HEATING PERFORMANCES OF ARRAY APPLICATOR FOR INTERSTITIAL MICROWAVE HYPERTHERMIA: NUMERICAL SIMULATION AND CLINICAL TRIAL

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Abstract: The authors previously studied array applicator composed of few coaxial-slot antennas for minimally invasive microwave thermal therapy of cancer. In this paper, the heating characteristics of the array applicator composed of four coaxial-slot antennas are described. Moreover, result of clinical trial using the array applicator will be introduced.

INTRODUCTION
In recent years, various types of medical applications of microwaves have widely been investigated and reported [1]. In particular, minimally invasive microwave thermal therapies using thin applicators are of a great interest. They are interstitial microwave hyperthermia [2] and microwave coagulation therapy (MCT) [3] for medical treatment of cancer, cardiac catheter ablation for ventricular arrhythmia treatment [4], thermal treatment of BPH (Benign Prostatic Hypertrophy) [5], etc. Up to now, the authors have been studying such thin coaxial antennas for the interstitial microwave hyperthermia.

Hyperthermia is one of the modalities for cancer treatment, utilizing the difference of thermal sensitivity between tumor and normal tissue. In this treatment, the tumor is heated up to the therapeutic temperature between 42 and 45 °C without overheating the surrounding normal tissues. We can enhance the treatment effect of other cancer treatments such as radiotherapy and chemotherapy by using them together with the hyperthermia.

The interstitial microwave hyperthermia is applied to the localized tumor by inserting thin microwave antennas into the targeted tumor. In addition, an array applicator composed of few thin microwave antennas is employed for the treatment of large-volumed tumor. Therefore, we have investigated the array applicator composed of few coaxial-slot antennas, which are one of the thin microwave antennas.

In this paper, first, the structure of the coaxial-slot antenna is explained. Then, the heating characteristics of the array applicator composed of four coaxial-slot antennas are introduced. Finally, the result of clinical trial by use of the presented array applicator is described.

STRUCTURE OF THE ANTENNA
The authors have been studying the coaxial-slot antenna [6] for minimally invasive microwave thermal therapies. Figure 1 shows the structure of the coaxial-slot antenna. Here, the operating frequency is 2,450 MHz, which is one of the ISM (Industrial, Scientific, and Medical) frequencies. The coaxial-slot antenna is composed of a thin semi-rigid coaxial cable. Some ring slots are cut on the outer conductor of a thin coaxial cable and the tip of the cable is short-circuited. Here, $L_{ts}$ is the length from the tip to the center of the slot close to the feeding point, and $L_{ls}$ is the length from the tip to the center of the slot close to the tip. We confirmed the possibility of generating a localized heating pattern by employing two slots, especially $L_{ts}$ and $L_{ls}$ are set to 20 mm and 10 mm respectively. In addition, we also confirmed that the heating pattern of this coaxial-slot antenna is independent of the antenna insertion depth.

ARRAY APPLICATOR
Structure of the array applicator. In order to heat the large-volumed tumor, we construct the array applicator composed of few coaxial-slot antennas. This time, we employed the array applicator composed of four coaxial-slot antennas. Figure 2 shows the structure of the 4-element array applicator. Here, the antenna insertion depth and the array spacing are 30 mm and 20 mm, respectively. We set these parameters based on the clinical trial described later.

Calculated SAR distributions. In this paper, we estimated the heating performance of the array applicator by...
calculating the SAR distribution in and around the array applicator using the FDTD calculations. The SAR takes a value proportional to the square of the electric field generated around the antenna and is equivalent to the heating source created by the electric field in the tissue. Figure 3 shows the SAR distributions in and around the array applicator. The SAR observation planes and the FDTD space are defined in Fig. 2. From Fig. 3, we can observe that the high SAR regions exist not only near each antenna but also at center of the array applicator (x=y=0). The high SAR regions at the center of the array applicator are caused by the mutual coupling between each antenna element and will generate a relatively high temperature region at the center of the array applicator.

Recently, the array applicator composed of four coaxial-slot antennas could be applied to clinical trial. The patient is a male of 61 years old with a tumor in his right shoulder portion. Figure 4 shows the photograph of the patient during the treatment.

Figure 5 shows the positions of the antennas and the thermo sensors (fluoroptic temperature probes). In this case, we employed three thermo sensors in and around the targeted tumor for reliable heating. Here, the positions of sensor A, B, and C are located at the center of the array applicator, in the targeted tumor, and directly under the skin, respectively.

Figure 6 shows the transitions of the temperature. This time, the net input power of the array applicator is approximately 18.0 W. Although sensor B was placed outside of the targeted tumor, the minimum temperature of the sensor was 42 °C at the steady state (5 min < t). Therefore, in this case, we may say that the targeted tumor was completely covered by the therapeutic temperature. In addition, Figs. 7(a) and (b) show the tomogram of the patient before the treatment and the one after 2 weeks of treatment, respectively. In Fig. 7(b), we can observe a low density area, which is the area of necrosis, at the tumor portion. At present, we are observing the situation of the targeted tumor.

![Fig. 1 Basic structure of the coaxial-slot antenna.](image1)

![Fig. 2 4-element array applicator.](image2)

![Fig. 3 SAR distributions in and around the array applicator.](image3)

**CLINICAL TRIAL**

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CONCLUDING REMARKS

The heating characteristics of the array applicator composed of four coaxial-slot antennas are described. First, we explained the structure of the antenna and the array applicator. Next, we showed the calculated SAR distributions in and around the array applicator. From this result, we can observe that the high SAR regions exist not only near each antenna but also at center of the array applicator. Finally, the effectiveness of the array applicator has been proved by clinical trial.

As a further study, a treatment combined with interstitial radiotherapy will be performed by use of an array applicator for the treatment of uniradiocurable tumors.

REFERENCES