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Relationship between dynamic infrared thermal images and blood perfusion rate of the tongue in anaemia patients

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HIGHLIGHTS

- The blood perfusion of anaemia patients' tongue is lower than control subjects.
- The tongue surface temperature of anaemia patients decreases rapidly.
- A transient heat transfer mathematical model of the tongue was proposed.
- The low blood perfusion rate can cause faster decrease of the tongue temperature.

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ABSTRACT

The relationship between dynamic infrared (IR) thermal images and blood perfusion rate of the tongues of anaemia patients was investigated. Blood perfusion rates at multiple locations on the tongues of 62 anaemia patients and 70 control subjects were measured. For both groups of subjects, dynamic IR thermal images were also recorded within 16 s after the mouth opened. The results showed that the blood perfusion rates at different sites (apex, middle, left side and right side) on the tongues in anaemia patients (3.49, 3.71, 3.85 and 3.77 kg/s m^{-3}) were significantly lower than those at the corresponding sites in control subjects (4.45, 4.66, 4.81 and 4.70 kg/s m^{-3}). After the mouth opened, the tongue temperature decreased more rapidly in anaemia patients than in control subjects. To analyse the heat transfer mechanism, a transient heat transfer model of the tongue was developed. The tongue temperatures in anaemia patients and control subjects were calculated using this model and compared to the tongue temperatures measured by the IR thermal imager. The relationship between the tongue surface temperature and the tongue blood perfusion rate was analysed. The simulation results indicated that the low blood perfusion rate and the correlated changes in anaemia patients can cause faster temperature decreases of the tongue surface.

1. Introduction

Medical studies indicate that the pathological and physiological changes in the human body can often influence the body surface temperature. Therefore, infrared (IR) thermal imaging diagnostic techniques have recently received growing attention from researchers and physicians. Using IR thermal imaging to measure the thermal radiation distribution on the body surface, symptoms and diseases can be analysed and diagnosed based on minor temperature changes measured on the body surface [1,2]. IR thermal imaging is convenient, objective, non-invasive and non-contact and has no side effects. Several significant research achievements have been made related to IR thermal imaging. This technique is used to evaluate neural system diseases (e.g., spinal cord and peripheral nerve damage [3]), vascular diseases (e.g., Raynaud's disease [4] and lower extremity peripheral arterial disease [5]), and joint and bone diseases (e.g., myofascial pain syndrome [6], rheumatoid arthritis [7] and sports injuries [8,9]), to obtain an early diagnosis of breast cancer [10,11], xerophthalmia [12], skin diseases [13] and diabetes [14], and to assess infertility [15]. In addition, dynamic IR thermal imaging can record body temperature changes over time, providing additional information and, therefore, has gained increasing attention from researchers [16–18].

According to heat transfer theory, skin temperature is influenced by various factors, including tissue thermal conductivity, the peripheral environment, metabolism, and physiological

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conditions (e.g., the thickness of subcutaneous fat and subcutaneous tissue blood perfusion) [2]. Among these factors, blood perfusion is a critical factor. The local skin surface temperature is directly related to subcutaneous blood circulation. Pavlidis et al. [19] and Sagaidachnyi et al. [20] monitored changes in blood perfusion on the body surface by utilizing IR thermal imaging. Francis et al. [21] also proposed a method for measuring skin surface blood perfusion via IR thermal imaging. Using IR thermal imaging, Wang and He [22] investigated variations in fingertip temperature during vascular reactivity test. Jin et al. [23] proposed a method for measuring blood flow velocity in superficial arteries using dynamic IR thermal imaging. An abnormal body surface temperature distribution may occur due to abnormalities in blood flow within arteries and veins. Troilius et al. [13] found that an increase in perfusion is typically accompanied by an increase in skin temperature during the first day after treating port-wine stain.

For anaemia patients, the reduction in skin blood flow is a necessary compensatory measure to increase blood flow in the lungs. Thus, anaemia patients exhibit lower blood flow on the skin than normal subjects [24], and this abnormal subcutaneous circulation may affect the body surface temperature of anaemia patients. However, in addition to blood perfusion, skin temperature is also affected by other factors, such as subcutaneous fat and environmental temperature, which cause difficulties in studies that seek to investigate the skin temperature features of anaemia patients. The tongue is a collective tissue of muscle fibres. The tongue surface temperature is significantly correlated with blood perfusion rate [25]. Additionally, the colour and appearance of the tongue could reflect the health condition of an individual [25]. Therefore, our study focused on investigating the tongue surface temperature. The relationship between abnormalities in tongue temperature and tongue surface blood perfusion rate in anaemia patients was analysed. First, an IR thermography instrument and a laser Doppler flowmeter were employed to measure the dynamic tongue surface temperatures and the blood perfusion rates at multiple sites on the tongues of anaemia patients. The measured data were compared to data from control subjects. Then, a transient heat transfer model of the tongue was developed to simulate the effects of differences in blood perfusion rates on the dynamic changes of the tongue surface temperature.

