

Original Article

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Safe Combination of Cisplatin and Metformin Reverts the Malignant Ascites in a Mouse Model to a Solid Tumor by Downregulation of Δ Np63 and Induces Tumor Dormancy via mTOR/ p21 Mechanism

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Abstract

Background: Currently, combination therapy has become the cornerstone of cancer treatment. The combination of different anticancer mechanisms can induce tumor cell quiescence. However, toxicity to normal tissue is the major limitation of existing combined drugs.

Method: In this experimental study, Ehrlich ascites carcinoma (EAC) inoculated into mice was targeted with just one dose of cisplatin and later doses of metformin, a safe antidiabetic drug with an anticancer effect, to maintain EAC cells in the quiescent state and secure a longer survival time without tumor recurrence.

Results: The group that underwent dual therapy developed a delayed solid tumor instead of a malignant ascites. The induction of chemo-quiescence in the EAC cells was proven by the downregulation of mechanistic target of rapamycin and the upregulation of cyclin-dependent kinase inhibitor 1 (p21) expressions. Intriguingly, the conversion of free neoplastic cells into a solid tumor was associated with a significant decrease in Δ Np63 immunostaining in EAC cells.

Conclusion: Taken together, a single dose of cisplatin followed by metformin doses could overcome the aggressiveness of malignant ascites by the conversion into a solid tumor, induction of chemo-quiescence, and the extension of survival time.

Keywords: Chemo-quiescence, Ehrlich ascites carcinoma, Mechanistic target of rapamycin (mTOR), Metformin, Cisplatin, Δ Np63

Introduction

By 2040, 27.5 million new malignancy cases are expected every year worldwide if the recent rate of

cancers incidence and population development continues in the future.¹ In many types of malignancy, ascites

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is a prognostic sign of advanced stages, with only 11% of patients surviving for more than six months.² Combination of therapeutic modalities has become the cornerstone of cancer therapy.³ Basically, the combined agents work in a synergistic or additive effect, and thus, the required therapeutic dose of each agent is low.⁴ The treatment with multiple drugs increases the opportunity of targeting all cancer cells, including cancer stem cells that accused of drug resistance and cancer recurrence.⁵ In contrast, the treatment with a constant single compound activates alternative salvage pathways in the cancer cell

which confers a subsequent drug resistance.⁶ The majority of existent combined chemotherapeutic drugs for cancer treatment are still limited by their toxicity to healthy cells.⁷ Another challenge is that many chemotherapeutic drugs induce tumor dormancy, where cancer cells are in the quiescent state, i.e. G0. They tend to resume proliferation when the general environment becomes available, resulting in tumor relapse. To overcome these problems, there is a strategy called “locked-in”, in which pharmacological agents can be used to maintain cancer cells in the quiescence (G0) state to prevent further tumor growth, recurrence, and/or metastasis throughout the lifetime of a patient.⁸ The pursuit of safe and alternative chemoquiescence adjuvants work in different anticancer mechanisms for combination therapy becomes necessary.

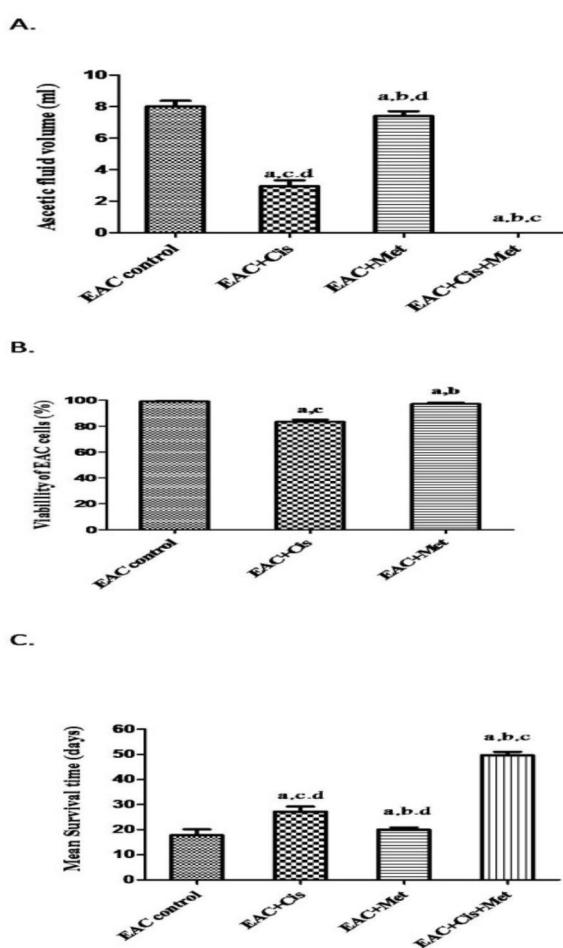


Figure 1. The effect of metformin and cisplatin as single drugs or in combination on the tumor progression parameters of EAC-bearing mice. A. Ascitic fluid volumes (ml) collected from the groups that had ascitic fluids on the 15th day post tumor inoculation. B. EAC cells viability% in peritoneal fluids from the control and treated groups. C. Mean survival time (MST) of the treated groups within the experimental period (50 days). Data presented as a mean±SD of six animals. $P \leq 0.05$ compared to all groups.

Cis: Cisplatin; Met: Metformin; a: Significant versus EAC control group; b: Significant versus EAC+Cis group; c: Significant versus EAC+Met group; d: Significant versus EAC+Cis+Met group; EAC: Ehrlich ascites carcinoma; SD: Standard deviation

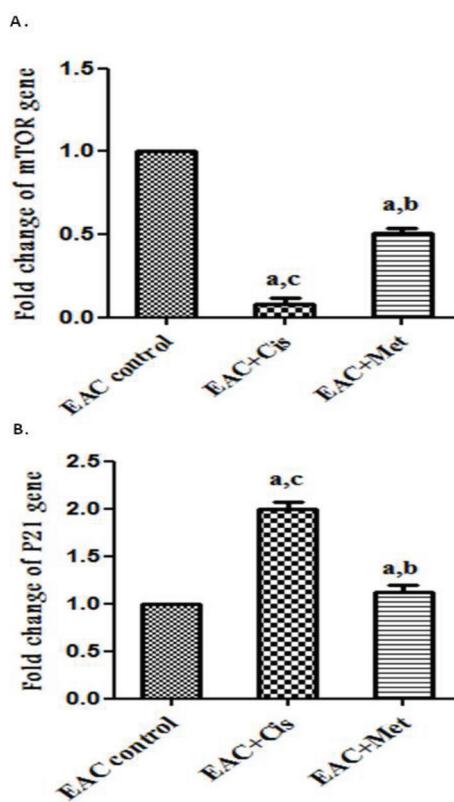


Figure 2. Synergistic effect of metformin and cisplatin on the relative expression of and p21 genes EAC cells. A. fold change of and B. p21 in EAC cells collected on the 15th day post tumor inoculation. The data are normalized to GAPDH (internal control). The results are expressed as a mean±SD of six animals. $P \leq 0.05$ compared with all groups.

