Hyperthermia에서는 온도를 예측하는 것이 매우 중요합니다.
온도를 예측하는 방법으로 thermocouple을 직접 삽입하거나 MRI를 사용해야하는 등의 방법을 사용하고 있습니다. 이는 비효율적이며 과도한 비용이 문제입니다. 또한 장비의 QA방법도 단순 RF power를 측정하는 방식을 주로 사용하고있어 신체 전반부 각 부분에 흡수되는 열의 양을 알 수 없다는 단점이 있습니다.

이를 해결하기 위해 본 연구에서는 hyperthermia 장비의 전기적 특성과 LED의 휘도를 이용하여 tumor의 온도를 예측하고, 이를 장비의 QA에도 사용할 수 있도록 하는 것이 목표입니다.

Specific Absorption Rate(SAR)이란 전자파 흡수율로써 생체 조직의 단위 질량당 흡수되는 에너지의 비율을 나타내는 단위입니다. 식으로 표현하면 다음과 같습니다.

$$\mathbf{SAR} = \frac{\sigma}{2\rho}|E|^2$$

SAR을 이용하여 생체조직의 온도 또한 예측 할 수 있습니다. 이는 Pennes' Bio-heat Transfer Equation으로 나타낼 수 있는데 식은 다음과 같습니다.

$$\mathbf{0} = \nabla(\mathbf{k}\nabla\mathbf{T}) - \boldsymbol{\rho}_\mathbf{b} \times \mathbf{c}_\mathbf{b} \times \mathbf{w}_\mathbf{b}(\mathbf{T}_\mathbf{a} - \mathbf{T}) + \mathbf{Q}_\mathbf{m} + \mathbf{SAR} \times \boldsymbol{\rho}$$

이를 통하여 SAR을 통해 온도를 예측 할 수 있게 됩니다.

이때, 본 연구에서 주목한 점은 SAR이 전기장의 절댓값의 제곱에 비례한다는 것입니다. 전기장은 V/m으로 전압과 비례한다는 것을 이용하여 이를 LED의 휘도와 전압간의 관계를 이용하여 시각적으로 표현하고자 했습니다.

신체 전반부의 각 point별 온도를 예측하고자 phantom을 총 149 point로 나누어 실제 온도와 휘도를 각 point별로 측정하였습니다.

측정한 결과를 바탕으로 휘도를 통한 온도 예측 식을 fitting하였으며 이를 통해 예측한 온도를 상용화된 시뮬레이션 프로그램의 온도와 비교하였습니다.

실제 측정한 온도와 휘도를 통해 예측한온도, 시뮬레이션을 통해 예측한 온도를 각각 비교하여 각각의 오차는 3%이내로 신뢰성을 확보했습니다.

본 연구를 통해 hyperthermia 시 LED의 휘도를 통한 온도예측의 가능성을 확인하였으며, 이를 통해 hyperthermia 시 치료의 정확도를 상승 시킬 수 있을 것입니다.

추가보완사항으로는 본연구에서 사용된 phantom은 균일한 재질로 만들어진 phantom으로 체내 각 기관의 특성을 표현하지 못했다는 단점이 있습니다. 또한, 혈액의 흐름에 대한 내용을 포함하지 못했습니다.

추가적인 연구를 진행하여 이 두 가지 한계를 해결하게 되면 phantom만을 이용한 hyperthermia 치료계획을 수립 할 수 있을 것입니다.

Prediction of Tumor Temperature in Regional Hyperthermia by Using LED Luminance

Jaehyeon Lee[*†], Jinho Hwang[*†§], Yunji Seol[*†], Taegeon Oh[*†], Na young An[*†], Kyumin Han[*†], Hong Seok Jang[†‡], Byung Ock Choi[†‡], and Young-nam Kang[†‡]

*Department of Biomedicine & Health Sciences, The catholic University of Korea**
Advanced Institute For Radiation Medical Technology, College of Medicine, The catholic University of Korea†
Department of Radiation Oncology, Seoul St. Mary's Hospital, College of Medicine, The catholic University of Korea, Republic of Korea‡
Department of Radiation Oncology, Incheon St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea§

Introduction

Hyperthermia is used to destroy tumors by generating heat in the body (40-45° C). In particular, regional hyperthermia entails intense heating of tumors rather than raising the temperature of the body. In regional hyperthermia, the prediction of the tumor temperature before treatment is essential to ensure treatment efficiency and patient safety. The goal of this study is to predict the temperature of tumors in regional hyperthermia by using a light emitting diode (LED).

