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Thermal imaging as a non-invasive tool to analyze microcirculation and heat distribution. A cross-sectional observational study.

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Abstract
Background
Microcirculation plays a vital role in tissue perfusion and thermoregulation. Early alterations in microvascular blood flow often precede structural changes and remain undetected by conventional diagnostic methods.
Aim
To assess the usefulness of infrared thermal imaging as a non-invasive tool for analyzing microcirculation and heat distribution.
Materials and Methods
This cross-sectional observational study included 100 adult participants evaluated over 11 months at Laxmi Chandravansi Medical College and Hospital, Jharkhand. The majority of participants were aged 31–45 years (38%). Thermal images were captured under standardized conditions. Mean surface temperature, thermal asymmetry, and heat distribution patterns were analyzed using Student’s t-test and Pearson correlation.
Results
The mean surface temperature was significantly higher on the right side (32.4 ± 1.2°C) compared to the left (31.8 ± 1.3°C) ($p = 0.004$). Thermal asymmetry ≥0.5°C was observed in 42% of participants. A statistically significant positive correlation was found between thermal asymmetry and clinical indicators of microcirculatory dysfunction ($r = 0.61$, $p < 0.001$).
Conclusion
Infrared thermal imaging is a reliable, non-invasive modality for assessing microcirculation.
Recommendation
It can be used as a screening and monitoring tool in clinical practice, especially in resource-limited settings.

Keywords: *Thermal imaging, Infrared thermography, Microcirculation, Heat distribution, Non-invasive diagnostics*
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Introduction

The microcirculation, composed of arterioles, capillaries, and venules, plays a fundamental role in tissue oxygenation, nutrient exchange, and thermoregulation [1]. Alterations in microvascular blood flow are frequently observed in metabolic, inflammatory, and vascular disorders and may precede overt structural pathology [2]. Impaired microcirculatory regulation has been implicated in diabetes mellitus, peripheral vascular disease, systemic

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inflammatory conditions, and neuropathic disorders [3,4].

Conventional diagnostic modalities such as Doppler ultrasonography and angiography primarily evaluate macrocirculatory flow and may not adequately capture functional microvascular changes [5]. Capillaroscopy and laser Doppler techniques provide additional insights but are limited by operator dependency and restricted field assessment [6,7].

Infrared thermography detects infrared radiation emitted by the body surface and converts it into temperature-mapped images [8]. Since cutaneous temperature reflects local perfusion and metabolic activity, thermal imaging offers indirect evaluation of microvascular function [9]. The physiological principle of bilateral thermal symmetry has been widely recognized; deviations beyond 0.5°C are often considered clinically relevant [10].

Previous clinical applications of thermography have included assessment of diabetic foot risk, inflammatory joint disorders, vascular insufficiency, and burn evaluation [11–13]. The method offers several advantages, including non-contact measurement, absence of ionizing radiation, and feasibility for repeated monitoring [14].

Despite increasing interest in functional vascular imaging, regional data evaluating thermography for microcirculatory assessment remain limited. The present study was therefore conducted to analyze cutaneous heat distribution and thermal asymmetry in an adult population using standardized infrared imaging techniques.

Materials and Methods

Study Design

This study was a **cross-sectional observational study** conducted to evaluate the utility of infrared thermal imaging in assessing microcirculation.

Study Setting

Laxmi Chandravansi Medical College and Hospital (LCMCH) is a tertiary care teaching hospital providing outpatient and inpatient services across multiple specialties, including medicine, surgery, and diagnostic services.

Study Duration

Data collection was carried out from **January 2025 to November 2025**.

Study Population and Sample Size

A total of **100 adult subjects** were included in the study. The sample size was determined based on feasibility and previous thermographic studies evaluating microcirculatory parameters in clinical settings.

Inclusion Criteria

Subjects fulfilling the following criteria were enrolled:

Age ≥ 18 years

Willingness to participate and provide informed consent

Ability to comply with study procedures and instructions

Exclusion Criteria

Subjects were excluded if they had:

Acute febrile illness at the time of evaluation

Local skin lesions, burns, or dermatological conditions affecting the imaging area

History of recent trauma or surgery involving the region of interest

Application of topical agents, oils, or medications to the skin prior to thermal imaging

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Conditions likely to interfere with accurate surface temperature measurement

Bias Control

Potential sources of bias were minimized by standardizing environmental conditions, ensuring uniform subject preparation, and using calibrated equipment. Observer bias was reduced by following a structured imaging protocol.

