Original Contribution

Fundamental Study of a Combined Hyperthermia System with RF Capacitive Heating and Interstitial Heating

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Abstract : Interstitial RF heating with an inserted electrode allows the heating position selection in a subject, but the narrow heating region is problematic. This study elucidates development of new interstitial RF heating methods, combining with external RF heating using paired electrodes, heating the subject broadly in advance in order to selectively extend the heating region. Two kinds of heating system were developed by controlling a differential mode and a common mode of RF currents. Heating experiments with a liquid adhesive subject enabled a wider effective heating region with higher initial temperatures of heating subjects by external RF heating, and larger interstitial electrode diameter.

Key Words : interstitial RF heating, external RF heating, concentrated heating, expansion of heating region, interstitial electrode

Introduction

There are two kinds of RF (radio frequency) -based hyperthermic oncology. One is external RF heating, which heats a subject using external electrodes mounted on a body surface[1-4]. The other is internal RF heating, which heats the subject directly from an electrode inserted into the human body[5-13]. Concerning internal RF heating, an interstitial RF heating that heats with an electrode directly inserted into the body through the skin[5-11] and an intracavital RF heating that heats by an electrode inserted into cavities such as urethra and esophagus[12)13] have been developed. Interstitial RF heating methods have the problem that the heating region is narrow while the insertion position is heated selectively. Although several improving methods such as a method for redesigning the interstitial electrode shape[8-10)12] and a method combining other methods[6)7)11] were proposed to widen the heating region, they have not been used in clinical practice. On the other hand, external RF heating methods have a problem that it is difficult to limit the heating position and to concentrate the heating region, despite easy application in clinics because of noninvasiveness.

In the present paper, we develop systems that heat a wide region of the selected position in a subject by considering both external and interstitial RF heating method characteristics. In other words, a wide

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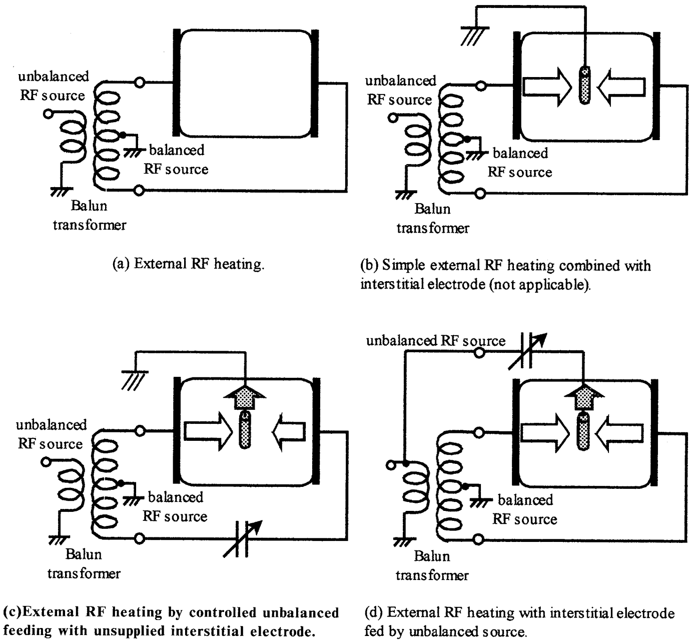


Fig. 1. Principle of RF heating based on external RF capacitive heating combined with an interstitial electrode.

region of the subject is heated with external RF heating beforehand and a localized region is heated with interstitial RF heating in turn or simultaneously. A reference electrode is required for interstitial RF heating with an interstitial electrode. Paired electrodes of the external heating serve as the reference electrode for interstitial heating. External and interstitial heating was realized with one RF source. Two kinds of heating system were developed by controlling the differential mode and a common mode of RF current. In experiments with interstitial electrode of various diameters, heating characteristics were examined with a subject of liquid adhesive having various initial temperatures.

Materials and Methods

Principle of external and internal heating

For external RF heating, when the subject is sandwiched in with paired electrodes arranged in parallel and excited with a high frequency electric current of a differential mode, subject temperature increases due to impedance between paired electrodes. Supposing a homogeneous subject and equal surface area of the two electrodes, a wide region of the subject is heated uniformly without electric current concentration (Fig. 1 (a)).

On the other hand, for interstitial RF heating, when a high frequency electric current is induced in a cylindrical interstitial electrode inserted into the subject, temperature increases due to impedance between the interstitial electrode and the reference electrode. Generally, a peripheral portion of the interstitial electrode is heated through high electric current density when the reference electrode surface area is greater than that of the interstitial electrode. Only a selected location can be heated intensively using this method. Heretofore, heating regions have been limited to small areas and it is difficult to extend them using only interstitial RF heating. Without practical knowledge, it may be thought that the heating region is enlarged by increasing excitation power, but experiments show that a heating region diameter with a 0.5 mm diameter needle electrode becomes about 20 mm and extra excitation power serves only to vaporize water. This is a difficulty in heating region enlargement with an interstitial electrode. Here, we consider a heating method that enlarges the heating region without excitation power limitation.

