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An Analysis of the Application of Infrared Thermography in Traditional Chinese Medicine

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Abstract: ***Traditional Chinese Medicine (TCM), with its long history spanning thousands of years, is deeply rooted in both cultural and historical contexts. TCM is based on a holistic view and the concept of dynamic balance, utilizing diagnostic methods such as observation, auscultation, inquiry, and palpation to assess the health status of the body, emphasizing disease prevention and the restoration of the body's internal balance. However, with the advancement of modern medical technologies, the visualization of TCM's effects and the objective evaluation of its therapeutic outcomes have been subject to external skepticism. Infrared thermography, an advanced medical imaging technology, has shown unique value in various medical fields in recent years. It detects the infrared radiation naturally emitted by the human body and generates thermal images that reflect the distribution of body surface temperature. This technology is non-invasive, painless, and can monitor temperature variations continuously or periodically, providing important physiological information to doctors. This paper aims to analyze the principles and equipment of infrared thermography, and to provide examples of its application in TCM in recent years, in order to highlight the potential and future prospects of infrared thermography in clinical TCM practice.***

Keywords: Infrared thermography, Traditional Chinese Medicine, Medical imaging technology, Infrared radiation**.**

1. Overview of Infrared Thermography

Infrared thermography is a non-invasive diagnostic tool that measures and visualizes temperature distribution by capturing infrared radiation emitted from the surface of objects. This technology has broad applications in various fields, including medicine, industrial testing, and environmental monitoring [1]. In the medical field, it is particularly useful for disease screening, inflammation monitoring, and real-time assistance during surgeries.

1.1 Basic Principles of Infrared Thermography

Infrared thermography is based on the fundamental physical principle of infrared radiation emitted by objects. According to Planck's law of blackbody radiation, all objects above absolute zero emit infrared radiation [2]. Infrared thermography systems capture this radiation and convert it into temperature values, thereby creating visual thermal images that represent the temperature distribution on the surface of the object. The following briefly explains the scientific foundation and operational mechanism of this technology.

1.1.1 The Physical Basis of Thermal Radiation

The key to infrared thermography lies in understanding thermal radiation. Thermal radiation is electromagnetic radiation emitted by an object due to its thermal energy. The amount of radiation energy and its wavelength distribution are directly dependent on the temperature of the object [3]. According to the Stefan-Boltzmann law, the radiated energy of an object is proportional to the fourth power of its absolute temperature, meaning that even small temperature changes can cause significant variations in radiated energy [4].

1.1.2 Detection of Infrared Radiation

Infrared thermography systems use sensors to detect infrared radiation emitted by objects. These sensors are sensitive to specific infrared wavelength ranges, typically between 3 microns and 12 microns, which allows them to detect radiation from the human body and other organic materials. The sensors convert the received infrared radiation into electrical signals, which are then transformed into digital format for image processing and temperature calculation [5].

1.1.3 Formation and Interpretation of Infrared Images

The image processing system in a thermal camera converts the data collected by the sensors into thermal images. These images use different colors to represent varying temperature levels. Warmer regions might appear red or yellow, while cooler regions are shown in blue or green. Thermal images provide an intuitive way to identify and analyze the temperature distribution on the surface of an object. This capability is extremely useful for detecting mechanical faults, monitoring medical conditions, or evaluating thermal effects in environmental assessments.

1.2 Equipment and Instruments of Infrared Thermography

Infrared thermography relies on a series of precise devices and instruments that work together to capture infrared radiation emitted from the target object and convert it into analyzable temperature images. The core components include infrared sensors, optical systems, signal processing systems, and display and control systems. Each part plays a crucial role in the imaging quality and accuracy.