Materials & Methods

✓Materials

- The experiment was conducted using REMISSION 1 ˚C (AdipoLabs, Republic of Korea), hyperthermia with a frequency of 0.46 MHz, at 120 Watt.
- Luminance meter (HD2102.1, DELTA OHM, Italy) was used to quantitatively check the brightness distribution of LED.
- Temperature distribution was measured by a thermometer (OPTOCON, Weidmann, Germany) at the same point where each LED was located.
- Voltage was measured by a oscilloscope (TDS3032, Tektronix, USA)

✓Methods

- The SAR is a measure of the amount of RF energy absorbed by the human body. The equation is

$$\mathrm{SAR} = \frac{\sigma}{2\rho}|E|^2 \qquad (1)$$

- Where σ(S/m) is the electric conductivity, E(V/m) is the electric field, and ρ(kg/m^3) is the density of the material. Because the unit of the electric field is V/m, the electric field can be determined by measuring the voltage. Pennes' Bio-heat Transfer Equation is a standard model for predicting the distribution of tissue temperature:

$$0 = \nabla(k\nabla T) - \rho_b \times c_b \times w_b(T_a - T) + Q_m + \mathrm{SAR} \times \rho \qquad (2)$$

- Where k(S/m) = tissue conductivity, ρ_b(kg/m^3) = blood density, c_b($J/kg/°C$) = blood specific heat, w_b= blood perfusion, T_a(°C)= arterial temperature, T(°C)= tissue temperature, Q_m(w/m^3) = power generated by metabolism, and ρ(kg/m^3) = tissue mass density. Based on the two equations above, the heat absorption rate maybe shown non-invasively by measuring the voltage and finally predicting the temperature.
- The composition of phantom consists of 4.8L of water, NaCl 17.28 g and Agar powder 105.8g

Properties of the agar phantom

Heat capacity	4200 J/kg•°C
Thermal conductivity	0.498 W/(m·K)
Conductivity	2.97 S/m
Relative electric permittivity (ε/ε₀)	74.15

Table 1. Properties of the agar phantom.

- The agar phantom was made of a cylindrical shape with a thickness of 13 cm, width of 30 cm and height of 20 cm.

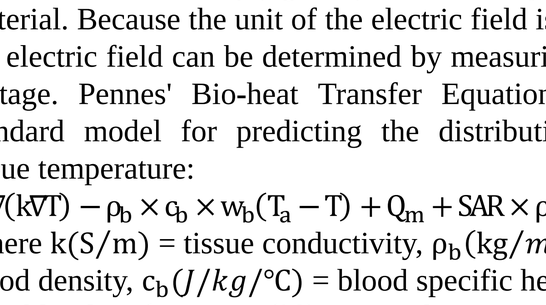

Fig 1. Design of phantom

- LED was used to check the distribution of electric field.
- The 110 mm size of electrode was used.
- The cathode and anode of LED were placed at 10 mm intervals, and the gap between LEDs was 10 mm. The luminance of the LED was measured by luminance meter. (measurement position was 1 cm apart from each LED)
- Luminance was measured by excluding the influence of surrounding LEDs.

Fig 2. Luminance measurement

- The temperature was measured using an 8-channel fiber optic thermometer which was unaffected by high frequency

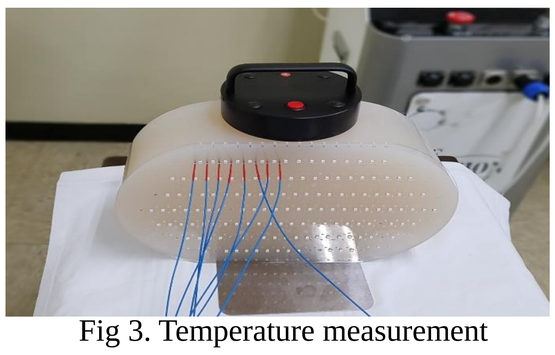

Fig 3. Temperature measurement

- The relationship between the distribution of electric field and temperature was verified by comparing the corresponding values at each point.

Results

- Fig 4. shows LED luminance distribution.

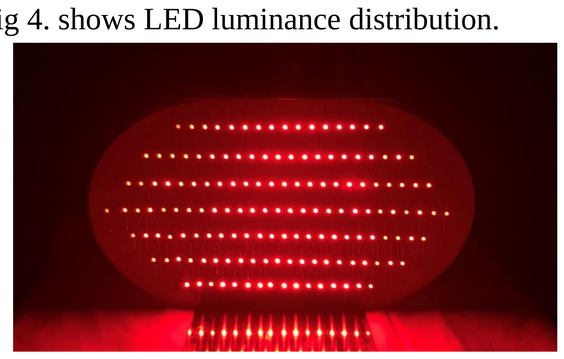

Fig. 4. LED luminance distribution

- Fig 5. shows the temperature of phantom in the same row.