Cis: Cisplatin; Met: Metformin; a: Significant versus EAC control group; b: Significant versus EAC+Cis group; c: Significant versus EAC+Met group; EAC: Ehrlich ascites carcinoma; SD: Standard deviation

Table 1. The effect of cisplatin and metformin as single drugs or in combination on the level creatinine, urea, ALT, AST, and total proteins in serum of the different groups

| | Normal | EAC control | EAC+Cis | EAC+Met | EAC+Cis+Met |
|----------------------|-------------|-------------|------------------|------------------|------------------|
| Creatinine (g/dl) | 0.54 ± 0.06 | 1.53±0.09# | 2.48±0.26a,c,d | 2.1±0.07a,b,d | 2.79±0.15a,b,c |
| Urea(mg/dl) | 43.76±2.21 | 62.43±0.56# | 66.65±0.80a,c,d | 63.06±0.14b,a,d | 56.53±0.85 a,b,c |
| Total protein (g/dl) | 6.08±0.16 | 4.18±0.39# | 5.00±0.54a,c,d | 4.66±0.07a,b,d | 3.75±0.12 a,b,c |
| ALT(U/L) | 27.44±0.9 | 76.66±0.46# | 68.27±0.46a,c,d | 71.00±0.62 a,b,d | 81.58±0.38 a,b,c |
| AST(U/L) | 93.85±0.52 | 138.7±0.57# | 125.22±1.05a,c,d | 130.00±1.73a,b,d | 141.30±0.96a,b,c |

Data presented as mean±SD of six animal analyzed using one-way ANOVA ($P \leq 0.001$) followed by a Tukey test for comparison of all columns. Cis: Cisplatin. Met: Metformin; #: Significant versus normal control group; a: Significant versus EAC control group; b: Significant versus EAC+Cis group; c: Significant versus EAC+Met group; d: Significant versus EAC+Cis+Met group; EAC: Ehrlich ascites carcinoma

Currently, there is a tendency to use a category of pharmaceutical agents as anticancer drugs although they are primarily used for other therapeutic purposes.⁹ Fortunately, a great benefit is associated with such an approach because existing drugs would have already undergone FDA procedures of drug safety and have identified pharmacokinetic properties.¹⁰ Metformin, the first-line drug for diabetes type 2, can act as a safe anticancer agent through decreasing glucose utilization, the fuel for tumor initiation and growth.¹¹ Moreover, it suppresses mechanistic

target of rapamycin (mTOR) activity, a major regulator of cell growth, proliferation, and survival, which is highly expressed in malignant tissue.^{12,13} There are initial indications of activating cellular quiescence by metformin, the mechanism that reduces glucose uptake by malignant cells leading to cell cycle arrest.¹⁴

Cisplatin is the alkylating agent that has been applied for decades to treat many cancers, such as ovary, neck, lung, testis, head, and breast cancer. However, it causes toxicity to bone marrow, hair, and stomach.¹⁵ The main dose-limiting toxicity

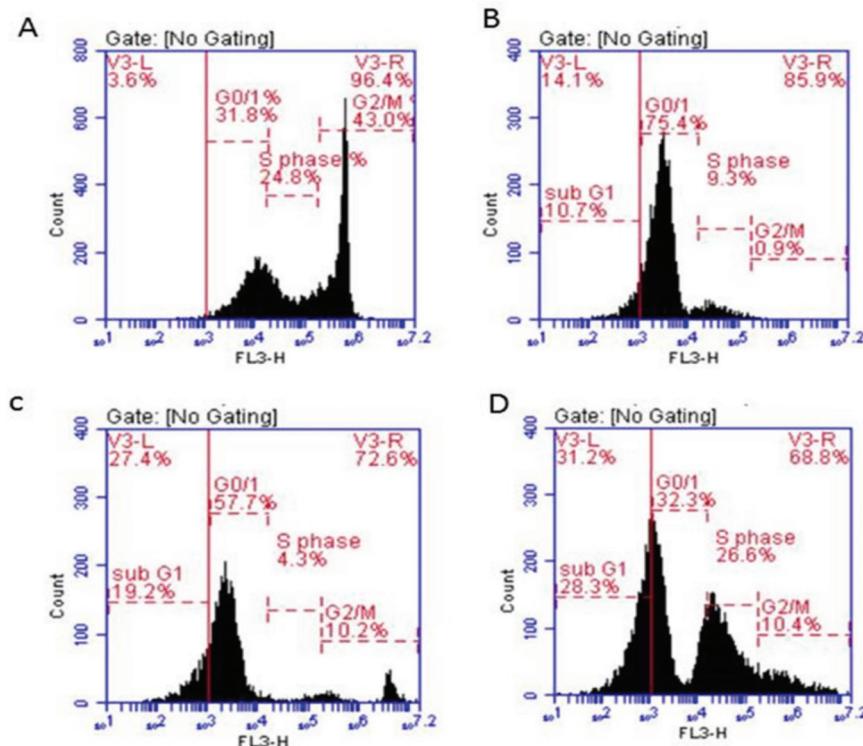


Figure 3. Cisplatin and metformin arrest the majority of EAC cells in the quiescent phase G0/G1. DNA histograms represent EAC cells distribution in cell cycle phases in the control group (A), groups treated with cisplatin (B), metformin (C), and the combined drug (D). Numeric data shows the proportions of cells in different cell-cycle phases.