1.2.1 Infrared Sensors

Infrared sensors are the core components of thermal cameras, responsible for receiving infrared radiation emitted from the surface of objects. Depending on the application, sensors can be classified into two main types: cooled and uncooled. Cooled sensors improve sensitivity and resolution by

lowering their own temperature, making them suitable for high-precision scientific research and military applications. In contrast, uncooled sensors, while having lower sensitivity, are more cost-effective, require less maintenance, and start up quickly, making them more suitable for commercial and industrial markets.

1.2.2 Optical System

The optical system consists of a series of specially designed lenses primarily used to focus infrared radiation onto the sensor. Lens materials such as germanium, zinc selenide, or zinc sulfide are chosen for their high transparency to infrared wavelengths, allowing effective transmission of radiation energy while minimizing energy loss. Additionally, the lens system is precisely designed to reduce optical distortion and optimize image quality.

1.2.3 Signal Processing and Image Processing Systems

The key task of the signal processing stage is to convert the detected analog infrared signals into digital signals and perform preliminary image processing [7]. This includes signal amplification, noise filtering, and analog-to-digital conversion. Subsequent image processing steps use various algorithms to improve image readability, such as edge enhancement, contrast adjustment, and false color mapping, making temperature differences more visually apparent.

1.2.4 Display and Control Systems

The display and control systems form the user interface, through which users interact with the thermal camera. Modern thermal cameras typically feature high-resolution LCD screens that display thermal images in real-time. Operators can adjust parameters such as temperature range and focus to suit different testing needs. Moreover, advanced analysis software can further process thermal images, providing detailed temperature analysis and data statistics, enhancing the utility and flexibility of infrared thermography in various applications.

By coordinating the use of these highly specialized devices and instruments, infrared thermography provides accurate temperature monitoring and detailed image analysis, leading to revolutionary improvements in medical diagnostics, industrial testing, and various other fields [8].

2. Application of Infrared Thermography in Traditional Chinese Medicine

In recent years, with the integration of modern technology and traditional medicine, infrared thermography has started to be applied in the diagnostic and therapeutic processes of Traditional Chinese Medicine (TCM) due to its unique non-invasive nature and ability to visually display the body's thermal distribution. The introduction of this technology has not only provided a new perspective and method for TCM, but also enhanced the accuracy and efficiency of TCM diagnosis and treatment. The author conducted a review of the application of infrared thermography in the field of TCM by searching and selecting articles from the China National Knowledge Infrastructure (CNKI) and PubMed databases using keywords such as "infrared thermography" and "Traditional Chinese Medicine," with the aim of demonstrating how this technology helps TCM better adapt to the demands of modern healthcare.

2.1 Supporting the Study of TCM Basic Theories

Zhang Yuxuan and Chen Qianfeng [9] conducted a study involving 80 subjects, divided into an observation group (40 patients with wind-heat invading the lungs) and a control group (40 healthy subjects). Infrared thermography was used to capture temperature data of the lung area, eyes, ears, nasal passages, and lips before and after recovery for both groups. The results showed statistically significant differences in temperature between the lung and nasal areas ($P<0.05$), while no significant differences were found in other areas ($P>0.05$). This finding demonstrated that the wind-heat invading the lungs caused an increase in the temperature of the lung and nasal areas, further validating the TCM theory of "the lung opens to the nose" in the context of organ-portal relationships.

Huang Shixia [10] used infrared thermography to observe temperature data from 100 healthy subjects before and after moxibustion at the Taiyuan and Hegu acupoints. The temperatures of the lung, heart, liver, spleen, kidney, large intestine, small intestine, gallbladder, stomach, bladder regions, as well as the lung and large intestine meridian acupoints (such as Feishu, Zhongfu, Dachangshu, and Tianshu) were recorded. The comparison of temperatures before and after moxibustion showed statistically significant differences in the lung and large intestine regions ($P<0.05$), while no significant differences were found in other regions ($P>0.05$). This conclusion, verified by infrared thermography, validated the TCM theory of "the lung and large intestine being internally and externally connected, " and provides data support for future clinical diagnosis and treatment.

