HEATING CHARACTERISTICS OF SMALL AND HIGH EFFICIENCY IMPLANT FOR THERMAL THERAPY

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ABSTRACT

A small implant with the characteristic of highly efficient temperature rise is proposed for thermal therapy. This has been developed not from material compositions but from electrical circuit theory viewpoint. This implant is composed of a small coil and a microchip condenser. A small implant of the coil diameter and the coil length being 6.5mm and 1.6mm, respectively shows an increase of more than 20°C in the depth of 10cm at the frequency of 4MHz using a ferrite core applicator with the output power of 500W.

INTRODUCTION

To achieve deep hyperthermia at depth of more than 6cm, many kinds of applicator system have been developed [1][2]**.** One of the authors has also developed an inductive deep heating applicator system [2][3]. However, these applicator systems have been limited to regional heating.
In this paper, a localized inductive heating method using a small implant is newly proposed, which enables the selective heating for a small tumor [4]. Generally, it is very difficult to make a small millimeter sized implant, that's because any implant materials cannot be heated well by inductive heating when the implant size becomes smaller than ten millimeters. This fact is based on the inherent nature of eddy current induced by applying magnetic fields to the implant. Therefore, the development of a small implant with the characteristic of highly efficient heat generation has been demanded. To resolve this problem, a new type of small implant has been examined not from material compositions but from electrical circuit theory viewpoint. That is, the new implant consists of a small coil and a microchip condenser to make a resonant circuit. The temperature rise more than 20°C is obtained at 15cm depth of agar phantom with a flat shape implant with a diameter and high of 5.6 mm and 1.6mm, respectively, when a resonant frequency and an output power are 4 MHz and 500 W, respectively. This paper describes particularly in detail the fundamental heating characteristics, the method of constructing smaller and highly efficient heating implants, and an omni-directional implant.

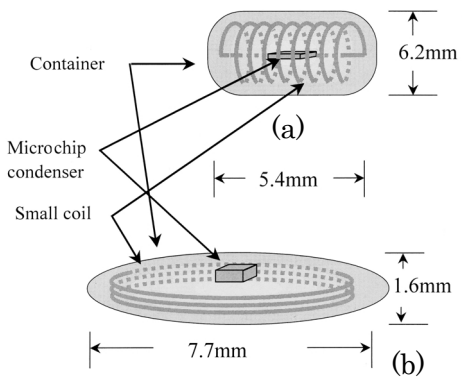
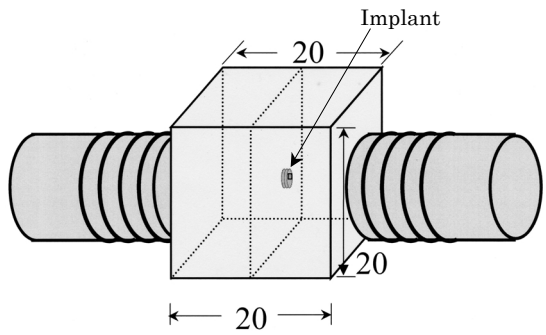


Fig. 1 Fundamental construction of implant



Resonant frequency : 4[MHz]
Output power : 500[W]
Phantom size : 20×20×20[cm]

Fig. 2 Heating System

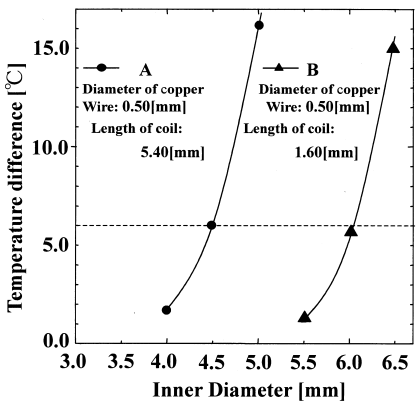


Fig. 3 Heating characteristics taking the inner diameter of small coil as a parameter

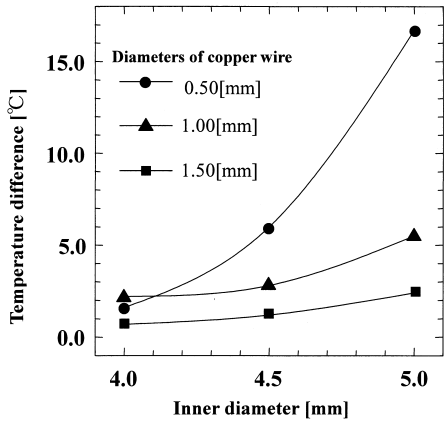


Fig. 4 Heating characteristic taking a coil wire diameter as a parameter

CONSTRUCTION

This implant is composed of a small coil and a microchip condenser as shown in Fig. 1. Fig. 1(a) and Fig.1 (b) show a prolate spheroid and an oblate spheroid shape, respectively. These shapes are called Type A and Type B, respectively in the subsequent investigations. The implant is covered with a harmless material. The coil and the microchip condenser constitute a series resonant circuit together with coil resistance. When an alternative magnetic field is applied to the small coil, a large coil current flows due to resonance. As the result, the coil generates Joule heat with high efficiency.

INVESTIGATION OF HEATING CHARACTERISTIC

Heating characteristics have been investigated for several kinds of new implant. Fig. 2 shows a ferrite core applicator that is used for present implant heating at the frequency of 4MHz and the output power of 500W. The heating tests have been conducted using an agar phantom being subjects to the guideline assigned by the Quality Assurance Committee (QAC, JASHO). The 20cm cube phantom is used in the present heating experiment. The implant is placed in the central position of the phantom.