EAC: Ehrlich ascites carcinoma

of cisplatin is nephrotoxicity.¹⁶ Furthermore, drug resistance has been observed in many cisplatin-treated patients who have relapsed in later years after remission.¹⁷ Correspondingly, the combination therapy of cisplatin has become the mainstream of several cancer treatments to reach the desired therapeutic effect with low toxicity and resistance possibility.¹⁸

Combating cancer cells with serial non-toxic therapeutic agents that differ in the mechanisms of action enhances the treatment efficacy with a low chance of tumor recurrence in later years and extends the survival rate. Herein, we targeted Ehrlich ascites carcinoma (EAC)-bearing mice

with one dose of cisplatin and subsequent doses of metformin, to induce EAC quiescence and improve the survival time.

Methods

Drugs and chemical reagents

Cisplatin was purchased from Mylan (10mg/10mL vial; Saint-Priest, France). Metformin from (Sigma-Aldrich, St. Louis, MO, USA) was dissolved in sterile water to make a solution of a concentration of 0.15 M to be used in the experiment. All other chemicals/reagents were of analytical grade.

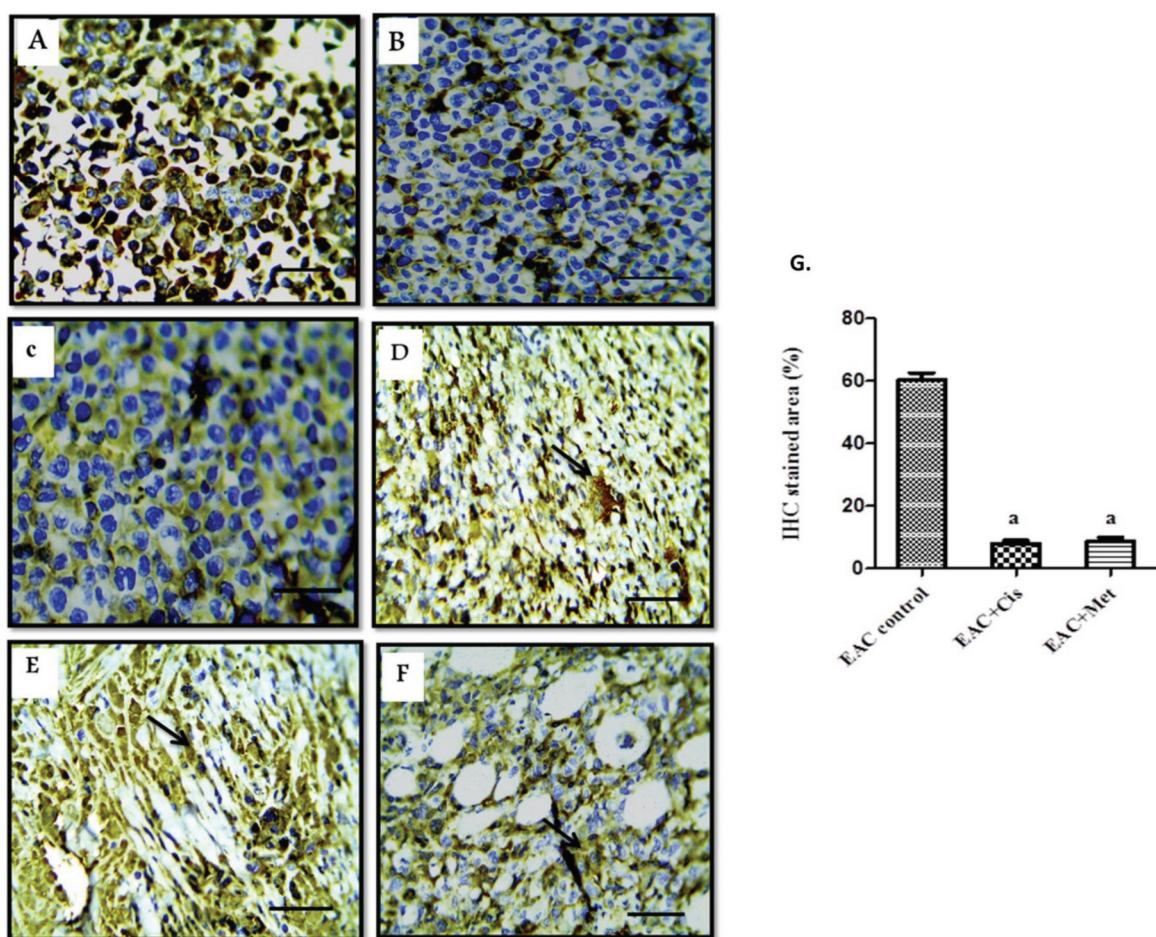


Figure 4. Low Δ Np63 immunostaining induced by metformin and cisplatin in Ehrlich ascites carcinoma (EAC) on day 15 or solid tumor on day 40. A. An EAC control group with a strong positive yellow immunolabelling in multiple EAC cells. B. The group treated with cisplatin shows a mild positive yellow immunolabelling for Δ Np63 in aggregation of EAC cells. C. EAC cells treated with metformin have a moderate positive immunolabelling for Δ Np63 in few EAC cells. D. Solid tumor from a group receiving the combined treatment had a strong positive immunolabelling for Δ Np63 is seen in the capsule of EAC cells (arrows). E. In surrounding muscle (arrows). F. In adipose tissue (arrows) IHC counterstained with Mayer's hematoxylin $\times 200$ bar 100. G. Comparison between the stained areas of Δ Np63 in EAC control group and the groups that comprise ascitic fluids on day 15 using Image J. Stars means significant when $P < 0.05$.

EAC: Ehrlich ascites carcinoma; IHC: Immunohistochemistry

Animal care and handling

In this experimental study, a total of 75 female Swiss albino mice aged 6-8 weeks and weighed 18-25 g were purchased from National Research Center (Cairo, Egypt). In wire cages, mice underwent one-week acclimatization at identical conditions (27 ± 2 °C; 70-80 % humidity; 12-h light/darkness cycle) and supplied with standard pellet diet and water ad libitum. All performed experiments followed the guidelines for the care and the use of laboratory animals was approved by the Mansoura University Animal Ethical Committee.

