

<sup>a</sup> Values are expressed as No. (%).

while the lowest number was related to catheter samples (6.9%).

#### 4.4. Antibacterial Sensitivity Test

Urine samples yielded the highest number of isolates (43.1%), followed by blood (24.2%), wound (15.5%), respiratory secretions (10.3%), and catheters (6.9%).

#### 4.5. Detection of Carbapenemase Genes

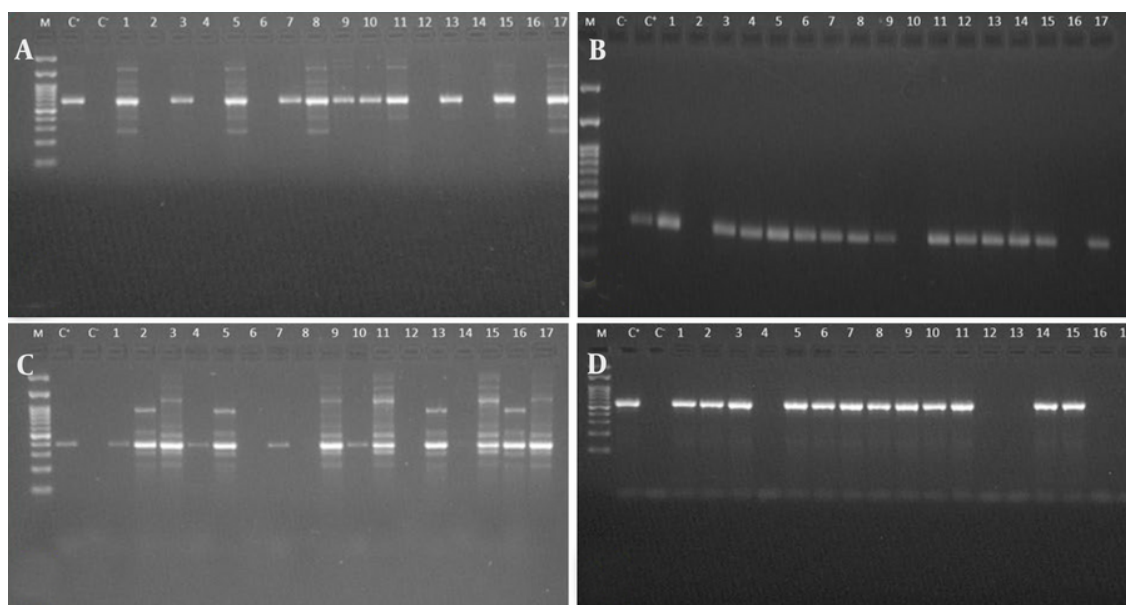
The *bla*<sub>NDM</sub> gene was detected in 12 isolates (21%), while the *bla*<sub>VIM</sub> gene was found in 14 isolates (24%), and the *bla*<sub>OXA-23</sub> gene was detected in 15 isolates (26%). Additionally, the *bla*<sub>OXA-48</sub> gene was identified in 13 isolates (22%) (Figure 3A - D). The frequency of each gene is summarized in Table 4.

### 5. Discussion

The findings of this study reveal a concerning prevalence of carbapenemase genes among *A. baumannii* isolates from Al-Azizya Hospital. The *bla*<sub>OXA-51</sub> gene, an intrinsic marker for *A. baumannii*, was detected in all isolates, confirming their identity. This aligns with global studies reporting the ubiquity of *bla*<sub>OXA-51</sub> in *A. baumannii* isolates, often accompanied by other

carbapenemase genes such as *bla*<sub>OXA-23</sub> and *bla*<sub>OXA-58</sub> (24). The presence of these genes is particularly alarming due to their association with MDR, a significant challenge in healthcare settings (25). The detection of *bla*<sub>OXA-23</sub> (26%), *bla*<sub>VIM</sub> (24%), *bla*<sub>OXA-48</sub> (22%), and *bla*<sub>NDM</sub> (21%) highlights the genetic diversity of carbapenem resistance mechanisms in this region. These findings are consistent with studies in the Middle East, such as in Iraq and Egypt, where *bla*<sub>OXA-23</sub> was the predominant gene among CRAB and *Klebsiella pneumoniae* isolates, with *bla*<sub>NDM</sub> also contributing significantly to resistance profiles (15, 16, 26). Similarly, a Jordanian study reported high resistance to meropenem (98.1%) and imipenem (87.7%), mirroring our observed rates (96% and 95%, respectively) (14).

