Q-r curve of thermal tomography and its clinical application on breast tumor diagnosis

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Abstract: Heat is the product following the metabolism of cells, and the metabolism is closely related with the pathological information of living organism. So, there are strong ties between the heat distribution and the pathological state in living organism. In this paper, the mathematical function $\delta$ is introduced in the classical Pennes bio-heat transfer equation as the point heat source. By simplifying the boundary conditions, a novel bio-heat transfer model is established and solved in a spherical coordinate system. Based on the temperature distribution of human body surface, the information of heat source is mined layer by layer, and the corresponding q-r curve of heat intensity varying with depth is acquired combining the fitting method of Lorentz curve. According to a large number of clinical confirmed cases and statistics, the diagnostic criteria judging diseases by q-r curve are proposed. Five typical clinical practices are performed and four of the diagnosis results are very consistent with those of molybdenum target (MT) X-ray, B-ultrasonic images and pathological examination, one gives the result of early stage malignant tumor that MT X-ray and B-ultrasonic can’t check out. It is a radiation-free green method with noninvasive diagnostic procedure and accurate diagnosis result.

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1. Introduction

Life is the exchange process of matter and energy. The heat and mass transfer in biological tissue is one of the most basic characteristics of living system [1–3]. The metabolism of cells is always accompanied with the generation of heat, which means the thermal information of living body is closely related with the metabolism [4–6]. When the lesions occur in some part of living body, the metabolism of cells will be abnormal at first, and then the structural changes of bio-tissue or organ will happen with the course of disease [7, 8]. So, there are strong ties between the thermal information and the pathological changes. If 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 [9–11]. However, at the early stage of lesion, the human body can’t perceive the temperature changes of cells, only if the temperature of abnormal cells reaches to a quantitative change, the uncomfortable symptoms will be perceived [10–13]. Therefore, to detect the temperature changes of human body as early as possible, the specialized medical inspection equipment has to be used. Based on the principle of black body radiation, the medical infrared detector can detect the thermal distribution information of body surface, display the temperature field of human body with false-color image, and record the infrared information that can’t be identified by naked eyes with thermal image in real time [14]. However, the method taking the temperature distribution and temperature difference information of body surface as the basis for diagnosis of diseases has many limitations, because it is ignored that the internal thermal...
distribution of lesion in human body carries lots of valuable disease information, which is of great importance for the diagnosis of diseases [15–18]. At present, the medical imaging technologies being commonly used such as magnetic resonance imaging (MRI), X-CT imaging, ultrasonic imaging etc., can provide some related biochemical and pathologic information, nevertheless these technologies have a fundamental constraint, that is they can only display the shape changes of body tissue, but not reflect functional changes of body tissue [19, 20]. When the structural lesions emerge in the human body, the qualitative changes of the patient’s condition have taken place [21–25].

In order to mine the valuable 3-dimensional heat distribution data based on temperature distribution of body surface, many research groups have carried out in-depth studies and made a series of achievements [7–26]. This present paper aims to acquire the q-r characteristic curve of the heat intensity varying with depth of tomography based on the temperature distribution characteristics of tumor in different stages. 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. Several typical clinical practices were performed to prove the validity of this novel approach for the diagnosis of breast diseases. The practical results of thermal tomography are compared and analyzed with those of diagnosis of breast diseases, B ultrasonic and pathological examination. As a new medical diagnosis method, it is a green diagnostic technology with non-invasive, non-radiative and fast examining process.

| Nomenclature          | Greek symbols |
|-----------------------|---------------|
| c                     | specific heat capacity (J/Kg·K) |
| k                     | thermal conductivity (W/m·K)    |
| T                     | temperature (K)                |
| Qm                    | metabolic heat rate (W/m3)     |
| wb                    | perfusion rate of blood (Kg/m3·s) |
| ρ                     | density (Kg/m3)                |
| ρb                    | blood density                  |
| ρcb                   | blood thermal capacity         |
| Ta                    | temperature of arterial blood   |
| Qm                    | metabolic heat rate            |
| ρ                      | density (Kg/m3)                |
| c                      | thermal capacity (J/Kg·K)      |
| k                      | thermal conductivity (W/m·K)    |
| T                      | temperature (K)                |
| Qm                    | metabolic heat rate (W/m3)     |
| wb                    | perfusion rate of blood (Kg/m3·s) |
| ρ                     | density (Kg/m3)                |
| ρb                    | blood density                  |
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| wb                    | perfusion rate of blood (Kg/m3·s) |
| ρ                     | density (Kg/m3)                |
| ρb                    | blood density                  |
| ρcb                   | blood thermal capacity         |
| Ta                    | temperature of arterial blood   |
| Qm                    | metabolic heat rate            |
| ρ                      | density (Kg/m3)                |
| c                      | thermal capacity (J/Kg·K)      |
| k                      | thermal conductivity (W/m·K)    |
| T                      | temperature (K)                |

