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A METHOD OF HURTLESS DETERMINATION TISSUE METABOLIC RATE AT STEADY TEMPERATURE FIELD

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Abstract - **this paper presents a method of hurtless determination of tissue metabolic rate at steady temperature field. On the assumption that the relationship T (x) between the temperature T of inner body at the different position and these positions x is a quadratic equation, getting surface temperature of human body by infrared thermography. We deduced the relationship between the apparent conductivity and different position according to classical bio-heat transfer function. And then calculated the tissue Metabolic rate at the corresponding position under the conduction of the temperature field of inner body is keeping stable, and verified this method by experiment and calculation at last.**

***Keywords* - steady temperature field, hurtless measure, tissue metabolic rate, apparent conductivity, infrared thermography**

I. INTRODUCTION

The absolute difference between the biology and other materials on heat transform is that the former has inner heat source, which is produced through metabolism. This heat-produced metabolism is important for the biology. One of the major functions of it is making the biology maintain a very steady body temperature. Metabolize plays an important role in the course of human body' s energy transform and heat production. Metabolic rate is the speed rate of transformation from system chemical energy to heat energy. There are obviously differences lie in the metabolic rates of different tissues and organs while the basal metabolic rate depends on the living' s activate degree [1].

One important object of the bio-heat transfer research is to measure these metabolic rates and put it into application. Blood perfusion and metabolic rate are two the most important and unclear thermal parameters in the bio-heat transfer research [2]. At present, a lot of papers focus on blood perfusion that indicates the affection to heat transforms caused by blood stream, but few on inner heat source [3][4]. The metabolic rate may be the least known parameter in the biology heat transformation equation. Due to the difficulty of measuring some physiological parameters such as local oxygen consume and so on, the local tissue metabolic rate seems hardly to be directly measured and the measured results are not very accurate. So the determination of the living tissue metabolic rate is the difficult problem, much less than detection without hurt. But many researchers have done a lot work in field of biology thermal parameters determination and provided some measure value of these parameters for reference, and some scholars among them deduced the relation between inner blood perfusion and metabolic rate [5][6].

On the base above mentioned, getting surface temperature of human body by infrared thermography as boundary condition, we create the quadratic equation model of inner temperature field distribution under the conduction of inner temperature filed keeping stable. And we try to deduce the relationship between the apparent conductivity and different position according to classical bio-heat transfer function. Then calculate the tissue Metabolic rate at the corresponding position . So it presents a method of hurtless determination of tissue metabolic rate at steady temperature field.

II. METHODOLOGY

A. Theory

According to classical Pennes bio-heat transfer model[7]:

$$rC\frac{\partial T}{\partial t} = \nabla\cdot(K\nabla T) + w_b C_b r_b (T_a - T_u) + Q_m \qquad (1)$$

Where:

K : thermal conductivity, kJ/m・K・s

W_b : blood perfusion , kg / m^3 ・s

Q_m : tissue metabolic rate, kJ/ m^3

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Generally these three significant thermal parameters are varied with different time and position. Considering in bio-heat transfer research field the most basal measure parameter is the temperature at different position of inner body, these temperature are defined by the heat balance status, while the coefficients of heat balance equation are just the thermal parameters. So we can depend on the reasonable heat transfer model to get the thermal parameters at the different position of inner body, only using the surface temperature of body as know condition. When the temperature field is keeping stable, the thermal parameters K(x)、W_b(x) and Q_m(x) at different positions are unvaried, so the regulation of thermal parameters varied with temperature at different position will be obtained by determining these parameters in different stale temperature filed.

B. Model

In order to measure hurtlessly the temperature of inner body, supposing the temperature distribution T(x) from the core to the surface of body as eq.(2), T is the temperature, x is the distance of a inner position of body to body core.

$$T(x) = a_0 + a_1 x + a_2 x^2 \qquad (2)$$

considering boundary condition:

$$\begin{cases} T(0) = T_c \\ T(r) = T_s \\ \dfrac{dT}{dx}\Big|_{x=0} = 0 \end{cases} \qquad (3)$$

Where:

Tc: temperature of body core

Ts: temperature of body surface

So get :

$$T(x) = T_c - \frac{T_c - T_s}{r^2} x^2 \qquad (4)$$

for the eq. (1), if we consider the whole effect of K and W_b ,and use the apparent conductivity λ to indicate this effect[8]. then when the temperature field is keeping stable , there is :

$$0 = \nabla \bullet (\lambda \nabla T) + Q_m \qquad (5)$$

Considering eq.(3), (4) is :

$$0 = \lambda'(x)\left(\frac{2x(T_s - T_c)}{r^2}\right) + 2\lambda(x)\frac{(T_s - T_c)}{r^2} + Q_m(x) \qquad (6)$$

Considering the relationship between the metabolic rate and blood perfusion, deduce to:

$$\lambda(x) \big/ Q_m(x) = 0.002 kg/J \qquad (7)$$

Considering eq. (5) and eq. (6), get:

$$\lambda(x) = \lambda_p \left(\frac{r}{x}\right)^{1+q} \qquad (8)$$

$$q = 1000 \times r^2 / (T_s - T_c) \qquad (9)$$

Where:

λ p is the apparent conductivity of surface, and it can be calculated by eq. (10):

$$\lambda_p = \alpha r (T_s - T_e) \big/ 2(T_c - T_s) \qquad (10)$$

where α is the heat exchange coefficient between body surface and environment, T_e is environment temperature.

