Colistin as A Good Monotherapy to Restrain the Pathogenicity of Acinetobacter baumannii In vivo and In vitro

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Abstract:

Acinetobacter baumannii (A. baumannii) is a major opportunistic nosocomial pathogen, mostly resistant to several groups of antibiotics. Colistin is now used as a last-line treatment for isolates that are highly resistant. The purpose of this study is to identify the importance of LptD; which is involved in the translocation of LPS from the inner membrane to the outer membrane in compartment with LptA and LptC of A. baumannii and its indispensable role as a virulence factor, and the efficiency of colistin as a monotherapy. In the current research, two isolates of A. baumannii were used, the local isolate HHR1 isolated from urine sample and the global strain ATCC 17904, and three antibiotics (colistin, rifampicin and Fosfomycin) were used as a monotherapy and synergic therapy in vivo and ex vivo. The results demonstrated that A. baumannii HHR1 was more resistant to Antimicrobial peptides (AMPs) than the standard strains. The effect of AMPs on A. baumannii was increased by increasing the concentration and the time of incubation, and also AMPs were shown to be lethal on A. baumannii growth spatially at high concentration (2 µg ml⁻¹) in monotherapy and (1.5, 2 µg ml⁻¹) in synergic. The susceptibility of isolates towards antibiotics was variable, where colistin exerts significant growth had defect as a monotherapy and in combination with others. The results showed that the expression of lptD, lptA genes of A. baumannii HHR1 were higher than of the same genes in A. baumannii ATCC 17904 in the presence of 2 µg ml⁻¹ colistin, while lptE gene of the A. baumannii ATCC 17904 showed an upregulation pattern than in A. baumannii HHR1. Furthermore, colistin influences the adhesion ability of A. baumannii on epithelial cells (A-549 lung cancer cell) by reducing the number of cells, and thus could colistin be a good candidate for A. baumannii treatment.

Keywords: Acinetobacter baumannii, AMPs, lipopolysaccharide, q-PCR.

Introduction:

Acinetobacter spp. is a non-fastidious Gram-negative bacterium, which belongs to gammaproteobacteria, aerobic and non-motile, non-fermenting. In addition to the high GC content, it is reported to be negative for oxidase and positive for catalysis. The genus Acinetobacter contains 31 well-known species that occur chiefly in nature and are mainly concerned with nosocomial infection, urinary tract infection, skin and other soft tissues, and in the blood stream.

The prevalence of multidrug-resistant pathogens has gradually increased and become a source for serious concern for both nosocomial and community-acquired infections. Presumably, A. baumannii is sensitive to most antibiotics, at present, the pathogen performs to show broad resistance to most first-line antibiotics. Antimicrobial peptides exhibit wide-spectrum and intense antimicrobial activity against bacteria, fungi and viruses. Amongst the main constituents of the innate immune system are AMPs which were identified in a variety of species, such as bacteria, fungi, animals and plants, and the majority of cationic AMPs that play an important role in antimicrobials. Colistin is an AMP that works on LPS. The LPS is a macromolecule containing the hydrophobic group (lipid group) and a hydrophilic group (the primary oligosaccharide), and O antigen. LPS is biogenesis occurred in the inner membrane (IM) and translocate to the outer membrane (OM) by the LPS vector comprising seven subunits, LptA, LptB, LptC, LptD, LptE, LptF, and LptG.

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Therefore, transporting the LPS across the water-filled ocean and the LptD barrel is quite challenging. However, it is suggested that the outermost LptD/E membranous proteins are responsible for the formation of the periplasmic segment with LptA and LptC to translocate LPS from the IM to the OM. Colistin is an AMP that binds to the outer cell membrane of Gram-negative bacteria. Its mechanism starts on the binding to the lipopolysaccharides in the outer membrane, and then an electrostatic reaction takes place between the alpha and beta-diaminobutyric acid of colistin and the phosphate groups in the lipid region A of the lipopolysaccharide (LPS). The divalent cations (Ca2+ and Mg2+) was competitively replaced from the phosphate groups of membrane lipids. As a result, the distraction of LPS may increase the permeability of the OM and intracellular contents leakage, and cell death. Unfortunately, the development of colistin-resistant isolates has been commonly recorded over the last few decades, which has increased the incorrect usage of this agent, particularly as monotherapeutic treatment, and thus could be the cause of this problem. Unfortunately, the rapid development of colistin resistance among clinical isolates of A. baumannii, as a result of misuse of colistin has led to threatening the future life with increasing usage of this antibiotic. Using rifampin and fosfomycin as a monotherapeutic agent didn’t end up with complete killing for both isolates, whereas, using synergism combination of colistin-rifampin, and colistin-fosfomycin was remarkably inhibited the viability of both isolates.

Materia and Methods:

Bacterial Sample Preparation

A. baumannii ATCC 17904 and local isolates HHR1 with the accession no. (MH685112.1) were used in this study. The standard isolate was purchased and the HHR 1 was isolated from patient urine. The isolates were routinely cultured on Nutrient Agar (NA) and MacConkey Agar (MAC) media under aerobic condition at 37°C for 24 hours. For growth curve, bacterial isolates were overnight cultured and in Mueller Hinton (MH) broth under the conditions above with genital shaking at 180 rpm. Bacterial growth curve was performed either under normal conditions as a control, or with the presence of AMP. In both cases, the growth of bacterial isolate was monitored by the measurement of OD600 against the relevant media as a control (blank). The growth was observed every hour started from OD600≈0.1 to approximately OD600 1.5.

