Online at: https://researchtrendsjournal.com ISSN No: 2584-282X

INTERNATIONAL JOURNAL OF TRENDS IN EMERGING RESEARCH AND DEVELOPMENT

Volume 2; Issue 1; 2024; Page No. 13-17

Received: 01-10-2023
Accepted: 08-11-2023

Efficacy of infrared thermography in early detection of type 2 diabetes mellitus

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Abstract

This study investigates the potential of non-contact infrared thermography as an early diagnostic tool for type 2 diabetes mellitus (T2DM) by analysing peripheral skin temperature patterns in diabetic and non-diabetic subjects. Employing a cross-sectional study design, thermal images of 100 participants were evaluated to identify distinctive thermal signatures associated with T2DM. The study found significant differences between the thermal patterns of diabetic patients and control subjects. These differences were especially noticeable in the lower limbs, where lower temperatures indicate poor peripheral circulation, a common problem in T2DM. Statistical analysis demonstrated the sensitivity and specificity of infrared thermography, supporting its potential as a non-invasive diagnostic tool. The findings suggest that infrared thermography could complement traditional diagnostic methods, allowing for earlier detection and intervention in diabetes management. The study highlights the need for further research to validate these findings and explore the integration of this technology into clinical practice.

Keywords: Type 2 diabetes mellitus, infrared thermography, non-contact diagnosis, peripheral skin temperature, early detection, diagnostic tools

Introduction

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterised by high blood glucose levels due to insulin resistance and relative insulin deficiency. It is one of the most prevalent diseases globally, affecting millions of people and posing significant health, economic, and social burdens. According to the World Health Organisation (WHO), the global prevalence of diabetes among adults over 18 years has risen from 4.7% in 1980 to 8.5% in 2014, with the majority being Type 2 diabetes cases (World Health Organisation, 2016) [16].

Early diagnosis and intervention are critical in managing T2DM, as they can significantly mitigate the risk of severe complications such as cardiovascular disease, kidney failure, and retinal damage. However, current diagnostic methods, primarily based on blood glucose levels and glycated haemoglobin (HbA1c) tests, require blood samples, which can be invasive and uncomfortable for the patient. Furthermore, such methods often fail to capture early physiological changes that precede elevated glucose levels, which can delay preventive measures (American Diabetes Association, 2014) [1].

Noncontact, non-invasive technologies are gaining attention in the quest for improved diagnostic tools. Among these, infrared thermography is a promising method due to its ability to detect subtle physiological changes through skin temperature patterns. Infrared thermography measures the heat emitted by the body and visualises it as a thermal image, providing a unique "thermal signature." This technology has been used in various medical applications, including vascular disorders, breast cancer, and inflammatory diseases, demonstrating its potential to detect anomalies in physiological functions (Ring & Ammer, 2012) [9].

Recent studies have indicated that peripheral skin temperature variations, detectable through infrared thermography, may correlate with underlying metabolic conditions like diabetes. For instance, diabetic patients often exhibit altered thermal profiles due to microvascular and macrovascular complications that affect blood flow and, thus, skin temperature (Neves *et al*., 2016) [7]. A study by Lawson (2010) [6] demonstrated that specific thermal patterns in the lower extremities could help identify patients with diabetic neuropathy, suggesting a broader application for early detection of T2DM.

Furthermore, the non-contact nature of infrared thermography makes it an appealing option for frequent monitoring without discomfort, providing a patient-friendly approach to diabetes management. The ability to detect early peripheral thermal abnormalities could enable interventions at a pre-clinical stage, potentially delaying or preventing the onset of full-blown diabetes (Ng & Keevil, 2010) [8]. Given the rising prevalence of T2DM and the limitations of current diagnostic methods, there is a compelling need for innovative approaches that enhance early detection and management. This study investigates whether thermal patterns identified via infrared thermography can serve as early indicators of T2DM, providing a basis for non-invasive, non-contact screening tools that could transform current diagnostic paradigms.

Literature review

Infrared thermography (IRT) has been increasingly recognised as a valuable diagnostic tool in medical practice, particularly in identifying and understanding various health conditions that manifest through changes in body surface temperature. This section reviews the body of literature that explores the utility of IRT in medical diagnostics, with a specific focus on its application to diabetes and other metabolic disorders. It will also discuss the physiological basis for temperature variations in diabetic patients and summarise current diagnostic methods.

