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Original Article

LED photodynamic therapy of breast cancer based on wireless power transfer technology

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Abstract: Objective: The objective of this study was to investigate the effect of photodynamic therapy (PDT) induced by a LED light source using wireless power transfer technology. Killing effect tests were performed on MCF-7 breast cancer cells using the photosensitizer PSD007. Methods: The special inverter and light source was designed based on the principle of magnetic coupling resonant wireless power transfer technology. The inverter generates a high frequency square wave voltage which was loaded to the transmitting coil. The frequency tracking circuit ensured that the receiving coil and the transmitting coil were synchronized at the same resonant frequency for efficiently transition from the transmitting end to the LED light source. Alternating current powered LED light activated the photosensitizer and induced the photodynamic effect on MCF-7 cancer cells. Semiconductor light powered by direct current was also employed as contrast group. Four different photosensitizer concentrations and magnetic field exposed culture group were assessed for gradient and environment control. Killing and survival ratio were measured by the MTT method. Results: The LED and laser groups showed significantly ($P<0.01$) decreased in survival of MCF-7 cells under different concentrations of photosensitizer, blank control, and magnetic field exposed groups. No significant change in cell survival ratio was observed; therefore magnetic field irradiation had no obvious toxicity to cells. Conclusions: The LED light source based on wireless power transfer can significantly reduce the survival rate of MCF-7 breast cancer cells by photodynamic effect with the PSD007 photosensitizer. This showed a similar effect as with a traditional light source in PDT. The magnetic field irradiation showed less effect in the photosensitization. Convenience operation of wireless power transfer technology in PTD with embedding light thus shows a promising prospect for future application.

Keywords: Wireless power transfer, LED, photodynamic therapy, PSD007, MCF-7

Introduction

Breast cancer is one of the most common malignant tumors in women, showing a high morbidity and critical threat to women's health [1]. As progress in the study of biology and immunology of breast cancer, a new view has emerged that breast cancer is a systemic disease rather than local disease [2, 3]. At present, the main treatment modalities of breast cancer are surgery [4-6], radiotherapy, and chemotherapy. Since breast cancer is a systemic disease, surgical resection not only destroys healthy tissue but also cannot ensure the complete removal of tumor tissue which can lead to recurrence. In the early treatment of breast cancer, chemotherapy was most commonly was used, but resulted in development of tumor cell resistance. Radiotherapy can do harm through side effects on the human body [7], while it may increase the risk of heart disease [8]. With further research, new therapies for breast cancer growing have become more comprehensive [9, 10]. Photodynamic therapy is a new type of therapy with less trauma, fewer side effects, and no damage to healthy tissues. Photodynamic therapy (PDT) [11, 12] is a treatment involving visible light and a photosensitizer, used in conjunction with molecular oxygen to damage cancer cells. It is a selective treatment modality for local destruction of diseased cells and tissue [13]. At present, there has been

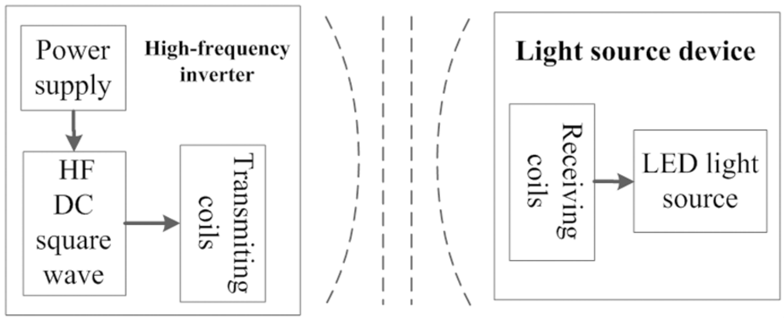

Figure 1. LED light source structure based on wireless transfer power.

wireless power transfer technology with the PSD007 photosensitizer, significant damage to human breast cancer cells can be achieved. And through *in vitro* cell experiments, to find the different killing effect of breast cancer cells between traditional light source and wireless power transfer light source in magnetic field.

a lot of research done on breast cancer [14, 15] and PDT has become a very effective treatment receiving more and more attention. The prevention, screening, diagnosis and treatment of breast cancer are constantly regulated and improved [16]. Early diagnosis and Breast Conserving Surgery (BCS) not only ensure the patient's health, but also improve cosmetic effects and the quality of life, and thus will become more favored surgical procedures [17, 18] with additional development. PDT as a minimally invasive surgery play a more important role in the breast-conserving treatment.