Genomic DNA Extraction and Polymerase Chain Reaction

A- DNA Extraction

DNA extraction from isolates was done by using wizard kit’s protocol (Promega) according to the manufacturer’s instructions. DNA was stored at −20°C for further use. The genes of interest two A. baumannii isolates amplified by PCR using primers listed in Table 1 were purchased from Alpha DNA/Canada. The purity and concentration of the DNA were estimated by nanodrop device. The concentration of each primer was adjusted to 10 μM using dH2O. Specific primers that were needed for amplifying fragment of LptD-F/LptD-R, LptE-F/LptE-R, LptA-F/LptA-R, and rplB-F/rplB-R were listed in Table 1.

Table 1. Primers used in this study

<table>
<thead>
<tr>
<th>Primer name</th>
<th>Primer sequence</th>
<th>Reference</th>
<th>Gene product size</th>
</tr>
</thead>
<tbody>
<tr>
<td>LptD-F</td>
<td>5’GAGCTCGGTACCGGGGATCCTCTAGAGTCGCGCATCCATAAGCATATAC-3’</td>
<td>Designed in this study</td>
<td>720 bp</td>
</tr>
<tr>
<td>LptD-R</td>
<td>5’AAAGCTTATCGATGATAAGCTGTCAACATGCTAACTGTACTCGGCCTTG-3’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LptE-F</td>
<td>5’-CCTCGTCGTCGACTTTTAAAT-3’</td>
<td>100 bp</td>
<td></td>
</tr>
<tr>
<td>LptE-R</td>
<td>5’-ACTACGAGCTGCGGTATTTAAAG-3’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LptA-F</td>
<td>5’-CCGTCTGGACGTCAAATACAAA-3’</td>
<td>100 bp</td>
<td></td>
</tr>
<tr>
<td>LptA-R</td>
<td>5’-CCTGCTCAATCAGCAGACATTA-3’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rplB-F</td>
<td>5’-TGAGAGCGTATTGAATACGATCCTAACC-3’</td>
<td>330 bp</td>
<td></td>
</tr>
<tr>
<td>rplB-R</td>
<td>5’-CACCACCCACCATGCCTGATC-3’</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

B- Preparation of PCR Mixture

All reactions were performed with GoTaq Green Master mix (Promega). 25μl PCR reaction was used that contained 12.5μl Mastermix, 2.5μl of each primer, 2μl of genomic DNA as a template, and sterilized water to make final volume up to 25μl. Amplification program was conducted as follows: initial denaturation step at 95°C for 5min, followed by 35 cycles at 95°C 30sec for denaturation, annealing at 66°C for lptD and 60°C for lptE, and
**Effects of AMP on A. baumannii (In vitro)**

**Colony Counting Assay**

In order to determine the effect of AMPs on the viability of A. baumannii isolates, a fresh culture of isolates in MH broth was incubated as previously mentioned, the growth was monitored, and the OD_{600} was adjusted to 0.5 prior to AMPs addition. A 96 microtiter wells plate was used to measure the activity of different AMPs toward A. baumannii isolates. Serial dilution was conducted with bacterial cells of 5.8 × 10^{-8} c.f.u in the presence of several concentrations of AMPs all plates were incubated under aerobic conditions, and 20 µl of antibacterial culture was serially diluted in MH broth. 010 µl of all dilutions was spotted on MH agar for CFU calculation after 24 hr incubation. All assays were performed in triplicate.

**RNA Extraction and Quantitative PCR Analysis (qPCR)**

RNA of A. baumannii isolates was extracted by using TRIzol™ Reagent according to the protocol described by the manufacturer. RNA was extracted from fresh bacteria culture, and the concentration of extracted RNA was detected by using Quantus Fluorometer. Quantitative PCR analysis (qPCR) of lptD, lptE, lpta and rplB was employed by using GoTaqR 1-Step RT-qPCR System, this system was a reagent system for quantitative analysis of RNA using a one-step reverse transcription-quantitative PCR (RT-qPCR) protocol. The primer sequences for genes are listed in Table 1. The gene rplB was used as a housekeeping gene for the quantification of lptD, lptE and lpta. The optimization program was done as listed in Table 2. Cycles of reverse transcription were at 37°C for 15 minutes, initial denaturation/ RT inactivation was at 95°C for 10 minutes. Then 40 cycles of denaturation at 95°C for 15 seconds was done, annealing was done at 66°C for lptD, 60°C for lptE, lpta and 50 for rplB for 30 seconds, and extension was performed at 72°C for 30 seconds in each cycle. The Quantitative PCR analysis (qPCR) of samples was done by using Mic qPCR Cycler (Bio Molecular System, Australia).

| Table 2. qPCR optimization program for the genes (lptD, lptE, rplB, and lpta). |
|-------------------------------|-----------------|-----------------|-----------------|
| Optimization                  | Temp. °C        | Time            | No. of cycles   |
| Reverse                       | 37              | 15 min          | 1 cycle         |
| Transcription Initial         | 95              | 10 min          |                 |
| Denaturation/ RT inactivation |                 |                 |                 |
| Denaturation                  | 95              | 20 sec.         |                 |
| Annealing                     | lptE 60         | 20 sec.         | 50 cycle        |
|                              | lpta            |                 |                 |
|                              | lptD 66         |                 |                 |
|                              | rplB 50         |                 |                 |
| Extension                     | 72              | 20 sec.         |                 |

**Colistin Activity on Cell Line (ex vivo)**

**Cell Cultures**

Lung cancer A-549 Cell lines were attained from the Iraqi biotech Cell Bank Unit and these cells were preserved in RPMI-1640 supplemented with 10% Fetal bovine, 100 units m.mL^{-1} penicillin, and 100 µg ml^{-1} streptomycin. Cells were equipped with Trypsin-EDTA and reseeded at 50% confluence twice a week, and incubated at 37°C.

