Bioelectric Notes

Note 1

8 April 2008

Electrode Design for Concentration of Electric Field at Skin Cancer

Carl E. Baum
Department of Electrical and Computer Engineering
University of New Mexico

Abstract

For treating skin cancer with fast electric pulses, appropriate electrode configurations are needed. This paper discusses a technique for enhancing the electric field at the tumor, while decreasing it elsewhere.

This work was sponsored in part by the Air Force Office of Scientific Research.

1. Introduction

For some biological applications, one would like to expose tissue (especially tumors) to intense pulsed electric fields [2]. Figure 1.1A shows a typical configuration in which two electrodes of oppose polarity (voltage) contact the skin in a way which stradles the near-surface tumor which is to be exposed to such high pulsed fields. Except for the local perturbation of the field in the vicinity of the tumor, the tumor is exposed to an approximately uniform electric field parallel to the skin surface. A disadvantage of this technique concerns the high electric fields near the electrodes (which might even penetrate the skin), even higher than the fields illuminating the tumor.

A recent paper [1] has discussed some improvements in this technique. As in Fig. 1.1B, one can have four electrodes. This makes the field incident on the target more uniform, with optimal positions for the electrodes discussed in [1]. For a given field at the target this reduces the current flowing into or out of each electrode less. In other words the field of the electrodes is reduced (in magnitude).

This technique can be extended by increasing the number of electrodes. Instead of needles piercing the skin, one can also envision distributed electrodes which contact the skin over some area, thereby reducing the high current densities near the electrodes.

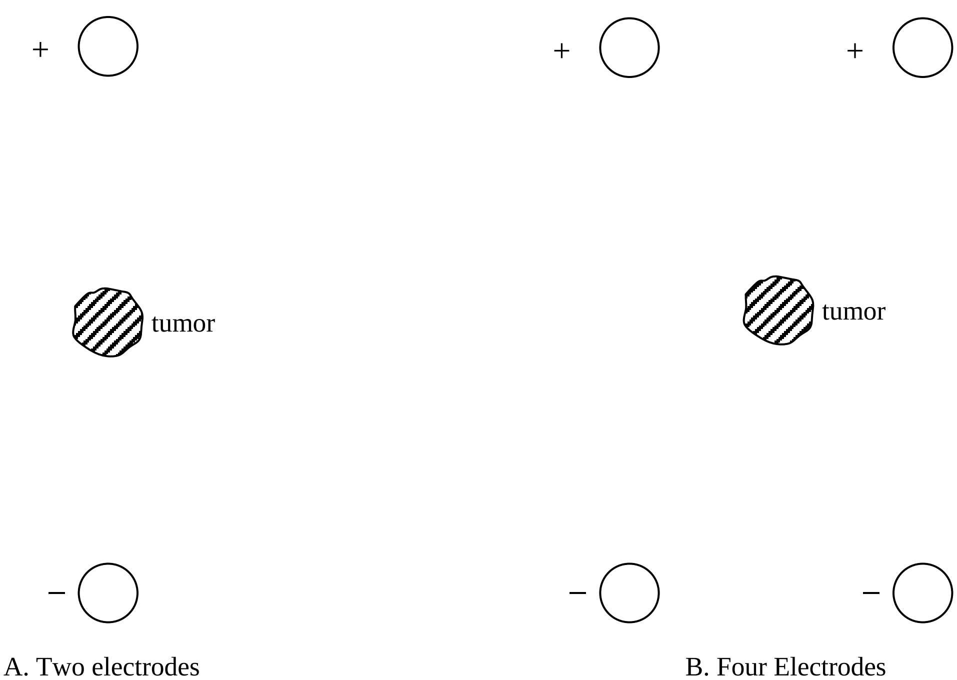


Fig. 1.1 Electrode Configuration for Placing Electric Field on Near-Surface Cancer Cells.

