Antibacterial and Antibiofilm Activities of 3-Iodoindole against Multidrug-Resistant *Acinetobacter baumannii* Isolated from Urinary Tract Infections

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ABSTRACT

Background: *Acinetobacter baumannii* is an important opportunistic pathogen associated with urinary tract infections and notable multidrug resistance. Biofilm formation further complicates treatment and contributes to persistence in clinical settings. **Objective:** This study aimed to evaluate the antibacterial and antibiofilm activities of 3-iodoindole against multidrug-resistant *A. baumannii* isolates recovered from patients with urinary tract infections in Baghdad, Iraq. **Methodology:** A total of 150 urinary isolates were collected from hospitals and laboratories in Medical City, Baghdad. Isolates were identified by conventional culture methods and the VITEK 2 Compact system. Antimicrobial susceptibility was assessed by the Kirby-Bauer method and VITEK 2 AST cards. Biofilm formation was quantified using a microtiter plate assay, and the antibacterial and antibiofilm activities of 3-iodoindole were evaluated at different concentrations. **Results:** Of the 150 isolates, 100 (66.7%) were confirmed as *A. baumannii*. High resistance rates were observed against several commonly used antibiotics, whereas colistin and tigecycline remained the most active agents. Biofilm assays showed that 79% of isolates were biofilm producers, including moderate and strong biofilm-forming phenotypes. Strong biofilm formers exhibited significantly higher $_{OD600}$ values at 24 h than weak biofilm formers. 3-Iodoindole demonstrated marked antibacterial activity, achieving a >3-log reduction in viability at 250 µg/mL within 15 min and significantly reducing biofilm biomass in a dose-dependent manner. **Conclusion:** 3-Iodoindole exhibited potent antibacterial and antibiofilm effects against multidrug-resistant *A. baumannii* and may represent a promising candidate for further development as an alternative or adjunctive antimicrobial agent.

Keywords: Antibacterial activity, antibiofilm activity, 3-iodoindole, multidrug resistance, *Acinetobacter baumannii*, urinary tract infection.
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INTRODUCTION

Acinetobacter baumannii is a Gram-negative, aerobic, non-fermenting coccobacillus that has emerged as a major opportunistic pathogen in healthcare settings worldwide. It is capable of persisting on environmental surfaces and medical devices, facilitating transmission and survival in hospital environments (1–3). The clinical importance of *A. baumannii* has increased substantially due to its involvement in a wide range of infections, including bacteremia, ventilator-associated pneumonia, and urinary tract infections, particularly among critically ill and immunocompromised patients (1,2).

A defining characteristic of *A. baumannii* is its remarkable ability to develop resistance to multiple classes of antimicrobial agents. As part of the ESKAPE group of pathogens, it exhibits both intrinsic and acquired resistance mechanisms that enable it to evade the effects of commonly used antibiotics (3,4). The global rise of multidrug-resistant (MDR) *A. baumannii* represents a serious public health concern, contributing to increased mortality, prolonged hospitalization, and significant economic burden (5,6). The dissemination of resistance determinants, including carbapenem-hydrolyzing class D β-lactamases and other β-lactamase enzymes, has further limited the

effectiveness of conventional therapies (7-9). In addition to antimicrobial resistance, biofilm formation plays a critical role in the pathogenicity of *A. baumannii*. Biofilms are structured microbial communities embedded within a self-produced extracellular matrix that enhances bacterial survival under hostile conditions (10-11). Within these structures, bacterial cells exhibit reduced susceptibility to antimicrobial agents and host immune responses, contributing to persistent and recurrent infections (10). Recent research has focused on alternative antimicrobial agents capable of targeting both planktonic and biofilm-associated bacteria. Among these, indole and its derivatives have gained attention due to their ability to modulate bacterial physiology and interfere with quorum sensing, motility, and virulence gene expression (11). Halogenated indole derivatives, particularly 3-iodoindole, have demonstrated enhanced antimicrobial properties compared to non-halogenated analogs (4,12). Previous studies have shown that 3-iodoindole exhibits potent antibacterial activity, inhibits biofilm formation, and eradicates persistent cells (13,14,15). These effects are attributed to mechanisms such as membrane disruption, oxidative stress induction, and interference with bacterial regulatory pathways (11,16). Additional studies have also demonstrated the effectiveness of related compounds in inhibiting biofilm formation, supporting the broader therapeutic potential of this class of molecules (17). Despite these promising findings, the activity of 3-iodoindole against MDR *A. baumannii*, particularly clinical isolates associated with urinary tract infections, remains insufficiently explored. Therefore, the present study aimed to evaluate the antibacterial and antibiofilm activities of 3-iodoindole against MDR *A. baumannii* isolates obtained from patients with urinary tract infections in Baghdad, Iraq.

