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Experimental study on characteristic of bioheat transfer and numerical simulation for the temperature fields in transverse and longitudinal sections of pig tongue

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Abstract

The influence factors of the tongue tissue structure on the temperature fields are importantly laid on the diameters and positions of arteries. Then temperature fields of certain sections are simulated by the finite element method (FEM). The results show that temperature gradients of the tongue in length are wider than in depth as a result of the specific vascularity. Thereby the relationship between temperature fields of tongue surface and those in transverse and longitudinal sections can be developed. This work will be further referential to study on the characteristics of heat transfer in human tongue, and will promote the development of bioheat transfer science.

Keywords: Tongue; Temperature field; Blood vessel; Blood perfusion; Mammal

1. Introduction

For more than fifty years, we made progresses in basic theories of Traditional Chinese Medicine (TCM). At present many people concentrate on TCM, but there are a lot of deficiencies in this field. Because of this, the diagnosis and treatment of TCM are restricted. The main reason is that the traditional unscientific conceptions had a great influence on this subject. Therefore we may make great developments with combination of numerous subjects. By observing the tongue color we can make a diagnosis with the theories of TCM. And we found there was a consanguineous relation of temperature and color on human tongue. Many intricate heat transfer mechanisms are involved in the biological systems. Our study is carrying out research on this in relation to bio-heat transfer. The heat transfer problems of human tongue concentrate into many complicated characteristics of man's viscera (Zhang et al., 1991). The technology of applying infrared thermal imaging on tongue and related clinical research has preliminarily revealed the characteristic of temperature of human tongue and has validated that the temperature in different sub areas of the tongue surface is related to the health state in different viscera (Zhang et al., 1989). The study of the temperature of the tongue surface is helpful in the tongue inspection in TCM. In fact, the temperature of the tongue surface is mainly influenced by such parameters as the blood perfusion, the oxygen content of the blood, and the blood rheology. And the influence of blood perfusion on the temperature of the

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Nomenclature

X	position or direction along the tongue width
Y	position or direction along the tongue length
Z	position or direction along the tongue thickness
T	Temperature (°C)
K	the heat conduction coefficient (W/m °C)
Q_{met}	the metabolic heat generation (kJ/m^3 S)
W_b	the blood perfusion rate per unit volume of tissue (kg/m^3 S)
ρ_v	the density of the tissue (kg/m^3)

tongue is related to the degree of the vasodilation in the tongue. Along with the increase of the blood perfusion, the arterial blood vessels including the tiny ones, which shrink under low blood perfusion, are distended because of the higher blood pressure, thus the temperature fields in the whole tongue including that in the tongue surface are changed (Zhu et al., 2003). In order to develop the theory in tongue inspection of TCM, it is important to study the relationship between the temperature fields on the tongue surface and that in any transverse or longitudinal section of the tongue. In this paper, in view of the physiological structure of pig's tongue is very similar to that of human, the temperature fields in the specific transverse and longitudinal sections of pig tongue were numerically simulated and the temperature distribution characteristic of the inner regions of the tongue was studied on the basis of foregoing work (Zhu et al., 2003).

2. Experimental study

Fourteen minipigs (15–20 kg) were randomly divided into three groups: normal, increasing and decreasing blood stream groups. The increase and decrease of the blood stream were realized by means of modeling. The experiments conducted were within the animal welfare regulations and guidelines for China. The aim of this paper was to investigate the characteristic of heat transfer of the tongue by a method of combining animal experiments and numerical simulation, in consequence, the case of normal blood stream group was an important control.

2.1. Experimental instruments

The AGA infrared thermal imaging system and relevant data processing systems were used to measure the temperature fields in the tongue surface. The self-made φ0.1 mm thermocouples were employed to measure the inner temperature of the tongue. In addition, the flow model and MP100 BIOPAC System in the CBI-8000 physiologic Research System US were used to measure the blood flow.

2.2. Experimental processes

(1) The thermal images of the tongue surface were taken after the pig was anaesthetized.
(2) An operation was performed on the neck of the pig to expose its tongue artery and vein. Then a tiny crystal sensor of the CBI-8000 physiologic Research System was put around the artery. And again the thermal images of the tongue surface were taken to compare with the status before the operation.
(3) The temperature distribution inside the tongue and the blood temperature of the tongue artery together with that of tongue vein were measured by the thermocouples.
(4) The blood temperatures of the tongue artery and the tongue vein are measured by the thermocouples injected into them.
(5) The arterial and venous blood was phlebotomized for the blood gas analysis to determine the variation of oxygen content in the blood in the whole tongue.
(6) After the experiment in vivo, the transverse and longitudinal pathology sections of the tongue were made at the assigned locations shown as Fig. 1. The blood vessel sections were observed through a magnifying microscope 100 times and recorded by medical software. Thereby the database of the area and coordinate of vessels at many transverse and longitudinal sections in pig tongue are processed.

The experimental results validate that physiological parameters of blood and the tissue structure of tongue of pigs are both similar with human ones; thereby the experimental data will be referential to studies on the characteristics of bioheat transfer in the human tongue.

3. Numerical computations

The statistical model of heat transfer in perfused tissue from Baish (1994) was based on the statistical structure of the blood vessels and the statistical velocity of the blood flux. In this paper, we were able to make predictions because the microstructure and the blood flow situation of the tissues were available.