2. Methods

2.1 Q-r curve of thermal tomography

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 is written as:

$$\rho_c \frac{\partial T}{\partial t} = \nabla (k \cdot \nabla T) + w_p \rho_b c_b (T_a - T) + Q_m.$$  (1)

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

$$k \cdot \Delta T + q_v = c \rho \frac{\partial T}{\partial t}.$$  (2)
Where, $\Delta$ is the Laplace operator. In steady state ($\partial T / \partial t = 0$), the heat transfer equation is:

$$\Delta T + \frac{1}{k} q_r = 0. \tag{3}$$

The mathematical function $\delta$ is introduced in Eq. (3). Here the internal heat source term can be expressed 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:

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

If the diseased area is not large, or the size of the 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 $\delta$ is introduced here to simplify the form of bio-heat transfer equation and make it more feasible to solve.

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

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

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

$$\frac{1}{r^2} \frac{d}{dr} \left( r^2 \frac{dT}{dr} \right) = -\frac{q}{r} \delta(r). \tag{5}$$

With Gauss theorem, $T$ can be acquired by solving Eq. (5):

$$T = \frac{q}{4\pi kr}. \tag{6}$$

Equation (6) is the solution of heat transfer equation of point heat source, where $r$ is the distance from the internal heat source to some point of body surface, and $T$ indicates the temperature function. In practical application, the temperature value of various points at body surface can be acquired from infrared thermal detector.

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.
It’s shown as Fig. 2, \( d \) is the depth from the internal heat source to origin \( O \), \( x \) is the distance from origin \( O \) to arbitrary point on body surface. So, the temperature distribution function of body surface can be written as:

\[
T(x) = \frac{q}{4\pi k r} = \frac{q}{4\pi k \cdot \sqrt{d^2 + x^2}}. 
\]  

(7)

Where, \( q \) is the heat intensity, and \( d \) is the depth of point heat source. In consideration of the influence of environmental temperature \( T(\infty) \), Eq. (7) can be amended as:

\[
T(x) = \frac{q}{4\pi k \cdot \sqrt{d^2 + x^2}} + T(\infty). 
\]  

(8)

As can be seen from Eq. (8), the temperature distribution of body surface can be acquired as long as knowing the information of internal heat source. However, in the practical application, the temperature of body surface can be easily acquired with infrared thermal detector, and the information of internal heat source is just what we want to acquire. This is an inverse problem relative to Eq. (8), and a method given by the authors is adopted to solve this inverse problem [27]. The resolutions are shown as Eq. (9) and Eq. (10).

\[
d = \frac{x \cdot T(x)}{\sqrt{T^2(0) - T^2(x)}}. 
\]  

(9)

\[
q = 4\pi r \cdot T(0) \cdot \frac{x \cdot T(x)}{\sqrt{T^2(0) - T^2(x)}}. 
\]  

(10)

However, it is very difficult to apply such an inverse operation to clinical application [27, 28]. So, based on Eq. (8), we propose a novel method of thermal tomography to acquire more information about the heat intensity.

It’s supposed that the density, thermal conductivity and thermal capacity of the biological tissue are all constants, and the internal heat source is an ideal point one. Then setting a straight line through the point where the temperature is highest on the body surface, the temperature distribution along the straight line will fit the Lorenz curve well [28]. In the clinical application, one can set a straight line through the center of pathological high temperature area on the infrared image (Fig. 3). Twelve points are chosen equidistantly along the straight line, and one of the points should lie in the center of high temperature area. The temperature of every point can be extracted (Table 1). In Fig. 4, \( R \) denotes the distance from the center point of pathological high temperature area to the point chosen on the straight line, and \( T \) denotes the temperature of the corresponding points. The sign before the abscissa values indicates the two sides of center point. As can be seen from Fig. 4, the distribution curve of temperature along the straight line has a good fitting with the Lorenz curve.
Contrasting Eq. (8) with the standard Lorentz equation \( y = A\omega^2/(x^2 + \omega^2) + y_0 \), it can be acquired that \( d = \omega \) and \( q = 4\pi kdA^{1/2} \), which means the heat intensity \( q \) is relative with the peak height and peak width of temperature distribution curve [27]. According to this theory, the practical operation is divided into the following steps:

**Step 1:** Make a circle with radius \( r_1 \), and the center of the circle is chosen at the center of pathological high temperature area (Fig. 5(a)). Divide the circle equally with \( n \) line segments whose length is \( 2r_1 \), and along one of these line segments, the distribution curve of temperature can be acquired. By fitting it with the Lorentz curve, the value \( q \) can be acquired. In the same way, the distribution curves of temperature along the other segments can be acquired. Then, the mean value \( q_1 \) of \( n \) heat intensity values is determined.

**Step 2:** Shown as Fig. 5(b), enlarge radius of the circle with the same center (The radius is represented with \( r_2, r_3, ..., r_n \)). Repeat **Step 1**, one can acquired \( q_2, q_3, ..., q_n \) that shown as Fig. 5(c), where L-axis indicates the straight line set on body surface and its direction.

**Table 1. Points on Straight Line and Their Corresponding Temperatures**

| Points | \( P_1 \) | \( P_2 \) | \( P_3 \) | \( P_4 \) | \( P_5 \) | \( P_6 \) | \( P_7 \) | \( P_8 \) | \( P_9 \) | \( P_{10} \) | \( P_{11} \) | \( P_{12} \) |
|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Coordinate values (cm) | -3.85 | -3.30 | -2.75 | -2.20 | -1.65 | -1.10 | -0.55 | 0 | 0.55 | 1.10 | 1.65 | 2.20 |
| Temperature (°C) | 32.0 | 32.1 | 32.3 | 32.9 | 33.4 | 34.2 | 34.6 | 34.7 | 34.3 | 34.2 | 33.9 | 33.6 |

Fig. 3. Straight line set on infrared image.

Fig. 4. Fitting of temperature distribution curve and Lorentz curve.

Table 1. Points on Straight Line and Their Corresponding Temperatures
Step 3: Taking the diseased tissue as the center of analysis, a q-r curve can be drawn (Fig. 6(a)). From the q-r curve, it can be seen the temperature of diseased tissue is high, and around the diseased tissue the temperature decreases gradually. However, in case of taking the normal tissue as the center, there is no significant temperature difference compared with the tissue around (Fig. 6(b)). As can be seen in Fig. 6, there are two numbers at the upper left corner, which express the coordinate values of the point chosen to analysis (The coordinate system is created in the original infrared image, the bottom left corner of the infrared image is taken as the origin, the bottom edge is taken as the abscissa axis, and the left edge is taken as the vertical axis. The coordinate values are expressed with the number of pixels). In Fig. 6(a), for instance, the analyzed point corresponds to the lateral 162nd pixel and the longitudinal 280th pixel from the bottom left corner of the original infrared image. It should be explained that the infrared images appearing in the following passage are cut out from the original ones, it is just for highlighting the diagnosed parts of human body. Here, the coordinate values are very important for the positioning of analyzed point.

Fig. 5. Resolving of thermal tomography. (a) Equal division of circle. (b) Circles with the same center point. (c) Heat intensity and its corresponding depth.

Fig. 6. Plotting of q-r curve: horizontal axis represents depth r, vertical axis represents quantity of heat q. (a) q-r curve of diseased tissue. (b) q-r curve of normal tissue.
2.2 Establishment of diagnostic criteria for breast tumor

Tumor is classified malignant and benign ones. The benign tumor is composed of mature cells and grows slowly, the temperature difference is small between the body surface mapping tumor tissue and the skin around, and in most instances, it is within 1°C. The malignant tumor is composed of immature cells and grows rapidly, it has multiple blood vessels and vigorous metabolism, which leads to the obvious difference in temperature between the body surface mapping tumor tissue and the skin around. However, in the middle and advanced stage, the liquefactive necrosis appears at the center of malignant tumor, and it will affect the trend of the end part of q-r curve.

The shape of q-r curve reflects the status of heat distribution in human body, i.e. the status of metabolism. Our study focuses on four kinds of cases, they are malignancy, benign, mastitis and hyperplasia or normal. The key problem is how to distinguish them according to the distribution and trend of q-r curve.