However, contrasting results have been reported in other regions. For instance, a study in South Korea found a lower prevalence of *bla*<sub>NDM</sub> (5%) among *A. baumannii* isolates, with *bla*<sub>OXA-23</sub> dominating at 80%, suggesting regional variations in resistance gene distribution (13). In Europe, particularly in Greece, *bla*<sub>VIM</sub> was more prevalent than *bla*<sub>OXA-23</sub> in some hospital settings, highlighting differing resistance mechanisms (12, 18, 22). These comparisons underscore



**Figure 3.** Agarose gel electrophoresis of PCR products for carbapenemase genes detection in *Acinetobacter baumannii* isolates. A, Lanes: (M) DNA size marker (100 - 1500 bp), (C-) negative control, (C+) positive control, 1 - 17, PCR products from isolates, displaying predictable bands (621 bp), indicative of the amplified *bla*<sub>NDM</sub> gene; B, lanes: (M) DNA size marker (100 - 1500 bp), (C-) negative control, (C+) positive control, 1 - 17, PCR products from isolates, exhibiting expected bands (390 bp), representing the amplified *bla*<sub>VIM</sub> gene; C, lanes: (M) DNA size marker (100 - 1500 bp), (C+) positive control, (C-) negative control, 1 - 17, PCR products from isolates, displaying expected bands (390 bp), corresponding to the amplified *bla*<sub>OXA-23</sub> gene; D, lanes: (M) DNA size marker (100 - 1500 bp), (C-) negative control, (C+) positive control, 1 - 17, PCR products from isolates, showing a band at 390 bp, representing the amplified *bla*<sub>OXA-48</sub> gene.

**Table 4.** Frequency of Studied Genes<sup>a</sup>

Target Gene	Positive Isolates
<i>bla</i> <sub>OXA-51</sub>	58 (100)
<i>bla</i> <sub>NDM</sub>	12 (21)
<i>bla</i> <sub>VIM</sub>	14 (24)
<i>bla</i> <sub>OXA-23</sub>	15 (26)
<i>bla</i> <sub>OXA-48</sub>	13 (22)

<sup>a</sup> Values are expressed as No. (%).

the need for region-specific surveillance to tailor infection control strategies.

The presence of *bla*<sub>OXA-23</sub> is particularly concerning due to its association with high-level carbapenem resistance and its role in hospital outbreaks. This gene is often linked to insertion sequences that enhance its expression and mobilization, contributing to the virulence and resistance of *A. baumannii* (27). Similarly, detecting *bla*<sub>VIM</sub> and *bla*<sub>NDM</sub>, which encode metallo-β-lactamases, further complicates treatment options. These genes confer resistance to a broad range of β-

lactam antibiotics, including carbapenems, which are often considered last-resort treatments for severe infections (28). The emergence of these resistance genes poses a significant public health threat, necessitating alternative treatment strategies such as combination therapies or newer antibiotics like ceftazidime (29).

The antibiotic resistance patterns observed in this study reflect a global trend of increasing resistance among *A. baumannii* isolates. The highest resistance rates were observed against ceftazidime (100%), meropenem (96%), and imipenem (95%), which are



critical antibiotics for treating MDR infections. These findings are consistent with reports from other regions, highlighting the urgent need for enhanced surveillance and infection control measures to mitigate the spread of resistant strains (14). The COVID-19 pandemic has further exacerbated these trends, with shifts in bacterial prevalence and resistance profiles observed during this period (30). The resistance to cephalosporins and carbapenems underscores the need for alternative treatment options and stricter antibiotic stewardship programs. Newer agents such as ceftazidime-avibactam, meropenem-vaborbactam, and cefiderocol have shown promise against resistant strains and should be considered in treatment regimens (31). Effective stewardship programs are essential to optimize antibiotic use, reduce unnecessary prescriptions, and monitor resistance patterns, thereby preserving the efficacy of existing antibiotics (32).

