RESONANT INDUCTIVE APPLICATOR FOR NECK HYPERTHERMIA

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ABSTRACT

We have designed and phantom tested an inductive applicator especially suited for producing hyperthermia in cancerous regions in the neck. The applicator is tuned to resonate near 27 MHz; its inductive nature has the advantage of efficient coupling to the irregular neck anatomy. An inhomogeneous neck phantom consisting of an outer fat layer and bone and air columns was constructed. The heating pattern in the phantom was relatively uniform within the cross-sectional area, indicating promise for clinical applications.

INTRODUCTION

The use of heat to treat cancerous regions in conjunction with radiotherapy is receiving careful attention in research labs and clinics around the world. Tumors in some areas of the body, in particular at surface locations, are relatively easy to heat with microwave or ultrasound applicators. Tumors in other locations are more difficult to bring to therapeutic temperatures, either due to their depth, inhomogeneous tissue properties, perfusion variations, irregular overlying tissue topology, or a combination of these factors. This represents one of the most significant challenges in hyperthermia today.

The neck region of the body is one of the difficult areas to heat. The air-filled trachea and boney spinal column both represent a large inhomogeneity in the tissue properties (in perfusion and electromagnetic characteristics). The curved and irregular neck surface limits access and makes the use of conventional radiating applicators difficult.

INDUCTIVE APPLICATOR

In the situations described above, inductive heating (i.e., heat deposition via eddy currents produced by time-varying magnetic fields impressed upon the tissue) has certain advantages: it requires no water-coupling bolus, it is relatively insensitive to patient movement, and the applicator is not required to be a significant fraction of a wavelength in size.

A concern with the induction method is the uniformity of the heating pattern. The induced eddy currents unavoidably circulate around a null located somewhere inside the tissue. The number, severity and location of these nulls is profoundly affected by the specific tissue anatomy, so assessment of any applicator must be based upon testing with a realistic, inhomogeneous phantom.

We designed a horseshoe-shaped inductive applicator composed of a 0.25 mm thick copper sheet folded into a one-turn resonant structure, as shown in Fig. 1. The inductance of the the loop is resonated with overlap capacitance at the backside of the device (actually, several interleaved plates, separated by 0.38 mm thick Teflon insulating film, are connected in parallel to increase the capacitance). The amount of capacitance is chosen to provide a resonant frequency near 27 MHz. The coaxial feed is attached across opposite capacitor plates.

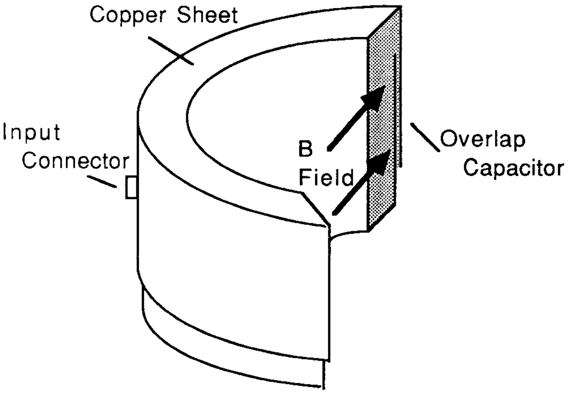

Figure 1 - Inductive neck applicator. The inside diameter is 13 cm; the height is 8 cm.

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PHANTOM TESTS

We fabricated an inhomogeneous phantom whose cross-section gives an approximation to the anatomy of the neck. The outer layer is a 1.0 cm thick fat phantom composed of 78.5% (by weight) type A resin epoxy, loaded with 19.2% aluminum powder and 2.3% acetylene black. Inside are two columns: an air-filled 2.5 cm diameter PVC pipe to approximate the trachea, and a 2.5 cm diameter epoxy cylinder (same composition as above) to model the bones of the spinal column. The remaining space is filled with muscle phantom: polyethylene powder, a gelling medium, and saline. The muscle phantom formula was adjusted to have a complex relative permittivity of 114.5 - j 441 at 27 MHz, as tested by a vector impedance meter and custom probe. The complex relative permittivity of the fat was 24.65 - j 17.56. The cross-sectional spacings and sizes of the phantom components were based upon anatomical data. The structure is uniform in the axial direction.

Numerous temperature monitoring tracts, composed of 0.8 mm inside diameter tubing oriented in the axial direction, were located in the muscle phantom. Two additional paths were placed in the bone and air columns. Nonperturbing temperature probes (semiconductor fiberoptic sensors) were used for sequential measurements of temperature rise (from the initial temperature) at each measurement site. Care was taken to keep the time of heating exposure short enough (15 minutes) to stay within the linear portion of the temperature rise curve, thereby minimizing thermal conduction effects.

For the heating tests, a radiofrequency generator was connected to the applicator via a π-circuit matching network. At the resonant frequency, the best match gave 75W forward power into the matching network. The resulting temperature rise data are shown in Fig. 2. The plane of measurement was centered top-to-bottom with the applicator.

RESULTS AND CONCLUSIONS

As given in Fig. 2, the temperature rise is relatively uniform throughout the phantom cross-section, with the exception of much lower temperatures in the muscle region directly between the bone and air columns. This apparently can be attributed to low eddy current density in this area. Temperature rises were also low in the bone and air columns themselves, undoubtedly due to the low conductivity of these tissues. The measured temperature rise at one point in the outer fat layer (point not shown) was lower than that in the muscle, which is consistent with the low fat heating expected of inductive heating.

Future plans include trying different orientations of the magnetic field (longitudinal rather than transverse) and conducting animal studies.

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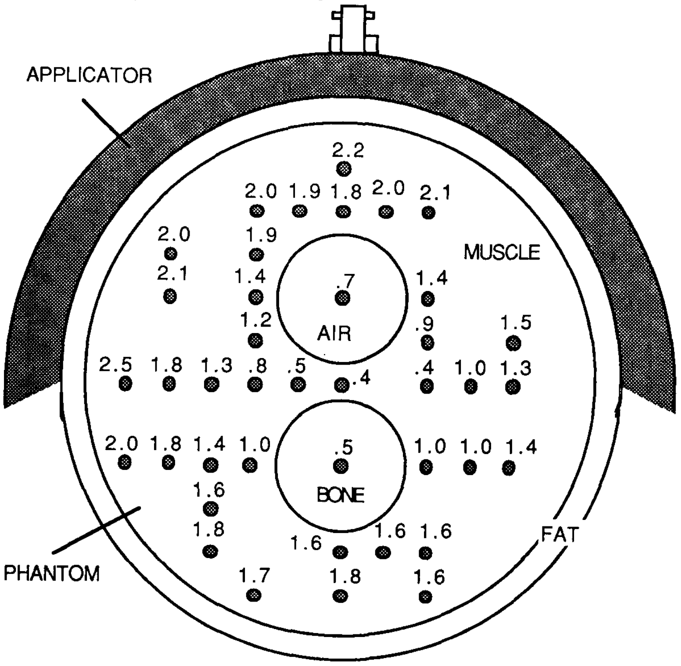

Figure2 - Temperature rise in °C for 15 min. heating with 75W forward power at 26.5 MHz.