Sono and Photo Sensitized Gallium-Porphyrin Nanocomposite in Tumor-Bearing Mice: new Concept of Cancer Treatment -  

Samir Ali Abd El-Kaream¹*, Gihan Hosny Abd Elsamie² and Abtisam Jasim Abbas²,³

¹Department of Applied Medical Chemistry, Medical Research Institute, Alexandria University, Egypt
²Division of Environmental Health, Dept. of Environmental Studies, Institute of Graduate Studies and Research, Alexandria University, Egypt
³College of Science, University of AL-Qadisiyah, Iraq

*Address for Correspondence: Samir Ali Abd El-Kaream, Department of Applied Medical Chemistry, Medical Research Institute, Alexandria University, Egypt, Tel: +012-838-262-75; ORCID ID: orcid.org/0000-0003-4899-9338; E-mail: Samir.ali852006@yahoo.com

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ABSTRACT

This study was directed at study the effectiveness of cancer targeted therapy using the activated Gallium-Porphyrin Nanocomposite (Nano-GaP). Study was applied on male Swiss albino mice, implanted with Ehrlich Tumor (EAC) divided into six groups. Two energy sources were used; laser and ultrasound. Results showed that Nano-GaP is a potential sensitizer for photodynamic or sonodynamic treatment of tumor. Nano-GaP plays an important role in tumor growth inhibition and cell death induction. Activated Nano-GaP with both infrared laser and ultrasound has a potential antim tumor effect. The results indicated that Folic Acid-Nanographene Oxide-Gallium-Porphyrin Nanocomposite (FA–NGO–GaP) could be used as a unique nanocomposite for cancer targeted Sono-Photodynamic Therapy (SPDT).

Keywords: Nano-gallium-porphyrin; Sonodynamic therapy; Photodynamic therapy

INTRODUCTION

Cancer is the major cause of death worldwide. During 2012, there were 14 million new cancers and 8 million cancer decease worldwide and by 2030, the cosmopolitan burden is predictable to reach to 22 million incoming cancer patients and 13 million cancer decease [1-3]. Current treatments used for cancer treatment include surgery, chemotherapy, and radiotherapy. Despite these treatments have been practiced and accepted for decades, they have their disadvantages and unfavorable effects. Removal of tumors by surgery is limited to large tumors and is available. Chemotherapy drugs target rapidly proliferating cells, so killing not only cancer cells but also destroying normal cells such as bone marrow cells and immune cells. These lead to extensive "collateral damage" in the patient’s body. Radiotherapy involves the use of high-energy rays such as x-rays and rays to either destroy cancer cells, which inevitably leads to harmful effects on healthy tissue along the path of radiation. It is clear that the need for advanced technology to play an important role in cancer treatment is clear in statistics indicating that rates of cancer incidence, mortality and mortality are still at very high levels [4,5].

In recent years, there has been increasing interest in using of Photodynamic Therapy [PDT] to treat different types of cancers, either on its own or in combination with other anticancer treatment methods. PDT involve the administration of a Photosensitizing (PS) drug and subsequently illuminating the target area with light corresponding to the absorbance wavelength of the PS, triggering a series of biological effects [5-8].

Sonodynamic Therapy [SDT] has been raised as a promising noninvasive approach derived from PDT. The low penetration depth of light, PDT is not effective for the treatment of deep tumors. A great advantage of SDT on a PDT is that it can penetrate soft tissue up to tens of centimeters therefore; SDT overcomes the limitation of PDT [9-12].

Sono-Photodynamic Therapy [SPDT] is a new therapeutic method that utilizes a safe agent with sono and photo sensitive properties. PDT and SDT have been applied for years as separate processes for the treatment of cancer with variable results. PDT alone is used for more superficial tumor, but when combined with SDT, it has been shown to be efficient for deep-seated as well as metastatic tumors [13].