**Bacterial Adherence Assay**

Lung cancer cell was planted in 24 well tissue culture plates at density 1×10^5. After 24 hr, cells were infected with both strains of A. baumannii ATCC 17904 and HHR1 at a ratio of 50:1 (MOI of 50). The cells infected with bacteria in the presence and absence of (colistin) at concentration MIC 2 µg ml^{-1} were incubated in a 5% CO2 at 37°C for 8 hr. The cells were washed 3 times with PBS, then fixed with 4% PFA for 30 min, washed as above and stained with Giemsa's stain.

**Results:**

**Gene Detection**

In order to detect the genes involved in LPS biogenesis, DNA was extracted from both strains, and genes of interest lptD, lptE, lpta were PCR amplified as described previously (Fig. 1). The PCR products were electrophoresed on 1% agarose gel,100 V for 60 min. The PCR products for all samples were visualized and appeared as a clear band with corresponding size of 720 bp for lptD and 100bp for lptE, lpta respectively (Fig. 2).
The genes of interest were PCR amplified using the designed primer pairs (A) lptD gene organization map with the upstream and downstream genes; (B) gene organization map of lptE refers to its location and amplified base pairs (C) lpta with upstream and downstream genes.

Figure 1. Gene map of Detected of lptD, lptE and lpta genes in A. baumannii.

Figure 2. Agarose gel of electrophoresis of lptD, lptE, lpta genes in A. baumannii. The PCR products of genes of interest in A. baumannii isolates were loaded on 1% agarose gel, 100 v for 60 min. (A) The 720 bp products refer to lptD gene and indicated by black arrow. (B) lptE gene with the relative size of 100 bp as indicated by blue arrow refer ;(C) the red arrow refers to lpta with the size of 100 bp. In all cases, lane 1 represents the standard strains ATCC 17904, and lane 2 refers to the local isolate HHR.

Bacterial Growth Curve
Effect of AMP on A. baumannii Growth

In colistin, the growth of both isolates reached up to OD 600 of 0.5, while the control ended up to OD 600 of 1.0 in A. baumannii ATCC. Most notably, the growth of A. baumannii HHR1 was monitored at OD 600 0.19,0.130,0.09 after 12 hrs incubation for 1, 1.5, and 2 μg ml⁻¹ respectively, while the growth of ATCC at OD 600 0.1,0.12,0.08 for 1, 1.5, and 2 μg ml⁻¹ respectively after the same period (Fig. 3 A, B).

In the presence of fosfomycin, and the growth of the three concentrations after 12 hours of the incubation period, the control reached up to OD 600 of 0.89 in A. baumannii ATCC. In contrast, the growth of both isolates ended up at OD 600 0.69 and 0.68,0.61, in A. baumannii ATCC and 0.79, 0.77, 0.72 in A. baumannii HHR1 respectively. (Fig. 3 C, D). On the other hand, with rifampicin, after the same incubation period, the control reached up to OD 600 of 0.96 in A. baumannii ATCC and 0.970 in A. baumannii HHR1, whereas when the growth of both isolates after 12 hours of incubation, the control reached up to OD 600 of 0.96 in A. baumannii ATCC and 0.970 in A. baumannii HHR1, and the growth of both isolates were reached in the presence of 1, 1.5, and 2μg ml⁻¹ up to OD 600 0.805 and 0.694,0.634,0.69 in A. baumannii ATCC and 0.77, 0.71, 0.69 in A. baumannii HHR1 respectively (Fig. 3 E, F).

In the combination of serial concentrations of colistin-fosfomycin, colistin rifampicin (Fig. 4 A, B, C, D), the growth of both isolates in the first hour reached up to OD 600 of 0.52, 0.443, 0.440 in A. baumannii ATCC, and 0.533, 0.439, 0.429 in A. baumannii HHR1 in comparison to the control that ended up to OD 600 of 1.05 after 12 hrs incubation.

Cytotoxic Effect of AMPs on A. baumannii

There is no significant difference between the first three concentrations of colistin, while, 2 μg ml⁻¹ exerts significant differences (***P<0.0002) between both strains of A.baumannii (Fig. 5 A). In fosfomycin there is no significant difference between the first three concentrations while, the
high concentration (35 mg ml\(^{-1}\)) significantly differs (****\(P<0.0001\)) between both strains of \(A.baumannii\) (Fig. 5 B). Similarly, the fosfomycin-colistin combination, no significant difference between the first three concentrations against \(A.\ baumannii\) strains, while, 2 μg ml\(^{-1}\) shows significant difference (*\(P<0.0110\)) between both strains of \(A.baumannii\) (Fig. 5C).