While aztreonam retains some utility against CRAB, with a resistance rate of approximately 59%, its effectiveness varies depending on the specific resistance mechanisms present. Susceptibility testing is therefore crucial before treatment (33). Similarly, the high resistance rates to aminoglycosides (50.2%) and fluoroquinolones (65.7%) among CRAB isolates further limit therapeutic options, necessitating the exploration of alternative therapies and combination treatments (34, 35).

The high prevalence of carbapenemase genes and antibiotic resistance in *A. baumannii* isolates from Al-Azizya Hospital underscores the urgent need for stringent infection control measures. The ability of *A. baumannii* to form biofilms enhances its persistence in clinical settings, complicating eradication efforts (36). To mitigate the spread of resistant strains, healthcare facilities must implement rigorous infection control protocols, including enhanced surveillance, strict hand hygiene, contact precautions, and environmental disinfection (37). Continuous education and training for healthcare workers are also vital to ensure compliance with these measures (38).

While this study provides valuable insights into the molecular characteristics of *A. baumannii* isolates, it is limited by a small sample size from a single hospital and a focus on carbapenemase genes without exploring other resistance mechanisms. Clinical variables such as patient age, underlying diseases, and immunodeficiency status were not examined. Future studies should incorporate these factors to identify risk factors for CRAB infections and inform targeted prevention strategies.

### 5.1. Conclusions

This study demonstrates the high prevalence of carbapenemase genes and antibiotic resistance in *A. baumannii* isolates from Al-Azizya Hospital in Wasit, Iraq. The presence of *bla*<sub>OXA-23</sub>, *bla*<sub>VIM</sub>, *bla*<sub>OXA-48</sub>, and *bla*<sub>NDM</sub> genes highlights the genetic diversity of carbapenem resistance mechanisms in this region. These findings underscore the urgent need for effective infection control measures, including strict antibiotic stewardship and enhanced surveillance of CRAB in Iraqi hospitals. Additionally, the development of new therapeutic strategies, such as combination therapies and novel antibiotics, is essential to combat the growing threat of multidrug-resistant *A. baumannii*.

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### Footnotes

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**Data Availability:** The dataset presented in the study is available on request from the corresponding author during submission or after publication.

**Ethical Approval:** This study obtained ethical approval from Ilam University, Ilam, Iran (IR.ILAM.REC.1403.041).

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### References

1. Nocera FP, Attili AR, De Martino L. *Acinetobacter baumannii*: Its clinical significance in human and veterinary medicine. *Pathogens*. 2021;10(2). [PubMed ID: 33513701]. [PubMed Central ID: PMC7911418]. <https://doi.org/10.3390/pathogens10020127>.

