Disign and Thermal Distribution of Intra-hyperthermia Microwave Antennas for Utero-cervical Applicators

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Intracavitary brachytherapy combined hypertermin for utero-cervical cancer seems to be a promising method for salvage treatments in persistent tumors and inoperable or previously irradiated cervical recurrences. In order to heat the vaginal apex and uterus, powerfull conical antennas which are suitable for afterloading cervical applicator have been designed for use in conjuction with intracavitary radiation therapy.

The antennas were constructed with conical conductive material to feed line and the effective lenght were designed proportional to microwave length, Power deposition profiles of 2450 MHz of conical antennas were studied in both phantom models and muscle tissue and compared to those of commonly used dipole antenna. Improvement of the heating pattern was found in both phantom and muscle tissue. The heating pattern produced by the conical antenna resembles an ellipsoid and then the temperature distribution in depth was extended to 2~3 cm from the effective antenna axis.

Key Words: Microwave, Intra-hyperthermia, Conical antenna

INTRODUCTION

A lot of cervical cancer and local recurrences following treatment with radiation therapeutic modalities are often difficult to manage. Normal tissue tolerance may prevent the use of additional full dose radiation therapy and therefore palliation is the therapeutic goal in these patients[1,2].

The rational for the use of hyperthermia in the treatment of cancer is firmly supported by experimental and clinical studies[3]. Temperatures in the range 41~45℃ clearly show cytotoxic and radiosensitizing effects when combined with low doses of ionizing radiation. The radiosensitizing effect is probably due to the ability of hyperthermia to inhibit the repair of sublethal radiation damage. Based on the promising clinical results obtained with irradiation combined with localized hyperthermia. The microwave antennas have been used for clinical interstitial hypertehermia treatment of intracranial neoplasms[4]. The dipole micro wave antennas restrict the applicability of intersitital microwave hyperthermia[5]. Because the operating frequency and dipole dimensions are major determinats of the radiated field, there is little flexibility in choosing the antenna length and total insertion depth in tissue to coincide with specific tumor dimensions. If suboptimal combinations of dipole length and implant depth are attempted, overheating of tissue at the antenna entrance site or otherwise unsuitable heating patterns can result[6,7]. Tissue near the center of such antennas is often not heated effectively, so that significant over implanting of the deep aspect of the tumor volume is required. We have developed te microwave antennas to be placed in the same plastic applicators which are used for the brachy therapy sources and designed the antenna as conductive conical shape to be homogeneous thermal distribution along to antenna axis. In the present study the power deposition profiles of conical antennas were compared at 2450 MHz to the performance of on interstitial dipole antenna. Extensive comparative studies in phantom models were followed by a verification of the results in muscle tissue.

MATERIAL AND METHODS

1. Design of The Conical Antennas

The conical antenna designed to provide enhanced center heating and a conventional diple antennas are shown in figure 1. Both antennas are manufactured from a section of 50Ω semi-regid coaxial cable with an outer diameter of 2.5 mm. The exposed insulated inner conductor of the conventional design is replaced by a brass cone in the improved design. The apex of the cone is soldered

*This work was supported by 1988 YUMC research fund.

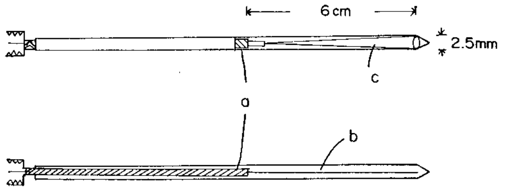

Fig. 1. Conventional antenna design (below) and conical antenna design (above). Both antennas are made from a section of coaxial cable (a) and the exposed inner conductor (b) is replaced by a cone (c).

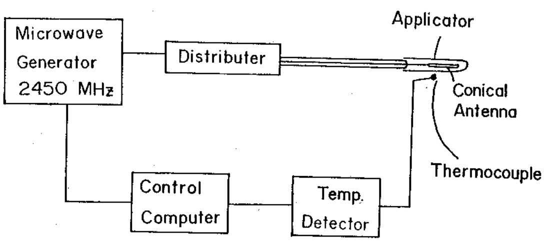

Fig. 2. Block diagram of intra hyperthermia system.

to the inner conductor. The active length of the antenna proposed to be resonance in microwave length and the active region of the antenna is completely encapsulated using a thin sheath of silicon rubber. The principle of operation is easily understood by recognizing the antenna as consisting of a conical tube over a ground plane. the configuration gives rise to a rather broad field pattern and shift toward the antenna tip. Antenna are designed to be used in afterloading applicator for intracavitary radiation therapy.