In order to improve the photodynamic therapy of breast cancer, combined with the future trend of wearable medical care [19], this paper proposes improving the light source device in photodynamic therapy. The traditional light source uses a laser light source, which is characterized by concentrated and uniform illumination, but also has the disadvantages of being expensive, bulky, and inconvenient to carry. Therefore, this article combines wireless power transfer technology and photodynamic therapy to better realize the concept of portable and wearable. A physics research group, led by Prof. Marin Soljacic at the Massachusetts Institute of technology (MIT) made a new progress in achieving medium-range Wireless Power Transmission by using the magnetically coupled resonant wireless power transfer technology to "light up" a 60 W light bulb at a 2 m (7 ft) distance [20]. With continuous development of magnetic coupling resonant wireless power supply technology, the application is also increasingly mature [21, 22]. In this paper, we propose applying magnetic coupling of resonant wireless power transfer technology to photodynamic therapy. By combining the light source based on magnetic coupling of resonant

Material and methods

Design of instrument

High-frequency inverter power supply is the part of the core of the instrument, including rectifier filter, DC chopper, full-bridge high frequency inverter, frequency tracking circuit (**Figure 1**).

The high-frequency square wave voltage was obtained by rectifying and filtering the AC power, the light source device included a receiving coil and an LED. The receiving coil adopted parallel resonance technology whereas the current in the capacitor counteracts the reactive component of the current in the admittance, greatly increasing the output power of the LED at the load. When the receive coil and transmit coil are at the same resonant frequency, the energy exchange occurs due to the principle of magnetic coupling resonance. In order to prevent detuning, a frequency tracking circuit was designed so that the two coils are always in the same resonant frequency to ensure efficient energy transmission. Power is transmitted to the receiving coil to light the LED. With the cooperation of the photosensitizer, light source was placed in the chest lesions to PDT treatment. The control process of wireless power transfer is shown in **Figure 2**, and demonstrate how to work in **Figure 3A**.

Reagents

Photosensitizer PSD007 purchased from Shanghai ZhangJiang Biological Technology Co., Ltd; The human breast cancer cell line MCF-7 was obtained from Institute of radiation medicine, Chinese Academy of Medical Sciences & Peking Union Medical College, LED light source device (DC drive and Wireless power transform

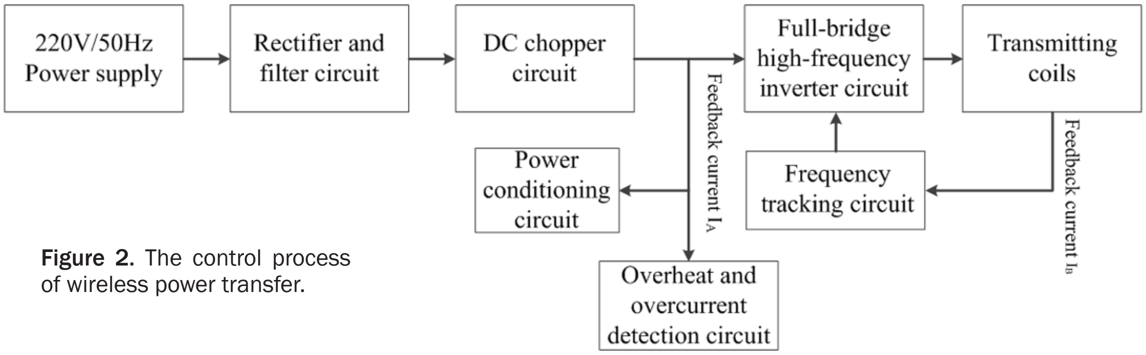

Figure 2. The control process of wireless power transfer.

