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A novel method of thermal tomography tumor diagnosis and its clinical practice

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HIGHLIGHTS

- We present a new heat-transfer mathematical model suitable for thermal tomography.
- The method of acquiring the q–r characteristic curve is provided.
- We propose the diagnostic criteria of female breast diseases by q–r characteristic curve.
- Four typical clinical practices and the corresponding comparisons are performed.

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ABSTRACT

When there exist diseases or functional changes in a certain part of the human body, the speed of blood flow and cell metabolism will change correspondingly, which will lead to the thermal variation in this area. To find out the relation between disease and heat distribution, a suitable bio-heat transfer model is established in this paper. Based on the infrared thermal image of human body surface, the q–r characteristic curve of heat intensity varying with depth is acquired combining the fitting method of Lorentz curve. According to a large number of clinical cases and statistics, the diagnostic criteria judging diseases by q–r characteristic curve are proposed. Several clinical practices are performed and the diagnosis results are very consistent with those of molybdenum target (MT) X-ray and B-ultrasonic images. It is a radiation-free green method with rapid diagnostic procedure and accurate diagnosis result.

1. Introduction

The early detection and diagnosis of tumor are very important for the tumor patients. The medical infrared thermal imager receives the information of infrared radiation passively from human body, so all the diseases that can cause the heat variation in human tissue, such as tumor, cardiovascular and cerebrovascular diseases, inflammation, gynaecopathia and so on, can be detected with it [1–3]. When some part of human body is in morbidity, the metabolism of tissue cell will change first, and such a change is ahead of the variation of human organ in function and form [4]. So the medical infrared thermal imager can often find the morbidity earlier than the other clinical detection methods [5,6].

The benign tumor is composed of mature cells whose reproduction is slow. The difference in temperature between the benign tumor and the skin around is small, mostly it is within 1 °C [7–9]. When the normal cells transform to be precancerous or malignant ones, the metabolism begin to be abnormal, and the tumor cells reproduce rapidly [10]. To meet the needs of cells' growth, the blood circulation will increase. Meanwhile, the virulence factors of tumor will also lead to angiectasis partially [11]. All the changes above must result in the increase of heat there. However, in the middle and advanced stage of malignant tumor, the temperature of tumor region appears low because of the liquefaction and necrosis in the tumor center [12–15]. Based on the temperature distribution characteristics of tumor in different stages, this present paper aims to acquire the q–r characteristic curve of the heat intensity varying with depth of tomography. Combined a large number of clinical cases and statistics, the diagnostic criteria judging the nature of diseases is designed through the q–r characteristic curve.

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Nomenclature

c	specific heat capacity (J/Kg K)
k	thermal conductivity (W/m K)
T	temperature (K)
Q_m	metabolic heat rate (W/m^3)
w_b	perfusion rate of blood (Kg/m^3 s)
n	number
q_v	heat rate of heat source (W/m^3)
O	original point of coordinate system
h	depth from the heat source to origin point (m)
x	distance from origin point to arbitrary point on body surface (m)
r	distance from internal heat source to arbitrary point (m)

Greek symbols

ρ	density (Kg/m^3)
Δ	Laplace operator
δ	mathematical function
θ, ψ	spherical coordinate (rad)

Subscripts

a	arterial blood
b	blood

2. Theory of thermal tomography

2.1. Model of bio-heat transfer

In bio-heat transfer field, the Pennes equation is generally considered as the most suitable one in all the bio-heat transfer models so far. It can be expressed as:

$$\rho c \frac{\partial T}{\partial t} = \nabla(k \cdot \nabla T) + w_b \rho_b c_b (T_a - T) + Q_m \quad (1)$$

