ELECTRICAL EFFECTS ON BIOLOGICAL AND HUMAN ORGANISMS IN PARTICULAR REFERENCE TO CANCER TISSUES WITH ELECTRICAL TREATMENT

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ABSTRACT

Electrical effects on biological and human organisms in reference to cancers are presented on the basis of electrohydrodynamics. While modern medicine is based on 'molecular biology' and 'magnetic effects', a cancer tumor forms a spherical double layer with a positively or negatively charged nucleus, surrounded by healthy tissues of a neutral plasma in macrostructure, analogous to a charged grain in dusty plasmas. The possibility of destroying tumors by DC electric field leads to a new method of remote voltage application to scattered fine-grained lymph or liver cancers in contrast to the existing direct injection of electrodes into a mono-tumor.

1. INTRODUCTION

It is now recognized that modern biology and medicine have been developed on the basis of 'molecular biology', 'biochemistry', 'biophysics' or 'microbiology' offered by physico-chemical concepts. In addition, the structure and function of biological matter can be understood by modern 'electrobiology' or 'bio-electromagnetics', since biological matter is a complex electrical system. With such a terminology, there is a growing interest in biological effects of electromagnetic fields not only for biology itself but also for medicine. Although electrobiology contains electric and magnetic effects, most of research in bio-medicine are mainly concerned with magnetic effects. This is particularly true for medical applications to clinical diagnostics. In contrast, a recent study of electric effects has led to the discovery of an electrostatic potential difference between the cancer tumor and surrounding healthy tissues with observations of a corona structure around the malignant tumor [1, 2]. Based on these observations, electro-plasma macrostructure and functioning of cancers are described in terms of 'eletrostatics' for equilibrium (Secs.2 and.3) and, for nonequilibrium in a DC electric field, on the basis of electrohydrodynamics (EHD) (Sec.4). While the established cancer treatments mainly utilize a knowledge of bio-medicine offered by chemistry, a basic study of electrical effects for cancer and other disease has led to the possibility of destroying cancers by applied DC or quasi-DC electric field perturbations, and a new method of remote voltage or electric field application to cancer tissues is proposed, following a quick overview of the existing method of direct injection of electrodes into a mono-cancer tumor (Secs.5 and 6).

2. OBSERVATIONS OF ELECTRO-PLASMA MACRO-STRUCTURE OF CANCER TISSUES

The structure, function, and properties of biological matter may be described in two ways, cell or molecule description for microstructure and continuum (fluid) description for macrostructure. For the latter, there is a general principle that biological matter manifests a self-organization to heal itself which normally appears as increased electric potential between the injured place and surrounding healthy tissues. Along this line, an electric potential difference between the tumor and surrounding healthy tissues has been found with a corona structure around malignant tumors, as shown in Fig.1 [1, 2]. The center of the tumor has a rather broad nucleus and its border often possesses fine structure irregularities with sharp or gentle slope in potential to the surrounding healthy tissue. Typically its potential drop is measured to be 10 mV or so, and the size of a tumor extends up to

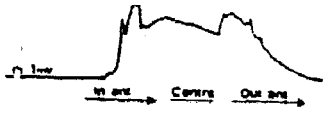

Fig.1. Potential difference between the tumor and surrounding tissues

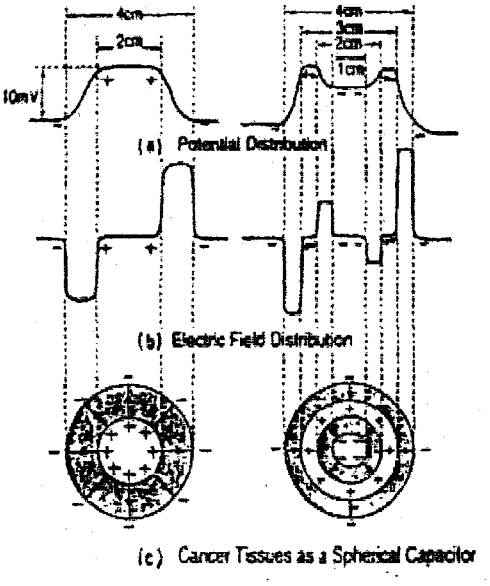

Fig.2. Electro-plasma structure of cancer tissues as a spherical double layer or capacitor.

several to some twenty cm (Fig.2).