We believe that increasing initial subject temperature beforehand is one method to magnify the heating domain. Subject temperature is first increased by external RF heating and a limited location is heated by interstitial RF heating in turn or simultaneously. A heating system for hyperthermic oncology

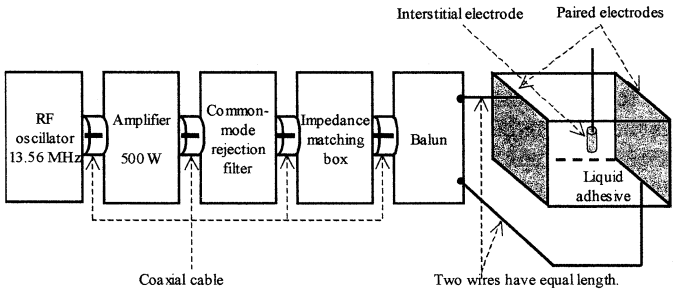


Fig. 2. RF heating system.

should be as simple as possible. A system with only one high frequency oscillator is constructed and paired electrodes for external RF heating serve as a reference electrode for interstitial RF heating. Caution must be observed. Concentrated heating of the interstitial electrode vicinity is difficult by simply combining two methods because a high frequency electric current of a differential mode between paired electrodes does not pass through the interstitial electrode (Fig. 1 (b)).

Modified combination systems with external and interstitial RF heating are realized in two ways : 1) One method is to control the quantity of an electric current drifting to two paired electrodes (Fig. 1 (c)). By this method, a high frequency electric current of a common mode exists in addition to that of a differential mode between paired electrodes and common mode current heats the interstitial electrode periphery by electric current flowing through it. 2) The other is a method that excites the interstitial electrode while exciting paired electrodes (Fig. 1 (d)). A high frequency electric current of a differential mode generated by a balun excites paired electrodes ; and a high frequency electric current of a common mode excites between the interstitial electrode and the ground. Interstitial electrode electric current is controlled with a capacitor connected in series to achieve heating with one high frequency power supply. If two high frequency power supplies were used, a part of their respective output power came to a counterpart amplifier such that it would be recognized as a reflection wave ; the protection circuit of an amplifier functioned, output power fell, and heating was not achieved well.

Heating system

Fundamental heating system composition is shown in Fig. 2. The system consists of a high frequency oscillator (ICOM, IC-775DXII), an amplifier (ICOM, IC-PW1), a common mode rejection filter (RF Inquiry, CF5kV), an impedance matching box, a balun, paired electrodes, and an interstitial electrode. High frequency power is set at 13.56 MHz, which is standard, and amplifier output is monitored with a wattmeter. The paired electrode high frequency source is balanced while that of a generator is unbalanced. For balance-unbalance conversion of a high-frequency transmission channel, a hand-made " balun" with a coaxial line (10D2V) is used ; an impedance matching box adjusts matching between the high frequency source and the balun. Paired copper electrodes, 130 mm × 165 mm, are set parallel to the sandwiched subject. Six kinds of electrodes are used for interstitial electrodes : a 40 mm long hollow cylindrical copper electrode with diameters of 5 mm, 10 mm, 15 mm, and 22 mm ; and a 40 mm long solid cylinder with diameters of 2 mm and 3 mm. Materials for these electrodes are easily obtained on the market. Electrodes with diameters of 2 mm and 3 mm are used for interstitial heating and those with diameters of 5 mm, 10 mm, and 15 mm are used for intracavitary heating.

Two types of connections of paired electrodes and the interstitial electrode are shown in Figs. 3 (a) and (b). Fig. 3 (a) shows one method for insertion of a capacitor (VC1) between the balun and one of the paired electrodes to control electric current unbalance into paired electrodes. Fig. 3 (b) is another