To resolve this problem, we collected 34977 confirmed biopsy-proven cases of breast disease and their corresponding q-r curves from six large cooperative hospitals (Huaxi Hospital, General Hospital of Chinese PLA, People’s Hospital of Hubei province, Zhongnan Hospital, Hubei Tumor Hospital and Hubei Hospital of Traditional Chinese Medicine). Among these confirmed cases, there were 10566 ones of mastitis, 12973 ones of malignant breast tumor, 9280 ones of benign breast tumor and 2158 ones of hyperplasia of mammary glands or normal. Here, a flat surface was created, and all the q-r curves were moved in. The curves were classified with the type of disease, and different kind of q-r curves were indicated with different color. Based on the distribution of q-r curves and statistics, it was found the q-r curves of most malignant tumor lay in section A, the q-r curves of most benign tumor lay in section B, and the q-r curves of most mastitis lay in section C. For most of the hyperplasia or normal cases, the q-r curves lay in section D. The four sections were acquired with three straight lines whose included angles with the horizontal axis were 46°, 29° and 15° (Fig. 7). The detailed statistics is shown as Table 2. It can be seen that the criteria are established with a high standard. (The criteria are only for female breast at present.)

![Fig. 7. Section division of thermal tomography curve for female breast.](image)

2.3 Device scheme and prototype

In order to make this novel method to be applied for clinical purposes, we have developed a set of thermal tomography system for tumor diagnosis. The schematic diagram is shown as Fig. 8. First, the infrared thermal detector is adopted to detect the infrared radiation of human body, and translate the thermal information into temperature information displayed with infrared thermal image. Second, a point is chosen in the ROI (Region of Interest) of thermal image, based on the data processing technology and the approach of thermal tomography presented in
this paper, the internal heat information q-r curve can be acquired. Finally, according to the distribution and trend of q-r curve, the corresponding diagnosis can be suggestion on the basis of diagnostic criteria.

| Classification | Number of cases | Distributional situation of q-r curves | Distributional statistics of q-r curves |
|----------------|----------------|----------------------------------------|----------------------------------------|
| Mastitis       | 10566          | Section A: 559                         | Section A: 5.29%                       |
|                |                | Section B: 84                          | Section B: 0.80%                       |
|                |                | Section C: 9908                         | Section C: 93.77%                      |
|                |                | Section D: 15                          | Section D: 0.14%                       |
| Malignancy     | 12973          | Section A: 12359                        | Section A: 95.26%                      |
|                |                | Section B: 361                         | Section B: 2.44%                       |
|                |                | Section C: 227                         | Section C: 2.14%                       |
|                |                | Section D: 26                          | Section D: 0.20%                       |
| Benign         | 9280           | Section A: 256                         | Section A: 2.76%                       |
|                |                | Section B: 8752                        | Section B: 94.31%                      |
|                |                | Section C: 93                          | Section C: 1.00%                       |
|                |                | Section D: 179                         | Section D: 1.93%                       |
| Hyperplasia or| 2158           | Section A: 5                           | Section A: 0.23%                       |
| Normal         |                | Section B: 38                          | Section B: 1.76%                       |
|                |                | Section C: 29                          | Section C: 1.34%                       |
|                |                | Section D: 2086                        | Section D: 96.66%                      |

Fig. 8. Schematic diagram of thermal tomography system for tumor diagnosis.

In the original infrared thermal image, we set a reference object of scale whose size is constant, and that is a basis of ratiometric conversion between the infrared thermal image and its corresponding physical object. The prototype of thermal tomography system for tumor diagnosis and its related illustration are shown as Fig. 9. This system is mainly composed of control console, computer processing system, highly sensitive infrared imager, examining room and rotary round stool. The control console can control the data processing of computer, the movement of infrared camera and electrical platform, the medical record printer and so on. The computer processing system can process and analyze the infrared thermal image. The highly sensitive un-cooled focal plane infrared thermal imager, whose temperature resolution was 0.08°C, spatial resolution was 1.4 mrad, pixel was 320 × 240 and focusing range was 0.5m ~∞, is taken as the temperature measuring tool of human body surface. The examining room is the place where the patient seat and accept examination. The rotary round stool can be rotated...
360 degrees to make the image information of different body parts be more visualized and precise.

Fig. 9. Prototype of thermal tomography system for tumor diagnosis.