Tumor cell line

EAC is developed from a high grade of malignant mouse breast adenocarcinoma. As the mice were acclimatizing, EAC cells (1×10^6 cells) obtained from the National Cancer Institute (Cairo, Egypt) were transplanted into the peritoneal cavity of a mouse to propagate. After 10 days, ascitic fluid containing EAC cells had developed and cells viability was tested for in vivo experiments by trypan blue dye exclusion method and counted by a hemocytometer. The percentage of viable cells=[(total number of cells – number of trypan blue positive cells)/total number of cells] * 100.19

Tumor transplantation and experimental design

On day zero, all mice were divided into five groups, 15 mice per group. Four groups were inoculated with 2.5×10^6 EAC cells (0.2 ml PBS/mouse) and one group was left as a normal healthy group and injected intraperitoneally by 200 µL saline for 14 days. 24 hours later, the inoculated groups with Ehrlich cells were classified according to the treatment mode as following: EAC control group was the tumorized mice. EAC+Cis group was given one dose of cisplatin. EAC+Met group were treated with metformin for three consecutive days. EAC+Cis+Met represented the group receiving the dual-combination treatment which involved one dose of cisplatin then two days interval followed by metformin doses for the next three days. All the tested therapeutic agents are injected intraperitoneally. Cisplatin was injected at dose of 3.5 mg/kg, while the metformin dose was 200 mg/kg. All groups were treated daily with 0.2 ml

saline solution after 24 hours of the last therapeutic dose until the 14th day of post tumor inoculation.

Sampling

On the 15th day, six mice from each group were anesthetized, blood was collected via cardiac puncture, and then mice were killed by cervical dislocation. Peritoneal fluids were collected from the groups that had ascitic fluids for immediate measurement of tumor growth parameters (volumes of ascitic fluids and cells viability), and then EAC cells were isolated by centrifugation (2,000 rpm for 10 minutes at 4 °C) and divided for later experiments. The organs were also preserved in a 10% neutral buffer formalin for the histopathological investigation. The remaining mice in each group (n = 9 mice/ group) were left alive to estimate the mean survival time (MST).²⁰

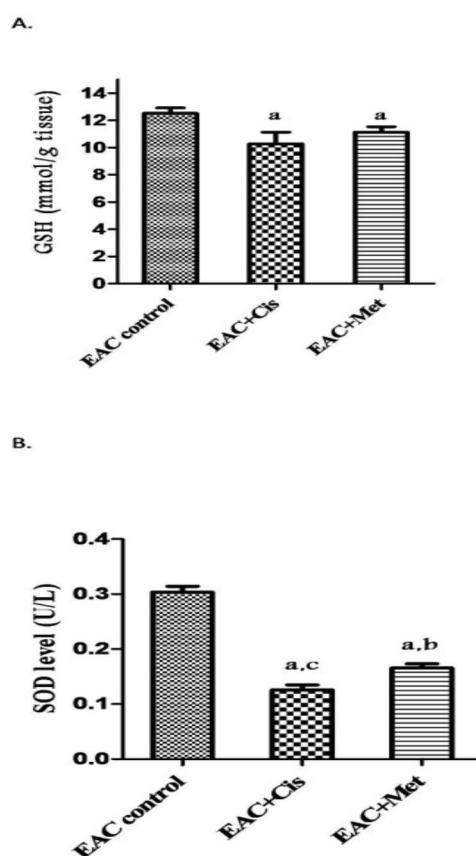


Figure 5. Cisplatin and metformin inhibit SOD and GSH enzymes in EAC cells. A. GSH and B. SOD levels in EAC cells treated by metformin or cisplatin collected on the 15th day following the tumor inoculation. Data is presented as mean±SD of six animals. P≤0.05 compared to all groups.

Cis: Cisplatin; Met: Metformin; GSH: Reduced glutathione; SOD: Superoxide dismutase; a: Significant versus EAC control group; b: Significant versus EAC+Cis group; c: Significant versus EAC+Met group; EAC: Ehrlich ascites carcinoma; SD: Standard deviation

On the 40th day, 3 mice from the group that had developed a solid tumor were dissected to collect solid tumors for cell cycle analysis, immunohistochemistry and histopathological examination. Total experimental period was 50 days.

qPCR analysis

On the 15th day, 4×10^6 cells were isolated from the groups that had ascitic fluid, then washed and suspended in a cold 1ml PBS for immediate gene expression analysis. Total RNA was extracted from 4×10^6 cells using a TRIzol™ Plus RNA Purification Kit (Invitrogen, Carlsbad, CA, USA,

cat. no. 12183555) according to the manufacturer's instructions. The extracted total RNA was quantified by measuring the optical density at 260 nm using a spectrophotometer. The expression of cyclin-dependent kinase inhibitor (p21), mRNA, and GAPDH mRNA as a housekeeping gene was estimated according to the manufacturer's instructions of the One-Step RT-PCR Kit (Power SYBR® Green RNA-to-CTTM one-Step Kit, Applied Biosystems, USA). The following primer pairs were designed using online OligoPerfect Designer Software (Thermo Fisher