2. Gedefie A, Demsis W, Ashagrie M, Kassa Y, Tesfaye M, Tilahun M, et al. *Acinetobacter baumannii* biofilm formation and its role in disease pathogenesis: A review. *Infect Drug Resist.* 2021;**14**:3711-9. [PubMed ID: 34531666]. [PubMed Central ID: PMC8439624]. <https://doi.org/10.2147/IDR.S332051>.
3. Ching C, Yang B, Onwubueke C, Lazinski D, Camilli A, Godoy VG. Lon protease has multifaceted biological functions in *Acinetobacter baumannii*. *J Bacteriol.* 2019;**201**(2). [PubMed ID: 30348832]. [PubMed Central ID: PMC6304660]. <https://doi.org/10.1128/JB.00536-18>.
4. Towner KJ. *Acinetobacter*: An old friend, but a new enemy. *J Hosp Infect.* 2009;**73**(4):355-63. [PubMed ID: 19700220]. <https://doi.org/10.1016/j.jhin.2009.03.032>.
5. Dettori M, Piana A, Deriu MG, Lo Curto P, Cossu A, Musumeci R, et al. Outbreak of multidrug-resistant *Acinetobacter baumannii* in an intensive care unit. *New Microbiol.* 2014;**37**(2):185-91. [PubMed ID: 24858645].
6. Vazquez-Ucha JC, Maneiro M, Martinez-Guitian M, Buynak J, Bethel CR, Bonomo RA, et al. Activity of the beta-lactamase inhibitor LN-1-255 against carbapenem-hydrolyzing class D beta-lactamases from *Acinetobacter baumannii*. *Antimicrob Agents Chemother.* 2017;**61**(11). [PubMed ID: 28807908]. [PubMed Central ID: PMC5655052]. <https://doi.org/10.1128/AAC.01172-17>.
7. Vahhabi A, Hasani A, Rezaee MA, Baradaran B, Hasani A, Samadi Kafil H, et al. A plethora of carbapenem resistance in *Acinetobacter baumannii*: No end to a long insidious genetic journey. *J Chemother.* 2021;**33**(3):137-55. [PubMed ID: 33243098]. <https://doi.org/10.1080/1120009X.2020.1847421>.
8. De Oliveira DMP, Forde BM, Phan MD, Steiner B, Zhang B, Zuegg J, et al. Rescuing tetracycline class antibiotics for the treatment of multidrug-resistant *Acinetobacter baumannii* pulmonary infection. *mBio.* 2022;**13**(1). e0351721. [PubMed ID: 35012353]. [PubMed Central ID: PMC8749419]. <https://doi.org/10.1128/mbio.03517-21>.
9. Elshamy AA, Saleh SE, Alshahrani MY, Aboshanab KM, Aboulwafa MM, Hassouna NA. OXA-48 carbapenemase-encoding transferable plasmids of *Klebsiella pneumoniae* recovered from Egyptian patients suffering from complicated urinary tract infections. *Biology (Basel).* 2021;**10**(9). [PubMed ID: 34571766]. [PubMed Central ID: PMC8469419]. <https://doi.org/10.3390/biology10090889>.
10. Kim YA, Jeong SH, Shin JH, Shin KS, Shin JH, Kim YR, et al. Four genotypes of carbapenem-resistant *Acinetobacter baumannii* strains lacking OXA-23 production in Korea. *Ann Clin Microbiol.* 2024;**27**(2):143-7. <https://doi.org/10.5145/acm.2024.27.2.8>.
11. Douraghi M, Kenyon JJ, Aris P, Asadian M, Ghourchian S, Hamidian M. Accumulation of antibiotic resistance genes in carbapenem-resistant *Acinetobacter baumannii* isolates belonging to lineage 2, global clone 1, from outbreaks in 2012-2013 at a Tehran burns hospital. *mSphere.* 2020;**5**(2). [PubMed ID: 32269158]. [PubMed Central ID: PMC7142300]. <https://doi.org/10.1128/mSphere.00164-20>.
12. Muller C, Reuter S, Wille J, Xanthopoulou K, Stefanik D, Grundmann H, et al. A global view on carbapenem-resistant *Acinetobacter baumannii*. *mBio.* 2023;**14**(6). e0226023. [PubMed ID: 37882512]. [PubMed Central ID: PMC10746149]. <https://doi.org/10.1128/mbio.02260-23>.
13. Bae IK, Hong JS. The distribution of carbapenem-resistant *Acinetobacter* species and high prevalence of CC92 OXA-23-producing *Acinetobacter baumannii* in community hospitals in South Korea. *Infect Drug Resist.* 2024;**17**:1633-41. [PubMed ID: 38707988]. [PubMed Central ID: PMC11068040]. <https://doi.org/10.2147/IDR.S459739>.
14. AlFaris EA, Al-Karablieh N, Odat NA, Rafei R. Carbapenem-resistant *Acinetobacter baumannii* from Jordan: Complicated carbapenemase combinations. *Jordan J Biol Sci.* 2024;**17**(2):355-61. <https://doi.org/10.54319/jjbs/170216>.