3. Clinical application and analysis

The trend and distribution of q-r curve reflects the temperature field and heat distribution of internal body tissue (i.e. the status of metabolism), which is closely related with the pathological information of human body. For the sake of verifying the novel approach of thermal tomography tumor diagnosis and its diagnostic criteria (The diagnostic criteria are only for female breast tumor at present.), the clinical practices were performed in Galactophore Dept. of Hubei Tumor Hospital. The environment temperature was 18.5°C.

3.1 Diagnosis of early stage malignant breast tumor

Woman A, 35 years old, whose infrared thermal image of breast was shown as Fig. 10(a). There was an abnormal high temperature area on the upper left side of the left breast. A point was chosen at the selected area to do q-r curve analysis of thermal tomography, and the result was shown as Fig. 10(b). As could be seen from Fig. 10(b), the vast majority of the q-r curve lay in the section of malignancy and the heat intensity q increased conspicuously with the depth of thermal tomography. So, it was diagnosed as malignant tumor by the q-r curve analysis. Figure 10(c) was the corresponding image of molybdenum target (MT) X-ray with breast catheter radiography processing, from which the intraductal carcinoma was excluded, and the tissue was relatively homogeneous, no obvious mass. However, there appeared a little short grained calcified cluster above the left papilla. Figure 10(d) was the corresponding image of B-ultrasonic, which showed there was a hypoecho at the upper side of the left breast, the echoic mass was homogeneous with irregularity boundary, and no obvious Doppler signals. The two examinations above could not give the result of malignant tumor. By pathological examination, it was diagnosed as lower-level catheter preinvasive carcinoma, a kind of early stage malignant tumor, which agreed with that of q-r curve.

3.2 Diagnosis of malignant breast tumors

Woman B, 32 years old, whose infrared thermal image of breast was shown as Fig. 11(a). There was an abnormal high temperature area on the upper left side of the left breast. A point was
chosen at the selected area to do q-r curve analysis of thermal tomography, and the result was shown as Fig. 11(b). As could be seen from Fig. 11(b), the vast majority of the q-r curve lay in the section of malignancy and the heat intensity $q$ increased conspicuously with the depth of thermal tomography. So, it was diagnosed as malignant tumor by the q-r curve analysis. Figure 11(c) was the corresponding image of molybdenum target (MT) X-ray, from which it could be seen there was a high density mass behind and above the left papilla, the boundary was clear and appeared invasive, and rare calcification could be seen. Figure 11(d) was the corresponding image of B-ultrasonic, which showed there was a hypoechoic mass at the upper side of the left breast, the profile was irregular and the boundary was obscure, the Doppler signals were not strong inside and around the mass. The two examinations above also gave the result of malignant tumor. By pathological examination, it was diagnosed as 2nd stage of invasive ductal carcinoma, which agreed with that of q-r curve, MT X-ray, and B-ultrasonic.

3.3 Diagnosis of benign breast tumors

Woman C, 31 years old, whose infrared thermal image of breast was shown as Fig. 12(a). There was an abnormal high temperature area on the upper left side of the left breast. A point was chosen at the selected area to do q-r curve analysis of thermal tomography, and the result was shown as Fig. 12(b). As could be seen from Fig. 12(b), the vast majority of the q-r curve lay in the section of benign and the heat intensity $q$ increased with the depth of thermal tomography. So, it was diagnosed as benign tumor by the q-r curve analysis. Figure 12(c) was the corresponding image of MT X-ray, from which it could be seen there was a low-density shadow at the posterolateral side of the left breast, the boundary was not clear, and clustered calcification could be seen. Figure 12(d) was the corresponding image of B-ultrasonic, which showed there was a hypoechoic area at the posterolateral side of the left breast, the boundary was not clear, and at the posterior of shadow, there was no significant change in the echo. The Doppler signals were weak. The two examinations above also gave the result of benign tumor. By pathological examination, it was diagnosed as galactocele.

3.4 Diagnosis of mastitis

Woman D, 28 years old, whose infrared thermal image of breast was shown as Fig. 13(a). There was an abnormal high temperature area above the right breast. A point was chosen at the selected area to do q-r curve analysis of thermal tomography, and the result was shown as Fig. 13(b). As could be seen from Fig. 13(b), the vast majority of the q-r curve lay in the section of mastitis and the heat intensity $q$ increased conspicuously with the depth of thermal tomography. So, it was diagnosed as mastitis by the q-r curve analysis. Figure 13(c) was the corresponding image of MT X-ray, from which it could be seen there existed asymmetrical density and irregular structure in the right breast, there was no obvious mass and calcification. Figure 13(d) was the corresponding image of B-ultrasonic, which also showed there was asymmetrical density and irregular structure in the right breast, and there was no obvious mass and calcification. The Doppler signals were strong. The two examinations above gave the result of mastitis. By pathological examination, it was diagnosed as mastitis.