Methodology

1. Bacterial Isolation and Sample Collection

A total of 150 clinical isolates were collected from patients diagnosed with urinary tract infections (UTIs) attending hospitals and diagnostic laboratories in Medical City, Baghdad, Iraq. Demographic and clinical data, including age, sex, residence, hospital ward, sample source, and date of collection, were recorded.

2. Identification of *Acinetobacter baumannii*

Primary isolation was performed on blood agar and MacConkey agar plates, followed by Gram staining. Presumptive identification was confirmed using the VITEK 2 Compact system (bioMérieux, France) with ID-GNB cards, according to the manufacturer's instructions.

3. Antimicrobial Susceptibility Testing

Antimicrobial susceptibility testing was performed using the Kirby–Bauer disk diffusion method on Mueller–Hinton agar according to CLSI guidelines. Susceptibility profiles were further confirmed using the VITEK 2 Compact system. *Escherichia coli* ATCC 25922 was used as a quality control strain.

4. Quantitative Biofilm Formation Assay

Biofilm formation was quantified using a microtiter plate assay as previously described (10). Briefly, bacterial cultures were adjusted to a 0.5 McFarland standard and diluted 1:20 in tryptone soya broth (TSB). Aliquots (200 µL) were added to 96-well plates and incubated at 37°C for 24 h.

After incubation, wells were washed with phosphate-buffered saline (PBS), stained with 0.1% crystal violet, and the bound dye was solubilized with 33% acetic acid. Optical density was measured at 630 nm. Biofilm classification was performed based on OD cutoff values (10).

5. Determination of Minimum Inhibitory Concentration (MIC)

The minimum inhibitory concentration (MIC) of 3-iodoindole was determined using the broth microdilution method in accordance with protocols (18). Serial dilutions of 3-iodoindole (1–250 µg/mL) were prepared in Mueller–Hinton broth, followed by inoculation with bacterial suspension.

After incubation at 37°C for 24 h, resazurin dye was added to assess bacterial viability. The MIC was defined as the lowest concentration required to inhibit visible bacterial growth (18).

6. Antibiofilm Activity of 3-Iodoindole

The antibiofilm activity was evaluated using a static biofilm inhibition assay as described previously (15). Bacterial cultures were incubated with 3-iodoindole at concentrations of 50, 100, and 250 µg/mL for 24 h at 37°C.

Biofilm biomass was quantified using crystal violet staining, and absorbance was measured at 570 nm. Percentage inhibition was calculated relative to untreated controls (15).

7. Statistical Analysis

Statistical analysis was performed using SPSS version 16.0. Data were expressed as mean ± standard deviation. Differences between groups were analyzed using the chi-square test, ANOVA where appropriate. A *p*-value ≤ 0.05 was considered statistically significant.

Results

Identification and Demographics of *Acinetobacter baumannii* Isolates

In this study, 50 MDR isolates, which constituted 25% of the total bacterial isolates, were identified. Among these MDR isolates, 20 (40%) were found to be biofilm producers.

Of the 150 clinical urinary isolates collected, 100 (66.7%) were confirmed as *A. baumannii* by culture-based methods and the VITEK 2 Compact system, with 99% classified under "good" or "excellent" identification categories.

Table 1. Distribution of *A. baumannii* Isolates by Age Group (n = 100)

Age Group	Frequency	Percentage (%)
<18 years	10	10.0%
18–60 years	54	54.0%
>60 years	36	36.0%
Total	**100**	**100.0%**

Chi-square test: $\chi^2 = \mathbf{17.56}$, $p = \mathbf{0.00015}$

The distribution of isolates across age groups was statistically significant ($p \leq 0.05$), indicating a non-uniform age distribution.