15. Abduljabar KA, Mawlood AH. Multilocus sequence typing analysis and molecular characterization of carbapenemase related genes in *Acinetobacter baumannii* isolated from hospitalized patients in Erbil city, Iraq. *Cell Mol Biol (Noisy-le-grand).* 2023;**69**(11):116-24. [PubMed ID: 38015532]. <https://doi.org/10.14715/cmb/2023.69.11.18>.
16. Alzaidi JR. Prevalence of OXA genes responsible for carbapenem-resistance among *Acinetobacter baumannii* isolated from clinical samples in Iraq. *Med J Babylon.* 2023;**20**(3):632-7. [https://doi.org/10.4103/mjbl.Mjbl\\_828\\_23](https://doi.org/10.4103/mjbl.Mjbl_828_23).
17. Odih EE, Sunmonu GT, Okeke IN, Dalsgaard A. NDM-1- and OXA-23-producing *Acinetobacter baumannii* in wastewater of a Nigerian hospital. *Microbiol Spectr.* 2023;**11**(6). e0238123. [PubMed ID: 37796014]. [PubMed Central ID: PMC10714947]. <https://doi.org/10.1128/spectrum.02381-23>.
18. Theriault N, Tillotson G, Sandrock CE. Global travel and gram-negative bacterial resistance; implications on clinical management. *Expert Rev Anti Infect Ther.* 2021;**19**(2):181-96. [PubMed ID: 32815412]. <https://doi.org/10.1080/14787210.2020.1813022>.
19. Ababneh Q, Abulaila S, Jaradat Z. Isolation of extensively drug resistant *Acinetobacter baumannii* from environmental surfaces inside intensive care units. *Am J Infect Control.* 2022;**50**(2):159-65. [PubMed ID: 34520789]. <https://doi.org/10.1016/j.ajic.2021.09.001>.
20. Clinical & Laboratory Standards Institute. *Performance standards antimicrobial susceptibility testing.* Wayne, PA: Clinical & Laboratory Standards Institute; 2023. Available from: <https://clsi.org/shop/standards/m100/>.
21. Hajizadeh M, Pourahmad F, Nemati M. Isolation and screening of antibacterial activity of *Actinomycetota* from the medicinal plant, *anthesis pseudocotula* boiss. *Arch Razi Inst.* 2023;**78**(5):1638-46. [PubMed ID: 38590676]. [PubMed Central ID: PMC10998938]. <https://doi.org/10.22092/ARI.2023.78.5.1638>.
22. Vijayakumar S, Biswas I, Veeraraghavan B. Accurate identification of clinically important *Acinetobacter* spp.: An update. *Future Sci OA.* 2019;**5**(6):FSO395. [PubMed ID: 31285840]. [PubMed Central ID: PMC6609899]. <https://doi.org/10.2144/fsoa-2018-0127>.
23. Sathyanesan LK, Jose R, Valsan C, Joy LM. Genotypic characterisation of carbapenemases in clinical isolates of *Acinetobacter baumannii* in a tertiary care teaching hospital of Kerala. *J Med Bacteriol.* 2024;**12**(3). <https://doi.org/10.18502/jmb.v12i3.16608>.
24. Pitout JDD, Peirano G, Kock MM, Strydom KA, Matsumura Y. The global ascendancy of OXA-48-type carbapenemases. *Clin Microbiol Rev.* 2019;**33**(1). [PubMed ID: 31722889]. [PubMed Central ID: PMC6860007]. <https://doi.org/10.1128/CMR.00102-19>.
25. Shirmohammadlou N, Zeighami H, Haghi F, Kashefieh M. Resistance pattern and distribution of carbapenemase and antiseptic resistance genes among multidrug-resistant *Acinetobacter baumannii* isolated from intensive care unit patients. *J Med Microbiol.* 2018;**67**(10):1467-73. [PubMed ID: 30175954]. <https://doi.org/10.1099/jmm.0.000826>.
26. Mohanna ZA, Al-Yasseen AK. Distribution of carbapenemase genes among carbapenem-resistant *Klebsiella pneumoniae* isolates from the patients in Najaf, Iraq. *Biomed Biotechnol Res J.* 2024;**8**(3):297-304. [https://doi.org/10.4103/bbrj.bbrj\\_212\\_24](https://doi.org/10.4103/bbrj.bbrj_212_24).
27. Yungyuen T, Chatsuwan T, Plongla R, Kanthawong S, Yordpratum U, Voravuthikunchai SP, et al. Nationwide surveillance and molecular characterization of critically drug-resistant gram-negative bacteria: results of the research university network Thailand study. *Antimicrob Agents Chemother.* 2021;**65**(9). e0067521. [PubMed ID: 34181474]. [PubMed Central ID: PMC8370234]. <https://doi.org/10.1128/AAC.00675-21>.
28. Garg A, Garg J, Kumar S, Bhattacharya A, Agarwal S, Upadhyay GC. Molecular epidemiology & therapeutic options of carbapenem-resistant Gram-negative bacteria. *Indian J Med Res.* 2019;**149**(2):285-9. [PubMed ID: 31219096]. [PubMed Central ID: PMC6563745]. [https://doi.org/10.4103/ijmr.IJMR\\_36\\_18](https://doi.org/10.4103/ijmr.IJMR_36_18).