Gallium-porphyrin; GaP or [7, 12-bis (1-decylxyloxyethyl) - Ga(III) - 3, 8, 13, 17 – tetramethylporphyrin - 2, 18 – dipropionyldiaspartic acid] is one of the metal-deuteroporphyrin complexes as SPS for SPDT, the gallium complexes exhibit long phosphorescence lifetime. This long phosphorescence lifetime can be of a great advantage in the efficient generation of singlet oxygen to induce significant tumor tissue destruction.

The aim of this work was to study the effectiveness of gallium-porphyrin in activated cancer-targeted therapy. To achieve our goal the following was done:

MATERIALS AND METHODS

Synthesis of Nanographene Oxide (NGO), conjugation of Folic Acid with Nanographene Oxide (FA–NGO) and photosensitizer gallium-porphyrin loading on FA–NGO (FA-GO-GaP) according to Abd El-Kareem SA, et al. [14]. In the present work gallium-porphyrin was used as sono-photosensitizer; chemically active by absorption of light and/or ultrasound. Gallium-porphyrin was purchased from Molbase Chemicals Co. India. The sono-photosensitizer obtained as powder stored in dark bottle at -20°C temperature and with purity: 99.9% by HPLC analysis. GaP was dissolved in a sterilized phosphate buffer saline solution with pH = 7.4 and mixed with FA-NGO (0.5 mg/ mL) at room temperature for 24 h. The loading efficiency of GaP was approved using UV absorbance at 663 nm. FA-NGO-GaP administered to tumor-bearing mice Intraperitoneal (IP) injection for 15 days 18-20 hours before exposure to either photo and/or sonodynamic treatment modality.

Experimental design and tumor implantation

This study was conducted on one hundred and thirty male Swiss albino mice. Ehrlich ascites carcinoma tumor cells, 2 x 106 human female mammary cells in origin, diluted approximately ten times in 0.9% saline were inoculated subcutaneously on the left abdominal region of mice purchased from national cancer institute, Cairo University. The animals were housed in plastic cages and were kept under natural light with diet and water at available. When tumors reach to 10 mm in diameter on day 10 after implantation, the treatment study was started. Use of experimental animals in the study protocol was carried out in accordance with the ethical guidelines of the medical research institute, Alexandria University (Guiding Principles for Biomedical Research Involving Animals, 2011). Mice were grouped into the following:

Group I: (30 mice); a) 10 mice: Control without tumor, b) 10 mice: Tumor bearing mice without treatment, c) 10 mice: Tumor bearing mice treated with (FA–NGO–GaP) only.

Group II: (20 mice, laser irradiated group); a) 10 mice: were exposed to Infra-Red Laser, 4000Hz, for 3 minutes, b) 10 mice: were exposed to Infra-Red Laser, 7000Hz, for 3 minutes.

Group III: (20 mice, ultrasound group); a) 10 mice: were exposed to pulsed ultrasound for 3 minutes, b) 10 mice: were exposed to continuous ultrasound for 3 minutes.

Group IV: (20 mice, (FA-NGO–GaP), laser group); Tumor bearing mice of this group were injected (IP) with (FA-NGO-GaP),...
then the tumor sites were irradiated to laser light at same conditions of group II.

**Group V:** (20 mice, (FA-NGO-GaP), ultrasound group); Tumor bearing mice of this group were injected (IP) with (FA-NGO-GaP), then were divided into 2 sub-groups. The tumor sites were irradiated to ultrasound at same conditions of group III.

**Group VI:** (20 mice, combined treatment groups); a) 10 mice: were irradiated to laser light for 3 minutes, followed by ultrasound for 3 minutes, b) 10 mice: Injected (IP) with (FA-NGO-GaP), then tumor sites were irradiated to laser light (7000 Hz) for 3 min, followed by pulsed ultrasound for 3 minutes.

