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A Possibility of Hyperthermia Treatment using MRI Equipment

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***Abstract*— A possibility of hyperthermia treatment using a magnetic resonance imaging (MRI) is discussed. A resonant circuit consisting of a closed connection of an inductor and a capacitor raised its temperature by an applied magnetic field. As the resonant circuit is heated efficiently, it can be used as an implant for the hyperthermia. It was indicated that a RF pulse of a commercial MRI system under normal diagnosis procedure could be used for the excitation source.**

I. Introduction

HYPERTHERMIA is a therapeutic procedure of raising the body temperature for cancer treatment. Although various established treatments of surgical operation, radiotherapy and chemotherapy suffer from risks of scar and harmful side effects, the hyperthermia has an advantage that those risks are reduced. The hyperthermia elevates the local temperature to between 42.5 and 44 °C to kill cancer and most normal tissues are not damaged at the temperature below 44 °C. When the body temperature rises, the heat is dissipated by cooling through blood circulation. A sluggish blood flow in the cancerous tissues leaves them vulnerable at the elevated temperature. This process of killing the cancer is safe for surrounded healthy tissues.

A technique for local heating is essential in terms of capability of warming the cancerous tissue locally as compared with whole body heating. Among various warming methods proposed for the local heating, the hyperthermia using implants is expected to warm cancerous tissue in deeply located and to avoid risk of burn. The implants of tiny elements inside of the body are heated up by an external energy source. A combination of magnetic materials as the implants and a magnetic field applied from outside of the body has attracted much attention [1,2]. Recently fundamental research using magnetic nanoparticles has been also popular [3]. In order to minimize harmful effects associated with high frequency magnetic field to the body, the external magnetic field should be less intense with lower frequency as possible. It is expectable to use a resonance circuit for the implant, which generates heat efficiently by the applied external magnetic field [4]. It was found that the resonant circuit was heated up to 40 °C by the weak applied magnetic field of 3.4 μT at 63.9 MHz [5]. It has been also proposed to use a RF pulse (high frequency magnetic field) from a magnetic resonance imaging (MRI). As a preliminary result, RF magnetic field of the MRI with a low duty factor could raise the circuit temperature up to 13 °C. In this paper, the temperature rise of the resonant circuit excited by RF field of the MRI is clarified and an advantage of implant hyperthermia using the MRI equipment is discussed.

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II. Implant Hyperthermia Using MRI

A. Resonant circuit implants delivered through catheter

In case that size of implants is as small as 1mm, it is possible to deliver them to a tumor through a catheter as illustrated in Fig.1. This delivery method offers a cancer treatment with less scar, which can not be achieved by surgical operation including endoscopic resection. A risk of infectious disease can be also reduced. A resonant circuit is one of the promising implant from the viewpoints of its size and high heat efficiency.

The resonant circuit used in this study was consisted of a closed connection of an inductor and a capacitor. When an ac magnetic field is applied to the inductor coil, a current flows by an electromotive force induced in the coil, v as shown in Fig. 2. An electric power consumed in the circuit, P in active power, is described as

$$P = \frac{r_s}{Z^2} v^2 \tag{1}$$

where Z and r_s are impedance and residual resistance of the circuit, respectively. In case that the frequency of the applied ac field equals to the resonant frequency of the circuit, the power P is described as

$$P_{resonance} = \frac{1}{r_s} v^2 \tag{2}$$

because the reactance in $Z(= j\omega L + \frac{1}{j\omega C} + r_s)$ is zero.

As the electromotive force induced in the coil, v is proportional to the frequency of the applied magnetic field, higher frequency is preferable for a higher temperature rise.