In addition, no significant difference has been observed between the first three concentrations of Rifampicin, while, 2 μg ml\(^{-1}\) shows significant differences (****\(P<0.0001\)) between both strains of \(A.baumannii\) (Fig. 5D), and there is no significant difference between the first two concentrations of Rifampicin-colistin combination used against \(A.\ baumannii\) strains, while, 1.5, 2 μg ml\(^{-1}\) is significant different (***\(P<0.0011\), *\(P<0.0129\)) between both strains of \(A.baumannii\) (Fig. 5E).

**Figure 3.** Growth of \(A.\ baumannii\) strains in the presence of AMPs: 100 ml of \(A.\ baumannii\) ATCC 17904 and HHR1 was taken. Cultures were grown overnight and the growth was prepared by inoculating each culture to an OD\(_{600}\) of 0.1, before being incubated under aerobic conditions. Three concentrations of AMP were added to each culture after 1 hour incubation period, otherwise, the cultures were left without AMP addition determined as control. In both cases, the growth was monitored every hour up to 12 hr. All assays were performed in three biological replicates.
Figure 4. Growth of *A. baumannii* strains in the presence of combination of AMPs: 100 ml of *A. baumannii* ATCC 17904 and HHR1 cultures were grown overnight and the growth was prepared by inoculating each culture to an OD<sub>600</sub> of 0.1, before being incubated under aerobic conditions. Three concentrations of AMP were added to each culture after 1 hour incubation period, otherwise, the cultures were left without AMP addition determined as control. In both cases, the growth was monitored every hour up to 12 hr. All assays were done by three biological replicates.

Figure 5. Antimicrobial susceptibility on the viability of *A. baumannii* strains. *A. baumannii* cultures were incubated with different concentrations of AMP (0.5, 1, 1.5, 2 µg ml<sup>-1</sup>) for 1 hr at 37°C, before being plated on MH agar plates for cfu determination. Error bars represent the standard error from the mean of three independent biological replicates.
Quantitative PCR Analysis (qPCR)

In this study, the mRNA levels of \( lptD, lptA \) were decreased in both strains at 2 µg ml\(^{-1} \) concentrations of colistin, but in HHR1 the levels were higher than in standard strain. (Figs. 6, 7) (55). On the other hand, the mRNA levels of \( lptE \) were strongly decreased in HHR1 in the presence of colistin compared with ATCC. (Fig. 7).

Effect of Colistin on Adherence of \( A. \) baumannii on A-549 Cell

The results showed that \( A. \) baumannii invaded and adhered to the A-549 (Fig. 8).

The Half Inhibitory Concentration (IC\(_{50}\)) of Colistin on \( A. \) baumannii

The IC50 values of colistin can be calculated from the viability results to determine the inhibitory concentration of the \( A. \) baumannii and cytotoxicity concentration on \( A. \) baumannii (Fig. 9).

Figure 6. Detection of \( lptD, lptE \), and \( lptA \) genes in \( A. \) baumannii. (A) \( lptD \) gene organization map. (B) \( lptE \) gene organization map. (C) \( lptA \) The location of \( lptD, lptE \), and \( lptA \) genes were determined and specific primers were designed.

![Figure 6](image)

Figure 7. Effect of colistin (2 µg ml\(^{-1} \)) on the expression levels of several genes that participate in antibiotic resistance in \( A. \) baumannii ATCC 17904 & HHR1.

![Figure 7](image)
Figure 8. Effect of colistin on adherence of *A. baumannii* on lung cancer cells. A-549 cells stained with Giemsa stain then examined under inverted microscope with 40X magnifications. (A) Normal A-549 cell. (B) A-549 cell infected with *A. baumannii* ATCC 17904. (C) A-549 cell infected with *A. baumannii* HHR1. (D) A-549 cell infected ATCC 17904 treated with 2 (µg ml⁻¹) of colistin. (E) A-549 cell infected with HHR1 treated with 2 (µg ml⁻¹) of colistin.

**A. baumannii ATCC**

Figure 9. IC₅₀ of colistin on both isolates of *A. baumannii* after 24 hr.

Discussion:

**Bacterial Growth Curve**

**Effect of AMP on *A. baumannii* Growth**

*A. baumannii* isolates exhibit a variable response to AMP, colistin is selected to determine its effect on the viability of *A. baumannii* isolates as monotherapy and synergic with other antibiotics (fosfomycin, rifampicin). Colistin is one of the most AMPs typically used due to its effectiveness, there is less variability in pharmacokinetic, and no regulation is required in the case of renal failure. The results exhibit that colistin affected the growth of *A. baumannii* as shown in Fig. 3 A, B.

The results revealed that different concentrations of colistin remarkably affected *A. baumannii* growth in the early hours. Most notably, the growth of *A. baumannii* HHR1 and *A. baumannii* has been decreased in the same period.

