Theoretical analysis of brain's physiological conditions during intravascular cooling

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***Abstract*—The heat transfer model of whole body was constructed including the model representing brain's physiological conditions, and it was validated by comparing with the clinical trial results of intravascular cooling. Furthermore, the PID control of brain tissue temperature was simulated for analyzing the transition of brain's physiological conditions during such control. In the results, the PID control of brain tissue temperature is so possible, when the control parameters are set considering the individual differences of physiological characteristics enough.**

I. INTRODUCTION

A mathematical model of brain's physiological conditions such as intracranial pressure and brain temperature was already constructed for using as the controlled object in its automatic control simulation, aiming at more advanced brain resuscitation treatment [1]. However, a model representing the control operation is also required for that simulation. In this research, a heat transfer model of whole body including the function of intravascular cooling (IVC) as one of the control operations was constructed for enabling the automatic control simulation of brain tissue temperature (BTT), and it was validated by comparing the results between the simulations and clinical trials. In Addition, the PID control was simulated by using this model for analyzing the transition of brain's physiological conditions during such control.

II. STRUCTURE AND ANALYSIS OF THE MODEL

As shown in Fig.1, the heat transfer model approximates the shape of a human body by a multi-segment concentric cylinder, in which the whole body is divided into 14 compartments, referring to Lu's model [1]. A mathematical model of brain's physiological conditions [2] was incorporated into brain compartment represented in Fig.1. In this model, the blood circulating in the whole body is cooled by a cooling catheter inserted into the inferior vena cava.

The 212 orders simultaneous differential equations were derived based on the physical laws of heat transfer between the compartments, as the model equation. The equations can be numerically analyzed by the Runge-Kutta method.

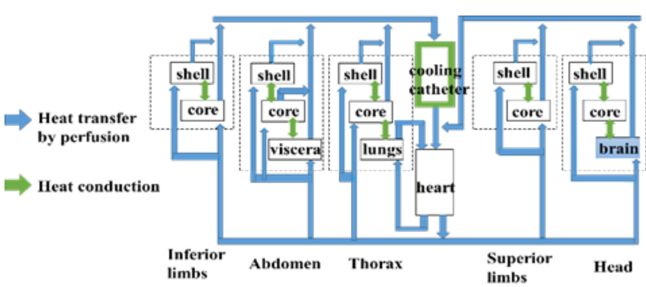

Figure 1. Schematic illustration of the constructed model

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First, the BTT in the model was respectively analyzed on the two conditions that the saline temperature (ST) circulating inside the cooling catheter were 30°C and 35°C. Then, the PID control of BTT was simulated, in which the target temperature, the initial ST, and KP, TI, and TD of the parameters in PID control were 32.5°C, 35°C, $1.0{\times}10^{-4}$, $1.0{\times}10^{5}$, and $1.0{\times}10^{2}$, respectively.

III. RESULTS AND DISCUSSION

The settling time and cooling rate of BTT changes were 74min, 5.26℃/h and 99min respectively, 1.21℃/h when the ST were 30°C and 35°C, which did not contradict the data measured in clinical practice. On the other hand, when the PID control, the settling time and overshoot of BTT were 50 minutes and 0.42°C, as shown in Fig.2. And ST's transition was almost consistent with BTT's transition, and the minimum of the ST was 30.62°C. These results did not contradict the clinical trial results during IVC. Therefore, the constructed model can reasonably represent body temperature changes during IVC and are useful for the PID control of BTT during IVC when the control parameters are set considering the individual differences of physiological characteristics enough.

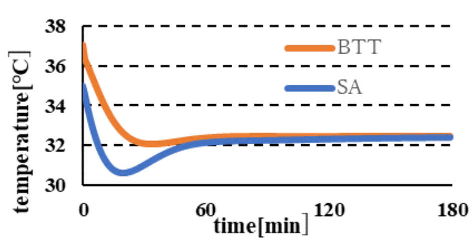

Figure 2. Transition of ST and BTT in PID control simulation

IV. CONCLUSION

The heat transfer model of whole body including the model of brain's physiological conditions was constructed and verified, aiming at the simulation of the PID control of BTT. The next challenges are to analyze the transition of brain's physiological conditions except BTT and to construct the control system adaptive to the individual differences.

REFERENCES

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