2. Experimental Procedures

Microwave generator for experiments is improved from commercial microwave oven which drived 2450 MHz continuous microwave power source and temperature controlled with microcomputer (Fig. 2). Power fed to each antenna was tuned with a double stub tuner for optimum impedance match to the generator. Tissue equivalent phantom was prepared using 75% water, 10% agar as gelling agent, 2% NaCl as conductive material and 5% NCl_2 for an antiseptic. The phantom material was plased inside a plastic container measuring 20×20×10 cm^3. The container could be split into two sections to allow measurements of heating patterns utilizing a thermographic film. The power required to elevate the temperature of the surrounding phantom approximately 42~43℃ in 5

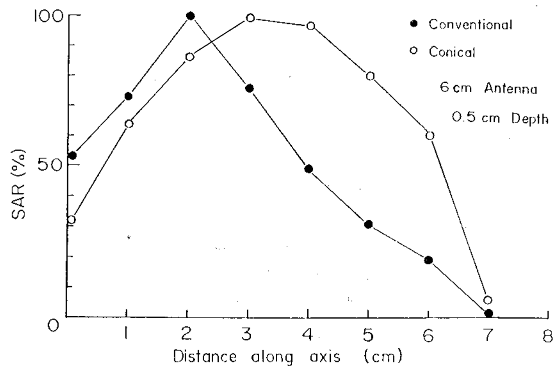

Fig. 3. The SAR distirubiton the 6 cm conical and conventional antennas.

minutes varied between 20~50 watt. The thermocouples were inserted in a catheter parallel to an 0.5 cm away from the antenna axis for measuring the temperature.

Thermal distribution were measured by moving the sensor probe 0.5 cm and repeating the heat trial after cool down of the phantom to initial conditions. Thus, multiple 3 minutes heat trials were performed the power deposition profile of each antenna configuration with the specific absorption rate (SAR).

RESULTS

A typical heating pattern produced by a conventional and conical microwave antenna placed in direct contact with tissue equivalent agar phantom is measured by thermocouples and thermography. The SAR (specific absorption rate) value can be calculated for each measuring point from the recorded temperature and time data during the phantom experiments. The SAR is given by $SAR = C\ \Delta T/\Delta t$, where C is the specific heat of the phantom and ΔT is the temperature rise during the time interval Δt. The time interval is selected as the initial 20 sec. of the heating. In Fig. 4, the SAR contour lines are shown for the phantom experiments. A normalization is done so that the maximum measured SAR value corresponds to 100 per cent. The three dimensional distribution of power deposition resembles an ellipsoid, most heating occurs in the region of the center and minimal power deposition accurs at the tip with the conical antenna.

The conventional antennas distribute the power more proximally compared to the conical ones. The reflected power level was 8.0 W for the conventional applicators and 4.5 W for the conical antenna. Fig. 3,4 shows the SAR values along to

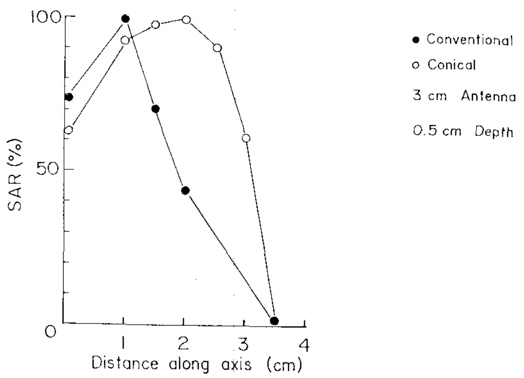

Fig. 4. The SAR distribution along the 3 cm conical and conventional antennas.

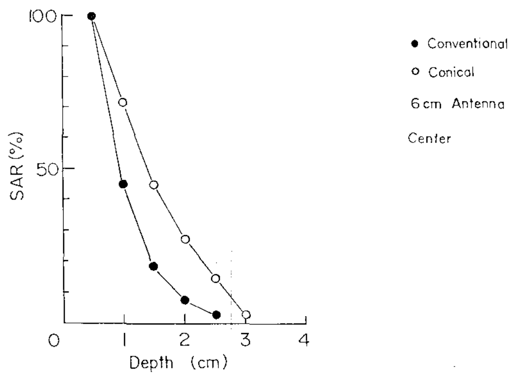

Fig. 5. The thermal distribution from the antenna axis of conventional and conical antennas.

axis of short and long length antennas of conical and conventional antennas. The more shorted length of antenna, the more homogeneous thermal distribution but the region of isothermal is smaller then long length antenna. Fig. 5 shows the SAR values at radial distance from antenna surface. The effective depth ($Tm/To=e^{-2}$) is 2~3 cm from the antenna surface. In order to heat the endocavitary after intracavitary brachytherapy, the conical antenna was inserted toward the tip of the same applicator tubes and one or two thermocouples to set in the interesting points. Planned temperature and heating time were controlled with computer control system and recorded the heating temperature of conical antenna in the utero-cervical apex.