Table 2. Distribution of *A. baumannii* Isolates by Sex (n = 100)

Sex	Frequency	Percentage (%)	Chi-square (χ^2)	p-value
Male	65	65.0%		
Female	35	35.0%		
Total	**100**	**100.0%**	**4.01**	**0.045**

Antibiotic Resistance Pattern

Antibiotic susceptibility testing revealed **extensive resistance to β-lactams, cephalosporins, and fluoroquinolones**, with notable exceptions: colistin (2% resistance) and tigecycline (7% resistance), rendering them the most effective agents.

Table 3. Antibiotic Resistance Rates of *A. baumannii* Isolates (n = 100)

Antibiotic Class	Antibiotic Name	% Resistant
Aminoglycosides	Amikacin	37%
	Gentamicin	62%
	Tobramycin	37%
Carbapenems	Imipenem	69%
	Meropenem	75%
Tetracyclines	Tetracycline	65%
	Tigecycline	7%
	Minocycline	23%
β-lactam + Inhibitors	Ampicillin/Sulbactam	60%
	Piperacillin/Tazobactam	80%
Cephalosporins I–IV	Cefazolin	99%
	Cefoxitin	99%
	Cefuroxime	97%
	Ceftazidime	77%
	Cefotaxime	85%
	Ceftriaxone	83%
	Cefepime	81%
Monobactams	Aztreonam	95%
Fluoroquinolones	Ciprofloxacin	83%
	Levofloxacin	62%
Folate Pathway Inhibitor	TMP-SMX	49%
Polymyxins	Colistin	2%

Biofilm Formation and Growth Analysis

The crystal violet assay showed that 79% of the isolates were biofilm producers, including 48 moderate and 31 strong biofilm formers. Phase-contrast microscopy confirmed the presence of dense multilayered biofilms on PVC and glass surfaces. To further assess growth characteristics, $_{OD600}$ was measured for 10 strong and 10 weak biofilm-forming isolates at 13 time points.

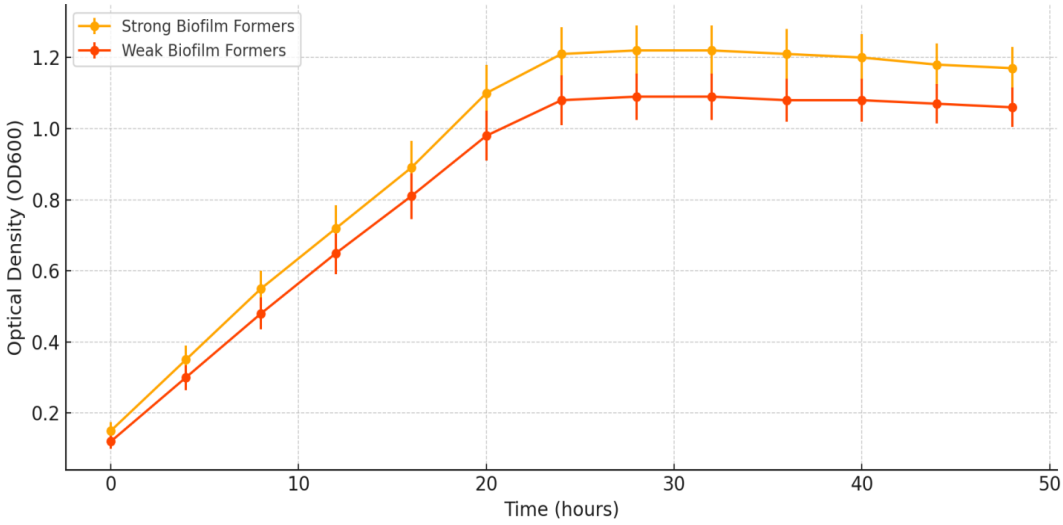

Figure 1. Growth Curve of Strong vs. Weak Biofilm Formers (Mean ± SD)

The growth curve showed a consistently higher growth trend in strong biofilm formers, particularly after 16 h, with a statistically significant difference observed at 24 h ($p = 0.036$).

Table 4. Comparative Summary of $_{OD600}$ Values at 24 Hours Between Strong and Weak Biofilm Formers

Group	Sample Size (n)	Mean ± SD	p-value (t-test)
Strong Biofilm Formers	10	**1.24 ± 0.24**	**0.036**
Weak Biofilm Formers	10	**1.01 ± 0.26**	—

These findings suggest that strong biofilm formers grow more rapidly and reach higher optical densities, contributing to more robust biofilm development and likely greater resistance to environmental stressors.