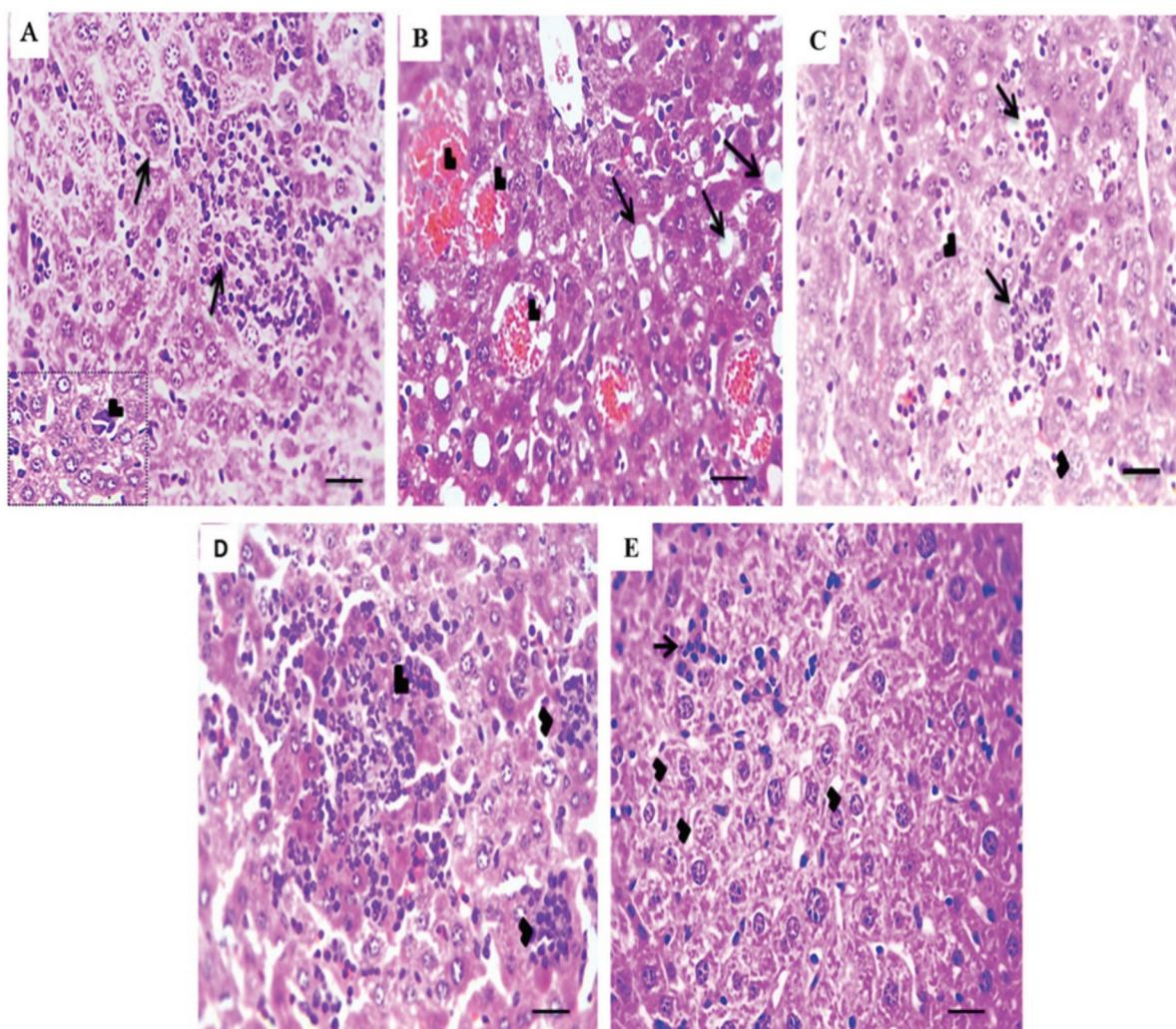


Figure 6. Assessment of metformin and/or cisplatin effects on liver histopathology after 15 days and 40 days of tumor inoculation. A. Liver of untreated EAC group demonstrates the activation of Kupffer cells with eosinophilic intranuclear inclusions (arrowhead), sinusoidal infiltration of single and clumps of tumor cells mixed with lymphocytes (arrows). B. Liver of cisplatin treated mice shows cytoplasmic vacuolation (arrows) sinusoidal congestion (arrowheads). C. Liver of metformin treated group represents the dilation of sinusoids with clumps of tumor cells (arrows) with hydropic degeneration of hepatocytes (arrowheads). D. On the 15th day, liver of Cis+Met group depicts focal areas of necrosis infiltrated with mononuclear cells, neutrophils, and clumps of EAC cells (arrowheads) (H&E, $\times 200$ bar 50). E. On the 40th day, liver treated with the dual therapy shows aggregation of tumor cells and leukocytes in sinusoids (black arrow) and mild hepatocytes swelling due to the degeneration (arrowheads) (H&E, $\times 400$ bar 50).

Cis: Cisplatin; Met: Metformin; EAC: Ehrlich ascites carcinoma

Scientific, USA) and their specificity was checked by BLAST analysis. (p21 forward, 5'-ACGGTG-GAACTTGACTTCG-3' and reverse, 5'-GAGTGCAAGACAGCGACAAG-3'; mTOR forward, 5'-CGTCACAATGCAGCCAACAA-3' and reverse, 5'-TGCCTTCACGTTCTCTCC-3'. GAPDH forward 5'-ATGGTGAAGGTCG GTGTGAAC-3' and reverse, 5'-TTGATGT-TAGTGGGGTCTCGC-3'. The relative expression of the gene amplification product was calculated using the $2^{-\Delta\Delta Ct}$ method.²¹

Cell cycle analysis by flow cytometry

2.5×10^6 EAC cells were collected from the groups that had ascitic fluids on the 15th day, besides solid tumors that excised from (EAC+Cis+Met) group on the 40th day were fixed in 1ml ice cold absolute alcohol and

preserved at +4°C for cell cycle analysis according to the Vindelov's method.²² The samples were run in a FACS Calibur system (BD, Sunnyvale, CA, USA). Data analysis was conducted using DNA analysis program MODFIT (verity software and CELLQuest software, version 3.3; Becton Dickinson).

Immunohistochemical analysis

EAC cells collected on the 15th day and Ehrlich solid tumors excised on the 40th day were fixed in formalin and paraffin embedded for Immunohistochemistry.²³ Three-micron of tissue sections were tested for the immune-histochemical detection of antigens with anti- Δ Np63 antigen (Clone 4A4, BioGenex, USA, cat.no. AM418-5M). Tissue sections visualized with Ultra vision LP detection system: HRP polymer/DAB plus