**Laser/ ultrasound exposure**

For laser and/or ultrasound exposure, the mice were anesthetized with diethyl ether. The hair over the tumors was shaved off. The mice were fixed on a board with the tumor upwards. The probe was placed nearly on the tumor, which was irradiated with laser and/or ultrasound for 3 minutes at the different conditions as mentioned before. After PDT, SDT and SPDT, animals were maintained in the dark to avoid skin irritation. Exposure of mice tumor to the laser beam was carried out using an Infrared diode laser, model LAS 50-Hi-Tech fysiomed, Germany operated at a wavelength of 904 nm and a peak power of 50 W at a frequency up to 7000 Hz. Exposure of mice tumor to the continuous and pulsed ultrasound was carried out using an ultrasonic therapy instrument (Model CSI Shanghai, No. 822 Factory, China). This instrument uses electronic tube to generate an electric oscillation with frequency 0.8 MHz and power output which converted to ultrasonic mechanical energy by means of ultrasonic transducer (calcium zirconate –titinate). The mechanical ultrasonic energy has a beam power density which can be adjusted from 0.5 to 3W/cm². This instrument operates at both continuous wave mode with output power from 0.5 - 3W/ cm² adjustable in 11 steps and pulsed mode (pulse frequency 1000 Hz, duty ratio 1/3 and average power density from 0.15-1 W/ cm²). For evaluation of the treatment effects to all studied groups the following investigations were done:

**Tumor growth/ inhibition assay**

During treatment session, tumor growth was examined regularly every day. Length and width of tumors were measured with a slide caliper and tumor volume (in mm³) was calculated by the use of the following equation.

\[ TV (\text{mm}^3) = \frac{22}{7} \times \frac{x}{4} \times (\text{length}/2) \times (\text{width}/2) \]

Two weeks after the treatment, the mice were sacrificed and the tumors were dissected out, weighed (in grams). The tumor volume growth ratio and tumor mass inhibition ratio were calculated as follows.

\[ \text{TMIR} = 1- \frac{\text{(average tumor weight of treated group/ average tumor weight of control group)}}{100} \]

**Biochemical examination**

Blood sample (2.5 ml of venous blood) was withdrawn from all mice group. This blood samples were allowed to clot thoroughly for 20 minutes then centrifuged at 3000 x g for 20 minutes for separating serum for biochemical examinations. All biochemical analysis was done on Indikdo Plus Auto-analyzer.

**Oxidative stress and antioxidant profile:** Lipid peroxidation (MDA) assay kit (BioVision Catalog # K739-100), Total Antioxidant Capacity (TAC) assay kit (BioVision Catalog #K274-100), Glutathione Reductase (GR) activity assay kit (BioVision Catalog #K761-100), Glutathione-S-Transferase (GST) activity assay kit (BioVision Catalog #K263-100), Superoxide Dismutase (SOD) activity assay kit (BioVision Catalog #K335-100), Catalase (CAT) activity assay kit (BioVision Catalog #K773-100), were used according to the manufacturer’s instructions.

**Kidney and liver biomarkers:** Creatinine (Sigma Catalog # MAK080), Alanine Transaminase (ALT) Activity Assay Kit (Sigma Catalog # MAK052), Aspartate Aminotransferase (AST) Activity Assay Kit (Sigma Catalog #MAK055) and γ-Glutamyl Transferase (GGT) Activity Assay Kit (Sigma Catalog #MAK089), were used according to the manufacturer’s instructions.