Ethical Considerations

The study protocol was approved by the **Institutional Ethics Committee of LCMCH**. Written informed consent was obtained from all participants prior to enrollment.

Thermal Imaging Equipment

Infrared thermal images were acquired using a **calibrated medical-grade infrared thermal camera** capable of detecting subtle variations in skin surface temperature. The device provided temperature resolution sufficient to identify differences as small as 0.1°C.

Environmental Standardization

To minimize external influences on skin temperature, all thermal imaging was performed under **strictly controlled environmental conditions**:

Ambient room temperature maintained between **22–24°C**

Absence of direct sunlight, airflow, or external heat sources

Uniform background and lighting conditions

Subject Preparation

Participants were instructed to:

Avoid strenuous physical activity, caffeine intake, and smoking for at least **2 hours** prior to imaging

Remove any accessories or clothing covering the area to be imaged

Before image acquisition, subjects were allowed an **acclimatization period of 15 minutes** in the imaging room to stabilize skin temperature.

Thermal Imaging Protocol

Thermal images were captured with subjects in a standardized posture, ensuring consistent positioning across participants. Bilateral anatomical regions were imaged simultaneously to allow direct comparison of corresponding areas.

The following parameters were recorded:

Mean surface temperature (°C) of selected regions

Temperature differences between symmetrical right and left sides

Visual heat distribution patterns based on color mapping

Representative thermographic images demonstrating normal symmetry and abnormal asymmetry were documented for qualitative assessment (Figures 1 and 2).

Outcome Measures

The primary and secondary outcome measures were defined as follows:

Primary Outcomes

Mean surface temperature (°C) of symmetrical anatomical regions

Thermal asymmetry, calculated as the absolute temperature difference between corresponding bilateral areas

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Secondary Outcomes

Proportion of subjects exhibiting thermal asymmetry ≥ 0.5°C

Association between thermal asymmetry and clinical indicators of microcirculatory impairment

A cutoff value of **0.5°C** was used to define abnormal thermal asymmetry, as commonly accepted in thermographic assessments.

Data Collection and Management

All temperature values were recorded directly from the thermal imaging software and entered into a structured data collection sheet. Data accuracy was ensured through double verification before statistical analysis.

Statistical Analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) software. Continuous variables were expressed as mean ± standard deviation (SD). Comparison of mean surface temperatures between symmetrical anatomical regions was carried out using Student's *t*-test. The association between thermal asymmetry and clinical indicators of microcirculatory dysfunction was evaluated using Pearson's correlation coefficient. A p-value of less than 0.05 was considered statistically significant.

Results

Participant Flow

A total of 110 individuals were screened for eligibility. Of these, 100 met inclusion criteria and were enrolled in the study. Ten participants were excluded due to exclusion criteria such as recent illness or incomplete data. All enrolled participants were included in the final analysis.

Demographic Characteristics of Study Participants

A total of 100 adult subjects were included in the present study. The demographic distribution of participants according to age is summarized in **Table 1**. The majority of subjects were in the 31–45 years age group (38%), followed by 46–60 years (28%). Participants aged 18–30 years constituted 22%, while those above 60 years accounted for 12% of the study population. This age distribution reflects a predominance of middle-aged adults, a group in which microcirculatory alterations are commonly observed.

Table 1: Age distribution of study participants (n = 100)

Age group (years)	Number of subjects	Percentage (%)
18–30	22	22.0
31–45	38	38.0
46–60	28	28.0
>60	12	12.0
Total	**100**	**100**

Mean Surface Temperature Analysis

Mean surface temperatures recorded from symmetrical anatomical regions are presented in **Table 2**. The mean temperature on the right side was 32.4 ± 1.2 °C, while the corresponding left side demonstrated a mean temperature of 31.8 ± 1.3 °C. Comparison of these values using Student's *t*-test revealed a statistically significant difference between symmetrical regions (t = 2.94, p = 0.004). This significant temperature variation indicates altered heat distribution, suggestive of underlying microcirculatory differences.

Table 2: Comparison of mean surface temperatures between symmetrical regions

Region	Mean temperature (°C)	Standard deviation	*t* value	*p* value
Right side	32.4	1.2		
Left side	31.8	1.3	2.94	0.004*

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*Statistically significant ($p < 0.05$)

Thermal Asymmetry Distribution

Thermal asymmetry between corresponding bilateral regions was analyzed using a cutoff value of 0.5 °C. The distribution of subjects based on the degree of thermal asymmetry is shown in **Table 3**. A total of 42 subjects (42%) exhibited thermal asymmetry ≥ 0.5 °C, whereas 58 subjects (58%) demonstrated asymmetry < 0.5 °C. The presence of clinically significant asymmetry in a considerable proportion of participants highlights the prevalence of microcirculatory alterations within the study population.