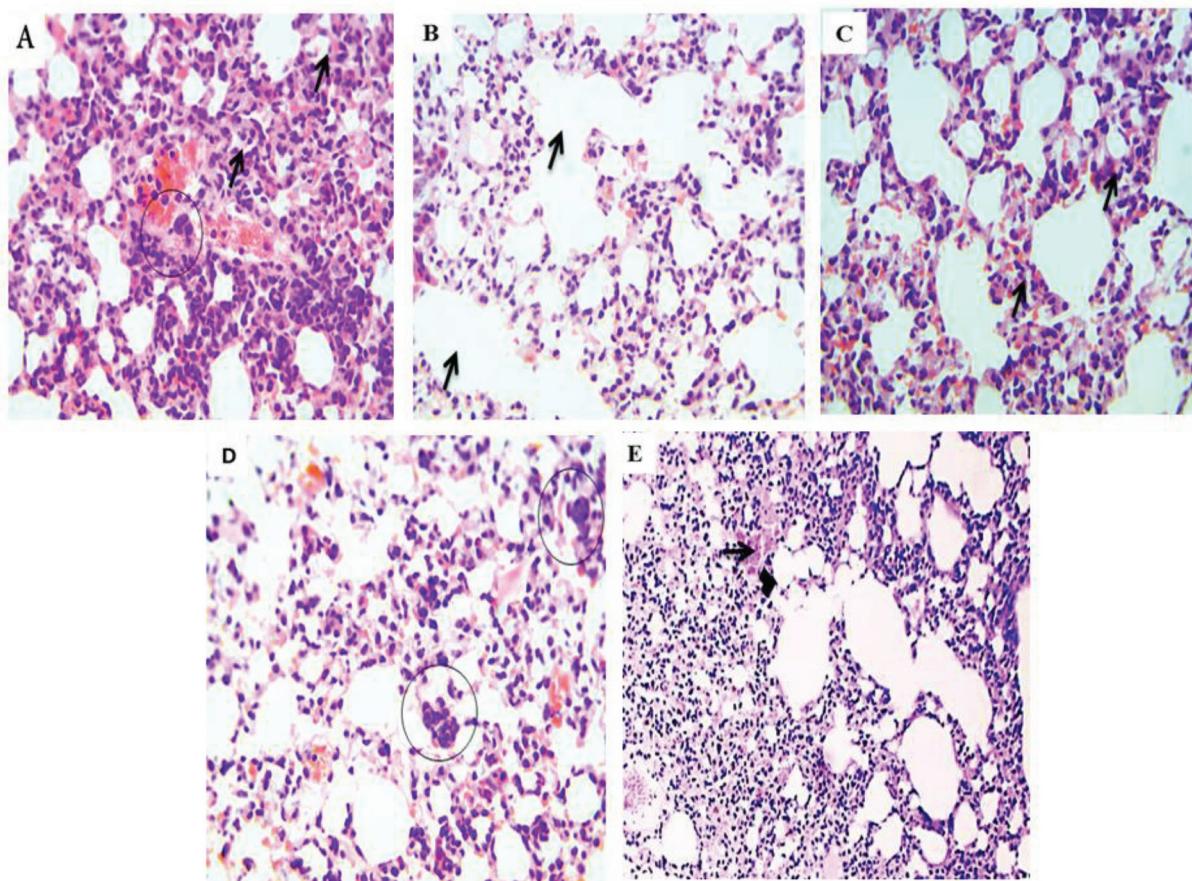


Figure 7. Assessment of metformin and/or cisplatin effects on lungs histopathology after 15 days and 40 days of tumor inoculation. A. On the 15th day, lung of untreated EAC-bearing mice displays a marked thickening of interstitial tissues with numerous areas of cellular infiltration, fibroblasts proliferation and congested blood vessels (arrows) and perivascular small clusters of tumor cells (circle). B. Lung of cisplatin-treated mice displays focal alveolar emphysema (arrows). C. Lung of metformin-treated mice showed mild interstitial thickening (arrows). D. group treated with the dual treatment reveals a mild thickening of interstitial tissues with the presence of single tumor cells (circle) (H&E \times : 200 bar 50). E. On day 40, the group receiving the dual treatment shows congestion (black arrows), alveolar emphysema (arrow head). (H&E \times :100 bar 100).

EAC: Ehrlich ascites carcinoma

Chromogen (TL-015-HD; Thermo scientific). Images were obtained with a light microscope (Binocular, Olympus Microscope; Shinjuku, Tokyo, Japan) for IHC quantification. The percentage of yellow Δ Np63 staining was evaluated with image J software (version 1.48, 32 bit).

Biochemical assays in serum and tumor homogenate

Serum samples were obtained by centrifugation at 3000 rpm/min for 20 min and stored at -20 $^{\circ}$ C.

for biochemical analysis. Creatinine, urea, aspartate aminotransferase (AST), alanine aminotransferase (ALT), and total proteins were estimated in serum through the use of commercial kits (Biodiagnostic Company for Laboratory Services, Giza, Egypt). Additionally, the levels of glutathione (GSH) and superoxide dismutase (SOD) were measured in the collected EAC cells using assay kits (Biodiagnostic Company for Laboratory Services, Giza, Egypt).