2.2 Assisting Clinical Research in Traditional Chinese Medicine

2.2.1 Application of Infrared Thermography in Evaluating TCM Constitution Theory

TCM constitution theory has been a hot research topic, and it is generally classified into nine types of constitution [11]. Different constitutions exhibit variations in thermal patterns, and these differences form the material basis for infrared thermography to identify constitutions [12]. Infrared thermography provides a scientific and effective objective method for determining constitutions and evaluating treatment efficacy, moving beyond subjective methods such as scales [13]. Zhang Jidong and others [14] selected 556 normal male individuals with a yang deficiency constitution and captured their infrared thermal images, obtaining data on temperature differences in organ regions, meridians, and acupoints. The analysis revealed that the infrared thermal images of the yang deficiency constitution were influenced by age, with the number of individuals with a yang deficiency constitution increasing as age progressed. Additionally, infrared thermal values showed a positive correlation with seasonal temperature variations. The lower abdomen, left chest, epigastric area, upper and lower abdomen, spleen shu point, and heart shu point were closely associated with the

yang deficiency constitution, and these points were most sensitive to seasonal temperature changes. Tong Hongxuan and others [15] applied infrared thermography to observe the surface thermal values of 25 regions on the upper body and head/face of middle-aged individuals with a qi stagnation constitution. They found that individuals with a qi stagnation constitution exhibit characteristics such as heat accumulation in the upper burner, loss of warmth regulation in the middle burner, and weak yang in the lower burner. As a result, the infrared thermal images of the qi stagnation constitution presented an overall pattern of "heat in the upper body and cold in the lower body, " reflecting the energy metabolism trends of the individuals.

2.2.2 Application of Infrared Thermography in Evaluating the Efficacy of TCM Modalities

Guided Exercises, such as those practiced in traditional Chinese medicine for thousands of years, aim to maintain health and prevent illness through specific movements and breathing exercises, such as Baduanjin, Wuqinxi, and breath regulation. These exercises are believed to regulate meridians, balance qi and blood, and harmonize organ functions, thereby strengthening the body, preventing and treating diseases, and prolonging life. In TCM theory, meridians are the channels through which qi and blood circulate. When guided exercises are performed to unblock these meridians, infrared thermography can detect temperature changes in the corresponding meridian pathways, providing insights into whether qi and blood are flowing smoothly. Tian Siwei, Song Jun, and others [16] recruited 120 participants to investigate the scientific basis of Baduanjin's effect on coordinating organs and promoting qi and blood circulation. Participants were randomly assigned to three groups: an experimental group, a control group, and a blank group, with 40 participants in each group. The three groups received different interventions: Baduanjin, the ninth set of radio calisthenics, and no practice. The results showed that, after intervention, the experimental group exhibited a significant increase in the temperature values of their organs compared to before ($P<0.01$), while the control and blank groups showed no significant changes ($P>0.05$). The comparison between the groups post-intervention revealed that the experimental group's organ temperature values were significantly higher than those of the control and blank groups ($P<0.05$ or $P<0.01$). This study demonstrated that TCM exercises, such as Baduanjin, can increase body or organ temperature, which can be visually confirmed by infrared thermography, providing a means of evaluating the therapeutic effects of these movements. Chen Jia [17] and colleagues, based on infrared thermography, studied the intervention effects of the ancient Jianqiao moxibustion method on individuals with a yang deficiency constitution. A total of 62 participants were randomly assigned to an observation group and a control group, with 31 participants in each group. The observation group received treatment with Jianqiao moxibustion, while the control group received conventional mild moxibustion therapy. The intervention effects were evaluated using the Yang Deficiency Constitution Questionnaire and infrared thermography of the governor vessel. The results showed that, after the intervention, the infrared radiation trajectories along the governor vessel were more prominent, indicating that both Jianqiao moxibustion and conventional mild moxibustion had a positive intervention effect on yang deficiency constitutions, with Jianqiao moxibustion demonstrating a more significant and comfortable effect.