Antibacterial Activity of 3-Iodoindole

The time-kill assay showed that 3-iodoindole at 250 µg/mL reduced *A. baumannii* viability by >3 log units within 15 min, whereas at 100 µg/mL the same reduction was achieved within 24 h. This activity exceeded that of gentamicin, colistin, and ciprofloxacin under the same experimental conditions.

Antibiofilm Activity of 3-Iodoindole

At concentrations ranging from 50 to 250 µg/mL, 3-iodoindole significantly inhibited biofilm biomass. The quantified reductions in biofilm biomass were as follows:

Table 5. Biofilm Reduction by 3-Iodoindole

Concentration (µg/mL)	Mean ± SD
50	62.0 ± 1.73
100	92.0 ± 2.0
250	94.0 ± 1.0

An analysis revealed a statistically significant dose-dependent reduction in biofilm (**$p < 0.01$**), supporting the strong antibiofilm potential of 3-iodoindole.

Integrated Heatmap Analysis of Growth, Resistance, and Biofilm Inhibition

To provide an integrated comparison between strong and weak biofilm-forming *Acinetobacter baumannii* isolates, a heatmap was generated using selected experimental parameters, such as 24-hour $_{OD600}$ values, percentages of resistance to important antibiotics, and biofilm inhibition rates at different concentrations of 3-iodoindole. As shown in Figure 2, strong biofilm formers exhibited a higher $_{OD600}$ value (1.24 vs. 1.01), indicating more active bacterial growth. Resistance levels were similar between groups, indicating that biofilm strength is independent of antimicrobial resistance. Nevertheless, pronounced biofilm inhibition was observed in both groups, with 3-iodoindole exerting dose-dependent activity (62% inhibition at 50 µg/mL, increasing to 94% at 250 µg/mL). This composite analysis highlights the strong antibiofilm activity of 3-iodoindole regardless of the underlying resistance profile or biofilm phenotype.

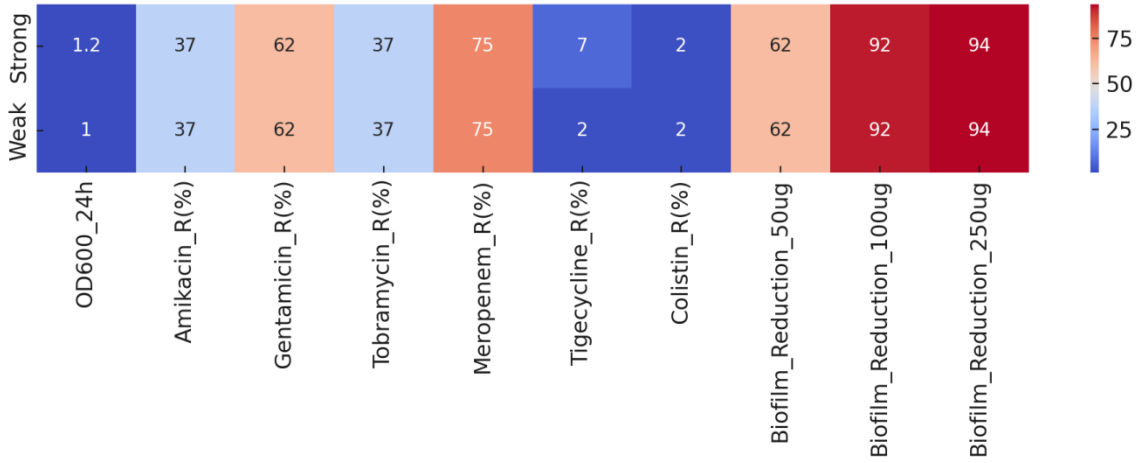

Figure 2. *Heatmap comparison of $_{OD600}$ values at 24 hours, antibiotic resistance percentages, and biofilm inhibition rates at varying concentrations of 3-iodoindole for strong and weak biofilm-forming A. baumannii isolates. The figure highlights key phenotypic and antimicrobial response differences, showing higher growth in strong biofilm formers and consistent, dose-dependent biofilm inhibition across both groups.*

