A new interstitial choke embedded antenna for microwave ablation

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Abstract: We propose an interstitial coaxial antenna with a choke embedded in the outer conductor and with an arrowhead cap for microwave ablation therapy, operating at 2.45 GHz. The cap consists of ceramic and conductor. The heating is suppressed along both the direction in the tip side and the feeding side of the antenna because of the cap and the choke. In addition, a catheter is not required. We numerically clarify these advantages by analyzing the temperature distribution of a spherical breast tumor.

Keywords: ablation, interstitial coaxial antenna, non-catheter type, choke, microwave heating

Classification: Electromagnetic Compatibility (EMC)

References

- [1] C. Brace, “Thermal tumor ablation in clinical use,” *IEEE Pulse*, vol. 2, no. 5, pp. 28–38, Sept./Oct. 2011. DOI:10.1109/MPUL.2011.942603
- [2] J. M. Bertram, D. Yang, M. C. Converse, J. G. Webster, and D. M. Mahvi, “A review of coaxial-based interstitial antennas for hepatic microwave ablation,” *Crit. Rev. Biomed. Eng.*, vol. 34, no. 3, pp. 187–213, 2006. DOI:10.1615/CritRevBiomedEng.v34.i3.10
- [3] S. Kuwano, K. Nemoto, and T. Michiyama, “A new interstitial antenna for microwave ablation,” *IEICE Commun. Express*, vol. 6, no. 5, May 2017, in press.
- [4] R. Sharma, J. L. Wagner, and R. F. Hwang, “Ablative therapies of the breast,” *Surg. Oncol. Clin. N. Am.*, vol. 20, pp. 317–339, Apr. 2011. DOI:10.1016/j.soc.2010.11.003
- [5] M. Converse, E. J. Bond, B. D. Van Veen, and S. C. Hagness, “A computational study of ultra-wideband versus narrowband microwave hyperthermia for breast cancer treatment,” *IEEE Trans. Microw. Theory Techn.*, vol. 54, no. 5, pp. 2169–2180, May 2006. DOI:10.1109/TMTT.2006.872790

1 Introduction

Microwave ablation (MWA) is a minimally invasive technique increasingly used for thermal therapy of tumors [1]. It requires efficient interstitial antennas that destroy spherical tumor of early stage and maintain a margin of healthy tissues while minimizing damage to the rest of the organ. A conventional coaxial antenna is that the radiated power extends all along the antenna and its feeding line. The heating region assumes consequently a teardrop, which is undesirable. In order to improve the radiation properties, many coaxial-based antennas including the monopole antenna, the dipole antenna, the slot antenna, and others, have been developed for MWA [2]. However, an insertion device is necessary because the caps of these antennas are almost flat.

We previously devised a new non-catheter type coaxial-slot antenna constructed by a needle of ceramic and conductor [3]. The usefulness of this antenna has proved experimentally by using the liver phantom.

In this letter, we propose an interstitial coaxial antenna with choke embedded in the outer conductor of the previous new structure in order to obtain a more spherical heating distribution.

2 Analysis and discussion

Fig. 1 illustrates the central vertical cross section (zx plane) of a proposed coaxial slot antenna where (a) and (b) are the whole and the enlarged choke part, respectively. The spacer between the coaxial inner and outer conductors is Teflon (relative permittivity: 2.1), and the cap is the arrowhead of ceramic (relative permittivity: 9.8) plate and copper plate [3]. The choke having a length of L and an adjusting length of l is newly embedded in the coaxial outer conductor. The slot width is represented by W .

