TECHNIQUES FOR HEATING BRAIN TUMORS WITH IMPLANTED MICROWAVE ANTENNAS

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ABSTRACT

Microwave antennas are inserted into an array of nylon catheters implanted in brain tumors and apply a localized heat treatment to raise the tumor to 43°C. Flexible antennas of various designs have been used such as dipole, choke dipole, modified dipole and helical designs. Phase shifting and phase rotation techniques have been incorporated into the treatment system to steer power in the tumor, as predicted by computer modelling. Choke antennas counter the sensitivity of dipole antennas to insertion length. Clinical results are discussed with the different antenna designs.

INTRODUCTION:

Hyperthermia or heat treatments of brain tumors has been ongoing at the Dartmouth-Hitchcock Medical Center and Thayer School of Engineering at Dartmouth since 1983 (Strohbehn et al. 1979). Our series of 23 brain patients has evolved from a multi-segmented research project into a clinical tool (Roberts et al. 1986, Coughlin et al. 1983). Through our multi-focus approach, we study the problem on several levels. For interstitial (in-catheter) microwave dipole antennas, we have solved the theory and have set up computer models to predict the power deposition (Trembly 1985) and temperature distribution (Mechling et al. 1986). We have verified the computer predications and treatment planning experimentally by measuring power deposition in brain equivalent phantom material (Ryan et al. 1990) and setting up an animal model (Ryan et al. 1991) for brain studies. The present phase of the ongoing research is the investigation of various types of microwave antennas (Ryan et al. 1987, 1991) as well as steering power through phasing of the array (Trembly et al. 1991).

RECENT WORK AND APPLICATIONS:

The evolution of an optimal antenna design is ongoing at Dartmouth. Dipole antennas (figure 1a)

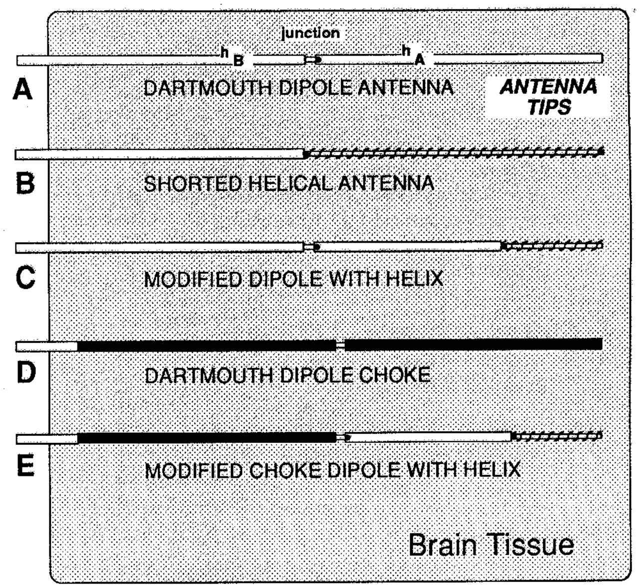

Figure 1

Figure 1. Five antenna designs used at Dartmouth. *The dipole antenna (1a) has a connection between the hA section and the inner conductor as shown by the black dot. The helical antenna (1b) has a connection at the tip between inner conductor and coil, and at the junction between the outer conductor and coil. The modified dipole (1c) has a 1.0 cm helix at the tip, with an open circuit at the tip as in the dipole design. The choke dipole (1d) has a limited active surface. The modified choke dipole (1e) combines all the features of the other antennas.*

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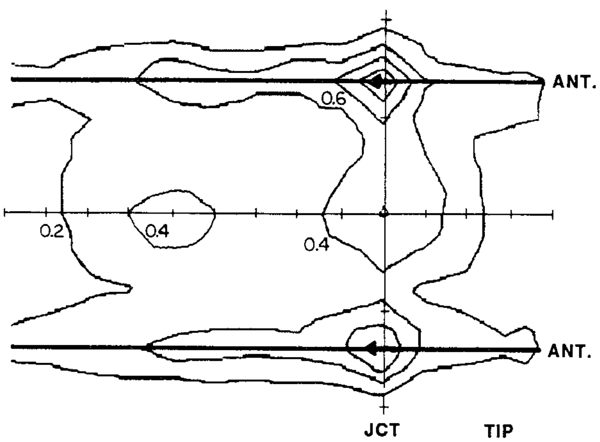
Figure 2a