**Molecular detection of osteopontin mRNA gene expression in excised tumor via RT-PCR:** RNA was extracted from the Ehrlich tumor of mice using QIAamp RNA tissue kit, was purchased from QIAGEN, USA according to the manufacturer’s instructions. Preparation of Full-Length First strand cDNA from RNA template using RevertAid TM First cDNA Strand Synthesis Kit. Reverse transcription reaction was carried out in a 20 μl reaction mixture using RevertAid TM First cDNA Strand Synthesis Kit # K1621, #1622, was purchased from MBI Fermentas, Lithuania according to manufacturer’s instruction. For amplification; to each PCR tube the following were added 5 μl (0.25 μg) Template osteopontin - cDNA, 10 μl Taq TM Green PCR Master Mix (2X) [dNTPs [0.4 mM of each dATP, dCTP, dGTP, dTTP], 0.05u/μl Taq DNA polymerase and reaction buffer] # k1081, was purchased from MBI Fermentas, Lithuania, 1.5 μl osteopontin forward primer: 5’-CTT CAATC GTCCCTCCA C-3, 1.5 μl osteopontin reverse primers: 5’-GCCTC TTGGAATGCTCAAGT-3 and deionized-RNase free water to final volume 20 μl. The reaction mixtures were gently vortexed, brieﬂy centrifuged to collection all drops to the bottom of the tubes, then were placed in the thermal cycler (Little Genius, Bioer Co), The PCR mixture was subjected to 35 amplification cycles. PCR thermal proﬁle was as follow: pre-denaturation (94°C, 2min), followed by 35 cycles of denaturation (94°C, 1min), annealing (52°C, 1min), and extension (72°C, 1min), with a ﬁnal extension (72°C, 7min). To verify the successful preparation of mRNA and as positive controls, samples were detected for the presence of Glyceraldehyde-3-Phosphate Dehydrogenase (GAPDH) mRNA. Forward primer: 5-AGGCCGGTGCTGAGTATGTC-3, reverse primers: 5-TGCCCTGCCAACCACACCTCT-3. Reaction tubes containing no cDNA control template and without cDNA sample addition were included as negative controls for each PCR reaction. For detection: Amplicons were analyzed with 2% (wt/ vol) ethidium bromide stained agarose gel. The bands were visualized on a 302 nm UV transilluminator (BIO-RAD, USA).The gel was examined for bands of 305bp and 530bp as determined by the molecular weight marker (Gene Ruler TM 100bp DNA marker #SM0323, was purchased from Fermentas, Lithuania) runs at the same time and then photographed using a digital camera.

**Histopathological examination**

Small pieces of Ehrlich tumor tissue of the experimental groups were processed and examined by Haematoxylin and Eosin (H&E) method as follows; small pieces of Ehrlich Tumor tissues were fixed at 10% formaldehyde, dehydrated in ascending grades using alcohol, embedded in paraffin to produce paraffin block, the blocks were cut
into 3-4 μm thick sections and floated in water bath, cleaned with xylene, rehydrated in descending grades of alcohol, stained with haematoxylin and eosin stain, cleaned again ethylene and covered by covering slides, thus the slides were prepared to be examined by light microscopy.

**STATISTICAL ANALYSIS OF DATA**

The findings were presented using One-Way Variance Analysis (ANOVA). Results were expressed as mean ± Standard Deviation (SD) and values of $P > 0.05$ were considered non-significantly different, while values of $P < 0.05$ were assumed significant. F probability expresses the general effect between groups.

**RESULTS**

Treatment with NGaP without activation has little or no effect on tumor volume and tumor weight. Up to one week, all treatment modulates have little effect on the tumor volume and tumor weight. After one week, treatment with IRL and ultrasound (pulsed or continuous wave) in the presence or absence of NGaP, become more effective. The presence of NGaP increases the effect of both IRL and ultrasound. Results obtained indicated that pulsed ultrasonic wave is more effective than continuous ultrasonic wave in the presences of NGaP. Pulsed wave ultrasound at 3W/ cm$^2$ was selected to combine with IRL at 7000 Hz. This combined treatment modality is more effective on tumor cells than using of Infrared Laser (IRL) or ultrasound alone (Figure 1-3).

**Oxidative stress and antioxidant profile**

In our study, the increase in lipid peroxidation was reported in controlled group which carried EAC. In all the irradiated groups and that irradiated and treated without NGaP, a significant increase in the levels of MDA was observed. Animals in groups irradiated with IRL or U.S or both with NGaP exhibited significantly low levels of MDA, as compared with the cancer control group or with treated mice without activation of NGaP, (Figure 4). The same table, the implanted mice with EAC showed decreased activities of antioxidants (SOD, CAT, GR, GST and TAC) in comparison with normal animals. On the other hand, there is a significant increase in the enzymatic and
non-enzymatic antioxidant guard in the groups irradiated with IRL or US or both with NGaP when compared with cancer control group or with treated mice without activation of NGaP.