3. ELECTROSTATICS OF CANCER TISSUES

Based on observations of electro-plasma macrostructure of cancer described in Sec.2, some idealized electro-plasma structures of cancer tissues are shown schematically in Fig.2. The upper, middle, and lower panels represent electric potential, field distributions, and their upper views, respectively. The left panel is the case of a flat nucleus, and the right is the case of a nucleus with a ring in potential. It is thus observed that the cancer tumor forms a 'spherical double layer or capacitor' with a positively or negatively charged nucleus, while the healthy tissue is considered a 'neutral plasma' with zero equipotential for equibrium in macrostructure. This is analogous to a dust grain, positively or negatively charged, in dusty plasmas [3]. The situation may be extended analogously to scattered fine-grained tumors which are considered dust grains, positively or negatively charged, in dusty plasmas. Along this line, it is inferred that its nucleus might be a small grain of a carcinogenic substance that has been electrically charged by radioactive rays, ultraviolet rays, or some other charging mechanism. Introducing 'electrostatics' to biological matter, the following relations hold:

$$\boldsymbol{E} = -\nabla\phi, \tag{1}$$

$$p_{\mathrm{E}} = \frac{1}{2}\varepsilon E^2 - \frac{1}{2}E_\rho^{\,2}\frac{\partial\varepsilon}{\partial\rho}, \tag{2}$$

$$\boldsymbol{f}_{\mathrm{E}} = -\nabla p_{\mathrm{E}} = -\frac{1}{2}E^2\nabla\varepsilon + \frac{1}{2}\nabla\left(E_\rho^{\,2}\frac{\partial\varepsilon}{\partial\rho}\right), \tag{3}$$

where $\boldsymbol{E}$ is the electric field, ϕ the electric potential, p_{E} the electric pressure, $\boldsymbol{f}_{\mathrm{E}}$ the electric force, ρ the mass density, $\varepsilon = \varepsilon_0\varepsilon_s$ the dielectric constant, ε_0 the dielectric constant in free space, and ε_s is the specific dielectric constant. At the boundary between a conductor and a dielectric, there is an electric force acting perpendicular to the surface on the conductor which is given per unit area is equal to the electric pressure.

3.1 Case of a Tumor with Trapezoidal Potential

Assuming spherical symmetry and referring to the left panel of Fig.2, the electric potential and field may be written as

$$\phi = \frac{Q}{4\pi\varepsilon r}, \qquad \boldsymbol{E} = -\frac{\partial\phi}{\partial r} = \frac{Q}{4\pi\varepsilon r^2} \tag{4}$$

where Q is the total charge of nucleus, and r is the radial position. The flat tumor-nucleus and surrounding healthy tissues are considered a conductor, while the boundary layer between them is a dielectric. Then the potential or voltage of the nucleus with respect to the background healthy tissue, and the capacitance of the tumor may be written as

$$V = \phi_{\mathrm{a}} - \phi_{\mathrm{b}} = \frac{Q}{4\pi\varepsilon}\left(\frac{1}{a} - \frac{1}{b}\right), \tag{5}$$

$$C = \frac{Q}{V} = \frac{4\pi\varepsilon ab}{b-a}, \tag{6}$$

where a and b are the radii of nucleus and cancer tissue. We are now interested in numerical estimates of the above quantities, taking a typical values: a = 1 cm, b = 2 cm, V = 10 mV, ε_s = 10. Substituting these into Eqs.(5) and (6), we have C = 22.24 pF, $Q = 2.224 \times 10^{-13}$ C.

3.2 Case of a Tumor-Nucleus with a Ring

Assuming also spherical symmetry and referring to the right panel of Fig.2, the electric potential and field for a tumor-nucleus with a ring may be written as

$$\phi = \frac{Q}{4\pi\varepsilon}\left(\frac{1}{r} - \frac{1}{b}\right), \quad \boldsymbol{E} = -\frac{\partial\phi}{\partial r} = \frac{Q}{4\pi\varepsilon r^2}, \qquad \text{for} \quad a \le r \le b, \tag{7}$$

$$\phi = \frac{1}{4\pi\varepsilon}\left[Q'\left(\frac{1}{r} - \frac{1}{b'}\right) + Q\left(\frac{1}{a} - \frac{1}{b}\right)\right], \quad \boldsymbol{E} = -\frac{\partial\phi}{\partial r} = \frac{Q'}{4\pi\varepsilon r^2}, \qquad \text{for } a' < r < b', \tag{8}$$

where Q is the total charge of the outer edge of the ring, Q' is the total charge of the hollow tumor-center, a and b the radii of the outer edge of the ring and the border of cancer and healthy tissues, a' and b' are the radii of a hollow nucleus and the inner edge of the ring. Then the potential or voltage of the ring and hollow nucleus, the capacitances of the ring, hollow nucleus, and between them, and between the ring and the healthy tissue may be written, respectively, as