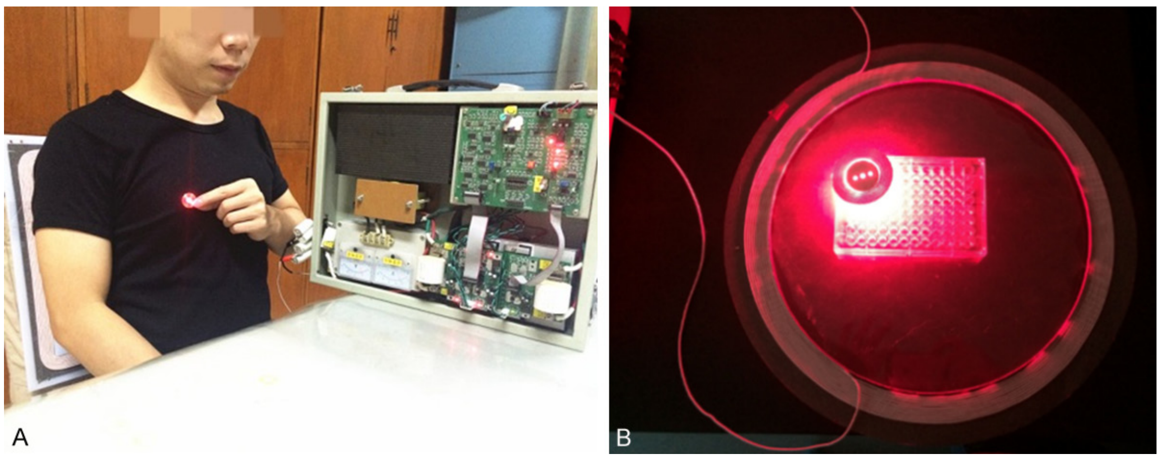

Figure 3. Wireless power transfer LED working simulation (A) and in vitro cell experiment (B).

system) was developed by Bioinformatics Testing and Processing Laboratory, Institute of Biomedical Engineering, Chinese Academy of Medical Sciences & Peking Union Medical College.

Cell culture

MCF-7 cells were cultured in RPMI-1640 (10% fetal bovine serum, 100 U of penicillin/ml, and 100 μg of streptomycin/ml). All cells were incubated in humidified conditions at 37°C and 5% carbon dioxide, digestion with 0.25% trypsin and 0.02% ethylenediaminetetraacetic acid was digested. logarithmic growth phase cells were employed for test. Three groups were divided into the following: blank control group, LED DC drive group (LDD), LED wireless power groups (LWP), vehicle group and magnetic field only group.

PDT treatments

After digestion and resuspension, MCF-7 cells were seeded at 8 × 10^4 /mL (125 μL per well) in 96-well plates and exposed to 5, 10, 20, 40 μg/ml Psd-007 in growth medium in the dark for 2 hours. The cells were irradiated with LED for 4 minutes in different groups. Wireless power transfer LED working was shown in **Figure 3B**. The wavelength was 625±5 nm and the output power was 20 mW/cm^2. In addition, the blank control group cultured without any treatment, vehicle group was treated with photosensitizer only, pure magnetic field group was cultured in same magnetic field intensity with wireless power transform LED group.

MTT assay

The cells were cultured 24 hours after PDT, and then exposed to MTT for 4 hours. Half of the supernatant was discarded and 100 μL DMSO was added to dissolve the formazan at 37°C at 5% CO_2 overnight. The absorbance values were determined at 490 nm by a UV-visible spectrophotometer. The viability rate of cells was determined and calculated with $(A_{treated} - A_{blank})/(A_{untreated} - A_{blank}) \times 100$ %.

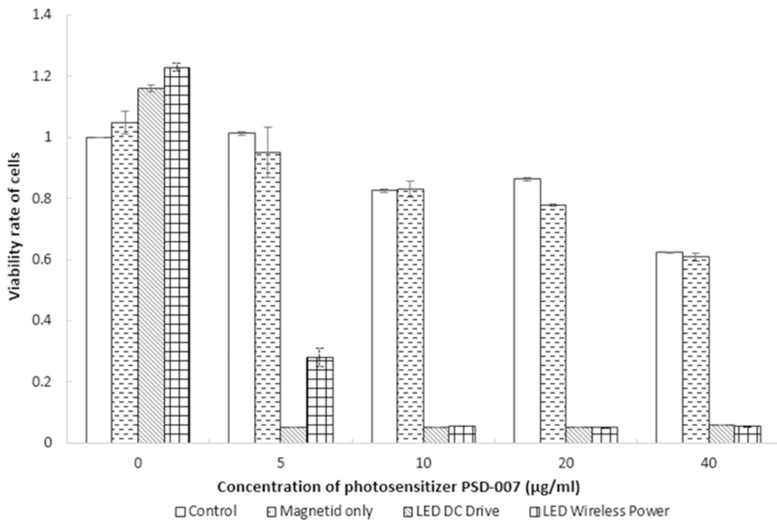

Figure 4. The viability rate of MCF-7 cells under different treatment.