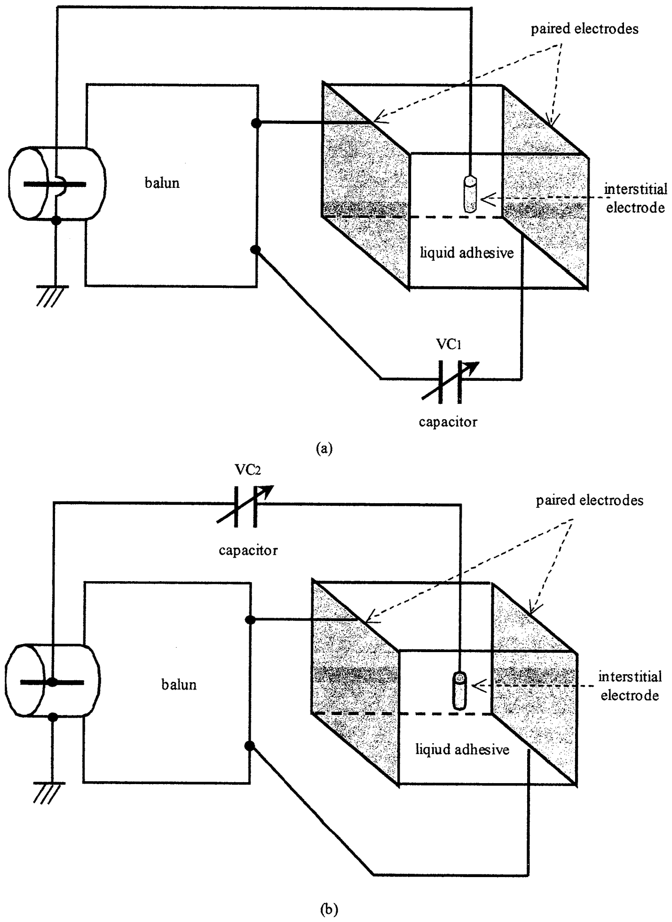


Fig. 3. Two heating systems.

method for insertion of a capacitor (VC2) between the unbalanced feeding point and the interstitial electrode to control an electric current into the interstitial electrode. In addition, to confirm effects of this system, heating systems which use only paired electrodes without an interstitial electrode (external heating), which use an interstitial electrode connected to ground directly, and which use only an interstitial electrode without paired electrodes (interstitial heating), were also constructed and examined in heating experiments.

A liquid adhesive composition (Sekisui Jushi Co. , Ltd. J-500) of synthetic resin with the characteristic of change from transparency to cloudiness when temperature exceeds 45.5°C (actual survey value) is used for the subject. When considering clinical use, the heating effect around 43°C should be evaluated. Temperature characteristics of existing materials are pictured around 45.5°C, a temperature which is higher than that of clinical use. Temperature distribution around 43°C or higher that is to be effective for hyperthermic treatment of the human body is estimated to be larger than the experimental results shown in this paper.

The liquid adhesive composition is put in a 185 mm × 300 mm × 240 mm water tank. Temperature of a wide region of the subject is controlled uniformly by stirring after external heating with paired electrodes. Temperature is managed using three alcohol thermometers (calibrated with a standard mercury thermometer) inserted into the left, center, and right sides of the subject. A digital camera (OLYMPUS, C-2020 ZOOM) is used to record heating results.

Results

This chapter describes a heating experiment of the interstitial RF heating system combined with external RF heating. 1) First, external RF heating without the interstitial electrode and with unexcited interstitial electrode connected to the ground are both tested as fundamental heating characteristics. 2) Next, heating characteristics by changing the balance of electric current flow into paired electrodes are tested with the grounded interstitial electrode. 3) Then, heating characteristics with both excited interstitial electrode and paired electrodes are tested. 4) Finally, heating characteristics with the excited interstitial electrode are tested without paired electrodes. Each experiment yields heating results with varying interstitial electrode diameters and initial subject temperatures.

Fundamental heating characteristics

Considering invasiveness to the human body, concentrated heat is desirable without insertion into the subject. We examined external RF heating with paired electrodes without any electrode insertion into the subject. Initial subject temperature was set to 37°C, nearly equal to human body temperature. As a result of external heating excited by paired electrodes without the interstitial electrode, a cloudy region, a region heated over 45.5°C, spread from the right- and left-side to the center of the subject about 10 minutes later with a 500 W output. This result indicates that concentrated heating at a limited position by this method is difficult.

Next, RF heating with the grounded interstitial electrode inserted at the center of the subject with a 500 W output was done. In this case, heating did not begin at the interstitial electrode circumference. For every interstitial electrode tried, the interstitial electrode circumference did not heat faster than the paired electrode vicinity and results were identical to those without the interstitial electrode.

Heating characteristics with unbalanced current paired electrodes

When the interstitial electrode was unexcited and connected to the ground, only a high frequency electric current of a differential mode existed because both electric currents flowing to paired electrodes were balanced. Therefore, concentrated heating was not possible if the interstitial electrode, connected to ground, was installed at the center of the subject. Changing the balance of electric current flow into paired electrodes generates a high frequency electric current of a common mode. Interstitial electrode circumference is heated concentrically because a high frequency electric current of a common mode flows into the interstitial electrode. A variable capacitor (VC1) of 200 pF maximum capacitance was connected between the balun and right paired electrode. In this case, the interstitial electrode is connected to the ground of the balun and does not excite as in the previous section.