Discussion

The present study demonstrates the potent antibacterial and antibiofilm activity of 3-iodoindole against multidrug-resistant (MDR) *A. baumannii* isolates recovered from UTI. These findings are consistent with previous reports highlighting the broad-spectrum antimicrobial properties of halogenated indole derivatives, particularly their ability to target both planktonic cells and biofilm-associated bacterial populations (13,15).The high prevalence of MDR *A. baumannii* observed in this study is consistent with global epidemiological reports highlighting its increasing clinical burden and resistance dissemination (5,6). The resistance patterns identified—especially the high resistance to carbapenems, cephalosporins, and fluoroquinolones—reflect the widespread dissemination of resistance determinants such as carbapenem-hydrolyzing class D β-lactamases and other β-lactamases (8,19). In contrast, the retained susceptibility to colistin and tigecycline supports their continuedrole as last-resort therapeutic agents, although concerns regarding toxicity and emerging resistance remain (9) .Biofilm formation was a prominent characteristic among the isolates, with a substantial proportion demonstrating moderate to strong biofilm-forming capacity. This observation is consistent with previous studies indicating that biofilm formation is a key virulence factor in *A. baumannii*, contributing to persistence on abiotic surfaces and increased tolerance to antimicrobial agents (10). The significantly higher OD600 values observed in strong biofilm formers further suggest enhanced growth dynamics and metabolic activity, which may facilitate rapid colonization and survival under clinical conditions. These findings emphasize the importance of targeting biofilm-associated phenotypes in the development of new antimicrobial strategies. The antibacterial activity of 3-iodoindole observed in this study was rapid and concentration-dependent, with a marked reduction in bacterial viability within a short exposure period. This strong bactericidal effect is consistent with previous studies demonstrating the efficacy of iodinated indole derivatives against MDR pathogens (15). Notably, the activity of 3-iodoindole exceeded that of commonly used antibiotics under comparable conditions, highlighting its potential as an alternative or adjunct therapeutic agent. In addition to its antibacterial effects, 3-iodoindole exhibited significant antibiofilm activity, with pronounced reductions in biofilm biomass observed in a dose-dependent manner. These findings are in agreement with earlier studies demonstrating that halogenated indoles can disrupt biofilm formation and eliminate persister cells, which are typically resistant to conventional antimicrobial therapies (12,13). These observations are further supported by studies demonstrating effective biofilm inhibition using novel antimicrobial materials and compounds (17), reinforcing the therapeutic potential of targeting biofilm-associated bacterial populations.

From a mechanistic perspective, the antimicrobial activity of 3-iodoindole is likely multifactorial. One proposed mechanism involves the induction of reactive oxygen species (ROS), leading to oxidative stress and subsequent damage to essential cellular components, including membranes, proteins, and nucleic acids (16). This mechanism is supported by evidence demonstrating the role of oxidative stress in bacterial killing by antimicrobial agents such as polymyxins (16). Additionally, indole derivatives have been shown to interfere with bacterial signaling pathways, including quorum sensing, thereby disrupting communication systems essential for biofilm formation and virulence regulation (11).The incorporation of iodine into the indole structure may further enhance antimicrobial efficacy by increasing molecular reactivity and facilitating the generation of reactive intermediates. This structural modification is believed to promote membrane destabilization and increased permeability, ultimately leading to bacterial cell death (4,15). Importantly, previous studies have indicated that halogenated indole derivatives exhibit relatively low toxicity in biological systems, supporting their potential for safe therapeutic application (12). Despite these promising findings, several limitations should be acknowledged. This study was conducted under in vitro conditions, and therefore the efficacy and safety of 3-iodoindole in vivo remain to be established. Furthermore, while the antibacterial and antibiofilm activities were clearly demonstrated, additional studies are required to elucidate the precise molecular mechanisms underlying its action and to evaluate its effectiveness against a broader range of clinical isolates and infection models.