*A. baumannii* can alter AMP resistance by completely losing the primary binding site, the lipid component A of the lipopolysaccharide, which is crucial for the survival of Gram-negative bacteria. Previous studies, revealed that the mutations in (*lpxA*, *lpxC*, and *lpxD*); the essential genes biosynthesis pathway of LPS in 13 individual derivatives of colistin-resistant *A. baumannii* ATCC 19606, increased the resistance patterns of isolates.
19. A. baumannii exerts variable resistance to colistin, as an apparent colistin susceptible strain harbored a small proportion of colistin-resistant cells 20. Under selective stress conditions in vitro and in vivo, heterogeneous strains of A. baumannii can rapidly lead to the development of strains with a high level of resistance to colistin 21,22. The main resistance mechanisms of colistin are the modulation of LPS by adding phosphoethanolamine to lipid A; so, this modification decreases the affinity of colistin with the surface of bacterial cells by decreasing the negative charge of the OM, and the mutation in genes for LPS synthesis, also this mechanism differs between strains of A. baumannii 19. Several studies have speculated that in vitro antimicrobial activity increased further when the exposure time simulates over 24 hours. The ability of some antimicrobials to completely kill or obliterate bacteria, enhances the activity of other AMPs to inhibit bacteria in synergism way 13,23. The killing activities of some AMPs as a monotherapy may produce rapid bacterial resistance with high concentration which may result in severe toxicity. Several studies revealed that bacterial resistance is related with monotherapeutic agent, e.g; rifampin displayed both in vitro and in vivo bactericidal activities against MDR A. baumannii in pneumonia experimental model, while, rifampin-resistant mutants exert rapid and short performance after the initiation of treatment 24,25. Colistin is a last resort treatment, a well-known AMP from the polymyxin family.

Although, colistin is efficient against MDR-A. baumannii isolates, the efficacy and consequence toxicity of colistin as a monotherapy which increased the potential resistance should be taken into consideration 26. Colistin employs a rapid bactericidal effect at high and low concentrations, by affecting the OM and increasing the permeability of Gram-negative bacteria, which facilitates the entry of excluded compounds 27. When fosfomycin is added to A. baumannii isolates, the growth is similar to the control of the three concentrations, and the growth increases when the incubation period is increased for both isolates after 12 hours of the incubation process in which the control of A. baumannii ATCC is slightly higher than all treatment. Later, after 12 hours of the incubation process both isolates decreased, although the results are similar to A. baumannii ATCC and HHR1. In ATCC the growth is slightly less than the local (Fig. 3 C, D). On the other hand, rifampicin is added to A. baumannii isolates, the growth is similar to the control of the three concentrations, and the growth increases when the incubation period is increased for both isolates after 12 hours of the incubation process which the control of A. baumannii ATCC is slightly higher than all treatment. Later, after 12 hours of the incubation process both isolates decreased, although the results are similar to A. baumannii ATCC and HHR1. In ATCC the growth is slightly less than the local (Fig. 3 E, F).

Furthermore, increasing resistant ability of A. baumannii strains toward general antibiotics, carbapenems in particular rose the potential using of colistin for infection treatment. Some of in vivo studies reported the individual using of colistin or in combination with rifampicin infections treatment. In the combination of serial concentrations of colistin-fosfomycin, colistin rifampicin (Fig. 4 A, B, C, D), the growth is slightly increased in the first hour where both isolates in comparison to the control after 12 hrs incubation.

Rifampicin is an antibiotic that is often used as synergism with other antibiotics; however, using rifampicin in combination depends on multiple conditions such as the rifampicin MIC or the methods used, for example 28,29. We have cast the light on the studies that tested the synergism effects of rifampin and colistin against both strains of A. baumannii in vitro. This study aims to examine the activity of rifampicin, colistin and fosfomycin as monotherapy and with a synergistic effect on both strains of A. baumannii. The range of MIC for rifampin and colistin is 1.5 μg ml⁻¹ and 2 μg ml⁻¹. Cytotoxic Effect of AMPs on A. baumannii

The viability calculation of A. baumannii strains after exposure to different concentrations of AMP (0.5, 1, 1.5, and 2 μg ml⁻¹ for colistin and rifampicin, and 15, 25, 30, and 35 mg ml⁻¹ for fosfomycin) was measured using Colony Forming Unit (CFU). A. baumannii treated with AMP exhibit a remarkable decrease in viability percentage compared with the control (bacteria lacking AMP).

These results improved the efficiency of AMP in decreasing the viability percentage of the A. baumannii as shown in Fig 5, they also revealed that the local isolate HHR1 exhibits high resistance to AMP than the standard strain, and also shows that viability percentage decreases by increasing AMP concentration, the former is approachable because of the rapid effectiveness, low cost, simple dosage requirement, and short time for serum concentration, the variability in pharmacokinetics is less, and no modification is required for renal failure. However, in our patient, using of colistin is required due to the need to covering of pulmonary nidus and the possibility of inhalation 30,31. The results show that there is no significant difference between the first three concentrations of colistin used against A. baumannii strains, while, 2
μg ml\(^{-1}\) exerts significant between both strains of *A. baumannii* (Fig. 5 A). Furthermore, fosfomycin is a broad-spectrum agent that is mainly used in combination therapy because it reduces the MIC of MDR strains and using as a monotherapy encourages the development of resistance 32. The results show that there is no significant difference between the first three concentrations of fosfomycin used against *A. baumannii* strains, while, the high concentration (35 mg ml\(^{-1}\)) is significantly differ between both strains of *A. baumannii* (Fig. 5 B). The synergy between colistin and fosfomycin was controversial. Previous studies revealed that the combination of colistin-fosfomycin showed a synergistic effect in half of their examined isolates. Few studies demonstrated the colistin-fosfomycin combination, the formulation of theses combining AMPs was revealed to demonstrate the cons of using colistin-fosfomycin against MDR *A. baumannii*. The opinion was different from one scientist to another, then the results show that there is no significant difference between the first three concentrations of fosfomycin-colistin combination used against *A. baumannii* strains, while, 2 μg ml\(^{-1}\) shows significant difference between both strains of *A. baumannii* (Fig. 5C).