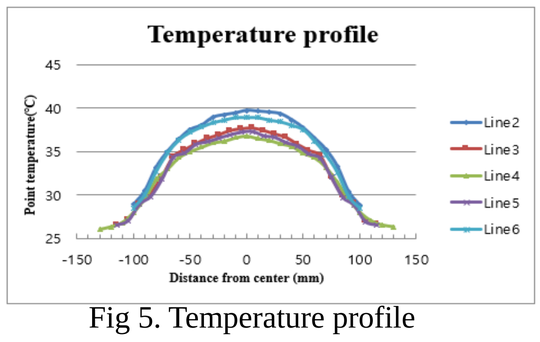

Fig 5. Temperature profile

- Fig 6. shows the luminance of LEDs in the same row.

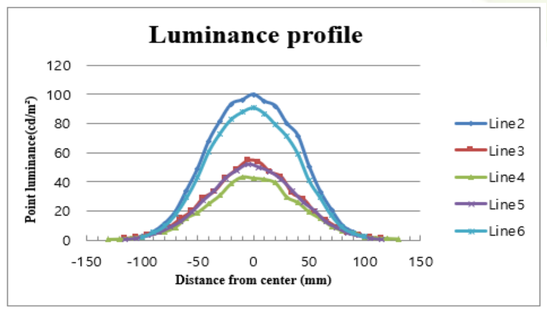

Fig 6. Luminance profile

- Fitting equation through voltage and luminance was derived.

$$\mathrm{Luminance} = a e^{-e^{-b-cV}}$$

- Where a = 1.035387E+04, b = 1.008857E+01, c = 4.900949E+00. The r2 value is 0.9997.
- Fig 7. show the Voltage-Luminance fitting curve

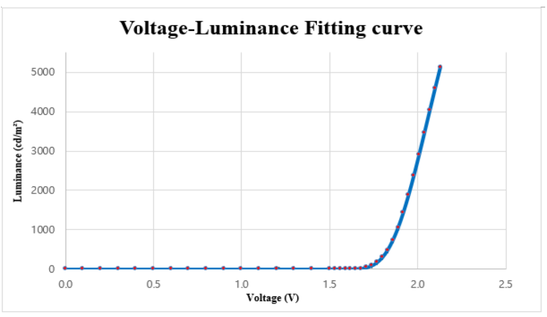

Fig 7. Voltage-Luminance fitting curve

- The temperatures measured directly and via simulation were compared to the temperature measured in order to verify the method of temperature prediction based on LED luminance. The error between the measured and the simulated temperature (M&S), the measured and the predicted temperature via luminance (M&P), and the simulated and the predicted temperature based on luminance (S&P) were compared. The error within the electrode size range was within 3%.

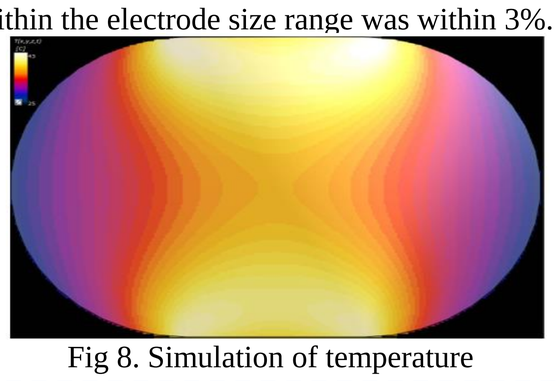

Fig 8. Simulation of temperature

Conclusions

- In this study, the temperature predicted by using the LED luminance, the temperature measured using a multichannel optical fiber thermometer, and the temperature obtained using the commercially available simulation program (Sim4life) were compared.
- The voltage was determined via the luminance. The SAR was predicted by using the acquired voltage. In the end, we confirmed that temperature prediction was possible using luminance.
- Through the use of LED phantom to determine the SAR distribution of the resistive electric transfer in hyperthermia, QA of the equipment ensures the safety of treatment.

Acknowledgement

This research was supported by Advanced Institute for Radiation Medical Technology(AIRFMT) at Catholic University of Korea.

This research was supported by AdipoLABs Co., Ltd.

THE CATHOLIC UNIVERSITY OF KOREA
CATHOLIC MEDICAL CENTER

Premier medical care founded in respect for life
CMC VISION 2020