**Kidney and liver biomarkers**

The renal function tests, namely; creatinine and urea, were estimated. The EAC caused a significant increase in the serum urea and creatinine levels in the studied groups. On the other hand the NGaP caused decrease in the levels of serum creatinine and urea which is probably an indication of renal protection (Figure 5). This also confirms the protective role of NGaP against renal toxicity. Also the hepatic function tests, ALT, AST and GGT, were estimated. The EAC caused a significant increase in the serum activities of ALT, AST and GGT of the tumor treated groups. However, in the EAC treated groups with NGaP a decrease in serum levels of ALT, AST, and GGT, were observed which is an indication of the hepatoprotection by NGaP, i.e., this confirms the protective role of NGaP against hepatotoxicity.

**Histological evaluation**

The histological evaluation revealed that all tumors from the group of mice bearing tumor without treatment working as a control group were highly malignant cells and the tumors showed 5-10% necrosis. Group of mice bearing tumor treated with (NGaP) only the similar percentage as only EAC group due to NGaP inactivation, Group of mice bearing tumor treated with 4000Hz, 7000Hz IRL only, showed significant areas of necrosis (40-55% respectively). In the group of mice injected IP with (NGaP) then the tumor site were irradiated to 4000Hz, 7000Hz showed significant areas of necrosis (56-67% respectively). Group of mice bearing tumor treated with continuous and pulsed ultrasound showed significant areas of necrosis (55-60% respectively). The group of mice injected IP with (NGaP), then the tumor site was irradiated to continuous and pulsed ultrasound the areas of necrosis (65-75% respectively), when compared with EAC untreated group. In case of two combination groups, mice bearing tumor treated 7000Hz followed by pulsed ultrasound only, and mice bearing tumor injected IP with (NGaP) then tumor site was irradiated to 7000Hz, followed by pulsed ultrasound, large foci of necrosis areas (80-82% respectively) were present which were distinctly appeared (Figure 6).

**Osteopontin gene expression**

Amplification of osteopontin gene expression in breast tissues of all studied groups using RT-PCR is shown in figure 7. PCR products were separated on 2% agarose gel electrophoresis. Products for osteopontin and GADPH gene expression were at 305 and 530bp respectively. Lane (a) is the molecular weight marker (50bp DNA ladder). All samples were positive to GADPH gene expression. Samples of lanes (1-3), lanes (4-6), lanes (7-9), and lanes (10-12) showed positive bands for osteopontin gene expression with different intensity; of EAC cancerous untreated group, EAC bearing group treated with laser, EAC bearing group treated with ultrasound,
EAC bearing group treated with combined laser and ultrasound, respectively in presence of nano-GaP.

DISCUSSION

In the present work, nano-GaP as sono-photosensitizer, IR laser photodynamic therapy and sonodynamic therapy were employed to investigate whether alone or combined together, could be safely administered, provide an increased local tumor cytotoxic response and represents a promising approach in cancer therapy.

The MDA level is used as an indicator of oxidative stress, indicating an increasing interest in studying the role that lipid peroxidation played in the development of cancer. A low-molecular-weight aldehyde MDA is generated from free radical attack on polyunsaturated fatty acids [15,16].

The probable cause of a high level of serum lipid peroxide in cancer may be due to a defective antioxidant system that leads to accumulation of lipid peroxides in the cancerous tissues followed by secretion in the bloodstream [17]. MDA is a product of high-toxic cytotoxic aldehydes of lipid peroxidation. It is said to inhibit protective enzymes. Thus, they can have both mutagenic and carcinogenic effects [18].