Rifampicin is used as a patient antibiotic that, despite its effectiveness as an individual drug, exhibits a potential activity when mixed with other antibiotics, colistin in particular, by increasing of the bacterial membrane permeability and increasing the effectiveness of the treatment 33. A new therapy proposal for patients with complex UTIs caused by MDR pathogens could be on the horizon. The addition of rifampin to all colistin regimens resulted in increasing bacterial killing and regrowth dilution similarly to monotherapy such that after 24 to 72 hours at least, no viable bacteria were detected. Moreover, increasing bacterial killing was particularly obvious for formulations containing colistin 0.5 or 2 mg l\(^{-1}\) systems, with synergism produced on all occasions from 24 h onwards. For example, while no viable bacteria were detected using either combination regimens of 0.5 and 2 μg ml\(^{-1}\) of colistin at 24 hours, significant bacterial killing occurred at 1.5 and 2 μg ml\(^{-1}\) of the colistin monotherapy regimen the results show that there is no significant difference between the first three concentrations of Rifampicin used against *A. baumannii* strains, while, 2 μg ml\(^{-1}\) gave significant differences between both strains of *A. baumannii* (Fig. 5D), and there is no significant difference between the first two concentrations of Rifampicin-colistin combination used against *A. baumannii* strains, while, 1.5, 2 μg ml\(^{-1}\) showed significant differences between both strains of *A. baumannii* (Fig. 5E). The synergistic treatment against colistin-susceptible isolate completely suppresses the development of colistin-resistant bacterial populations at both inocula. Previous studies showed that the combination of AMPs with 2 or 5 mg l\(^{-1}\) colistin regimen decreased the occurrence of colistin-resistant isolates under the limit of detection (i.e., 20 CFU ml\(^{-1}\)) at low inoculum 34.

This result referring to the use of colistin-rifampin in combination treatment resulted in high efficiency of killing and may restrain the development of de novo colistin resistance. The dual potential mechanism of using the combination of colistin-rifampin to enhance bacterial killing activity implies the damage of bacterial OM by colistin, which facilitate rifampin penetration, as it does not effectively penetrate the OM in Gram-negative pathogens due to its hydrophobicity 13. The combination treatment against a colistin-sensitive isolate completely inhibits the development of colistin-resistant populations in both vaccines 34. Generally, the mode action of rifampin towards Gram-negative bacteria is to attenuate the penetration across the outer membrane rather than reducing sensitivity to the specific target 35.

In Gram-negative bacteria, where colistin primary targets the LPS of the outer membrane, electrostatic interaction between the amine-positive groups of colistin and the phosphate, anionic groups of the phosphate and carboxylate on the LPS is initiated. This reaction resulted in displacement of the original divalent cations and disruption of the membrane, and subsequently increased the permeability of the OM not only to itself (the so-called self-absorption) but also to other compounds 36.

This may be attributed to intrinsic changes in the OM of *A. baumannii* linked with the emergence of resistance to colistin 37,38, that facilitate the influx of these drugs to their final target sites within cells. Our results showed for the first time that the using of colistin and rifampin together, with such concentrations is clinically approachable, which significantly increased the killing spectrum of both colistin-resistant and colistin-resistant MDR and such that therapy prevented or inhibited the development of colistin-resistant bacterial community. Clinical studies are necessary to improve the combination treatment with colistin and rifampin.

Heterogeneous and complete resistance to colistin has been clinically reported 39,40. The increasing use of colistin is believed to possess a risk of the emergence of new isolates that are resistant to this compound. In South Korea, levels of colistin resistance have been reported as high as
27.9 %, which indicated to the possibility of a potential emergence.

These findings emphasize the need to identify the pathways that mediate colistin resistance in A. baumannii. Some colistin resistance mechanisms are associated with mutations that interrupt drug interaction with LPS. Colistin acts by rupturing the outer membrane, via necessarily attachment to the lipid part of the lipopolysaccharide (LPS). As a result, for example, resistance may occur via mutations in the PmrAB two-component system; which located downstream the target site, PmrC, catalyzes lipid A modification of phosphoethanolamine.

This alteration decreases the colistin affinity for this subcellular target and the negative charge reduction of the outer membrane, so that mutations or insertions in the genes encoding the process of lipid biosynthesis mediate resistance by stopping the development of LPS and thereby removing the target of colistin. In addition, the development of resistant isolates by adaptive mutations during antibiotic therapy in human patients is well known in A. baumannii. Taken together, the results illustrate the ability of this organism to adapt and indicate that initial resistance towards AMPs therapy is mediated by genuine mechanisms in A. baumannii, which required adaptive mutations and resistance determinants. The molecular basis of the intrinsic resistance mechanisms in A. baumannii is largely unknown.

The use of combination treatment by two antibiotics reduces the concentration of each individual antibiotic that is used. On the other hand, the study showed that the majority of strains showed MIC value of 4 for rifampin (42%) and MIC value of 2 for colistin (30%). Most notably the MIC was measured independently for each antibiotic and then the sub-inhibitory concentration or lower MIC concentration was used to combine the two antibiotics. We therefore proposed a proportional experimental the combination of two antibiotics with a concentration of 2 µg ml⁻¹ for rifampin and 1 µg ml⁻¹ for colistin, based on our results, the concentration of AMPs is not arbitrary and can be different, depends on the tolerance capacity of the XDR or MDR strains.