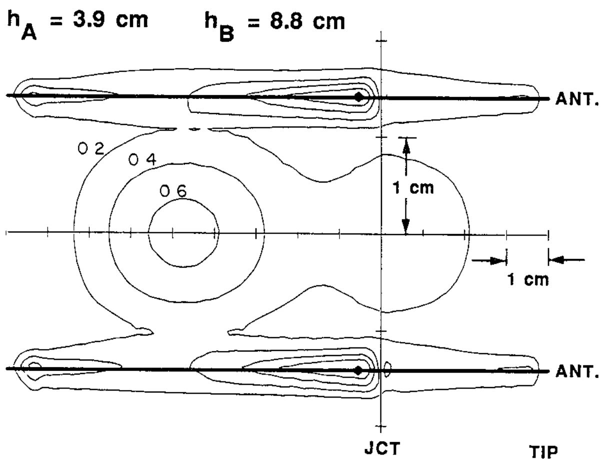
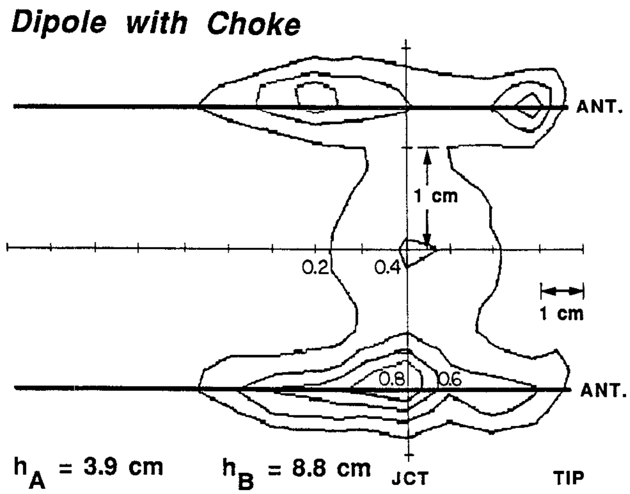


Figure 2b

Figure 2a,b. IsoSAR contours in the diagonal plane of 4 dipole antennas. *The experimental (figure 2a) and theoretical (figure 2b) results are shown for an insertion depth of 12.7 cm. A 40% contour is seen experimentally and 60% theoretically at about a quarter-wavelength from the insertion point, out of the junction plane (JCT).*

have traditionally been used, although their performance suffers from sensitivity to insertion depth (Ryan et al. 1990, James et al. 1989). One method of limiting the radiating length of dipole antennas is to fabricate a choke on the dipole (figure 1d). This has been verified experimentally (Ryan et al. 1990, and is being tested *in-vivo* and clinically. Another technique is to use a helical antenna (figure 1b) which preserves the same power deposition patterns regardless of insertion depth in tissue (Wu et al. 1987, Ryan et al. 1988). This antenna has proven to be excellent in in-vivo, normal brain studies but has shortcomings in the clinic due to the phase relationship between antennas. A new antenna (figure 1c) that combines the phase relationship of dipole antennas and the tip-heating characteristics of helical antennas is the modified dipole antenna developed by Ryan. A choke has also been applied to this antenna (figure 1e).

Figure 2c



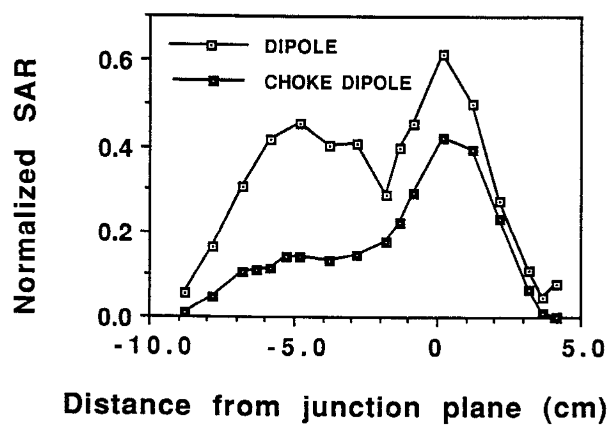


Figure 2d

Figure 2c,d. SAR results with choke dipoles substituted for dipoles in the array. *With choke antennas, maximum SAR along the central axis is shifted back into the junction plane. Figure 2d compares the central axis SAR between dipole and choke dipole antennas. Note how the choke dipole minimizes the secondary peak at -5 cm, which would be located out of the tumor region centered at 0.0 cm.*

Theoretical power deposition patterns or specific absorption rates (SARs) for dipole antennas in an array of 4 antennas in a boxlike configuration spaced 2 cm on a side are seen in figure 2a. IsoSAR contours of 20, 40, 60 and 80% are plotted and the antenna locations shown by heavy lines. These data are plotted in the diagonal plane containing opposite corner antennas and the array center. Presumably, the tumor center is located where the central horizontal axis meets the junction (JCT) axis. The results show that only 20% power is found at this point, but 60% power is found about 4.5 cm from the insertion point (left side). This is verified experimentally in figure 2b, with 40% found about 4 cm from the insertion point. This demonstrates the problem with shift of central power deposition out of the junction plane with depth of insertion. If choke dipoles are used with the active regions extending 3.9 cm on either side of the antenna junction (see figure 1d), the central SAR shifts back into the junction plane as seen in figure 2c. Figure 2d shows another comparison along the central axis with the antenna tips on the right side of the graph. Note how the secondary peak at -5.0 cm has been eliminated.