III RESULTS AND DISSCUSION

In the experiment of this paper, after the experimental subject has been quietly in lab for 30 minuets in which temperature and humidity are keeping stale and from which anything can affect temperature isolated, so we can think his temperature distribution of inner body is stable. We record the environment temperature and the finger radius of him, then take infrared thermography of his body surface temperature by NEC TH5108 ME. For take example, we choice the surface temperature distribution to research considered the shape of finger is nearly cylinder, for Pennes bio-heat transfer model is created on the base of supposing the living body is a cylinder. The point in Fig. 1 is the example point to calculate inner tissue metabolism rate under it.

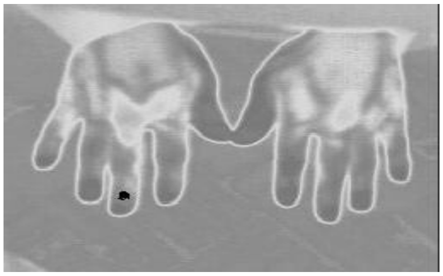

Fig. 1Thermography of hands

So using the equations above mentioned, we calculated the tissue Metabolic rate $Q_m(x)$at the different position of inner body, (in calculation, Tc was measured from rectum), the result is listed in Table 1.

Tab 1. the tissue Metabolic rates at different position of inner body

x(m)	T' (℃) by eq.(3)	λ (W/m.℃)	Qm (J/m^3·s)
0.00	36.7	→∞	M0
0.002	36.627	0.249	499.5
0.004	36.406	0.130	259.4
0.0006	36.039	0.088	176.8
0.008	35.525	0.067	134.7
0.01	34.863	0.054	109.1
0.012	34.055	0.049	91.8
0.014	33.1	0.040	79.3

The result indicates that using the surface temperature obtained by infrared thermography, applying the method presented above mentioned, finally we can get hurtlessly the tissue metabolic rate at the different position, and these calculated value consist with the classical average of Q_m in quantity level. Calculated all temperature point of surface with this method, the inner temperature filed distribution and the tissue metabolic rate distribution could be obtained hurtlessly.

IV CONCLUSIONS

In order to verify T(x) nearly is a quadratic equation, the temperature data of arm in Pennes experiment are used to fit and to calculate λ and Q_m at corresponding positions [6] , result is shown in Fig.2 and Table.2:

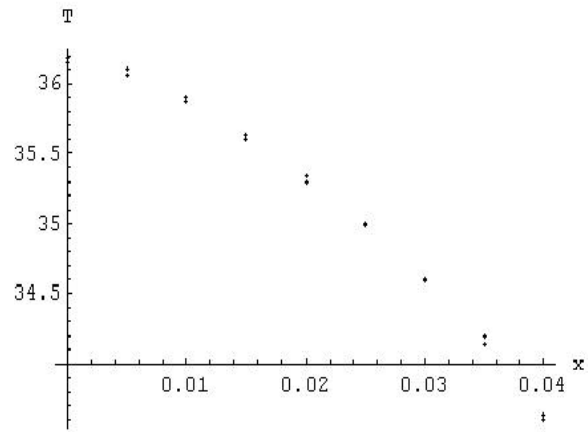

Fig 2 T~x distrubition

In Fig 2, the temperature distribution of Pennes's experiment data is compared with the quadratic equation value fitted by the former , and it is clearly that the latter point near the former and T(x) nearly is parabola. So it indicates the supposition that T(x) is a quadratic equation is reasonable and suitable.

Table 2 calculated result

x(m)	T(℃) measured	T' (℃) By eq.(2)	T"(℃) By eq.(3)	λ (W/m.℃)	Qm (J/m^3·s)
0.00	36.15	36.18	36.15	→∞	M0
0.005	36.1	36.05	36.11	0.732	1464
0.01	35.9	35.87	35.99	0.046	920
0.015	35.6	35.63	35.79	0.344	688
0.02	35.3	35.34	35.51	0.284	568
0.025	35.0	34.99	35.15	0.243	486
0.03	34.6	34.59	34.71	0.214	428
0.035	34.2	34.14	34.19	0.192	386
0.04	33.6	33.63	33.6	0.176	352

In Table 2, the temperature of every position in inner arm calculated by eq.(3) is near the measured value, and the calculated tissue metabolic rate of every point is in the same quantity level as the classical aveage Qm＝420(J/m^3·s). It indicates not only this method is can be used to obtain the inner temperature of body hurtlessly, and also the result is reasonable.

From eq.(8), It is can be know that the more inner position is, the larger tissue metabolic rate is. this conclusion is accord with the physiological fact. While on the condition of that Tc is larger than Ts, at the same position, the λ and Qm are larger with larger d, which is defined by Tc subtract Ts, than ones with smaller d. Fig 3 indicates the vary tendency of λ with different d accord to eq.(8).

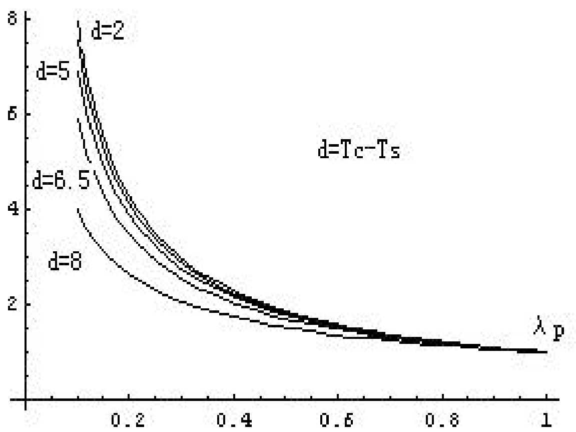

Fig 3 λ with different d

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