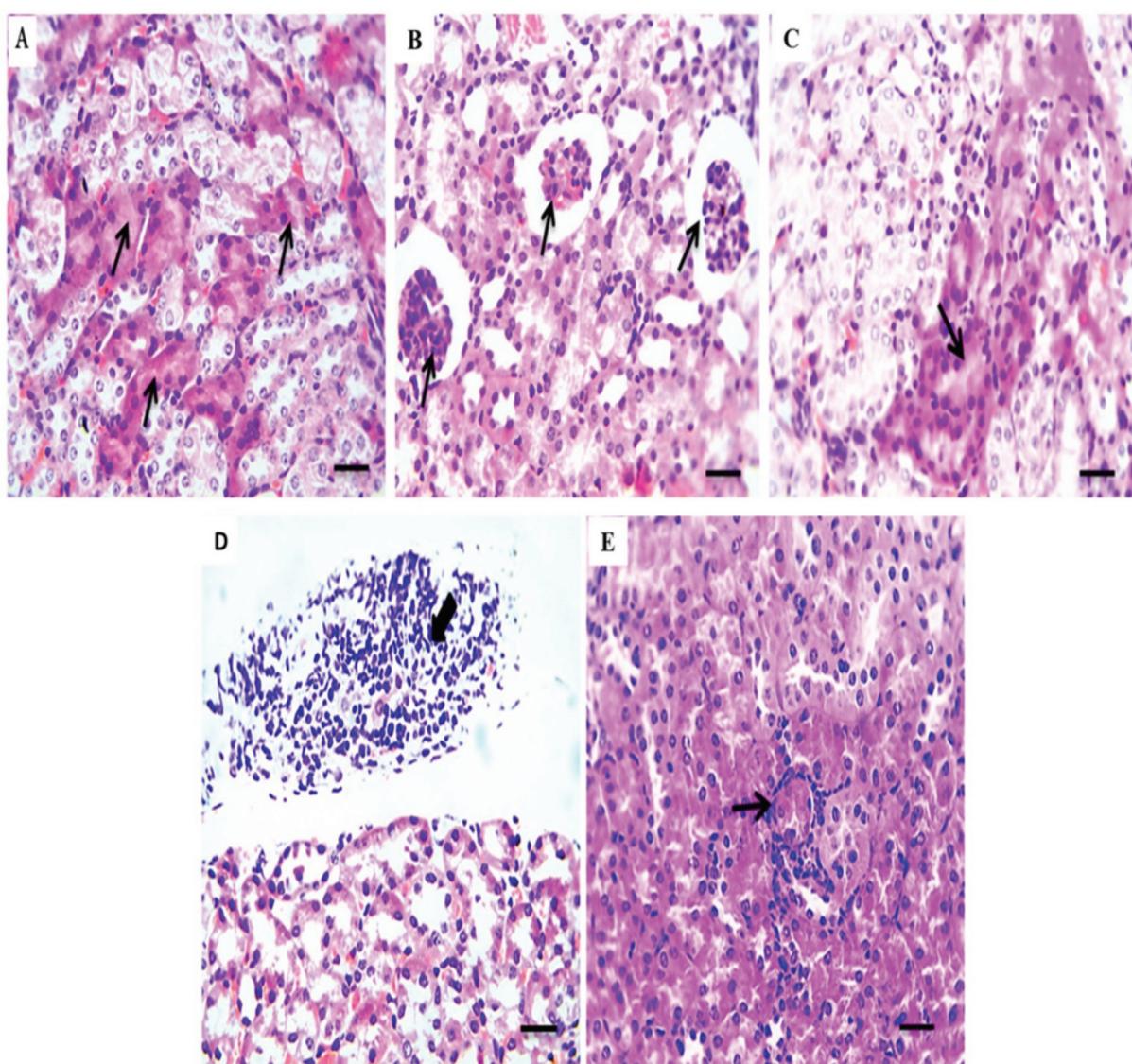


Figure 8. Assessment the effect of metformin and/or cisplatin on kidneys histopathology after 15 days and 40 days of tumor inoculation. On the 15th day, A. Kidney of EAC control group shows tubular necrosis (arrows), swollen and congested glomeruli (arrowheads). B. Kidney of cisplatin- treated mice shows shrunken collapsed glomeruli (arrows). C. Kidney of metformin treated group shows tubular necrosis. D. Kidney of Cis+met-treated mice shows few tumor cells admixed with neutrophils and lymphocytes adherent to the capsule of kidney without invasion into parenchyma (arrow) (H&E \times : 200 bar 50). On the 40th day, the kidney treated with the dual therapy shows perivascular aggregation of tumor cells and leukocytes around renal tubule (black arrow) (\times : 400 bar 50).

Cis: Cisplatin; Met: Metformin; EAC: Ehrlich ascites carcinoma

Histopathology analysis

Cytological changes in lungs, kidneys, and liver were studied by hematoxylin and eosin staining according to the method of Bancroft et al.²⁴ Organs were collected from all mice groups wither those were killed on the 15th or 40th day washed in PBS and to remove the blood. Tissues were then fixed in 10% neutral buffered formalin for 24 hours. Blocks of tissues were prepared, sectioned, stained with hematoxylin–eosin, and then examined with a light microscope (Binocular, Olympus Microscope; Shinjuku, Tokyo, Japan).

Statistical analysis

All data are expressed as mean \pm SD. One-way analysis of variance (ANOVA) followed by a Tukey's test was used to assess significant differences among all groups using GraphPad Prism Software 5 (LaJolla, CA, USA). *P* values were considered statistically significant at *P* < 0.05.

Results

Metformin enhances the anti-tumor potential of one dose of cisplatin on EAC cells

To assess the antitumor effects of metformin and cisplatin against EAC cells, changes in tumor volume, tumor cells viability, and the mean survival time of treated groups were observed (Figure 1). EAC-bearing mice treated with the combination therapy showed no ascitic fluid volume on the day 15 post tumor inoculation compared with the other groups (Figure 1A). There was a delayed tumor recurrence on day 25, as a solid tumor instead of developing peritoneal fluid containing tumor cells. Regarding cells viability, cisplatin and metformin displayed a significant decrease in EAC cells (*P* < 0.05) reached to $83.39 \pm 1.64\%$ and $97.16 \pm 1.15\%$, respectively, compared with the EAC control group (Figure 1B). Subsequently, the treatment with the combination treatment showed a significant increase in MST to 50 days compared with the control and other treated groups.

Effect of metformin and cisplatin on relative expression of mTOR and p21 genes in EAC cells

There was a reversal relationship between p21 and mTOR expressions after treatment with cisplatin or metformin. Cisplatin that was injected

as one dose and metformin caused a long-term significant increase of p21 expression and a significant decrease in mTOR expression compared with EAC control group (Figure 2).

Metformin and cisplatin induce cell cycle arrest in G0-G1 phase

The used treatments significantly increased arrest in the G0/G1 phase compared with EAC control group. Cisplatin arrested 75.4% of EAC cells in G0/G1, while metformin arrested 57.7% of EAC cells and 19.2% of cells were apoptotic cells (Figures 3B and C). After 40 days of tumor inoculation, the analysis of cell cycle of the solid tumor revealed that only 32.2% of tumor cells remained in the quiescent state, with 37.2% proliferating cells and the highest percentage of apoptotic cells among the other treated groups reached to 28.3% (Figure 3D).

Inhibitory effect of metformin and/or cisplatin on ΔNp63 level

In figure 4, the immunohistochemical analysis of ΔNp63 in EAC cells implies a strong positive yellow immunolabelling for ΔNp63 in multiple EAC control cells (Figure 4A). Mild was seen in cisplatin-treated cells and moderate in a few EAC cells treated with metformin (Figures 4B and C). However, after 40 days of tumor inoculation, Cis+Met group showed a strong positive immunolabelling for ΔNp63 in the capsule of the solid tumor (Figure 4D), surrounding muscle (Figure 4E) and adipose tissue (Figure 4F).