B. RF pulse of MRI

MRI is operated under a combination of strong dc and weak ac magnetic fields. The magnetic-flux density of the dc field in commercial MRI system is typically 0.2-2 T. MRI images of higher resolution can be obtained by using the higher dc magnetic filed. The frequency of the ac field is determined by a gyro-magnetic ratio of a detecting atom

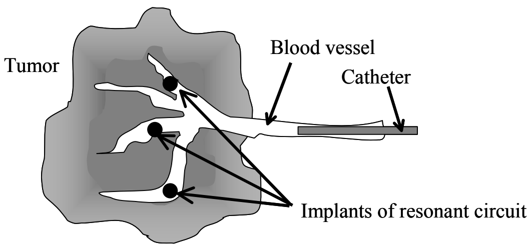

Fig. 1. Implants of resonant circuits delivered to a tumor through a catheter.

(normally hydrogen) and the strength of the dc field. The gyro-magnetic ratio of hydrogen is 42.6 MHz/T. This frequency is also referred as Larmor frequency or frequency for nuclear magnetic resonance (NMR). The dc filed strength of the commercial MRI equipment used in this study was 1.5 T. The 1.5-T type MRI equipment is widely distributed to hospitals. The corresponding ac frequency was 63.9 MHz. In order to observe recovery and decay of hydrogen nuclei magnetic moment, the ac field is applied as a pulse consisting of modulated sinc waveform [5]. So, the ac field in the MRI is called the RF pulse. The strength of the RF pulse is usually a few μT, but its duty ratio is quite low comparing with a continuous wave. Although this field strength is smaller than the terrestrial magnetism, its high frequency promotes the enough heating of the resonant circuit.

C. Temperature rise and MRI image

A temperature rise of a resonant circuit excited by a RF pulse of MRI was measured. The circuit was consisted of an inductor (2.07 μH) and a capacitor (3.0 pF). Its resonant frequency was 63.9 MHz. The diameter and number of turn of the coil were 15 mm and 6, respectively. The dimension of the capacitor was 2 mm × 3.5 mm × 0.63 mm. The temperature rise of the circuit was measured by an optical thermometer using laser and optical fiber, which was not affected by a magnetic field with high frequency. The circuit was covered by polyurethane material as a thermal insulation. The sensor tip was attached to the coil. Preliminary results of the temperature rise of the circuit excited by an ac magnetic field with continuous waveform have been reported [5]. It was found that the highest temperature rise was obtained when the frequency of the applied field matched to the resonant frequency of the circuit.

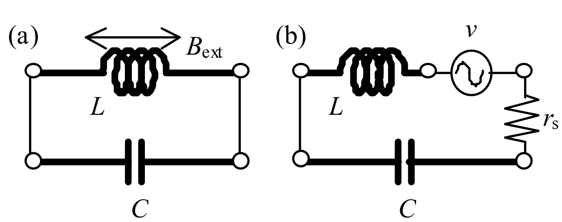

Fig. 2. Resonant circuit consisting of closed connection of inductor and capacitor (a) and its equivalent circuit under ac magnetic field (b).

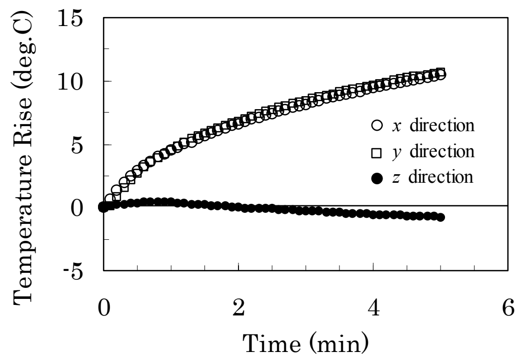

Fig. 3. Temperature Rise of resonant circuit (L=2.07mH, C=3.0pF) excited by RF pulse of MRI.