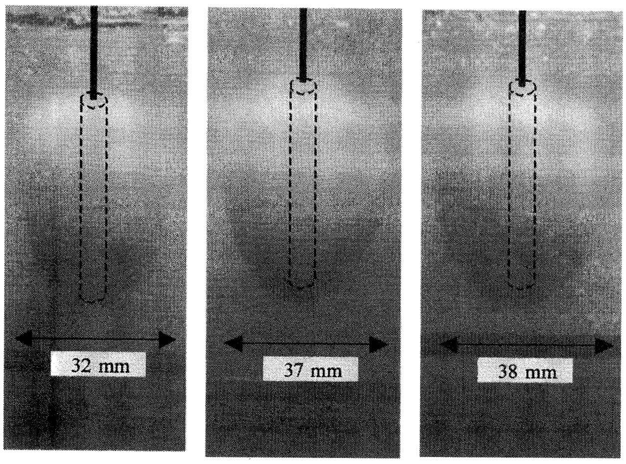


Fig. 4. Heating results using a 5 mm diameter interstitial electrode. Initial subject temperatures are (a) 37°C, (b) 39°C, and (c) 41°C, respectively.

Heating results using a 5 mm diameter 40 mm long cylinder type interstitial electrode are shown in Fig. 4. Figures 4 (a), (b), and (c) show results at initial temperatures of 37°C, 39°C, and 41°C of the subject, respectively. In addition, heating results using six interstitial electrodes are shown in Fig. 5 in the case of 41°C initial temperature. Each result shows regulated capacitance of the variable capacitor to cause cloudiness spreading equally through right and left areas mainly on the interstitial electrode (cloudiness appears circular when observed from above). From Figs. 4 and 5, cloudiness appears to spread over the right and left of the interstitial electrode equally in every case. From

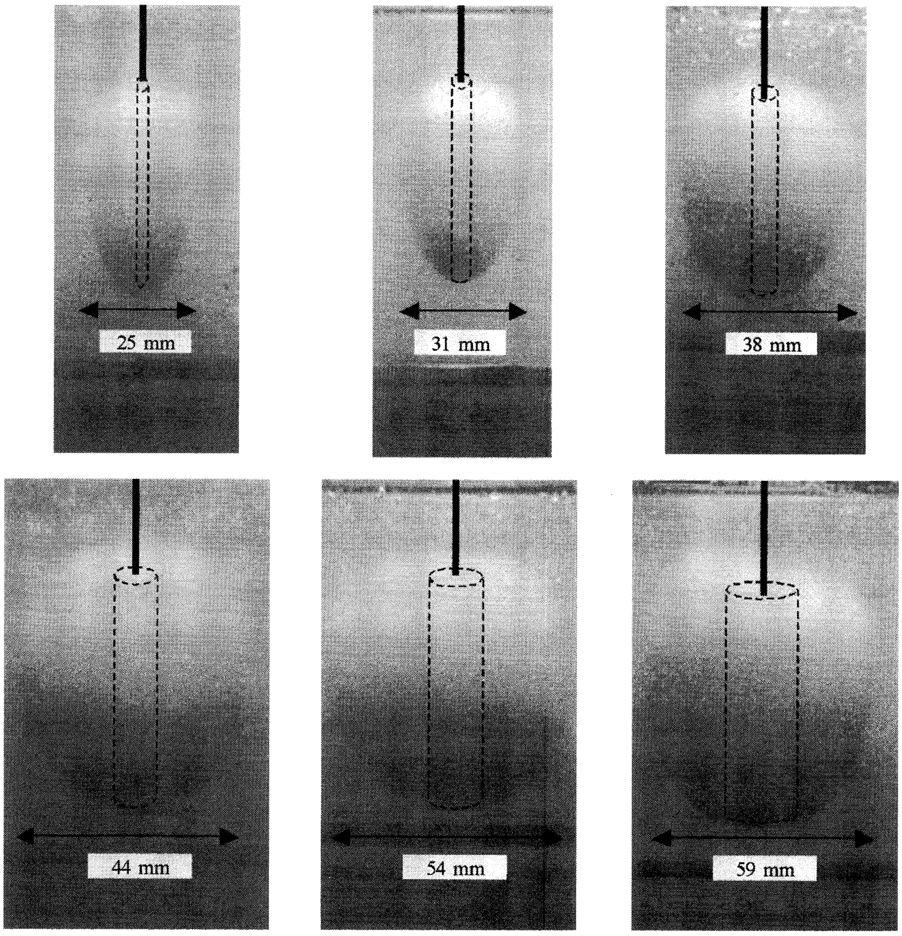


Fig. 5. Heating results using interstitial electrodes at 41°C initial temperature. Electrode diameters are (a) 2 mm, (b) 3 mm, (c) 5 mm, (d) 10 mm, (e) 15 mm, and (f) 22 mm, respectively.

results in Fig. 4, the higher the initial subject temperature, the larger the cloudy region diameter. Here, we refer to the outer diameter of the cloudiness region including the electrode as the heating diameter. From results in Fig. 5, the greater the interstitial electrode diameter, the larger the cloudy region diameter. Interstitial electrodes of 5 mm to 22 mm diameter are hollow while 2 mm and 3 mm are solid electrodes. There were no other differences between solid and hollow electrodes. We surmise that heating region diameter depends on electrode outer diameter. Furthermore, the two phenomena whereby cloudiness spreads to the right- or left-side of the interstitial electrode were altered by controlling variable capacitor (VC1) capacitance. The reason for these phenomena is described in Discussion.