Infrared thermography in medical diagnostics

Infrared thermography is a non-invasive imaging procedure that detects infrared energy emitted from the body and converts it to temperature, producing images (thermograms) that map skin surface temperature. IRT has been utilised in various fields of medicine, including vascular diseases, rheumatology, and dermatology, due to its ability to provide a visual map of the temperature distribution of the human body (Ammer, 2008; Ring & Ammer, 2012) [9, 2]. The application of IRT in the study of vascular disorders underscores its potential for diabetes research. Diabetes often leads to peripheral vascular abnormalities, which can be detected as changes in skin temperature due to reduced or irregular blood flow. Studies such as those by Gatt *et al*. (2011) [4] have demonstrated that IRT can identify areas of reduced circulation typical of diabetic neuropathy, a condition that significantly complicates diabetes management.

Application to diabetes and metabolic disorders

Metabolic disorders, including diabetes, manifest several physiological changes affecting skin temperature. Diabetes, for instance, alters blood flow due to microvascular and macrovascular complications, making IRT a potentially helpful tool for early detection and monitoring of the disease (Neves *et al*., 2016) [7]. Thermographic assessments have been used to detect diabetic foot syndrome, a severe diabetes complication, by identifying heat patterns indicative of inflammation or infection (Lahiri *et al*., 2012) [5]. A notable study by Armstrong *et al*. (2007) [3] demonstrated that thermography could predict diabetic foot ulcer formation weeks before it became clinically evident. This predictive capability is crucial for preventing some of the most challenging consequences of diabetes. It significantly improves over traditional methods that only recognise these conditions once they have developed.

Physiological basis for temperature variations

The physiological basis for temperature variations in diabetic patients is primarily related to abnormalities in blood flow. Diabetes causes endothelial dysfunction and a thickening of the vessel walls, leading to impaired microcirculation. This impaired circulation leads to changes in skin temperature, which can be systematically recorded through IRT (Ng & Keevil, 2010) [8]. Studies have shown that areas of the body with compromised circulation will exhibit cooler temperatures due to reduced blood supply. In contrast, areas of inflammation associated with ulceration or infection may show increased heat. By monitoring these temperature changes, IRT can provide valuable insights into the underlying pathophysiological changes in diabetic patients, potentially aiding in early diagnosis and management (Ring & Ammer, 2012) [9].

Current diagnostic methods

The current diagnostic criteria for diabetes are primarily based on blood glucose measurements, including fasting blood glucose, oral glucose tolerance tests, and glycated haemoglobin (HbA1c) levels. While these tests are practical for diagnosing diabetes, they do not provide information on the physiological changes that may precede the onset of diabetes symptoms (American Diabetes Association, 2014) [1].

Moreover, the invasive nature of these tests and the discomfort they may cause can be a barrier to routine screening. Thus, there is a significant interest in developing non-invasive methods that can detect diabetes and its complications at an earlier stage. IRT offers a promising alternative, providing a painless, non-invasive means of detecting early signs of diabetes by monitoring physiological changes, such as those related to blood flow and skin temperature (Lawson, 2010) [6].

Materials and Methods

This study utilises a cross-sectional design to compare the thermal patterns of individuals diagnosed with type 2 diabetes mellitus (T2DM) against those of non-diabetic control subjects. The subject pool comprises 100 participants, divided equally into diabetic and non-diabetic groups. Criteria for inclusion in the diabetic group include a formal diagnosis of T2DM as per the American Diabetes Association guidelines (2014) [1], with management through lifestyle changes or medication. The control group consists of individuals matched by age, gender, and body mass index (BMI) with no history of any metabolic disorder, confirmed by a recent medical examination and blood tests to rule out pre-diabetes or undiagnosed diabetes. Exclusion criteria for all participants include any condition that alters thermal emission, such as vascular disease, inflammatory conditions, or skin disorders.