Metformin and cisplatin effect on antioxidant enzymes In EAC cells

Cisplatin and metformin as single drugs inhibited SOD and GSH levels significantly (*P* < 0.05) in the EAC cells compared with that of EAC control group (Figure 5). The effect of cisplatin and metformin as a combination therapy would be higher.

Assessment of kidney and liver functions after treatment with metformin and cisplatin

Data presented in table 1 demonstrated that serum of Cis+Met group portrays the most significant changes in the tested serum parameters compared with other groups. There was an elevation in ALT, AST, and creatinine concentrations and a decrease in total proteins

and urea ($P < 0.05$) compared with other groups. In general, serum of EAC-bearing mice indicated a significant change compared with the normal mice ($P < 0.05$).

Histopathology findings

In our histopathological results, as the cytotoxicity of drugs increases, the number of infiltrative tumor cells also rise. Cis+Met treated group showed a high EAC metastasis compared with a single drug-treated group in liver, lungs, and kidney of the treated group (Figures 6-8). The other treated groups revealed no tumor infiltration. In general, the number of infiltrative tumor cells and damaged tissue structure had not been increased on the 40th day after tumor inoculation.

Discussion

In our work, just one dose of cisplatin followed by metformin doses could reverse the malignancy of free neoplastic cells in peritoneal ascites fluid to a solid neoplasm contributing to the extended survival time.

In the present study, the volume of ascitic fluid reflected the low proliferation rate and viability of cells treated with metformin and cisplatin. It has been reported that ascitic fluid is the direct source of nutrients for tumor cells and as the tumor cells proliferate rapidly, the volume of ascites fluid increases at the same levels.²⁵ The therapeutic potential of metformin and cisplatin in combination was observed in human ovarian cancer cells²⁶ and hepatocarcinoma cells;²⁷ suggesting the combination treatment of metformin and cisplatin has a remarkable inhibitory effect on EAC cells proliferation.

Our RT-PCR results revealed that one dose of cisplatin alone caused a long-term inhibition of the mTOR expression in malignant ascites cells. In addition, the results demonstrated that cisplatin increases the expression of p21, the matter that was confirmed by previous publications.^{28, 29} In the current study, metformin upregulated p21 expression. This is in agreement with Cai et al. who observed the upregulation of p53, p27 and p21 in a xenograft model of esophageal squamous cells carcinoma treated with metformin.³⁰ Also,

metformin acts as anticancer by its downregulation of mTOR and activation of AMPK.³¹ It is generally believed that mTOR inhibition maintains quiescence and suppresses senescence (geroconversion). High level of p53 response inhibits mTOR, which favors quiescence over senescence.³² p21 is a downstream target gene of the tumor suppressor p53.³³ It promotes the quiescent state by blocking G1 progression under serum stimulation.³⁴ Awakening of these dormant cancer cells leads to tumor recurrence which may occur after long periods.³⁵ Accordingly, the combination of metformin and cisplatin had driven the tumor cells into the deep quiescence state followed by tumor recurrence in form of solid tumor which is less malignant form than malignant ascites.

In accordance with the previous conclusion, our cell cycle analysis showed that the cell cycle arrest occurred at G0/G1 which was through the inhibition of mTOR and the activation of p21 as a result of metformin and cisplatin combination effect. Taken together, the result provided an explanation for the reason of delayed tumor development in case of using the combined treatment.

ΔNp63 isoforms are a class of p63, which bind to TAp63, p53, p21, and TAp73 and repress their functions, thus acting as oncogenes.^{36, 37} In the present study, the development of solid tumors instead of ascitic fluids confirmed that the combined effect of cisplatin and metformin to inhibit ΔNp63, leading to restriction of cancer progression. This is similar to the results of Yun-Feng He et al. that revealed that the ΔNp63 silencing can promote the adhesiveness of the human bladder carcinoma cell line 5637 cells by activating F-actin cytoskeleton synthesis.³⁸ Recently, it has been reported that ΔNp63 expression can deregulate tumor cell migration and tumor invasiveness.³⁹ Accordingly, there was a recurrent and localized peritoneal solid tumor instead of malignant ascites development.

Our analysis of antioxidant enzymes level showed that EAC cells treated with cisplatin had low SOD and GSH levels. This agreed with previous studies.^{40, 41} Also, metformin depleted

GSH and SOD levels. In accordance with this result, it was found that metformin acts as a pro-oxidant via downregulation of intracellular glutathione, inhibition of proliferation and induction of apoptosis of esophageal squamous cancer cells.⁴² It has been reported that an excessive ROS level can be toxic to cancer cells, the reason behind many trials for developing many ROS generating agents and antioxidant inhibitors.⁴³ Therefore, the combined effect of both drugs caused further accumulation of ROS leading to kill EAC cells.

In this work, metastasis increased among the treated groups. the cytotoxicity of the drug increased EAC cells invasion to liver, kidney, and lungs were marked with the combined therapy treated group. This may be attributed to chemotherapy increasing the invasion of cancer cells.^{44,45} Herein, as the Ehrlich cells metastasized to the surrounding tissues, they lost their malignant capacity. The histopathology results did not display increasing numbers of EAC cells after 40 days of post tumor inoculation. It has been observed that most EAC cells infiltrating into the liver may die or may become “dormant in the liver”.⁴⁶

Although cisplatin is known for its nephrotoxicity, which is dose-limiting toxicity. In the present investigation, there were no acute toxicity or histopathological complications in the lungs, liver, and kidney even after 40 days. In other words, the tissue damages were reversible and associated with significant changes in biochemical parameters in serum of the dual therapy. These findings supported that the tested combination treatment in the aforementioned doses is safe.

In summary, the value of this work was the restriction of a malignant ascites in a solid tumor in EAC xenografts by the inhibition of p63 level, the induction of chemo-quiescence by the inhibition and the upregulation of p21 expression besides the accumulation of ROS by the inhibition of antioxidant system. These effects achieved by non-toxic and existing drugs in combination comprising one dose of cisplatin and subsequent doses of metformin results in extending survival time. Further future research is required for

understanding the mechanism of tumor quiescence to keep the tumor cells trapped as long as possible in quiescence state and then develop an approach to target the quiescent tumor cells for elimination.

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Conflict of Interest

None declared.

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