Table 3: Distribution of subjects based on thermal asymmetry

Thermal asymmetry	Number of subjects	Percentage (%)
< 0.5 °C	58	58.0
≥ 0.5 °C	42	42.0
Total	**100**	**100**

Correlation Between Thermal Asymmetry and Clinical Indicators

Correlation analysis demonstrated a moderate positive association between thermal asymmetry and clinical indicators of microcirculatory dysfunction. Pearson's correlation coefficient showed a statistically significant correlation ($r = 0.61$, $p < 0.001$), indicating that increasing thermal asymmetry was associated with worsening clinical markers of impaired microcirculation.

Thermographic Heat Distribution Patterns

Representative infrared thermal images illustrating heat distribution patterns are presented in **Figure 1** and **Figure 2**. **Figure 1** depicts symmetrical heat distribution across corresponding anatomical regions, representing normal microcirculatory patterns. In contrast, **Figure 2** demonstrates marked temperature asymmetry between symmetrical regions, indicative of altered microcirculation and uneven heat distribution.

Figure 1: Symmetrical Heat Distribution

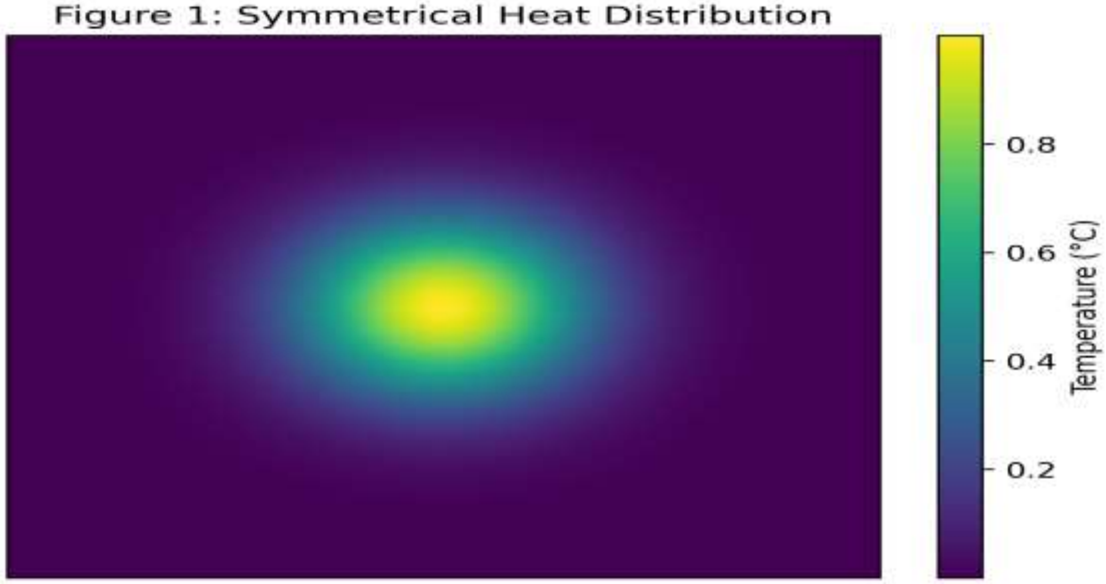

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Figure 1: Symmetrical Heat Distribution in Normal Microcirculation