In our study, the increase in lipid peroxidation was recorded during EAC which known with its carcinogenicity. All groups injected with EAC, have a statistical significant elevation in the levels of MDA as compared to the control group animals. The inhibition of peroxidation by nano-GaP is mainly attributed to the scavenging of the reactive free radicals involved in the peroxidation [19]. Animals in groups injected with nano-GaP as a treatment showed significantly low levels of MDA, compared to animals not treated with nano-GaP. This verifies the anti-lipid peroxidative role of nano-GaP by its ability to scavenge free radical generation.

For the purpose of preventing cellular damage caused by ROS, there is a lot of anti-oxidant defense system. The antioxidant defense system may detect ROS, which plays an important role in the initiation of lipid peroxidation, thus playing a protective role in the development of cancer [20]. This defense system works through enzymatic (including SOD, GPx, GST and CAT) and non-enzymatic components (mainly GSH) [21,22]. SOD is the basic step of the defense mechanism in an antioxidant system against oxidative stress, because it breaks down the superoxide anion (O2) into O2 and H2O2. It is said to inhibit the harmful effects of oxidative stress by removing free radicals, internal and external compounds and effectively protects cells against peroxides and hydroperoxides that lead to GSH oxidation [24]. Moreover, GST stimulates the coupling of functional groups of GSH atoms to electrophilic xenobiotics, leading to elimination or conversion of xenobiotic-GSH conjugate [25]. In such an interaction, GSH is oxidized into GSSG, which can be reduced to GSH by GR with NADPH consumption [26]. GSH is the most important non-enzymatic antioxidant in mammalian cells [27]. GSH is said to be involved in many cellular processes including detoxification of internal and external compounds and effectively protects cells against the harmful effects of oxidative stress by removing free radicals, removing H2O2, and suppressing lipid peroxidation [28].

Also, GPX has a high strength in neutralizing reactivated free radicals in response to oxidative stress and detoxification of peroxides and hydroperoxides that lead to GSH oxidation [24]. Moreover, GST stimulates the coupling of functional groups of GSH atoms to electrophilic xenobiotics, leading to elimination or conversion of xenobiotic-GSH conjugate [25]. In such an interaction, GSH is oxidized into GSSG, which can be reduced to GSH by GR with NADPH consumption [26]. GSH is the most important non-enzymatic antioxidant in mammalian cells [27]. GSH is said to be involved in many cellular processes including detoxification of internal and external compounds and effectively protects cells against the harmful effects of oxidative stress by removing free radicals, removing H2O2, and suppressing lipid peroxidation [28].

In the present study, the EAC bearing mice showed decreased activities of antioxidants (SOD, CAT, GR, GST and TAC) in comparison with control animals. The present data are consistent with previous findings [29,30]. Pradeep, et al. [30] reported that such subsequent lower in the antioxidant defense is due to the low expression of these antioxidants during mammary gland damage. On the other hand, there is a significant increase in the enzymatic and...
The present study open new trends for cancer treatment therapy that needs to be further verified. The study gave profound results involving the use of sono-photo-dynamic modality employing exposure to infra-red laser and ultrasound with (pulsed and continuous) in combination with nano-GaP as a sono-photo sensitizer for treating Ehrlich tumor inoculated to mice as an experimental animals. The possible application of nano-carrier-sono-photo-dynamic therapy as in vivo anti-malignancy can open new line of research for modern cancer therapy that needs to be further investigated. Nanomaterial with their effective drug delivery great potential for can permit the feasibility of targeted therapy for disease treatment that needs further research for optimizing and maximizing benefits. Conjugated nanomaterial therapy can potentially provide a very valuable application for amplifying the benefits of photodynamic therapy. Response can be improved utilizing sonodynamic targeted therapy to treat deep or multiple lesions simultaneously. Further research is required to validate this novel therapy to prove feasibility and safety of application.

**References**


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**CONCLUSION**

The present study opened new trends for cancer treatment therapy that needs to be further verified. It is strictly recommended to conduct further experimental protocols aiming to safely apply this up-to-date modality on human and recording other biochemical and/or biophysical parameter’s variations.

**RECOMMENDATION**

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