2.2.3 Application of Infrared Thermography in Assisting Disease Diagnosis

Certain types of diseases can lead to abnormal local body temperatures. Infrared thermography not only helps assess whether a particular therapy positively influences the temperature of the affected area, which can infer the therapeutic effects of the treatment, but it can also assist in diagnosing diseases. Zhu Manhua and others [18] studied the significance of infrared thermal imaging in guiding warm acupuncture treatment for cold-damp type lumbar pain. They found that, before treatment, the experimental group showed high temperatures in the lower back and low temperatures in the buttocks, with an uneven overall temperature distribution and a clear boundary. This indicated an inflammatory response in the lumbar region and circulatory dysfunction, preventing the smooth flow of qi and blood from the lower back to the buttocks. After treatment, in which both sides of the buttocks were selected for warm acupuncture therapy, the cold-damp condition in the buttocks was resolved, qi and blood circulation was restored, and the infrared thermal image changed significantly. The lumbar region presented orange-colored patchy areas, while the buttocks displayed green areas, with the boundary of temperature distribution becoming less distinct. The temperature difference between the lumbar and buttock areas significantly decreased. This study showed that infrared thermal imaging can guide warm acupuncture treatment for cold-damp type lumbar pain by visualizing temperature changes in low-temperature areas.

2.2.4 Application of Infrared Thermography in Research on Traditional Chinese Medicine (TCM)

In studying the pharmacological mechanisms of traditional Chinese medicine (TCM), infrared thermography can assist in observing the effects of herbal medicine on the body's metabolism. Changes in body metabolism can lead to alterations in surface temperature, and by observing these temperature changes, researchers can infer how a drug intervenes in metabolic processes, providing further insights into the pharmacological details of TCM. Huang Jiali [19] investigated the thermal characteristics of phlegm-damp constitution metabolic syndrome and explored the relationship between the formation of thermal states and brown adipose tissue (BAT), while also verifying the intervention and mechanisms of Chinese herbal medicine. Using network pharmacology methods, three formulations (Zhishuo granules, Compound Danshen Tablets, and Yi Yi Fu Zi San) were selected, and rats with metabolic syndrome and phlegm-damp constitution were identified. The study explored whether Chinese medicine could improve the surface thermal states of phlegm-damp metabolic syndrome rats by enhancing the expression of brown adipose tissue. The results showed that, compared to the control group, the model group rats did not exhibit significant changes in shoulder and abdominal temperatures after cold stimulation, with the average temperature being significantly lower than that of the control group ($P<0.05$ or $P<0.01$). In contrast, after cold stimulation, the average temperatures in the shoulder and

abdomen of the Chinese medicine-treated group increased significantly ($P<0.05$ or $P<0.01$). Blood flow was improved, and inflammatory and metabolic indicators related to brown adipose tissue were regulated to some extent.

3. Reflection and Outlook

Despite the many advantages brought by infrared thermography, its application in traditional Chinese medicine (TCM) still faces several challenges. These include issues related to the widespread adoption of the technology, operational complexity, and integration with traditional TCM theories and practices. Additionally, ensuring the standardization of its application and the reproducibility of results are critical obstacles to overcome in the promotion of the technology. Looking forward, further research and development on infrared thermography, especially more advanced techniques based on it, will need to focus on improving technical precision, developing customized diagnostic and treatment protocols, and promoting standardization and training. In particular, efforts should be made to enhance the reliability and accuracy of thermographic measurements to align them with the diverse and nuanced approaches of TCM. Overall, the introduction of infrared thermography provides strong support for the modernization and internationalization of TCM. With continued technological advancements and deeper application research, it is expected that infrared thermography will play an increasingly significant role in enhancing the scientific and clinical efficacy of TCM, thereby contributing unique value to global healthcare.

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