DISCUSSION

The management of local recurrences of the cervix carcinomas is a challenge for the clinician both surgery and radiation therapy reveal severe limitations as salvage treatment[1,9], hyperthermia has been shown to potentiate the efficacy of low moderate dose of irradiation. In an attempt to impove the local response of previously irradiated cervical stump recurrences, palliative doses of radiation were combined with intracavitary hyperthermia[10,11]. To achieve this we developed a conical microwave antenna configuration which can improve the heating field localization at depth in tissue and small size (3 mm)to be inserted into the intracavitary high dose rate cervical applicators. Comparative thermal dosimetry results indicated that the heating profiles of conical antennas showed significant improvement over simple dipole antenna configurations in terms of insertion depth inependent heating, more uniform heating along the antenna axis and effective antenna tip heating.

A conventional interstitial microwave applicator is insuficient in many clinical situations because of the least uniformly shaped temperature distribution in the longitudinal plane. An improved design for microwave interstitial applicatiors is needed in relation to longitudinal heating. The extended heating produced by the conical antenna is mainly due to an increased microwave current towards the center compared to the convensional antenna. Measurement of the SAR distribution must be done carefully. One should use the initial period of the heaing to evaluate the rate of temperature rise (℃/S). Since the time interval must be short to minimize thermal diffusion, the resulting temperature rise might be too small to be measurable. One must therefore use a high imput power to get measurable temperature rise values. In clinical use the effect of blood flow, distance to bone and differences in positioning of applicators and temperature probes will cause variations in temperature patterns. The conical microwave applicator presented in this paper should be a useful tool for efficient intracavitary hyperthermia treatment, and presents a good chance of combining hyperthermia and intracavitary radiation brachy therapy.

REFERENCES

1. **Field SB, Bleehen NM:** Hyperthermia in the treatment of cancer. Cancer Treat Reviews 6:63-94, 1986
2. **Morley GW:** Pelvic exenteration in the treatment of recurrent cervical cancer. Surgery in Gyn. Oncology, 174-183, 1984

3. **Oleson JR, Sim DA, Manning MR:** Analysis of prognostic variable in hyperthermia treatment of 161 patients. Int J Rad Oncology 10:223-2239, 1984
4. **Coughlin CT, Wong TZ, Strohbehn JW, etc:** Intraoperative interstitial microwave-induced hyperthmia and brachytherapy. Int J Rad Oncology 11:1673-1678, 1985
5. **Lin JC, Kantor G, Grods M:** A class of new microwave therapeutic applicators. Rad Science 17:1197-1235, 1982
6. **Emani B, Perez CA:** Intercomparison of microwave applicators for hyperthermia. Hyperthermia Oncology 1:46-52, 1984
7. **Gidman V, Roos D, Lind SB:** Intercomparison of microwave applicators for hyperthermia. Hyperthermia Oncology 1:46-52, 1984
8. **Nilsson P:** Physics and technique of microwave induced hyperthermia in the treatemtn of malignant tumor. Ph.D. thesis. Univ Lund Sweden 33-35, 1984
9. **Kantor G, Witters DM, Greiser JW:** The performance of a new direct contact applicator for microvave diathermy. IEEE, Microwave Theory and Techniques 26:563-568, 1978
10. **Lagendijk JW, Hofman P, Schipper J:** A clinical computer controlled microwave hyperthermia system. Hyperthermia oncology 1:699-702, 1984
11. **Meyer JL:** Clinical efficacy of localized hyperthermia. Cancer Res Suppl 44:4745-4751, 1984

= 국문초록 =

자궁강내 온열치료를 위한 마이크로파 안테나의 제작과 온열 분포

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자궁암치료에서 재발되거나 치료가 어려운 종양에 대하여 방사선과 온열요법을 병행함으로서 치료 성과를 다소 향상시킬 수 있었다. 더욱이 방사선 근접조사와 강내온열치료는 주위 건강조직의 피해를 줄이면서 종양에 집중손상을 줄 수 있었으며 강내방사선조사 기구를 공동으로 이용하므로서 시술이 간단하고 치료부위를 정확히 조준할 수 있었다.

그러나 강내조사용 안테나는 그 모양과 구성에 따라 온열 분포가 변하며 재래식 쌍극철심형 안테나는 끝부분 또는 연결부위의 가온이 급증하여 균등한 온열분포를 기대할 수 없었다.

저자들은 안테나의 길이를 마이크로파의 약수 즉 3, 6, 12 cm로 하여 공명이 잘 이루어지도록 하였으며 끝이 굵고 접촉 부위가 가느다란 고깔형(conical) 안테나를 제작하여 사용한 결과 안테나 축에 따라 거의 일정하거나 약간 타원형의 온도분포를 이루었으며 가온 깊이도 2~3 cm로서 비교적 깊은 곳까지 가열할 수 있어 강내 치료효과를 향상시킬 수 있다고 생각된다.