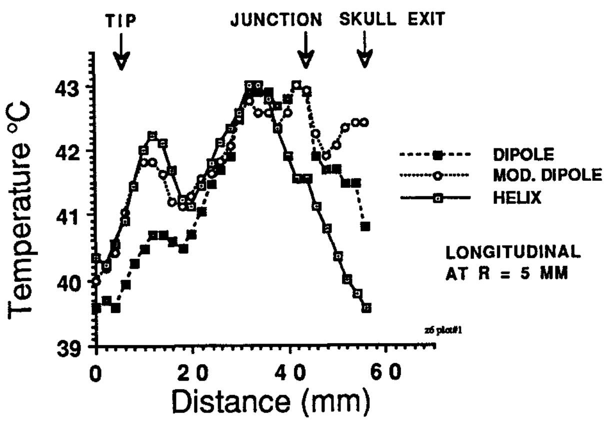
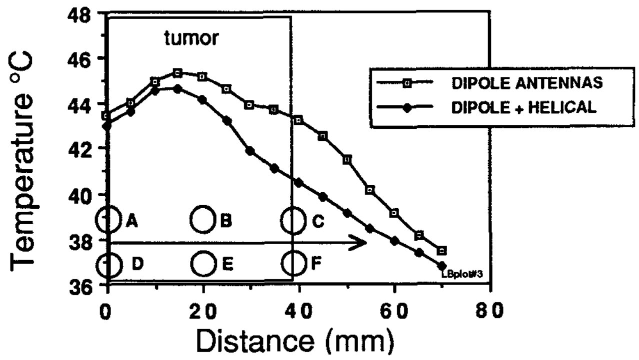


Figure 3

Figure 3. In-vivo results with 3 antennas. *Longitudinal steady-state temperatures were measured at 2.0 mm intervals at a radius of 5 mm from either a dipole, modified dipole or helical antenna. Note the tip heating found in the helical and modified dipole antennas. The helical antenna deposits the least power at the skull exit. The antenna tip and junction locations are marked.*

A plot comparing temperatures for 3 antennas (dipole, helical and modified dipole) in the in-vivo brain model is seen in figure 3. These are longitudinal measurements along a single antenna at a distance of 5 mm in brain. Note that the helical antenna heats at the tip and falls off rapidly as it approaches the skull exit. The dipole exhibits almost no tip heating and is hottest around the junction. The modified dipole exhibits the behavior of both antennas with tip and junction heating.

Figure 4a



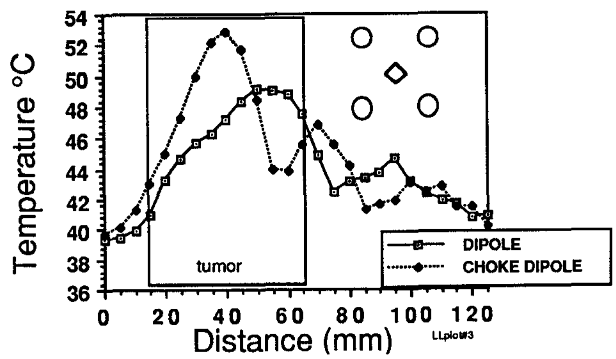


Figure 4b

Figure 4. Temperature measurements in brain from arrays of microwave antennas. *Six antennas were inserted in brain (labelled A-F) in figure 4a. Temperature maps were done in the direction of the arrow. Results of 6 dipole antennas in phase are shown by open squares. Replacing antennas C and F by helical antennas results in the temperature map shown by closed diamonds. Clearly, the dipoles deposit more power between antennas. Figure 4b shows the results of temperature maps along the central axis (open diamonds) of 4 antennas (open circles) spaced 2.0 cm apart. Results of dipoles (open squares) versus choke dipoles (closed diamonds) are shown. The planes of antenna tips and junctions are at 0.0 and 3.9 cm, respectively.*

Figures 4a and 4b reflect human data with brain tumors. The extent of tumor is shown by the box and the goal is to achieve all tumor points ≥ 43.0 °C. In figure 4a, a pullback is done between 2 planes of antennas (6 altogether), starting at the pair on the left side (antennas A and D). The "dipole antennas" sweep shows results when 6 dipole antennas are used and all points are ≥ 43°C. If the pair of antennas on the right side (C and F) are replaced by helical antennas with much less power deposited between antennas than their dipole counterparts, the results are shown in the "dipole and helical" sweep. Note that when the sweep enters the region between the helical antennas, a dramatic falloff is seen and the entire tumor is no longer therapeutic. Figure 4b compares a sweep of temperatures starting at the antenna tip plane and pulling back along the central axis of the 4 antennas. (The diamond is the location of the measurement catheter and the 4 circles represent the antenna locations). Note how the choke dipole antenna array centralizes the maximum temperature inside the tumor center since it is less affected by depth of insertion than the dipole array, for the same patient.

In conclusion, a multi-pronged effort involving theory, experimental verification, in-vivo models and clinical studies is underway to optimize brain tumor hyperthermia treatments by matching microwave antenna selection based on antenna performance to intended heating location. Helical, dipole, modified dipole and choke antennas have been used, with selection based on tumor location and size, relative to the spacing and number of antenna catheters implanted in the brain. Part of the selection process is assisted by a computer treatment planning system that allows placement of dipole antennas with any spacing and orientation and predicts power deposition patterns along with predicted temperatures for a particular value of blood flow.

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