学位論文の要旨

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学　位　論　文　名	Design of Hemispherical Radio Frequency (RF) Capacitive-type Electrode Free of Edge Effects for Treatment of Intracavitary Tumors
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論 文 内 容 の 要 旨

INTRODUCTION

The addition of hyperthermia to radiotherapy or chemoradiotherapy is expected to achieve better clinical results in cancer treatment. Radio Frequency (RF) capacitive-type heating, most commonly used in clinical treatment, generates Joule's heat when applying RF between two external electrodes, raising the temperature of the human tissue through which the electric current passes. However, the electric current tends to concentrate in the tissue around the peripheral area of the electrode, inducing an edge effect and excessive heating. The edge effect induces pain and fat necrosis, resulting in unsatisfactory clinical results.

We focused on creating an electrode shaped to allow a more uniform distribution of the electrical field, to minimize the edge effect. We devised a hemispherical-shaped electrode which does not produce an edge effect, and requires no E-field-modifying material such as an insulator or bolus. The heating characteristics were evaluated using both computer simulation and agar phantom experiments.

MATERIALS AND METHODS

Computer simulation (calculation model)

The electric field and the specific absorption ratio (SAR) distributions were calculated using finite element method software, COMSOL Multiphysics (COMSOL, Inc., Stockholm, Sweden). A cube-shaped muscle of 20 x 20 x 20 cm^3 was positioned as a phantom in air. A pair of aluminum flat plate electrodes 1 mm thick, and 5 x 5 cm^2 and 10 x 10 cm^2 square, respectively, with aluminum lead wires were placed on the top and bottom of the phantom, and an electric potential with a frequency of 13.56 MHz and an amplitude of 100 V was applied to the electrodes. Various E-field-modifying materials were simulated by changing the electrical properties, configuration thickness and coverage in order to minimize the induction of the edge effect. We then focused on reconfigured shapes of the electrode, including hemi-ellipsoidal and hemispherical shapes.

Phantom experiment using the prototype electrode

A prototype hemispherical electrode was prepared to confirm the heating characteristics of the proposed electrode obtained in the simulation results. The surface of a 3 cm radius rubber ball was completely covered with aluminum foil, and the upper half of the ball was then covered with insulating tape. The lower-half of the ball served as the hemispherical electrode and was connected to a conductor wire. A muscle-equivalent agar phantom of 15 x 15 x 13 cm^3, composed of water (95.68 w/w %), NaCl (0.22 w/w %), NaN3 (0.1 w/w %) and agar (4 w/w %), was prepared. The hemispherical electrode was embedded in the phantom. An external aluminum electrode 10 x 10 cm^2 in size was placed under the phantom and RF current was supplied for two minutes between the hemispherical electrode and the external electrode at a frequency of 9.0 MHz, and an output power of 5 W. The temperature distribution on the cross section of the phantom was then measured by thermogram.

RESULTS AND DISCUSSION

The simulations for edge effect arising in capacitive-type heating revealed that 1) insertion of a sheet of E-field-modifying material to the border of the electrode and the phantom did not eliminate the edge effect, regardless of thickness, shape, and dielectric property of the E-field-modifying material; 2) enfolding the electrode with E-field-modifying material did not eliminate the edge effect, regardless of thickness and shape; 3) the hemi-ellipsoidal electrode did not induce an edge effect, but the SAR distribution along the electrode was not uniform; and, 4) the hemispherical electrode did not induce an edge effect and the SAR distribution along the electrode was uniform.

The phantom experiments confirmed that an edge effect was not induced when the hemispherical electrode was used for RF capacitive-type heating. The reason for this is believed to be that the curvature radius of the electrode is uniform at all points on the electrode; the normal vector at the edge of the hemispherical electrode is parallel to the surface of the phantom and the radius of curvature at any point on the hemispherical electrode is identical, so the SAR along the hemispherical electrode is identical.

The RF capacitive-type heating advantage of deep penetration is limited by the edge effect, thus reducing its clinical usefulness. In this study, we developed a hemispherical electrode that does not cause the edge effect. We have confirmed the heating characteristics of RF capacitive-type heating with the new hemispherical electrode through computer simulation and phantom experiments. The proposed hemispherical electrode can be used for non-invasive heating, and its distinguishing shape permits placement adjacent to intra-cavity tumors within cavities such as the mouth and vagina. The hemispherical electrode that solves the edge effect problem, the weak point of RF capacitive-type heating, would potentially expand the clinical indication for RF capacitive-type heating.

CONCLUSION

A hemispherical electrode that generates no edge effect was developed to allow non-invasive heating of intra-cavity tumors for which RF capacitive-type heating was generally considered unavailable. This method is expected to make a significant contribution to the multidisciplinary treatment of intra-cavity tumors.