The 1.5-T type commercial MRI system was used. The center frequency of the modulated RF magnetic field was 63.9 MHz. The magnetic field of the modulated RF pulse was applied to the circuit under a normal procedure for the MRI diagnostics. The direction of the inductor coil was adjusted to the *x*-, *y*- or *z*-axis, where the *z*-axis was parallel to the direction of the dc magnetic field in the configuration of the MRI system. The RF pulse was applied in the directions of the *x*- and *y*-axes which were perpendicular to the *z*-axis. Figure 3 shows the temperature rise of the circuit as a function of the duration of the MRI operation. The circuit raised its temperature up to 10 °C after 5 min when the coil was aligned to *x*- or *y*-axis which was parallel to the direction of the RF pulse. The temperature did not rise in case that the RF magnetic field did not penetrate the coil aligned to *z*-axis.

Because the inductor acts as a magnet, the resonant circuit implant might degrades the MRI images as artifacts. Figure 4 shows the T1-weightened MRI image of a piece of pork meat with an inserted resonant circuit. Although the part of the tomographic image around the circuit was blackened, the surrounding part was clearly imaged enough for diagnosis.

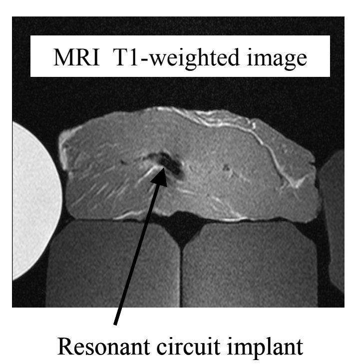

Fig. 4. T1-weighted MRI image of a piece of pork meat with inserted resonant circuit implant.

D. *Field strength and frequency for hyperthermia*

It is preferable to use a weak magnetic field with low frequency for safety to human body. It is expectable to use a resonance circuit. It has been reported that the product of magnetic field and its frequency, $H{\cdot}f$ should not be exceeded $4.85{\times}10^8$ A/m·s [6]. The temperature rise up to 40 °C was obtained in the resonant circuit excited by a magnetic field of 3.4 μT at 63.9 MHz with a continuous wave [5]. The product of $H{\cdot}f$ in this case was below the line of $4.85{\times}10^8$ A/m·s as shown in Fig. 5. It was also confirmed that the resonant circuits with their resonant frequency of 100 kHz order exhibited the significant temperature rise.

The RF magnetic field in the MRI is applied with sinc waveform of its modulated frequency (sinc frequency) at 1 kHz order. In order to collect tomographic images, the strength of the dc field is gradient along a required special direction. The frequency of the RF field is modulated approximately in the range of 63.9 ±1 MHz as to match the NMR frequency under the gradient dc field strength. The duty factor and the field strength of the RF pulse are restricted with an index of specific absorption rate (SAR) in consideration of any influence of metal in the body like dental metal, and a normal organization. Therefore the product of $H{\cdot}f$ for the MRI pulse under a normal diagnosis sequence is less than the calculated value for the continuous wave.

III. Conclusion

The hyperthermia treatment using a resonant circuit as an implant and a MRI system as an excitation source is discussed. It was found that the resonant circuit raised its temperature efficiently by the external magnetic field. The temperature rise of 10 °C was obtained by an applied magnetic field of RF pulse under a normal diagnosis procedure of the MRI system. It is advantageous that the commercial MRI equipment can be used for the hyperthermia because the therapeutic procedure can be repeated after confirming results from the MRI diagnosis.

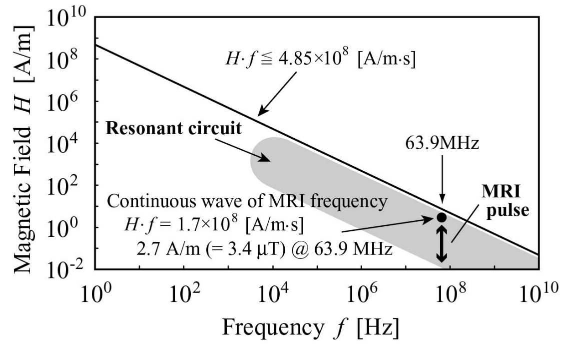

Fig. 5. Product of strength and frequency of applied magnetic field used for hyperthermia.

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