Table I. Experimental data for a 5 mm diameter interstitial electrode.

Initial temperature 〔°C〕	Power 〔W〕	Heating duration 〔min〕	Capacitor (VC1)value 〔pF〕	Heating diameter 〔mm〕
37	100	7	50	32
39	100	6	50	37
41	100	5	50	38

Measured diameter of cloudiness vs. interstitial electrode diameter with various initial subject temperature is shown in Fig. 6. Fig. 6 indicates that high initial subject temperature correlates with large diameter of cloudiness surrounding the interstitial electrode. We infer that when initial temperature is high, subject temperature approaches that of the interstitial electrode vicinity and cooling effects decrease.

When cloudiness mostly spread right and left equally with 5 mm interstitial electrode diameter, exciting power, heating duration, variable capacitor (VC1) capacitance, and heating diameter are shown

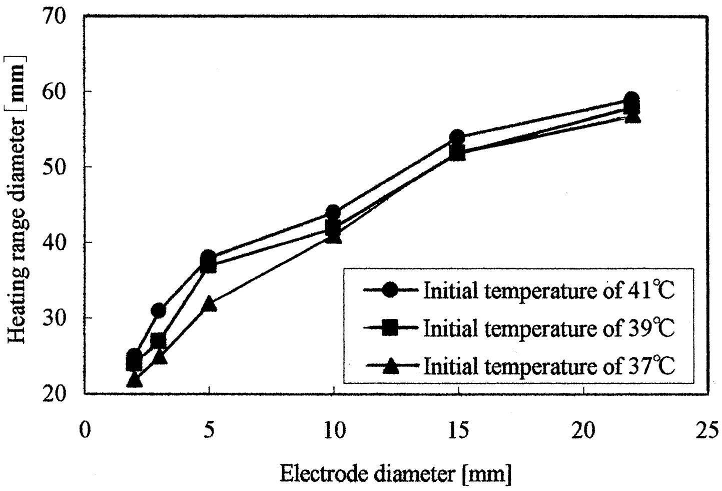


Fig. 6. Relationships between electrode diameter and heating range diameter for Fig. 3 (a).

Table II. Experimental data for 41°C initial temperature.

Diameter of electrode 〔mm〕	Power 〔W〕	Heating duration 〔min〕	Capacitor (VC2)value 〔pF〕	Heating diameter 〔mm〕
2	50	8	75	25
3	50	10	75	31
5	100	5	50	38
10	250	3.5	20	44
15	500	3	20	54
22	500	5	20	59

in Table I with initial subject temperatures of 37°C, 39°C, and 41°C, respectively. Results indicate that as initial temperature increases, the heated area over the interstitial electrode vicinity increases and heating time decreases. When cloudiness mostly spread in right and left equally with initial temperature of 41°C, exciting power, heating duration, variable capacitor (VC1) capacitance, and heating diameter are shown in Table II. We confirmed that smaller interstitial electrode diameter increases variable capacitor (VC1) capacitance and decreases exciting power.

Heating characteristics with interstitial electrode and paired electrode excitement

In the previous section, concentrated heating was realized by unbalancing electric currents of paired electrodes without excitation of the interstitial electrode because a common mode of electric current occurring from unbalanced electric currents of paired electrodes flows into the interstitial electrode. This common mode can be supplied by exciting the interstitial electrode. This section describes concentrated heating with both the interstitial electrode and paired electrodes, but only a high frequency electric current of a differential mode was supplied to paired electrodes without a capacitor. Here, one RF power supply serves both external and internal heating, so a variable capacitor (VC2) was connected to the interstitial electrode to control quantity of electric current flowing into the interstitial electrode.

It was shown that cloudiness spread over right and left of the interstitial electrode equally on every interstitial electrode (cloudy areas became circular when observed from above) as in the previous section. In addition, higher initial subject temperature and larger interstitial electrode diameter increase the area of the heating region as shown by cloudiness. Furthermore, the two phenomena whereby cloudiness spreads to the right- or left-side of the interstitial electrode can be controlled by variable capacitor (VC2) capacitance.

Measured cloudiness diameter of a heating region vs. interstitial electrode diameter with various initial subject temperature is shown in Fig. 7. Fig. 7 illustrates that when initial subject temperature increases, cloudiness diameter of the interstitial electrode circumference increases.