We target an early stage breast tumor that MWA has been shown to be clinically effective [4]. The CST MW-Studio (Electromagnetic field analysis: finite integral method, Thermal analysis: difference method of bio-heat equation [5]) was used in numerical analysis. The cells at the tip and the slot end of the antenna that the electromagnetic fields concentrate are divided small and densely in the analysis region. The breast has mainly a complicated tissue distribution of the mammary

Fig. 1. Cross section of a proposed antenna; (a) Whole, (b) Choke part.

gland and fat. At an operating frequency of 2.45 GHz, the relative permittivity and conductivity of the breast averaging them are 15.8 and 0.451 S/m, while those of the tumor are 53.4 and 1.84 S/m. In addition, the thermal constants are cited from Ref. [5]. The blood flow is not considered. The breast model is a rectangular block of 40 mm in length, 40 mm in width, 60 mm in height. The tumor is a sphere of a diameter of 16 mm centered 30 mm from the breast surface. We searched for the sizes of the choke that the temperature distribution becomes closer to spherical when $W = 2$ mm [3].

Fig. 2 shows the temperature distribution of the central vertical cross section (zx plane) of the breast model inserted of the antenna, where (a) represents the proposed antenna with the choke ($L = 18$ mm, $l = 3$ mm), and (b) and (c) represent the conventional antenna without the choke of the new cap [3] and copper cap, respectively. Also, the dotted circle represents the tumor, the heating time $t = 110$ s, the breast and tumor temperatures $T_b = 37^\circ\text{C}$, the air temperature $T_a = 24^\circ\text{C}$, and the convection coefficient between the breast and the air $H = 50\text{ W/m}^2\cdot^\circ\text{C}$. At 2.45 GHz, the reflection coefficient $|S_{11}|$ of the proposed antenna was -2.8 dB, while those of the conventional antennas of the new cap and copper cap were -4.7 dB and -5.7 dB, respectively. The reason for poor $|S_{11}|$ of the proposed antenna is designed for the liver tumor therapy [3]. The $P = 10$ W is given as the net input power because there are differences in the reflection coefficients of three antennas. We set the input power low to avoid a too high temperature rise of the tumor. It is understood that the temperature in the axial direction of the proposed antenna is suppressed by the expected effects of both the new cap and choke as compared with those of the conventional ones. The part of the distribution has not reached a therapy temperature above 60°C so that it is necessary to slightly pull up the antenna and to slightly increase the input power. The proposed antenna consequently reduces the excessive heating region of normal tissue than the conventional ones.

In order to estimate more clearly, Fig. 3 shows the temperature characteristics in the breast model on the z axis of $x = 1.5$ mm from the antenna center in Fig. 2 where the solid line represents the proposed antenna, and the broken and dotted lines represent the conventional antennas of the new cap and copper cap, respectively. In the axial direction, the therapy temperature of the proposed antenna is suppressed by about 68% than that of the conventional one of the new cap assuming 60°C at the breast surface. However, the effect of the new cap that suppresses heat diffusion to the tip direction is smaller than that of the new cap for the liver tumor therapy. This is because the fat tissue with low moisture content around the breast tumor is less likely to diffuse heat while the muscle tissue with high moisture content around the liver tumor is the opposite.

Finally, we will consider whether or not the proposed fine choke can be realized. Teflon as the choke spacer expands only by about 10^{-3} mm with a rise of 100°C at a thickness of 0.15 mm, as estimated from the thermal expansion coefficient. The heat resistant temperature of Teflon also is 260°C at maximum. We believe that current advanced microfabrication technology based on these data can produce the choke which can withstand practical use.

Fig. 2. Temperature distribution inside the breast model (dotted circle: tumor); (a) Proposed antenna, (b) Conventional antenna [3], (c) Conventional antenna, $W = 2$ mm, $f = 2.45$ GHz, $P = 10$ W, $t = 110$ s.

Fig. 3. Temperature characteristics in the breast model; $W = 2$ mm, $f = 2.45$ GHz, $P = 10$ W, $t = 110$ s.

3 Conclusion

We numerically analyzed the temperature characteristics of breast tumor by using a coaxial-slot antenna with choke embedded in the outer conductor of the previous new structure. As a result, the temperature in the axial direction is significantly suppressed as compared with those of the conventional ones. It is namely clarified that this antenna can be applied to the treatment of breast tumor.

The future task is to improve the reflection coefficient, and to perform a phantom experiment although it is difficult to make the choke.

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