$$\phi_2 = \frac{Q}{4\pi\varepsilon}\left(\frac{1}{a} - \frac{1}{b}\right), \quad Q > 0, \qquad \phi_{a'} = \frac{1}{4\pi\varepsilon}\left[Q'\left(\frac{1}{a'} - \frac{1}{b'}\right) + Q\left(\frac{1}{a} - \frac{1}{b}\right)\right], \quad Q' < 0, \tag{9}$$

$$C_a = C_{aa} = 4\pi\varepsilon\left(\frac{ab}{b-a} + \frac{a'b'}{b'-a'}\right), \quad C_{a'} = C_{a'a'} = 4\pi\varepsilon\frac{a'b'}{b'-a'}, \quad C_{ab} = 4\pi\varepsilon\frac{ab}{b-a}. \tag{10}$$

To obtain some numerical estimates of the above quantities, we take $a = 1.5$ cm, $b = 2$ cm, $a' = 0.5$ cm, $b' = 1$ cm, $V = 10$ mV, $V' = 8$ mV, $\varepsilon_s = 10$. Substituting these into Eqs.(9) and (10), we have $C_a = 77.84$ pF, $C_{a'} = 11.12$ pF, $C_{ab} = 66.72$ pF, $Q = 6.672 \times 10^{-13}$C, $Q' = 2.224 \times 10^{-14}$C.

4. ELECTROHYDRODYNAMICS OF CANCER TISSUES IN AN APPLIED ELECTRIC FIELD

In Sec.3, we considered electro-plasma structure and properties of cancer with no applied electric field. From the biological and medical (clinical) points of view, it seems most interesting to see how the tumor is affected by an applied DC or quasi-DC electric field. Fig.3 illustrates how the field lines of a charged tumor are deformed when it is placed in a uniform electric field. Then the field intensity of the charged tumor tends to be canceled by the applied field on its sink (illuminated) side, and to be added by it on its source (shadow) side. In other words, deelectrification of the tumor charge occurs on its half side illuminated, while the tumor charge on the shadow side is added by the applied field, causing unbalance of the electric pressure or the electric force acting on the nucleus boundary between the illuminated and the shadow side. If the applied field intensity is nearly equal to the tumor field at the nucleus boundary, $E^{(e)} \approx E_a$, the total field intensity E or the electric pressure p tends to vanish or double near the tumor boundary on the illuminated or shadow side respectively, holding the relations:

$$E_T \approx 0 \quad \text{or} \quad p_E \approx 0 \qquad \text{at} \quad x = -a, \qquad E_T \approx 2E_a \quad \text{or} \quad p_E \approx 4p_{Ea} = 2\varepsilon E_a^2 \qquad \text{at} \quad x = a, \tag{11}$$

where the origin of x–axis parallel to the applied field is a cancer center of the spherical tumor. Eq.(11) indicates that the tumor suffers a large electric pressure from the shadow to illuminated sides. If we assume the tumor-nucleus and the surrounding healthy tissue behaves like a rigid solid, the electrostriction force must be produced in the dielectric (double) layer to balance the above electric pressure as follows:

$$f_E = qE - \frac{1}{2}E^2\nabla\varepsilon + \frac{1}{2}\nabla\left(E_\rho^2\frac{\partial\varepsilon}{\partial\rho}\right) = 0, \qquad \text{at} \quad r = a, \tag{12}$$

on how the structure of the tumor would be deformed and relaxed temporally, where q and ρ are the charge and the mass density, respectively. This indicates that some disintegration might occur at the tumor boundary on the shadow side. At the same time, a direct deelectrification of the tumor by the applied field should be attained on the illuminated side. Thus a gradual breakdown of the tumor boundary could be expected, eventually leading to collapse of the tumor-nucleus, hopefully recovering to a healthy tissue sooner or later. Such effects of an applied DC electric field on a mono-cancer tumors are also extended to a number of scattered fine-grained tumors. The mechanism of disruption of tumors is the same as that of mono-tumors and is similar to that of dust grains in dusty plasmas, namely depending upon relative magnitudes of electrostatic tension and the tensile force.

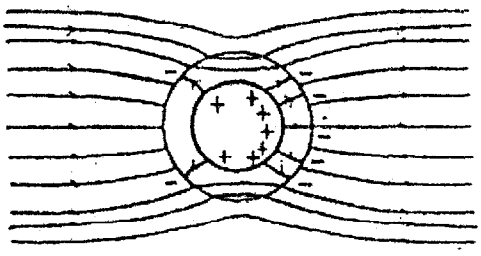

Fig.3. Cancer tumor in an applied uniform DC electric Field. The background is the healthy tissue.