When cloudiness mostly spread in right and left equally with the 5 mm diameter interstitial electrode,

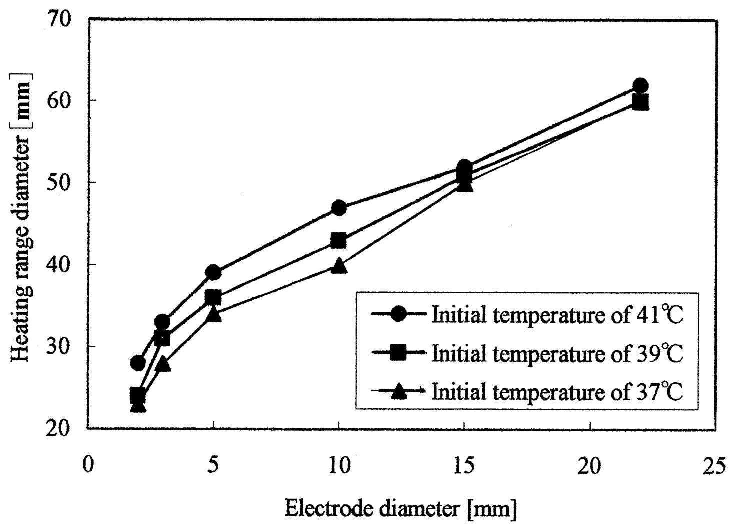


Fig. 7. Relationships between electrode diameter and heating range diameter for Fig. 3 (b).

Table III. Experimental data for a 5 mm diameter interstitial electrode.

Initial temperature 〔°C〕	Power 〔W〕	Heating duration 〔min〕	Capacitor (VC2)value 〔pF〕	Heating diameter 〔mm〕
37	500	7	20	34
39	500	4	20	36
41	500	5	20	39

Table IV. Experimental data for 41°C initial temperature.

Diameter of electrode 〔mm〕	Power 〔W〕	Heating duration 〔min〕	Capacitor (VC2)value 〔pF〕	Heating diameter 〔mm〕
2	500	4	10	28
3	500	7	12	33
5	500	5	20	39
10	500	3	30	47
15	500	4	30	52
22	500	4	70	62

exciting power, heating duration, variable capacitor (VC2) capacitance, and heating diameter are shown in Table III with initial subject temperatures of 37°C, 39°C, and 41°C, respectively. Results indicate that as initial temperature increases, a heated region area over the interstitial electrode vicinity increases and heating time decreases. When cloudiness mostly spread in right and left equally at initial temperature of 41°C, exciting power, heating duration, variable capacitor (VC2) capacitance, and heating diameter are shown in Table IV. We confirmed that the smaller the interstitial electrode diameter, the smaller the variable capacitor (VC2) capacitance.

Heating characteristics with only interstitial electrode

Heating experiments with an interstitial electrode have been done without paired electrodes to examine influence of paired electrode presence. Initial subject temperature was controlled at 37°C before inserting the interstitial electrode. For each interstitial electrode diameter, the cloudy area size was similar to that of the interstitial heating system combined with external heating at 37°C in Fig. 5 (a). These results are a consequence of the subject heated to 37°C before inserting the interstitial electrode.

Discussions

In current heating methods using an interstitial electrode, the heating region could not be enlarged despite increased heating power and the heating effect was limited to a specific region. To overcome this problem, methods to enlarge the heating region without limitation on excitation power have been explored. There are some cases where limited small parts of tumors should be selectively heated, such as heating for esophageal cancer, where important internal organs are adjacent to limbs and where selective reduction of cancers obstructing normal tissue is desired. In such cases, intracavitary heating without initial heating with external electrodes may be the most suitable method. This paper examines heating area enlargement combined with interstitial and external electrodes. Several heating systems, such as RF interstitial heating with remotely controlled after-loading system (RALS)[8], RF interstitial heating combined with brachytherapy[11], and RF capacitive intracavitary hyperthermia with considered opposite flat applicator[13], were proposed for improving heating effects. The important possibility that the heating area could be magnified with internal and external RF was examined from the engineering point of view.

As a result, we arrived at a heating system combining internal and external electrodes. Two electric power supply methods were proposed and their characteristics examined. The following section presents heating system characteristics. Quantitative handling of effective electrical power use shall be treated in the near future.

The present temperature distribution may not apply to clinics because a living body consists of inhomogeneous tissues (muscle, fat) and air. In addition, the interstitial electrode may not be always inserted in parallel to external electrodes, or the interstitial electrode may not be located in the center of two external electrodes. Such experimental conditions will be examined in the near future.

From experimental results, increasing the interstitial electrode diameter seems to be more effective for heating than increasing initial temperature. Considering application to internal organs of interstitial or intracavitary heating at actual clinics, the electrode diameter is limited. Therefore, the heating effect could be improved by increased initial temperature combined with internal and external heating even with the same interstitial electrode diameter. This phenomenon appears especially with electrodes of 5-10 ㎜ diameter, where the heating region spreads 20% over the maximum as shown in Fig. 4. The cloudy region that we showed with experimental results demonstrated temperature distribution equal to 45.5°C or higher. Temperature distribution of around 43°C is effective for hyperthermia treatment and is estimated to be larger than present experimental results.

Fundamental heating characteristics

We confirmed difficulty of heating a limited region using only external RF heating method by preliminary experiment of noninvasive methods. The wide region of the homogeneous subject was heated because electric currents of a differential mode flowed equally to each paired electrode through a common mode rejection filter (CF5kV).