Statistical analysis

Data results are expressed as standard error types of the mean (SEM). Comparisons between groups were made using One-way ANOVA. $P<0.05$ was considered statistically significant for all experiments. Statistical analyses were performed using SPSS v13.0.

Results

The optical power tester was used to test the optical power of LED light source. It was found that when the output power of high-frequency inverter was set to 45 W (I = 7.5 A, U = 6 V), the optical power of the LED light source could reach 10 mW from the transmitting coil 90 mm. The optical power of LED light source was tested by optical power tester. It was found that when the output power of high-frequency inverter is 45 W (I = 7.5 A, U = 6 V), the optical power of the LED light source can reach 10 mW from the transmitting coil 90 mm.

The viability of the MCF-7 cells was estimated using the MTT assay, which measures the ability of killing effect of PDT by LED DC drive light source and wireless power transfer LED light. As showed in the **Figure 4**, the cell viability of group without photosensitizer treatment increased than blank control group ($P<0.05$), PDT groups showed an increasing viability inhibition as the concentration of PSD-007, control and magnetic field only groups were also showed an inhibition effect increasing with concentration of photosensitizer, variability LDD group showed no different effect with LWP while LDD showed more efficiency in 5 μg/ml PSD-007 treatment.

Discussion

As early as 1900, Raab discovered that using the acridine and light can kill the microorganisms Paramecium. Von Tappeiner then uncovered the importance of oxygen during photodynamic therapy, which also marked the beginning of photodynamic therapy [23]. In the 1970s, many remarkable achievements, in the field of many tumors and benign diseases, were made by using the PDT, and in the procedure of many diseases, such as: skin cancer, colorectal cancer, dental caries, laryngeal cancer and so on, the PDT has been proved to be effective [24].

Breast-conserving surgery can improve the physical and cosmetic, thus the life quality of sufferers also need to be improved. So it has become the preferred surgical procedures of most I, II breast cancer patients. Many advantages of PDT such as less damage, fewer side effects, easy operation and reproducibility, made it to be particularly suitable for breast-conserving treatment of patients with early breast cancer. In addition, it is also particularly suitable for the following situations: elderly frail patients; pregnant women with breast cancer. Patient's who received radiotherapy may overdose in some areas, if the postoperative radiotherapy was given again and the patient whose breast cancer cells get the ability of drug resistance.

Because of complex equipment, inconvenient to carry and other shortcomings, laser photodynamic therapy of semiconductor light sources is not suitable for low-income countries and regions to promote [25]. Narrow band spectrum LED performed efficiency as alternative light source, in another hand, wireless power transfer LED might be used for portable or implantation therapy of PDT, while lights power transfer by electric wire seemed inconvenience. We developed the LED wireless power transfer system to discussion the viability based on magnetic field coupling resonant technology in low and medium frequency band (50 kHz), which has many advantages such as long-distance transmission, high transmission efficiency and non-magnetic material. So we applied this wireless power transfer LED light source in photodynamic therapy of breast cancer, and the PDT killing effect of LED light source to MCF-7 was evaluated by MTT method. Magnetic fields had no effect on PDT, while it was beneficial to cell proliferation same as the narrow band spectrum light. Low frequency alternating magnetic field might induce neuromuscular stimulation, and high frequency may overheat the biological tissue. Therefore, Medium frequency alternating magnetic field exposure was performed in medical application [26]. PDT of breast cancer in this article were using 50 kHZ to degrade the effect that gave a negligible impact on biological tissue.

In conclusion, a wireless power transformed light source was promising for implantation passive irradiation of PDT and *in vitro* experiments need to be performed in future work.

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Disclosure of conflict of interest

None.

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