2. Concentrating the Current at the Tumor

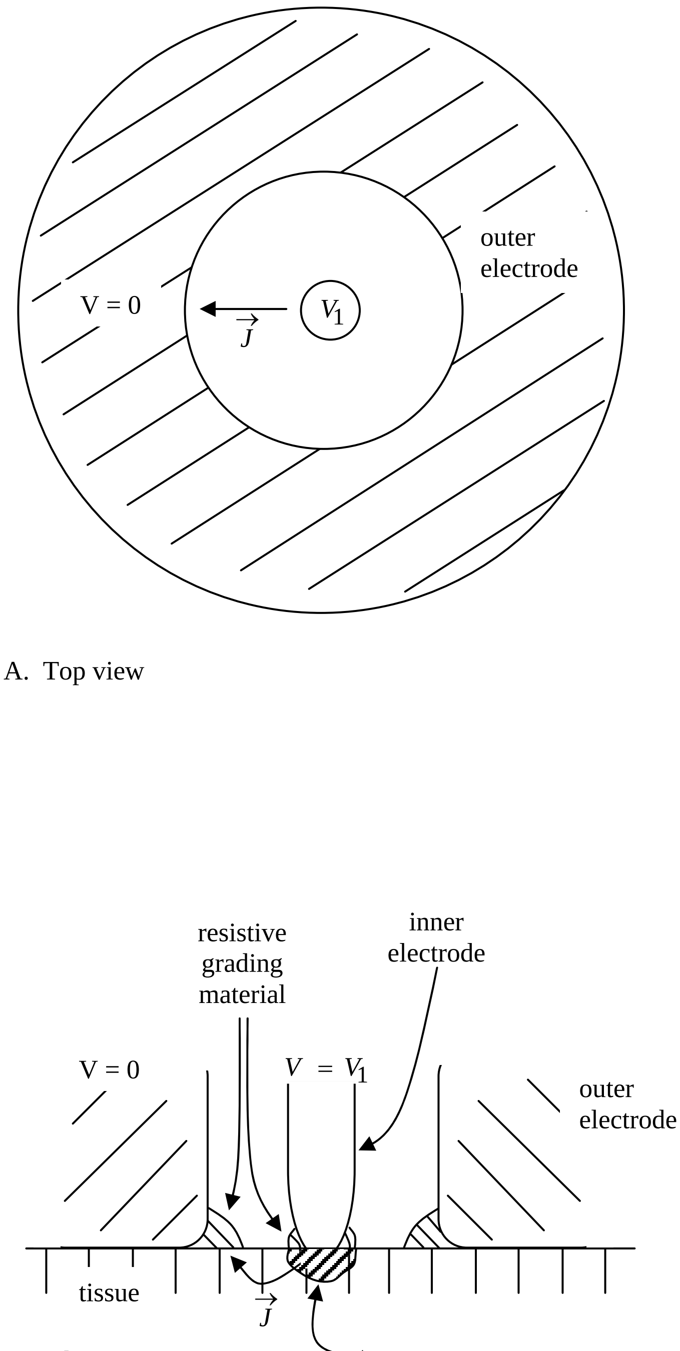
Instead of having a high current density at a position far removed from the tumor, let us turn the problem around. Let the high current density be at the tumor. This can be accomplished by a technique as in Fig. 2.1.

So now consider something like a coaxial structure. In this case the center conductor makes direct contact with the tumor, or the skin just above the tumor. The electrode diameter is chosen to match the tumor in some appropriate sense. Near the tumor the current density (and associated electric field) is approximately radial, falling off with increasing distance, *r*, as

$$
\begin{aligned}
J &= \frac{I}{2\pi r^2} \\
I &\equiv \text{total current}
\end{aligned}
\tag{2.1}
$$

With the radial electric field having a similar dependence, the deposited energy density falls off as r^{-4}. The effect is then highly concentrated at the tumor, with much less effect on the healthy tissue.

To complete the current path, let us have a circular ring, surrounding and at some distance from the center electrode, and in contact with the skin. As this electrode is much larger, the current density and electric field there are much smaller.



A. Top view

B. Side view

Fig. 2.1 Electrode Configuration for Concentrating Electric Field at Near-Surface Tumor

3. Shaping Electrodes

Where these electrodes contact the skin and/or tumor there can be large electric fields at the edges of such contact. Such singularities can be avoided by grading the electric field near such edges. As indicated in Fig. 2.1B, one can place resistive material near where the electrodes contact the skin. As the electrode contour moves away from the skin, current density is still allowed to flow between the electrode and the skin, smoothly decreasing as the observation position moves away from the electrode contact to the skin.

4. Concluding Remarks

There are then some improvements that can be made in the design of apparatus to apply electric-field pulses to tumors. Basically this involves placing one electrode on or near the tumor to give the maximum electric field (and associated current density) at that location. A much larger electrode at some distance away provides the return path for the current with a much smaller current density in the tissue.

Various details of the design need to be optimized. The tumor electrode needs to be properly sized. The electric field needs to be graded near electrode edges to avoid large fields at an edge singularity. The tissue surface may not be flat, so some allowance may need to be made for the electrode fixture to be able to more closely conform to the tissue surface.

References

1. C. E. Baum, “Electrode Positions at a Dielectric Interface for Uniform Electric Field”, Sensor and Simulation Note 510, March 2006.
2. K. H. Schoenbach, R. Nuccitelli, and S. J. Beebe, “Zap”, IEEE Spectrum, Vol 43, No. 8, 2006, pp. 20-26.