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Title: Parameter quantification for a simulation model of human cardiovascular system

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INTRODUCTION

Severe thermal environments cause human health problems. In the mechanism of the incidences, the changes in body temperature, blood pressure (BP) and blood flow rate (BFR) in vital organs are key factors. Numerical simulation with human thermophysiological model is one of the useful methods to evaluate the health risks caused by the severe thermal environments. Thus, we have been developing a new human thermophysiological model, which can predict not only body temperature but also BP and BFR (Figure 1). In our previous study (Sakamoto et al., 2015), we had measured some physiological quantities including BP and BFR to collect reference data, and developed a cardiovascular model to simulate the BP and BFR. In this study, we carried out some additional measurements and parameter tuning to quantify the parameters of this model.

METHODOLOGIES

Our cardiovascular model was developed based on Liang et al. (2009). This model consists of one-dimensional (1-D) model and lumped parameter (0-D) model. The 1-D model describes arterial tree, and its governing equations are (1) to (3) in Table 1. The 0-D model describes peripheral circulations, veins, heart and pulmonary circulation, and its governing equations are (4) and (5) in Table 1. In order to quantify some model parameters, a subjective experiment was carried out. The experiment was done in a climate chamber at Tohoku University, and the indoor temperature was set to 28℃, which is a neutral temperature for the subject. The subject was a healthy young male. He lay on a beach bed in a supine position with wearing only under pants and short pants during the experiment. The measurement items were BP, arterial blood flow rate, skin blood flow rate, heart rate (HR), artery cross-sectional area, left ventricular volume and pulse wave velocity (PWV). In order to quantify the other parameters which cannot be measured, some simulations were carried out with our model. The measured parameters were used for the simulation, and the other parameters, i.e. R, C and L of 0-D model, were tuned to make simulated BP and BFR correspond to measured values.

RESULTS AND DISCUSSION

From the measurements and parameter tuning, all model parameters were given. Figure 2 shows the simulated BP and BFR after the parameter tuning. The simulated values well agree with the measurements. However, BP and BFR change with thermal environment, because human body has autonomic thermoregulatory system. The changes of BP and BFR are mainly caused by regulations of peripheral resistance, vein compliance and HR. In our future study, we will develop a physiological model about these regulations and be able to simulate the changes of BP and BFR.

CONCLUSION

By means of measurements and parameter tuning, the cardiovascular model parameters under a basic condition, i.e. supine position and thermally neutral, were quantified. This model will be able to simulate BP and BFR under not only the basic condition but also hot/cold conditions, if the peripheral resistance, vein compliance and HR are given appropriately.

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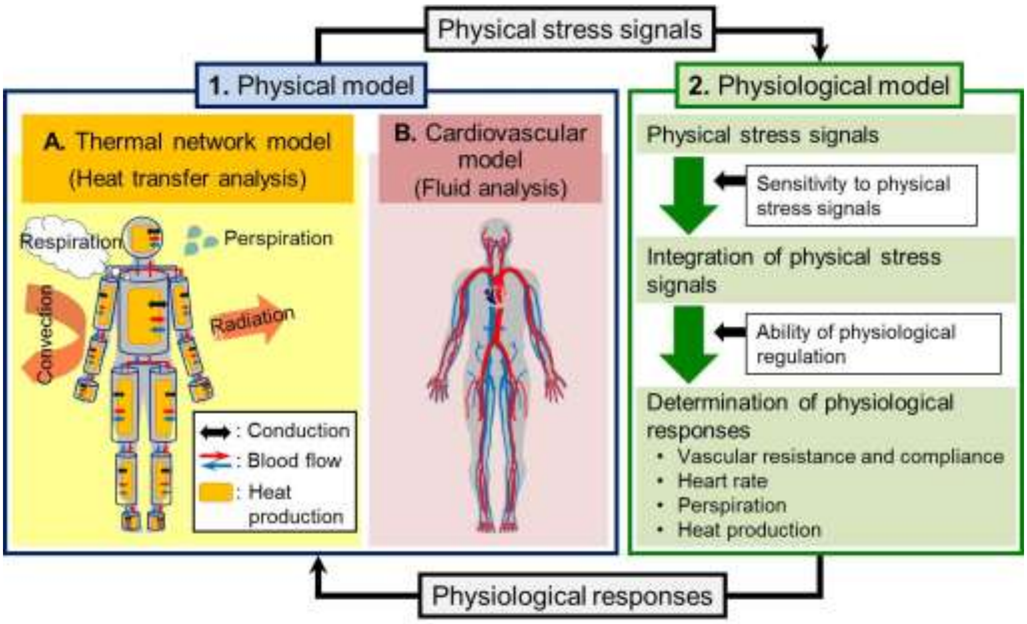