Next, we confirmed that when an unexcited interstitial electrode was used, concentrated heating did not occur on the interstitial electrode circumference. Because an electric current did not flow to the interstitial electrode and electric currents from each paired electrode were balanced due to a common mode rejection filter (CF5kV), the wide region of the subject is heated similar to the system without the interstitial electrode. Therefore, we inferred that concentrated heating became possible if electric currents flowed to each paired electrode were controlled to unbalance.

Heated region enlargement was confirmed in this proposed system. Heating region area increases when temperature is high in the interstitial electrode circumference because, generally, heat occurring with the interstitial electrode is dissipated in the circumference by heat conduction, but heat conduction is reduced if circumference temperature is high. As a result, the concentrated heating region is magnified

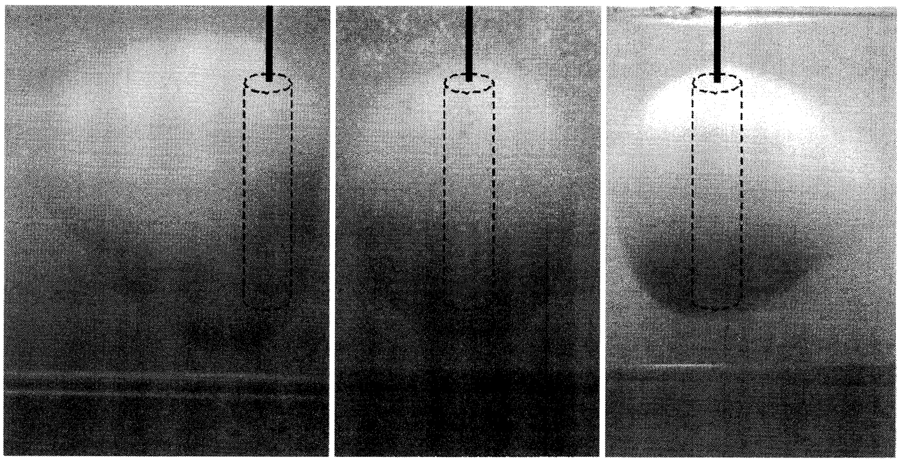
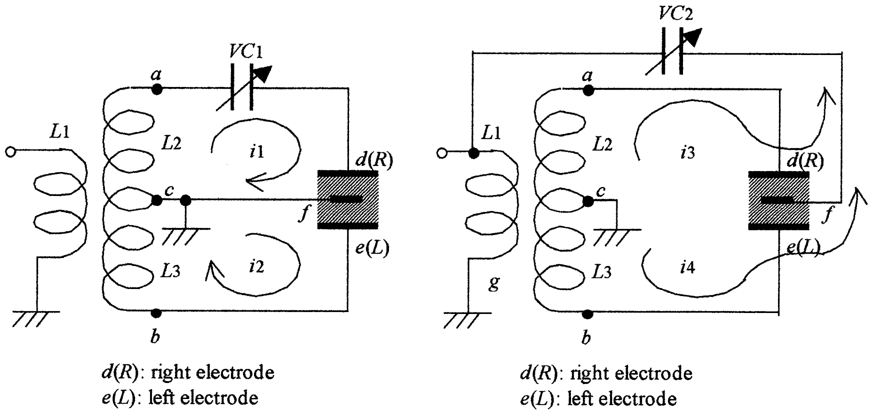


Fig. 8. Heating results using a 10 mm diameter interstitial electrode in Fig. 3 (a). Figs. (a), (b), and (c) show results of capacitor values of 3 pF, 20 pF, and 50 pF, respectively.



(a) Equivalent circuit of Fig. 3 (a). (b) Equivalent circuit of Fig. 3 (b).

Fig. 9. Principles of concentrated heating using an interstitial electrode combined with paired external electrodes.

in the interstitial electrode vicinity.

Heating characteristics with unbalanced current paired electrodes

We confirmed that the interstitial electrode vicinity was heated by the system with a variable capacitor (VC1) inserted into the right side of paired electrodes to change balance between electric currents of each paired electrode. Furthermore, in increasing capacitance of the capacitor from a minimum value to a maximum one, cloudiness spread consequently to the left side, center, and the right side of the interstitial electrode (Fig. 8). This is explained below.

Fig. 9 (a) shows an equivalent circuit of the heating system in Fig. 3 (a) including a balun, paired electrodes (d, e), an interstitial electrode (f), and a variable capacitor (VC1). Here, an electric current, i1, flows through L2, point a, VC1, Cdf (capacitance between the right side electrode of paired electrodes d and an interstitial electrode), point f, and point c; and an electric current, i2, flows through L3, point c, point f, Cef (capacitance between the left side electrode of paired electrodes e and an interstitial electrode), and point b. Voltage across L2 (Vac) is equal to voltage across L3 (Vcb) from the balun characteristics. If there is no VC1, the absolute value of i1 equals i2 and phase and electric current flow between f-c is zero (i1 - i2 = 0). When a small capacitance of VC1 is inserted into the right side of paired electrodes, i1 becomes small because reactance in the circuit of i1 increases. When VC1 capacitance exceeds that of the previous condition, a series resonance frequency in the i1 circuit coincides with the excitation frequency and i1 becomes larger than i2. Although there is a certain intermediate value of VC1 where absolute values of i1 and i2 meet, the value of i1 - i2 does not equal zero due to phase difference caused by VC1. For correspondence to these conditions, the subject is heated on the left side, the right side, and the center of the interstitial electrode. As a result, we infer that the proposed system can heat selectively on locations such as the left, the right, and the center of the interstitial electrode by controlling VC1 capacitance.