CONCLUSION

In conclusion, this study demonstrates that 3-iodoindole possesses potent antibacterial and antibiofilm activity against multidrug-resistant *A. baumannii* isolates associated with UTI. The compound exhibited rapid bactericidal effects and significantly reduced biofilm formation in a dose-dependent manner, highlighting its dual functionality against both planktonic and biofilm-associated bacterial populations. The observed efficacy of 3-iodoindole against highly resistant clinical isolates underscores its potential as a promising alternative or adjunct to conventional antimicrobial agents, particularly in the context of increasing global antimicrobial resistance. Its ability to disrupt key pathogenic mechanisms, including biofilm formation and bacterial survival, further supports its therapeutic relevance. However, given that the present study was conducted under in vitro conditions, further investigations are required to evaluate the pharmacokinetics, toxicity, and in vivo efficacy of 3-iodoindole. Future studies should also focus on elucidating its precise molecular mechanisms of action and assessing its potential for clinical application. Overall, 3-iodoindole represents a promising candidate for the development of novel antimicrobial strategies aimed at combating infections caused by multidrug-resistant *A. baumannii* and other clinically significant pathogens.

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Ethical approval

The study received ethical approval from the Research Ethics Committee of the University of Al-Nahrain, Forensic DNA Research and Training Center (Approval No.NG-2324-3; dated 1/9/2023. The research swas conducted in aacordance with international guidelines , including CIOMS, WHO standards.

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Conflict of Interest

The author declares no conflict of interest.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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الأنشطة المضادة للبكتيريا والمضادة لتكوين الأغشية الحيوية لمركبات 3-يودوإندول ضد عدوى الجهاز البولي الناتجة عن بكتيريا Acinetobacter baumannii المقاومة لعدة أدوية

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الخلاصة

خلفية عن البحث :يمكن أن تتأثر صحة اللثة لدى الأطفال ببعض المؤشرات البيولوجية مثل البروتينات الرابطة لعامل النمو الشبيه بالأنسولين-IGFBP 2و IGFBP-3 في اللعاب.كما أن الحالة النمائية، والتي تمثل بمؤشر كتلة الجسم والطول بالنسبة للعمر، قد تلعب دوراً في تحديد صحة الفم.**الهدف من الدراسة :** دراسة العلاقة بين مستويات IGFBP-2 و IGFBP-3في اللعاب وصحة اللثة.وذلك بالتوازي مع الحالة النمائية لدى الأطفال الذين تتراوح أعمارهم بين 10 و12 سنة .**المواد وطريقة العمل :**أُجريت دراسة مقطعية على 140 طفلاً سليماً من مدارس الجَنان الأهلية في بغداد.تم قياس مؤشر كتلة الجسم، الطول بالنسبة للعمر(Z-score) ، مؤشر اللويحة، مؤشر اللثة، ومستويات البروتينات في اللعاب.**التحليل الإحصائي :**تم استخدام الإحصاءات الوصفية، تحليل الارتباط، اختبار مان-ويتني، الانحدار المتعدد، ANOVA، كاي تربيع، تحليل المكونات الرئيسية والانحدار اللوجستي.أظهرت النتائج وجود ارتباط إيجابي قوي بين IGFBP-2 و.(r = 0.77, p < 0.001) IGFBP-3**النتائج :**وُجد ارتباط سلبي مهم بين كل من IGFBP-2 و-IGFBP 3ومؤشر التهاب اللثة(IGFBP-2: r = -0.43 ؛IGFBP-3: r = -0.49) كما أظهر تحليل الانحدار أن الطول بالنسبة للعمر يؤثر سلباً على التهاب اللثة.(p = 0.038) **نتائج إضافية :**أظهر اختبار ANOVA فروقاً ذات دلالة في مستويات IGFBP بين فئات النمو المختلفة.(p < 0.001) توقع الانحدار اللوجستي مشاكل اللثة الشديدة بدقة بلغت 90.5%، رغم أن نسبة التذكير للحالات الشديدة بلغت 43.% **الاستنتاج :**ترتبط مستويات IGFBP-2 و IGFBP-3في اللعاب بشكل ملحوظ بصحة اللثة والحالة النمائية.مما يشير إلى إمكانية استخدامهما كمؤشرات حيوية غير جراحية لمراقبة صحة الفم والنمو لدى الأطفال.

الكلمات المفتاحية :مضاد للبكتيريا ، مضاد لتكوين الأغشية الحيوية ، يودوإندولات ، مقاومة متعددة للأدوية(MDR) ، *Acinetobacter baumannii*.