Previously, we showed that A. baumannii exhibits an increased resistance to colistin in response to physiological concentrations of monovalent cation. Here we presented the discovery of more than 30 genes involved in colistin-induced tolerance in A. baumannii. The majority of these genes converge in mechanisms and systems involved in osmotic tolerance, including those elaborate in cell envelope biosynthesis as well as in protein folding, such as lpsB gene.

**Quantitative PCR Analysis (qPCR)**

In this study, the expression level of lptD, lptA and lptE has been measured, and it varied within the two strains. The mRNA levels of lptD, lptA were decreased in both strains at 2 µg ml⁻¹ concentrations of colistin, but in HHR1 the levels were lower than in standard strain. In addition, this study demonstrates that expression and transcription of genes depends on the type and dose of antimicrobial agents and also on bacterial type (Fig. 6, 7). On the other hand, the mRNA levels of lptE were strongly increased in HHR1 in the presence of colistin compared with ATCC, and this strongly supports the detrimental role of colistin on lptE and in pathogenicity especially in clinical strain (Fig. 5). Moreover, other reports revealed that porins participate in increasing the virulence of A. baumannii, and others reported that the expression level of this gene is deferring among A. baumannii isolates.

The removal of lptD produces a complete loss of LPS and reduces polymyxin resistance in A. baumannii, while the presence of lpsB protects A. baumannii from the bactericidal effect of colistin by encoding the glycosyltransferase that responsible for LPS synthesis. Furthermore, high resistance to colistin phenotype in A. baumannii is attributed to single mutation in the vacJ (R166N).

The main factor in metabolism is biotin, and it has been reported as a critical factor corresponding to polymyxin sensitivity in A. baumannii, and the increase levels of biotin lead to increases in the production of lipid A with a subsequent increase in colistin sensitivity. It was believed that knock out genes associated with biotin synthesis leads to a decrease in A. baumannii’s susceptibility to colistin.

In the previous studies, a small molecule targeting MsbA was discovered; the regulation of LPS biosynthesis is not directed by MsbA inhibition in the organism, although the most frequent resistance mechanism that observed is the inhibition of LPS biosynthesis. It was believed that the disruption in the essential steps in a pathway, cells are unable to stop LPS biosynthesis. However, apart from lpxACD, disruption of non-essential steps regulates LPS biosynthesis.

In particular, inactivation of LptD leads to a significant decrease in LPS levels, indicating the feedback response regulating LPS biosynthesis. In contrast, MsbA inhibition is unable to elicit the same response. It was speculated that the inhibition of MsbA increases the biosynthesis of LPS in the inner membrane, and changes the properties of the
membrane, and thus interferes with one or more of the basic processes that depend on their normal state. The dispersion of ATP or lacking the common precursors from other essential pathways, such as fatty acid biosynthesis, may exaggerate the inhibition of LPS.

The discovery of inhibitors of LPS biogenesis was challenging because the pathway included complex substrates made up of seven proteins and complex substrates with limited solubility. Using whole cells 50 indicates the feedback responses regulating LPS biosynthesis. In contrast, MsbA inhibition is unable to elicit the same response. It is speculated that the increase of LPS in the inner membrane resulting from MsbA inhibition changes the properties of the membrane, and thus interferes with one or more of the basic processes that depend on their normal state. This may be exacerbated by dissipation of ATP or depletion of common precursors from other essential pathways, such as fatty acid biosynthesis.

The discovery of inhibitors of LPS biogenesis was challenging because the pathway included complex substrates made up of seven proteins and complex substrates with limited solubility. Using whole cells, achieving a clearance of the LPS pathway confers resistance rather than sensitivity.

**Effect of Colistin on Adherence of A. baumannii on A-549 Cell**

The results showed that A. baumannii was able to invade and adhere to the A-549 cells because of the presence of OmpA protein which is responsible for the adhesion to epithelial cells, so when OmpA binds to cells, it causes mitochondrial dysfunction and promotes programmed cell death as shown in figure A-549 in which the cells were destroyed when they were invaded by A. baumannii strains (Fig. 8). Moreover, attraction depends on the bacterial strains, A. baumannii isolates harboring the blaPER-1 gene that increased the adhesion to epithelial cells, and then this gene plays an essential role in the association of A. baumannii with epithelial cells 51.

Moreover, previous studies have described that the AbFhaB/FhaC system in A. baumannii also has a role in binding to host cells because this structure binds to fibronectin which is the host receptor for A. baumannii 52. Moreover, other studies defined that OmpA protein binds to the host proteins that mediate the cell in cell adhesions, so it is connected to the desmosome and causes its perturbation, which facilitate the adhesion to epithelial cells 53.

In this study, the cytotoxic effect of A. baumannii-colistin treated on human A549 alveolar cells has been described. The ability of A. baumannii isolated to infect the A549 respiratory alveolar cell was evaluated using a microscope at 40X magnification. After incubation of the two strains of A. baumannii with A549 cells, the respiratory A549 cells were identified 54.