3.5 Diagnosis of breast hyperplasia

Woman E, 37 years old, whose infrared thermal image of breast was shown as Fig. 14(a). There was an abnormal high temperature area on the upper left side of the left breast. A point was chosen at the selected area to do q-r curve analysis of thermal tomography, and the result was shown as Fig. 14(b). As could be seen from Fig. 14(b), the vast majority of the q-r curve lay in the section of hyperplasia or normal and the heat intensity $q$ increased slowly with the depth of thermal tomography. So, it was diagnosed as hyperplasia by the q-r curve analysis. Figure 14(c) was the corresponding image of MT X-ray, from which it could be seen there existed nebulous masses at the inner side of the left breast. Figure 14(d) was the corresponding image of B-ultrasonic,
which also showed there was a hypoechoic area at the inner side of the left breast, and the boundary was clear. The Doppler signals were weak. The two examinations above gave the result of hyperplasia. By pathological examination, it was diagnosed as hyperplasia.

Fig. 10. Q-r curve analysis of woman A and the corresponding comparison. (a) The infrared thermal image of woman A. (b) The q-r curve analysis of woman A. (c) The image of MT X-ray of woman A. (d) The image of B-ultrasonic of woman A.
Fig. 11. Q-r curve analysis of woman B and the corresponding comparison. (a) The infrared thermal image of woman B. (b) The q-r curve analysis of woman B. (c) The image of MT X-ray of woman B. (d) The image of B-ultrasonic of woman B.

Fig. 12. Q-r curve analysis of woman C and the corresponding comparison. (a) The infrared thermal image of woman C. (b) The q-r curve analysis of woman C. (c) The image of MT X-ray of woman C. (d) The image of B-ultrasonic of woman C.
Fig. 13. Q-r curve analysis of woman D and the corresponding comparison. (a) The infrared thermal image of woman D. (b) The q-r curve analysis of woman D. (c) The image of MT X-ray of woman D. (d) The image of B-ultrasonic of woman D.

Fig. 14. Q-r curve analysis of woman E and the corresponding comparison. (a) The infrared thermal image of woman E. (b) The q-r curve analysis of woman E. (c) The image of MT X-ray of woman E. (d) The image of B-ultrasonic of woman E.
Through the six clinical practices and the comparisons above, it's found the diagnosis results by q-r curve are very consistent with those by molybdenum target (MT) X-ray and B-ultrasonic. This novel method of thermal tomography tumor diagnosis is non-contacting, noninvasive and nonradiative to patients, and also it is quick and convenient in implementation.

4. Conclusions

In order to establish a suitable bio-heat transfer model, the mathematical function δ is introduced as the point heat source, and the boundary conditions are simplified. Based on the thermal image of human body surface, the information of internal heat source is mined layer by layer, and then the q-r curve of heat intensity varying with depth is acquired combining the fitting method of Lorentz curve. The trend and the distribution of q-r curve are closely related to the metabolism status of human tissue. Based on 34977 clinical confirmed cases and statistics, the diagnostic criteria judging diseases by q-r curve are proposed. Five typical clinical practices are performed and four of them are very consistent with those of molybdenum target (MT) X-ray and B-ultrasonic, one clinical practice gives the result of early stage malignant tumor that molybdenum target (MT) X-ray and B-ultrasonic can’t check out, which agrees with that of pathological examination. Based on the principle of thermal tomography, this novel method is suitable for many parts of human body. The diagnostic criteria of female breast diseases have been established, and now the diagnostic criteria of thyroid diseases are in the process of establishing, in which a large number of relevant cases are needed. For the other parts, such as head, abdomen, pelvic cavity, waist, arms, legs etc., it is in our future working plan. Besides the diagnosis of diseases, this novel approach of thermal tomography can be also applied in the sub-health examination, the traditional Chinese medicinal research, the paired observation of curative effect and pesticide effect in the future. So, this method will be great valuable in clinical application.

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