The thermographic imaging is conducted using a highresolution infrared camera (FLIR T650sc), which captures temperature variations to a sensitivity of 0.02 °C. The procedure is standardised in an environmentally controlled room with a maintained temperature of 23±1 °C and humidity of 50±5%. Participants are acclimatised to the room conditions for 15 minutes before imaging to ensure thermal equilibrium with the environment. Imaging includes multiple views (anterior, posterior, left lateral, and right lateral), mainly on peripheral regions typically affected in diabetic patients, such as the lower extremities. Thermal images are analysed using FLIR Tools+software, which provides detailed temperature data and image analysis capabilities. Differences in average temperature, specific hot and cold spots, and limb thermal symmetry are recorded and compared between groups.

Table 1: Summary of Participant Characteristics and Imaging Protocol

Parameter	Diabetic Group	Control Group	Notes
Number of subjects	50	50	Equal distribution for comparison
Age (years)	45-65	45-65	Matched for age
Gender distribution	50% Male, 50% Female	50% Male, 50% Female	Gender-matched
BMI (kg/m²)	25-35	25-35	Matched for BMI
Imaging equipment	FLIR T650sc	FLIR T650sc	High-sensitivity thermal imaging
Room temperature	23±1°C	23±1°C	Controlled environmental condition
Humidity	50±5%	50±5%	Controlled environmental condition
Imaging views	Multiple	Multiple	Standardised views
Software used	FLIR Tools+	FLIR Tools+	For detailed image analysis

Results

The analysis of the thermal images obtained from both the diabetic and control groups revealed significant differences in skin temperature patterns, particularly in the peripheral regions of the body. The data, processed through statistical analysis, underscore the distinct thermal signatures associated with type 2 diabetes mellitus (T2DM).

Overall Thermal Patterns

The mean skin temperature of the lower extremities was consistently lower in the diabetic group compared to the control group. The average temperature recorded in the diabetic group was 28.5 °C, while the control group exhibited a higher average of 31.7 °C. This significant temperature difference ($p<0.01$) indicates reduced peripheral circulation, a common complication in diabetes.

Specific regional analysis

An in-depth analysis of specific body regions showed that the feet and lower legs displayed the most pronounced temperature differences. Diabetic participants exhibited cooler temperatures in these areas, with mean temperatures of 27.3 °C in the feet and 29.1 °C in the lower legs. In contrast, control participants had mean temperatures of 30.8 °C in the feet and 32.4 °C in the lower legs, demonstrating statistically significant differences ($p<0.01$).

The thermal symmetry between limbs was also evaluated, with diabetic subjects showing more significant asymmetry, particularly in the feet. The temperature difference between the left and right foot was more significant than 2.0°C in 40% of the diabetic subjects compared to only 5% in the control group, suggesting a more irregular and disrupted blood flow pattern ($p<0.05$).

Statistical analysis

Statistical tests included independent t-tests for comparing means between the two groups and Chi-square tests for categorical variables such as thermal asymmetry. The level of significance was set at $p<0.05$. The study confirmed statistically significant differences in thermal patterns between diabetics and controls. This suggests that infrared thermography could be used to find changes in thermal properties indicative of diabetic conditions.

Table 2: Summary of Thermal Imaging Results

Region	Diabetic Group Mean Temp. (°C)	Control Group Mean Temp. (°C)	p-value
Lower Extremities	28.5	31.7	<0.01
Feet	27.3	30.8	<0.01
Lower Legs	29.1	32.4	<0.01
Thermal Asymmetry (Feet)	40% (≥2.0°C difference)	5% (≥2.0°C difference)	<0.05

The results obtained from the thermal imaging analysis delineate the thermal discrepancies between subjects diagnosed with T2DM and healthy controls. The lower temperatures observed in the peripheral regions of diabetic patients align with documented symptoms of reduced peripheral blood flow and diabetic neuropathy, which are common complications of diabetes (Neves *et al*., 2016) [7]. The significant thermal asymmetry observed in diabetic patients also highlights potential areas of vascular compromise that may not be easily detected through traditional diagnostic methods.

Findings and Discussion

The analysis of thermal imaging results from this study reveals that significant differences in skin temperature patterns exist between individuals diagnosed with Type 2 Diabetes Mellitus (T2DM) and healthy control subjects, particularly in peripheral body regions. This section interprets these results, discussing the potential implications for T2DM diagnosis and evaluating the sensitivity and specificity of infrared thermography compared to traditional diagnostic methods.

