On the Disruption of Cell Multiplication by Oscillating Electric Fields

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This communication is a theoretical consideration explaining the benefits to reduce tumour growth *in situ* by interaction of ultrasound and strong magnetic fields. No documentation is presented.

Key words: Electric Field Cancer Treatment

Introduction

The principal problem of any cancer treatment is the need for the almost complete destruction of all cancer cells, because the "critical mass" from where a cancer can grow is not much more than 100 cells (Hoff, private communication). Even in surgery, such a small number can easily escape through the bloodstream into other parts of the body, establishing there a metastatic colony. Chemotherapy has the potential to destroy all cancer cells, but because it is not a "magic bullet" attacking only cancer cells, it cannot be applied arbitrarily often. The same is true for radiation treatment.

The Achilles' heel of cancer cells is their increased vulnerability during mitosis. It is for this reason that I had in the past proposed to synchronize the cancer cell mitosis by "seeding" the cancer cells with small ferromagnetic particles, triggering their simultaneous mitosis with a suddenly applied magnetic field (Winterberg, 1967a). The thusly synchronized cancer cells can in this moment be exposed to a much higher dosage of radiation, which integrated over time would account for a lower dosage if compared to a treatment without synchronization.

The "magic bullet" aspect of a successful cancer treatment is a call to physicists to search for such a "magic bullet".

More recently it has been reported by a research group in Israel that an oscillating electric field can disrupt cell multiplication during mitosis (Dekel *et al.*, 2004). To enhance this effect it is here proposed to treat cancer by the combination of a strong magnetic field with intense ultrasound. At the low electrical conductivity of tissue the magnetic field is not frozen into the tissue, and oscillates against the tissue which is brought into rapid oscillation by the ultrasound. As a result, a rapidly oscillating electric field is induced in the tissue, strong enough to disrupt cancer cell replication. Unlike radiofrequency waves, which have been proposed for this purpose, ultrasound can be easily focused onto the regions to be treated. This method has the potential for complete eradication of the tumour.

Magnetic and Electric Field Treatment

Besides X-rays, the physicist has other means which conceivably might be used in treating cancer. They are: 1. magnetic fields; 2. electric fields; 3. ultrasound.

All these fields are interesting because they can be externally applied, also at critical intensities where they are harmful to cancer cells, but not harmful to healthy cells.

Since cancer cells seem to have a smaller tensile strength than normal cells, I had proposed in the past to employ strong magnetic fields, which can be produced with superconductors, for the inhibition of cancer cell growth (Winterberg, 1967b). It was, I believe, the first time that very strong magnetic fields were proposed in cancer therapy. The research group in Israel has found that cancer cell replication can be disrupted in ~100-kHz alternating electric fields, at a field strength of the order ~$1\,V\,cm^{-1}$ (Dekel *et al.*, 2004). The same group also reported some *in vivo* evidence for tumour growth inhibition in brain tumour patients.

Combined Magnetic Field-Ultrasound Treatment

In the reported ~100-kHz alternating electric field treatment, the wave length of the corresponding electromagnetic radiation is of the order of km and, for this reason, cannot be focused onto a region as small as it is here required. At much higher frequencies focusing is possible but only with substantial heating. Also, because of the large impedance of cellular membranes, the elec-

tric field cannot easily diffuse into the interior of a cell.

To overcome these difficulties it is here proposed to generate the electric field by ultrasound inductively *in situ*. If placed in a strong magnetic field **B** the ultrasound makes the tissue oscillate against the magnetic field inducing in the tissue an electric field

$$\mathbf{E} = (1/c)\ \mathbf{v} \times \mathbf{B}, \tag{1}$$

where **v** is the velocity of oscillation and c is the velocity of light. **E** is measured in electrostatic units (esu) with 1 esu = 300 V^{-1}.

Let us assume that the tissue can withstand a sound wave pressure $p = 10^6$ dyn cm^{-2} (one atmosphere). Then the velocity of the oscillating tissue is ($\rho \approx 1$ g cm^{-3})

$$v \simeq \sqrt{p/\rho} \simeq 10^3 \text{ cm s}^{-1}. \tag{2}$$

For $B = 100$ kG which can be reached with superconductors, one finds that $E = 1$ V cm^{-1}. Instead of a superconductor one may use a strong permanent magnet. For gadolinium with a saturation field strength of 60 kG, the same electric field would be reached with a velocity $v = 1.7 \cdot 10^3$ cm s^{-1}, with a sound pressure $\rho v^2 \approx 3$ atmospheres, probably still too weak to be destructive.

We have to check if the magnetic field is not "frozen" into the oscillating tissue. The time τ for the magnetic field to penetrate the tissue of a thickness x is given by

$$\tau = \frac{4\,\pi\,\sigma\,x^2}{c^2}, \tag{3}$$

where $\sigma \approx 10^{12}$ s^{-1} is the electrical conductivity of blood. For an oscillating sound field in water or tissue where the velocity of sound is a few km s^{-1}, the wave length is of the order of a few cm.

Setting in (3) $x \sim 3$ cm, one obtains $\tau \sim 10^{-7}$ s, and therefore with $\omega \sim 10^5$ s^{-1}, $\omega\tau \ll 1$. With regard to the oscillating tissue the magnetic field therefore remains static in the rest frame reference system.

With a wave length of a few cm, the ultrasound wave can be easily focused down to a few cm. But because of the **v** x **B** dependence of the electric field, only the velocity component perpendicular to **B** leads to an induced electric field **E**. This suggests to focus and direct ultrasonic waves from at least 4 spatial directions onto the tumour (better from 6 directions).

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