2. Methods

2.1. Subjects

Sixty-two anaemia patients (35 male and 27 female) aged 32 ± 25 years were included. These patients comprised 33 cases of aplastic anaemia, 19 cases of secondary anaemia, and 10 cases of iron deficiency anaemia. The healthy control group included 70 individuals (35 male and 35 female) aged 39 ± 17 years.

2.2. Measurement methodology

For each subject, dynamic IR thermal images were captured, and the blood perfusion rate of the tongue surface was measured. The instruments utilized were an ML191 Laser Doppler Blood FlowMeter (ADI, Australia) and a ThermaCAM PM390 IR camera (FLIR, USA). During the measurements, the subject sat straight up with the mouth opened and the tongue out. The surface of the tongue was naturally extended, the tongue muscle was relaxed, and the tip of the tongue was pointed slightly downward. The temperature of the room where measurements were made was kept at 25 ± 1 °C, and the relative humidity was 50–60% with air conditioning off to avoid apparent air flow around the subjects. During measurements of the blood perfusion rate on the tongue surface, subjects were asked to close their mouths for 10 min prior to the measurement because prolonged tongue extension might influence blood flow. During the measurements, the laser optical fibre probe was in direct contact with the tongue but was not pressed down. The blood perfusion rates were recorded at 4 sites on the tongue: apex (at the median sulcus of tongue, approximately 0.5–1 cm from the tip of the tongue), middle (near the centre of the tongue), and left and right sides (mid-area of the tongue, approximately 0.5–1 cm from either side of the tongue). These measured results represent the blood perfusion rate of the 4 areas (apex, middle, left side, and right side of the tongue, as shown in Fig. 1). When recording the IR thermal images of the tongue surface, the subjects were also asked to close their mouths for 10 min prior to measurement to avoid influence from the environment on the initial temperature of the tongue surface. The recording of the IR thermal images began once the tongue was extended out. Consecutive images were taken 5 times, with one shot every 4 s.

2.3. Measurement results and analysis

The blood perfusion rates measured at 4 sites on the tongue for the 2 groups of subjects are provided in Table 1, which are presented as the mean ± standard deviation. The blood perfusion rates at these sites on the tongue surfaces of anaemia patients were all significantly lower than those at the corresponding sites in control subjects ($p < .01$ by Student's t test); the differences between the 2 groups at each site were similar. For both groups of subjects, the blood perfusion rates decreased in the order of left side > right side > middle > apex.

The IR thermal image sequences of the tongues of an anaemic patient and a control subject are shown in Fig. 2. The surface temperature gradually decreased from the base of the tongue to the tip of the tongue. After the mouth opened, as heat dissipated from the tongue to the environment, the tongue surface temperature showed a gradual decreasing trend in both groups of subjects.

Various analysis methods of IR thermal images have been used in the literature to obtain a representative temperature of a region of interest [26]. In this paper, due to thermal inertia, the IR thermal image taken at 0 s after the mouth opened was considered to reflect the temperature distribution on the tongue surface when the mouth is closed and to be subject to the influences of the internal thermal environment of the mouth cavity. In addition, the absolute temperatures of the tongue surfaces of different subjects are correlated with their body temperatures. Body temperature is

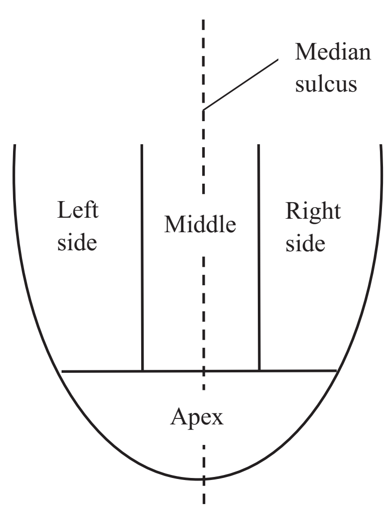

Fig. 1. Illustration of the areas of the tongue surface.