Correlation of thermal patterns with T2DM

The marked decrease in peripheral skin temperatures in diabetic patients as compared to controls correlates with the vascular and neuropathic complications associated with diabetes. Diabetic neuropathy and peripheral arterial disease (PAD), both prevalent complications of diabetes, can significantly impair blood flow, thus reducing skin temperature (Ng & Keevil, 2010) [8]. These conditions lead to an uneven distribution of blood, which is reflected in the thermal asymmetry observed more frequently in the diabetic group. The findings that the lower extremities, particularly the feet, exhibit notable differences in temperature between diabetics and non-diabetics underscore the potential of thermal imaging to identify early microvascular changes before they manifest clinically.

Sensitivity and specificity of infrared thermography

To evaluate the diagnostic utility of infrared thermography, the sensitivity and specificity were calculated based on the method's ability to correctly identify diabetic patients from thermal images. For this analysis, true favourable rates were defined by identifying thermal abnormalities consistent with diabetic complications. In contrast, true negatives were defined by standard thermal patterns observed in non-diabetic controls.

Based on the data collected, infrared thermography demonstrated a sensitivity of 85% and a specificity of 90% in identifying diabetic subjects. These figures suggest thermal imaging is highly effective for detecting T2DM-related physiological changes. However, it is essential to consider these results within the context of existing diagnostic methods. Traditional methods, such as fasting blood glucose and HbA1c tests, are susceptible and specific but do not provide information on physiological changes that may indicate the onset of complications (American Diabetes Association, 2014) [1].

Comparison with traditional diagnostic methods

While traditional diagnostic methods remain the gold standard for diagnosing diabetes, they are invasive and often fail to detect early systemic changes associated with diabetes complications. Infrared thermography, by contrast, offers a non-invasive means to detect these changes early by identifying abnormal thermal patterns that indicate underlying pathologies such as impaired blood flow and neuropathy. Thus, while not a replacement for biochemical tests, thermography could be a complementary toolfor ongoing monitoring and early detection of complications.

Table 3: Sensitivity and Specificity of Infrared Thermography

Diagnostic Tool	Sensitivity	Specificity	Comments
Infrared Thermography	85%	90%	High efficacy in detecting physiological changes
Fasting Blood Glucose Test	99%	98%	The gold standard for diabetes diagnosis
HbA1c Test	97%	95%	Effective for long-term glucose monitoring

Implications for clinical practice

The implications of integrating infrared thermography into clinical practice for diabetes management are profound. By enabling the early detection of peripheral changes associated with diabetes complications, thermography can facilitate timely interventions that might prevent the progression of such complications, ultimately improving patient outcomes and reducing healthcare costs. Further, the non-invasive nature of this technology makes it ideal for routine monitoring, particularly in patients at increased risk of developing diabetic complications.

Conclusion

The findings from this study underscore the considerable potential of non-contact infrared thermography as an effective early diagnostic and monitoring tool for type 2 diabetes mellitus (T2DM). The distinct thermal patterns observed in diabetic patients, especially in peripheral regions such as the feet and lower legs, provide critical insights into the physiological changes accompanying diabetes, such as impaired blood flow and neuropathy. Infrared thermography is much better than traditional diagnostic methods because it can find these changes without hurting the patient. These methods depend on biochemical markers and often miss early systemic changes that happen before symptoms show up.

Infrared thermography can tell the difference between people with and without diabetes based on their thermal signatures, which shows that it is sensitive and specific. This suggests that it could be helpful as an extra tool in addition to other diagnostic methods. This capability to identify early signs of diabetes and its complications could lead to timely medical interventions, potentially reducing the incidence and severity of long-term complications and thereby improving the quality of life for patients with diabetes.

However, while the results of this research are promising, they also highlight the need for further investigation. Larger-scale studies are necessary to validate these findings across more diverse populations and to refine the imaging and analysis techniques used in infrared thermography. Additionally, research should explore integrating this technology into routine clinical practice, examining its diagnostic accuracy and practicality, cost-effectiveness, and acceptability among patients and healthcare providers.

In conclusion, non-contact infrared thermography represents a promising frontier in the early diagnosis and management of T2DM. Its non-invasive, pain-free monitoring capabilities could enhance current diagnostic approaches. Continued research and development in this area are essential to fully realize its potential and establish guidelines for its application in the clinical setting, ultimately contributing to better preventive care and management strategies for diabetes.

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