Where T is the distribution function of internal temperature, $\partial T/\partial \tau$ is the derivative of temperature function with respect of time variable, ρ and c are density and thermal capacity of biological tissue respectively, k is the coefficient of heat conduction, w_b, ρ_b and c_b represents the perfusion, density and thermal capacity of blood respectively, T_a is the temperature of arterial blood and Q_m is the metabolic heat. In order to simplify the heat-transfer model, k is set as a constant, and the term $w_b \rho_b c_b (T_a - T)$ and Q_m are merged to be q_v. Here, q_v can be regarded as the internal heat source. So Eq. (1) can be simplified as:

$$k \cdot \Delta T + q_v = c\rho \frac{\partial T}{\partial \tau} \quad (2)$$

In Eq. (2), $\triangle$ is the Laplace operator. In steady state ($\partial T/\partial \tau = 0$), the heat conduction equation is:

$$\Delta T + \frac{1}{k} q_v = 0 \quad (3)$$

The mathematical function δ is introduced in Eq. (3). Here the internal heat source term can be indicated as $q \cdot \delta(r)$, in which q is the intensity of heat source, $\delta(r)$ denotes there is a heat source at $r = 0$, and no heat source at $r \neq 0$. So Eq. (3) can be written to be:

$$\Delta T = -\frac{1}{k} q \cdot \delta(r) \quad (4)$$

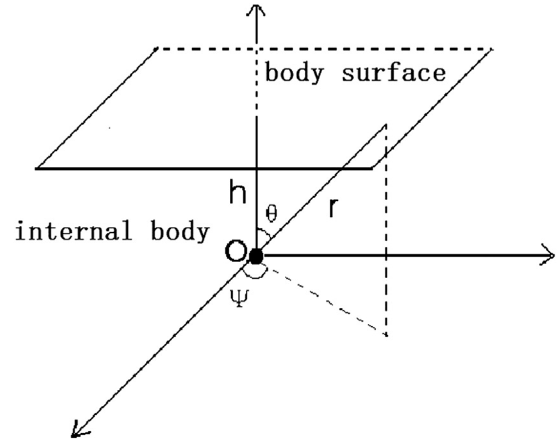

Fig. 1. Spherical coordinate system in internal human body.

If the diseased area is not large, or the size of diseased area can be neglected relative to the distance from diseased area to body surface, the heat source of diseased area can be regarded as a point heat source. The mathematical function δ is introduced here, which simplify the form of bio-heat conduction equation and make it more feasible to solve.

To solve Eq. (4), a spherical coordinate system is established, and the zero O is set at where the point heat source is. Any point of body surface and internal body can be expressed with (r, θ, ψ) (Fig. (1)).

In order to simplify the model, ρ, c and k are set as constants, which means the heat from point heat source in three-dimensional space possesses good spherical symmetries. So in the spherical coordinate system, only the term r is left in Eq. (4).

$$\frac{1}{r^2} \cdot \frac{\mathrm{d}}{\mathrm{d}r}\left(r^2 \cdot \frac{\mathrm{d}T}{\mathrm{d}r}\right) = -\frac{q}{k} \cdot \delta(r) \quad (5)$$

Using Gauss theorem, T can be acquired by solving Eq. (5), and the result is:

$$T = \frac{q}{4\pi k r} \quad (6)$$

Eq. (6) is the solution of heat conduction equation of point heat source, where r is the distance from the zero to some point of body surface, and T indicates the temperature function. In practical application, the temperature of various points at body surface can be acquired with infrared thermal imager.

On the body surface, the position of point O mapped from the internal heat source can be easily found, because it is the very point where the temperature is highest. Taking the point O as the origin, a polar coordinates OX is established as Fig. (2).

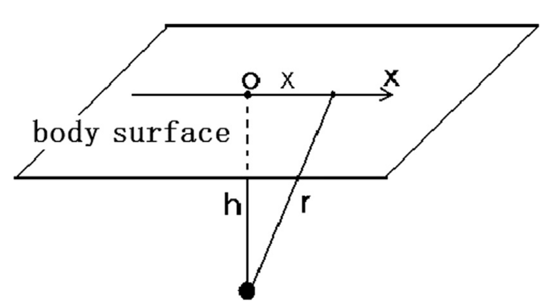

Fig. 2. Polar coordinate system on the body surface.