Figure 1. Schematic of new human thermophysiological model

Figure1

Table 1. Equations of cardiovascular model

1-D model

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \quad (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}+\frac{A}{\rho}P+gAH\right)+\frac{2\pi r\nu}{\delta}\frac{Q}{A}=0 \quad (2)$$

$$P=\frac{Eh}{r_0(1-\sigma^2)}\left(\sqrt{\frac{A}{A_0}}-1\right) \quad (3)$$

0-D model

$$C_j\frac{dP_j}{dt}=Q_j-Q_{j+1} \quad (4)$$

$$P_j-P_{j+1}=Q_jR_j+L_j\frac{dQ_j}{dt}+\rho gH \quad (5)$$

A	Cross-sectional area	[m^2]
C	Compliance	[m^3/Pa]
E	Young's modulus	[Pa]
g	Gravitational acceleration	[m/s^2]
H	Relative height	[m]
h	Wall thickness	[m]
L	Inertial resistance	[Pa·s^2/m^3]
P	Pressure	[Pa]
Q	Blood flow rate	[m^3/s]
R	Resistance	[Pa·s/m^3]
r	Vessel radius	[m]
t	Time	[s]
V	Volume	[m^3]
x	Axial coordinate	[m]
δ	Boundary layer thickness	[m]
ν	Blood kinematic viscosity	[m^2/s]
ρ	Blood density	[kg/m^3]
σ	Poisson's ratio (= 0.5)	
0	Reference state (P = 0)	
j	Segment number	

Figure2

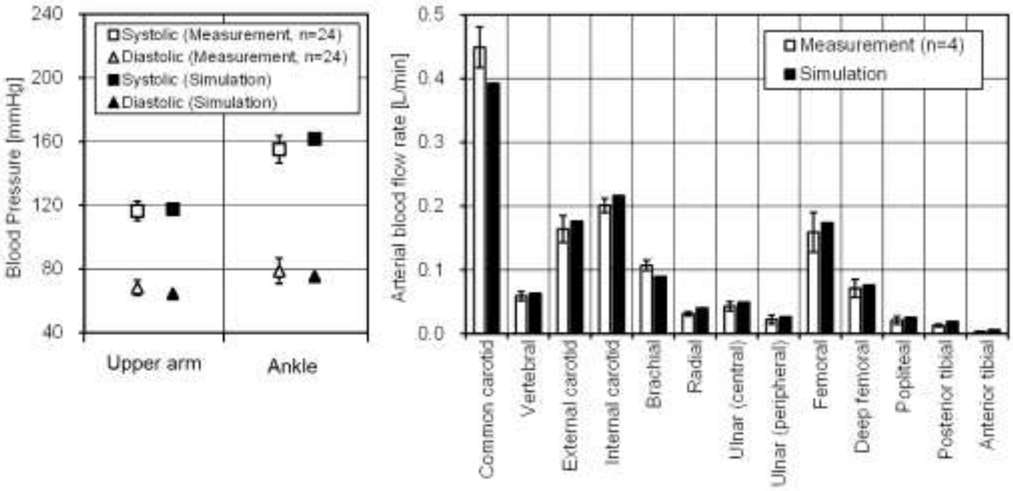

Figure 2. Blood pressure and blood flow rate

Figure3