Previous studies revealed that mixing A. baumannii ATCC 19606 WT strain with A549 cells reduces the viability of cells for about 65%. Similarly, when the A549 cells are incubated with A. baumannii pmrB mutant reduces the viability for about 57%, whereas, a slight decrease in A549 cell viability when they were incubated with both lpx mutants. Thus, lpx mutants exhibit an extremely low efficiency to complete inhibition of A549 respiratory cells 54.

Furthermore, the effect of t LPS in pathogenic bacteria in response to radiotherapy in several NSCLC cell lines was investigated. The clinical background is given by noting that pneumococcal bacterial infections exacerbate the prognosis of patients with lung cancer. LPS is the main causative agent of Gram-negative bacteria, which appears predominantly in lung cancer patients 55,56. The TLR-4 dependent pathways are activated by LPS, which also required the activity of EGFR protein kinase 57, three NSCLC cell lines for non-small cell lung cancer were selected for very differential. In LPS response with A549 (EGFR wild type) TLR-4 expression and (EGFR deficiency) are shown.

Previous studies demonstrated that tumor growth in various experimental designs of NSCLC in vitro, ex vivo and in vivo was effectively induced by LPS, using the A549 cell line 58. It is now observed that A549 colony formation ability is not affected by LPS. These results demonstrate a new aspect of LPS ability to modify the biology of NSCLC due to proliferation induction by LPS 58. However, the reproduction of tumor cells is not affected by LPS. Cancer cell reproduction is an important factor in tumor progression, progression, and recurrence after treatment. The radiation sensitivity of cancer cells in vitro is known to correlate well with the tumor's response to in vivo radiotherapy, and thus, an association between the stem in vivo and in vitro cloning has been proposed indicating the importance of intrinsic radiation sensitivity to cancer. Stem cells for radiation sensitivity to tumors of different tissues 59,60.

**The Half Inhibitory Concentration (IC50) of Colistin on A. baumannii**

The IC50 values of colistin can be calculated from the viability results to determine the inhibitory concentration of the A. baumannii and cytotoxicity concentration on A. baumannii (Fig. 9). The
concentration that inhibits 50% of cell growth was calculated by GraphPad Prism program.

Conclusion:
The results conclude that the local isolate of A. baumannii HHR1 has been more virulence than ATCC17904. The effect of AMPs on A. baumannii increases by increasing the time of incubation, and the standard isolate is more sensitive to AMPs than HHR1. The effect of AMPs on A. baumannii has also been increased by increasing the concentration, and HHR1 is more resistant to AMPs than ATCC17904. Colistin affects the expression level of lptD, lptE, and lptA genes, also the results prove that the expression of lptD, lptA of A. baumannii ATCC 17904 is higher than the same genes in A. baumannii HHR1. While lpt E gene of the A. baumannii ATCC 17904 shows an up-regulation pattern than A. baumannii HHR1. Colistin affects the adhesion of A. baumannii on epithelial cells (lung cancer cell A-549).

Authors' declaration:
- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for republication attached with the manuscript.
- The author has signed an animal welfare statement.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

Authorship contribution statement:
Title of manuscript: Colistin as A Good Monotherapy to Restrain the Pathogenicity of Acinetobacter baumannii In vivo and In vitro (NS was responsible for collecting the data from each assay or experiment, and analyzing the data as a part of her MSc project) (HH contributed in conception, design, acquisition of data, analysis, interpretation, drafting the MS, revision and proofreading

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عقار الكولستين علاج احادي جيد لكيح جماع الباكتيريا الراكدة البوامية
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الخلاصة:
تعتبر باكتيريا Acinetobacter baumannii من أحد مسببات الأمراض الانتهازية الرئيسية التي تقوم العديد من مضادات الحيوية. الكولستين هو مضاد حيوي يستخدم في الوقت الحاضر كطريقة لمعالجة أخطار العزلات ذات المقاومة الشديدة. الغرض من هذه الدراسة هو التعرف على أهمية جين LptD في الطبقة الدهنية LPS من باكتيريا A. baumannii، بالإضافة إلى أهمية دورها كعامل ضراوة. في الدراسة الحالية، تم استخدام عزلتين من باكتيريا A. baumannii، العزلة المحلية HHR1 والعزلة العالمية ATCC 17904، وتم استخدام ثلاث أنواع من المضادات الحيوية (الكوليستين، الريفامبيسين، والفسفوميسين) كعلاج احادي أو مزدوج خارج وداخل الجسم. النتائج الملاحظة أن A. baumannii HHR1 هي أكثر مقاومة لـ AMPs (Antimicrobial peptides) من السلالات العالمية، حيث أظهرت النتائج أن بالتولد الناتج من A. baumannii على تأثير AMPs على A. baumannii عند التركيز العالي (2 μg ml⁻¹) في الدم. علاوة على ذلك، كانت حساسية العزلات متغيرة، حيث أظهر الكولستين فاعلية متميزة في تثبيط النمو البكتيري كعلاج احادي أو عند المزج مع مضاد LPS. كما أن التعبير الجيني لجينات lptD من الكولستين، المعززة باكتيريا A. baumannii، ك-netE كانت العزلة القياسية ذات نمط تنظيم أعلى مما كان عليه في العزلة المحلية. علاوة على ذلك، يؤثر الكولستين على التصاق A. baumannii على الخلايا الظهارية، ويعزز نمو البكتيريا. النتائج المجردة: المضادات البكتيرية الببتيدية، العديد السكري الدهني، تفاعل البلمرة المتسلسل.

Acinetobacter baumannii