In addition, we predict that a heating region could be magnified even more if the subject is heated in turn on the left and the right side of the interstitial electrode by controlling variable capacitor (VC1) capacitance as small and large in a timed sequence.

Heating characteristics with interstitial electrode and paired electrode excitement

Results confirmed that the interstitial electrode vicinity was heated by exciting not only paired electrodes but also the interstitial electrode whose electric current was controlled by the variable capacitor (VC2) inserted between an unbalanced feeding point and the interstitial electrode. In the process of increasing VC2 capacitance, cloudiness spread to the right side, center, and left side of the interstitial electrode in order. These phenomena are explained below.

Fig. 9 (b) shows an equivalent circuit at having connected VC2 to series between the interstitial electrode and the unbalanced feeding point. A resonance frequency of a circuit consisting of VC2, L1, point g, point c, L2, and Cdf does not coincide with that of a circuit consisting of VC2, L1, point g, point c, L3, and Cef. Current i3 increases when a resonance frequency of an upper circuit including L2 is set to an excitation frequency by adjusting VC2. If VC2 capacitance is increased, i3 decreases because the upper circuit resonance frequency is out of the excitation frequency. As a result, i3 = i4. Furthermore, i4 increases according to larger VC2 capacitance because a resonance frequency of the bottom circuit including L3 coincides with excitation frequency. Corresponding to these conditions, the right, center, and left side of the interstitial electrode are heated. It appears possible to heat a required position located on the right or left side of the interstitial electrode selectively by adjusting VC2 capacitance.

In addition, a heating region can be magnified if the subject is alternately heated at the right and left side of the interstitial electrode in turn. The actual control method will be examined in near future.

Heating characteristics at having used only interstitial electrode

We confirmed that heating characteristics, i. e. the cloudiness size, at having used only the interstitial electrode without a paired electrode were similar to results with interstitial electrode and paired electrode excitement in the case of 37°C initial temperature. In other words, effective concentrated heating was done by the interstitial electrode after heating a wide region of the subject at high temperature with or without paired electrodes. However, it is impossible to control subject temperature beforehand when only the interstitial electrode is used. Moreover, it is more difficult to control the heating region without paired electrodes because blood flow carries away heat in a living body. In the present paper, effective heating was enabled by concentrated heating with the interstitial electrode together with initial wide region heating with paired electrodes.

Conclusions

External RF heating technique allows the advantage of heating a wide region of a subject while it has a disadvantage that it is difficult to limit the heating location. On the other hand, interstitial RF heating method allows ability to heat selectively only an affected part, while the heating region is limited at the electrode vicinity. This paper explored a heating method to enlarge the heating region without any limitation on excitation power. As a result, two heating systems were developed combining external RF heating with paired electrodes and interstitial RF heating with interstitial electrode and the possibility of heating region enlargement was examined using a liquid adhesive.

From experimental results, concentrated heating in an interstitial electrode vicinity was provided : 1) when the balance of electric currents flowed to each paired electrode was adequately adjusted by a variable capacitor with a grounded interstitial electrode ; and 2) when both paired electrodes and the interstitial electrode were excited. Cloudy region diameter of the heating location expansion by increasing initial subject temperature was examined with varying interstitial electrode diameters. Results confirmed that a heating region of the subject could be magnified if subject temperature was raised. Considering results mentioned above, two heating systems which used an interstitial electrode together with external electrodes were judged to be effective for concentrated heating region expansion. Heating tests with more efficient interstitial electrodes should be undertaken in the future for human body equivalent phantoms as heating subjects.

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RF 容量結合型加温併用による挿入電極の加温領域の拡大に関する基礎研究

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要　旨: 針状挿入電極だけを用いた内部加温法では, 被加温部位を限定できるが加温領域が狭いという問題があった. 本論文では, 選択的に加温できる内部 RF 加温法に, 対極板を用いた外部 RF 加温法を組み合わせて, あらかじめ生体全体を加温することにより, 加温領域を拡大する方法を開発した. ディファレンシャルモードとコモンモードの RF 電流を制御する加温システムを構築した. 2 種類の方法を工夫した. アドヘア糊を用いた加温実験の結果, 外部 RF 加温による被加温体の初期温度が高いほど, また円筒型電極の直径が大きいほど, 加温領域を効率的に拡大できることを示した.