29. Ramadan RA, Bedawy AM, Negm EM, Hassan TH, Ibrahim DA, ElSheikh SM, et al. Carbapenem-resistant *Klebsiella pneumoniae* among patients with ventilator-associated Pneumonia: Evaluation of antibiotic combinations and susceptibility to new antibiotics. *Infect Drug Resist.* 2022;**15**:3537-48. [PubMed ID: [35833009](#)]. [PubMed Central ID: [PMC9271681](#)]. <https://doi.org/10.2147/IDR.S371248>.
30. Zafer MM, Bassiouny DM, Ghosh S, Bornman C, Hussein AFA. Antimicrobial resistance patterns among critical priority pathogens in an intensive care unit at a tertiary hospital in Egypt: A descriptive analysis comparing pre- and COVID-19 eras. *J Med Microbiol.* 2024;**73**(6). [PubMed ID: [38916589](#)]. <https://doi.org/10.1099/jmm.0.001838>.
31. Ifedinezi OV, Nnaji ND, Anumudu CK, Ekwueme CT, Uhegwu CC, Ihenetu FC, et al. Environmental antimicrobial resistance: Implications for food safety and public health. *Antibiotics (Basel).* 2024;**13**(11). [PubMed ID: [39596781](#)]. [PubMed Central ID: [PMC11591122](#)]. <https://doi.org/10.3390/antibiotics13111087>.
32. Tilahun M, Kassa Y, Gedefie A, Ashagire M. Emerging carbapenem-resistant enterobacteriaceae infection, its epidemiology and novel treatment options: A review. *Infect Drug Resist.* 2021;**14**:4363-74. [PubMed ID: [34707380](#)]. [PubMed Central ID: [PMC8544126](#)]. <https://doi.org/10.2147/IDR.S337611>.
33. Spellberg B, Srinivasan A, Chambers HF. New societal approaches to empowering antibiotic stewardship. *JAMA.* 2016;**315**(12):1229-30. [PubMed ID: [26914942](#)]. [PubMed Central ID: [PMC5611826](#)]. <https://doi.org/10.1001/jama.2016.1346>.
34. Tozluyur A. Fosfomycin in the treatment of New Delhi Metallo- $\beta$ -Lactamase-5 (blaNDM-5)-producing *Escherichia coli* infection. *German J Microbiol.* 2024;**4**(1):1-5. <https://doi.org/10.51585/gjm.2024.1.0028>.
35. Zhang S, Di L, Qi Y, Qian X, Wang S. Treatment of infections caused by carbapenem-resistant *Acinetobacter baumannii*. *Front Cell Infect Microbiol.* 2024;**14**:1395260. [PubMed ID: [39081869](#)]. [PubMed Central ID: [PMC11287075](#)]. <https://doi.org/10.3389/fcimb.2024.1395260>.
36. Nirwati H, Hakim MS, Darma S, Mustafa M, Nuryastuti T. Detection of bla(oxa) genes and identification of biofilm-producing capacity of *Acinetobacter baumannii* in a tertiary teaching hospital, Klaten, Indonesia. *Med J Malaysia.* 2018;**73**(5):291-6. [PubMed ID: [30350807](#)].
37. Koo SH, Kwon KC, Cho HH, Sung JY. Genetic basis of multidrug-resistant *Acinetobacter baumannii* clinical isolates from three university hospitals in Chungcheong province, Korea. *Korean J Lab Med.* 2010;**30**(5):498-506. [PubMed ID: [20890082](#)]. <https://doi.org/10.3343/kjlm.2010.30.5.498>.
38. Woon JJ, Ahmad Kamar A, Teh CSJ, Idris N, Zhazali R, Saaibon S, et al. Molecular epidemiological investigation and management of outbreak caused by carbapenem-resistant *Acinetobacter baumannii* in a neonatal intensive care unit. *Microorganisms.* 2023;**11**(4). [PubMed ID: [37110495](#)]. [PubMed Central ID: [PMC10146162](#)]. <https://doi.org/10.3390/microorganisms11041073>.