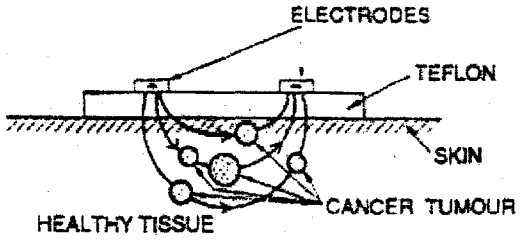

Fig.4. A new method of remote voltage or electric field application to cancer tumors

5. EXISTING ELECTRICAL TREATMENT OF CANCER

Up to date, the established treatments of cancer mainly utilizes a knowledge of biology offered by chemistry. When one is reminded, however, that biological matter largely involves electromagnetic organism and cancer tissues possess a potential anomaly, some electrical treatments should be feasible for defeating cancer. Along this line, Chinese physicians have developed a clinical test and reported the recently achieved results – close to 80 % – in defeating some kinds of cancer by applying electricity [4]. The method is very simple. Inserting one positive electrode into the center of tumor and one (or more) negative electrode(s) around the tumor, a DC voltage of several volts (5 ~ 8.5 V) is applied between positive and negative electrodes. Then a DC current of several tens of mA (30 ~ 80 mA) flows through the tumor whose

temperature goes up to 100 ~ 1,000°C, producing Joule heat. As a result, the tumor breaks down and disappears in many cases. Thus such an electrical treatment has proved effective and useful, particularly for mono-tumors such as skin cancer as well as some lung, liver, and breast cancer. Since the electrical treatment described above utilizes a relatively large breakdown or discharge current by directly inserting electrodes into tumors, it may be called 'in-situ current method' in contrast to a new method, 'remote voltage method' introduced in the following section.

6. A NEW METHOD OF REMOTE VOLTAGE OR ELECTRIC FIELD APPLICATION TO CANCER TUMORS

While the 'in-situ current method' is effective for mono-tumors, it may not be suitable for metastatic or scattered fine-grained tumors such as lymph or liver cancer, simply because it is rather difficult to insert electrodes into their cancer tissues. A new method particularly for such cases is proposed, based upon basic considerations of remote voltage or electric field application described in Sec.4 and upon its laboratory simulation [2, 5]. Fig.4 shows this method schematically. A DC or quasi-DC voltage is applied to two electrodes installed on a thin Teflon layer placed on the skin. Then the electric field lines tend to penetrate into the body across cancer tumors, providing them with a deelectrification effect or a disintegration after many hours running, basically as described in Sec.4. Change of polarity every many hours might be more efficient for disintegrating cancer tumors, since this could penetrate deelectrification effects into a number of scattered fine-grained tumors, as sketched in Fig.4. Maximum applied voltage and current may be 5 kV and be of the order of μA, assuming that the skin and the inner body resistance are 1 kΩ·cm and 100 Ω·cm, respectively.

7. CONCLUSION

A new model of cancer tissues has been introduced, based on some electrical measurements performed recently. The study reveals the following findings:

1. Besides a standard approach for biological matter based on 'molecular or cell biology', macroscopic approach based on 'electrobiology' or more specifically 'electrodynamics (ED)' and 'electrohydrodynamics (EHD)' as a continuum or fluid is feasible for 'cancer tissues'.
2. The tumor with a positively or natively charged nucleus is forming a 'spherical double layer or capacitor' with respect to the background healthy tissue.
3. A number of scattered fine-grained cancer tumors such as lymph cancer or some of liver cancer are considered to be dust grains, positively or negatively charged, in a dusty plasma. Consequently, the mechanism of disruption of tumors is thought to be similar to that of dust grains in dusty plasmas, namely depending upon relative magnitudes of electrostatic tension and the tensile force.
4. A new method of remote voltage or electric field application (DC or quasi-DC) to cancer tumors may be feasible for defeating cancer, in particular for metastatic or scattered fine-grained tumors such as lymph cancer or some of liver cancer in contrast to the existing 'in-situ current method'.
5. In addition, when the new method is combined properly with conventional chemical treatments, it should be expected that the cancer treatment could be substantially improved.
6. For further basic studies, examinations should be extended to how far one could apply the mechanisms of charging, coagulation, disruption, and levitation of dust in dusty plasmas to scattered fine-grained tumors. Thus similarities and differences between both cases should be investigated.

8. REFERENCES

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