Fundamental Heating Characteristics

Fig.3 shows that the heating characteristics when the inner diameter of small coil is taken as a parameter. The coil lengths are 5.4 and 1.6mm, respectively, keeping coil wire diameter constant of 0.5mm. It is found that temperature rises more than 15°C are obtained in those small implants.

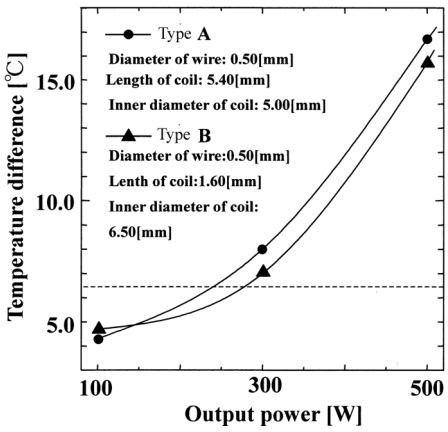


Fig. 5 Heating characteristics when output power is changed

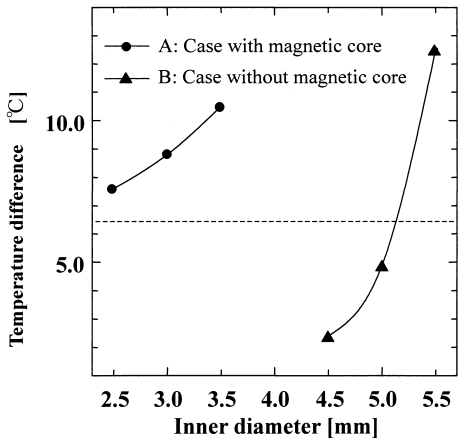


Fig. 6 Heating characteristics when the magnetic core is mounted inside a coil or not

Fig. 4 shows the heating characteristic when coil wire diameters is taken as a parameter. This experiment suggests that there is optimum wire diameter for the present coil.
Fig. 5 shows the heating characteristic when the output powers of ferrite applicator are changed. It is found that both types of implant, the prolate spheroid and the oblate spheroid shape are well heated by relatively low output power.
To make a smaller and implant with the function of high temperature rise, a magnetic material is introduced as a coil core. Fig. 6 shows the case where the magnetic core is mounted or not. The temperature rise is improved at 5~12 °C compared to the implant without a ferrite. We find that the magnetic material plays an important roll to elevate a temperature.

Heating Characteristics of Omni-directional Implant

The implants mentioned herein has a directivity to applied magnetic field. That is, only when the magnetic field is applied perpendicularly to the cross section of a coil, the coil is heated efficiently. The authors have proposed the ferrite core applicator which can change the magnetic field radiation's angle and its position by adopting the structure that each pole is separated as shown in Fig.2 [2]. Any implant proposed here can be heated using the ferrite core applicator system with the separated pole by adjusting the angle and the position of magnetic field radiation. However, a better way to avoid these procedures is to make an implant with an omni directional characteristic. For this purpose, a new implant like a spinning ball is developed as shown in Fig.7. Several times of heating tests are conducted by changing the angles of magnetic field radiation. The temperature rises more than 20°C is obtained as shown in Fig. 8. A good temperature rise characteristics against heating time are obtained.

CONCLUSION

Heating characteristics have been investigated in detail for the new implant.
1) To develop a new high efficiency implant, first, the optimum size of small coil and the wire has been examined empirically. A small implant of coil diameter and coil length being 6.5mm and 1.6mm respectively shows a temperature rise more than 20 °C at the surface of coil within 1 min when the implant is placed in the agar phantom in the depth of 10cm, using ferrite core applicator with the output power of 500W at the frequency of 4MHz.
2) Further, to make a smaller implant, a small magnetic material, ferrite is loaded inside the coil to concentrate magnetic fields. The temperature raise is improved by 5~12 °C compared to the implant without a ferrite.
3) The implants mentioned herein has a directivity to applied magnetic field. The authors have proposed the ferrite core applicator that can change the magnetic field direction by adopting separated poles. Every implants proposed here can be heated using this ferrite core applicator system. However, a better way to avoid this problem is to make an implant with an omni-directional characteristic. For this purpose, a new implant like a spinning ball is developed. The temperature rises of more than 17°C is obtained to any direction of magnetic field.

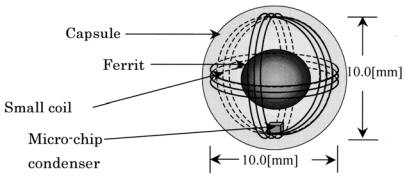


Fig. 7 Omni-directional implant

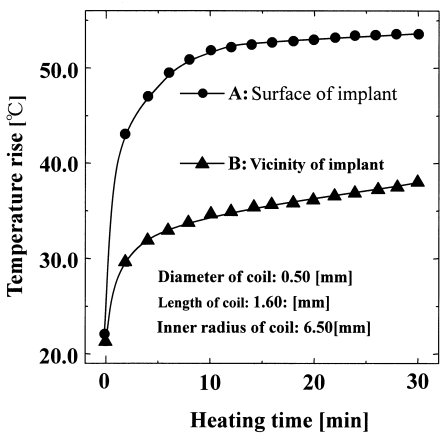


Fig. 8 Heating characteristics of small implant

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