EVALUATION OF 915-MHZ AND 2450-MHZ DIRECT CONTACT DIATHERMY APPLICATORS

ABSTRACT

The design, test, and evaluation of three 915-MHz, circularly polarized, direct contact diathermy applicators is discussed. The applicators were developed for the purpose of therapeutically heating biological tissue. The heating patterns produced by the applicators in a bi-layered planar tissue model were measured and compared to the heating patterns produced by a 915-MHz, linearly polarized applicator and a 2450 MHz circularly polarized applicator. Several performance criteria were obtained from the recorded heating patterns, including: peak Specific Absorption Rates (SAR), depth of penetration of energy and uniformity of SAR in the model.

Each 915-MHz applicator produced greater depths of penetration with significantly less heating of the superficial tissue than was produced by the 2450-MHz applicator. The width of uniform SAR was dependent on the size of the applicator aperture (i.e., as the area of the applicator aperture was increased, the width of the SAR also increased).

SUMMARY

I. Introduction

Currently, a need exists for devices which will provide selective heating of muscle tissue. Three direct contact, circular waveguide, aperture-type applicators have been developed for the purpose of therapeutically heating tissue. 8.9 cm and 11.1 cm diameter applicators are dielectrically loaded to permit propagation of a circularly polarized TE_{11} mode at 915-MHz. Another 11.1 cm diameter inhomogenously dielectrically loaded applicator (IDLA) was filled with concentric cylinders of different dielectric materials in order to create a more uniform electric field distribution at the waveguide aperture which in turn produced a more uniform heating distribution and the performance of each is compared to that of two other prototype direct contact diathermy applicators: (1) a 13 cm^2 915-MHz linearly polarized applicator developed by Guy, et.al. [1]; and a 15.2 cm diameter, 2450-MHz circularly polarized applicator developed by Kantor, et.al. [2].

II. Applicator Design and Testing

Each applicator consists of a dielectrically loaded waveguide with an aperture at one end of the waveguide and shorted at the other end. A circularly polarized TE_{11} mode is launched in the waveguide using two coaxial to waveguide probes which are placed in space quadrature with each other. A hybrid ring power divider presents the correct amplitude and phase at the input of each probe such that a circularly polarized wave is excited. A field shaping probe is placed midway between and on the opposite side of the waveguide from each input prove to minimize the ellipticity of the progagating wave. The dimensions of the applicators were empirically varied to optimize power transfer from the applicator to a planar bi-layered tissue-substitute model consisting of a 2 cm synthetic fat layer over a 10 cm synthetic muscle layer.

The heating patterns produced in the tissue model by the applicators were measured by thermography. Thermograph data were recorded to illustrate the heating patterns produced at three surfaces of the planar model: (1) the fat surface at the air-fat interface; (2) the muscle surface at the fat-muscle interface; and (3) a cross-sectional surface normal to the first two surfaces. In the past, recording the heating pattern as a function of depth into the model was limited to a condition where the transverse electric field vector of the incident wave had to be parallel to the plane of bi-section of the tissue model. For other cases, the dielectric discontinuity at the plane of bi-section produced inconsistent and distorted heating patterns in the model. The discontinuity is caused by machining irregularities in the solid synthetic fat and the polyethylene film placed at the model interface to hold the gelatin-like synthetic muscle intact. A significant improvement in the methodology of preparing the model allows for the exposure of the assembled model such that the transverse electric field vector may be oriented at any angle with respect to the plane of bi-section of the model without distortion of the fields at the

discontinuity. In the improved method the polythlene film is replaced by a synthetic mesh material stretched across each half of the model at the plane of bisection and across the top of the model on the fat surface. A thin coating of octyl alcohol is applied to the fat surfaces covered by the mesh material. The dielectric properties of octyl alcohol are sufficiently close to the dielectric properties of fat such that no discontinuities in the heating patterns are observed.

III. Experimental Results

The measured heating patterns in the exposed tissue model are represented by isothermal contour plots. Qualitatively, the heating patterns produced by the three 915-MHz circularly polarized applicators are circularly symmetrical in a transverse plane. The heating patterns produced in a transverse plane by the 915-MHz linearly polarized applicator and the 2450-MHz circularly polarized applicator are elliptically shaped.

From the isothermal plots, several pertinant performance parameters may be measured and computed, including: peak Specific Absorption Rate (SAR) in the fat and muscle; the ratio of the peak SAR values; the depth of penetration of energy (d) into the muscle; and the width of the heating pattern (w) in a transverse plane in the tissue model. The depth of penetration is defined as the maximum depth into the muscle where the SAR has decreased by a factor of $1/e^2$ from the peak muscle SAR. The width of the heating pattern is defined as the maximum diameter at which the SAR in muscle has decreased to one half of the peak SAR in muscle. The measured fat SAR to muscle SAR ratios for the 915-MHz applicators varied from 0.42 to 0.48 whereas the measured SAR ratio for the 2450-MHz applicator was approximately 1.0. The depths of penetration into muscle for the 915-MHz applicators ranged in value from 2.8 to 3.1 cm. The depth of penetration for the 2450-MHz applicator was 2.0 cm. The widths of the heating patterns for the experimental circular applicators were: w= 5.8 for the 8.9 cm diameter applicator; w= 7.2 cm for the 11.1 cm diameter applicator; and w= 8.3 cm for the 11.1 cm diameter IDLA. The widths of the elliptical heating patterns were w=9.7 and 8.4 cm for the square applicator; and w= 8.8 and 6.7 cm for the 15.2 cm diameter applicator.

References

1. Guy, A. W., J. F. Lehmann, J. B. Stonebridge, and C. C. Sorensen, "Development of a 915-MHz direct-contact applicator for therapeutic heating of tissues," IEEE Microwave Th. and Tech., August, 1978.

2. Kantor, G., D. M. Witters, and J. W. Grieser, "The design and performance of a circularly polarized direct contact applicator for microwave diathermy, IEEE MTT-S International Microwave Symposium Digest, 1977.