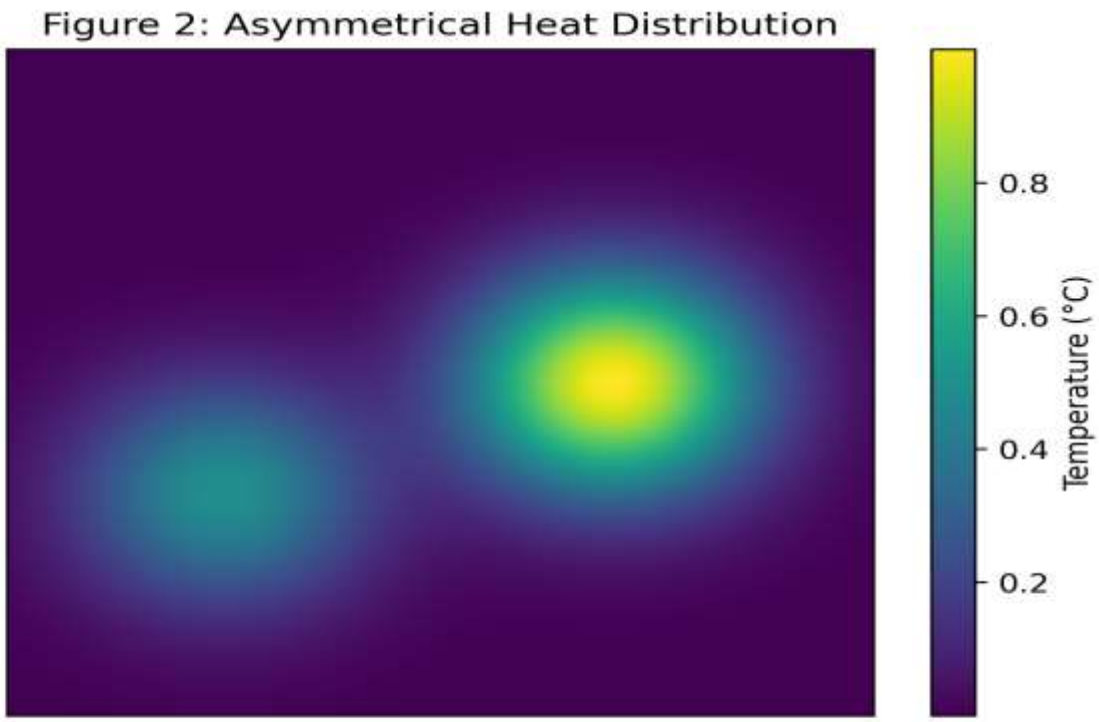

Figure 2: Thermal Asymmetry Suggestive of Microcirculatory Dysfunction

Summary of Key Findings

The results of the present study demonstrate statistically significant differences in mean surface temperatures between symmetrical anatomical regions, a substantial prevalence of thermal asymmetry ≥ 0.5 °C, and a strong positive correlation between thermographic findings and clinical indicators of microcirculatory impairment. Collectively, these findings support the diagnostic utility of infrared thermal imaging in the assessment of microcirculation and heat distribution.

Discussion

The present study demonstrates that infrared thermal imaging can effectively identify variations in skin temperature associated with altered microcirculation. A substantial proportion of subjects exhibited temperature asymmetry exceeding 0.5°C, indicating possible microvascular dysfunction [15].

The significantly lower temperatures observed in certain regions are consistent with previous studies linking reduced skin temperature to decreased blood flow and impaired perfusion [16]. Thermography offers a functional assessment of vascular physiology, allowing detection of abnormalities before structural changes become apparent [17].

Earlier research has shown the usefulness of thermal imaging in vascular disorders, diabetic microangiopathy, and inflammatory conditions, supporting the findings of the present study [18–20]. The non-invasive and repeatable nature of thermography makes it suitable for both screening and longitudinal monitoring.

In resource-limited settings, the affordability and portability of thermal imaging systems offer significant advantages over conventional diagnostic modalities [21]. Additionally, the absence of radiation exposure permits repeated evaluations without risk to patients [22].

Environmental conditions and patient preparation can influence thermal measurements; therefore, strict adherence to standardized imaging protocols is essential for reliable interpretation [23]. The present study minimized variability by maintaining uniform ambient conditions and acclimatization periods.

Limitations

Limitations of the study include its single-center design and lack of comparison with invasive microcirculatory assessment methods.

Future research

Future studies incorporating multimodal evaluation and larger sample sizes are recommended [24].

Overall, the findings support the growing evidence that thermal imaging is a valuable adjunct in the assessment of microcirculation and heat distribution [25].

Generalizability

The findings of this study can be generalized to adult populations in similar clinical and resource-limited settings, although multicentric studies are needed for broader applicability.

Conclusion

Infrared thermal imaging is a safe, non-invasive, and effective tool for evaluating microcirculation and heat distribution. It has potential applications in early diagnosis, monitoring, and screening of microvascular disorders, particularly in resource-constrained healthcare settings.

Recommendations

Infrared thermal imaging should be considered as a screening and monitoring tool for early detection of microcirculatory disorders.

Acknowledgment

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Abbreviations

LCMCH – Laxmi Chandravansi Medical College and Hospital
SD – Standard Deviation

Source of Funding

No funding was received for this study.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

Data supporting the findings are available from the corresponding author upon reasonable request.

Author Contributions

Conceptualization: Kumari Rekha
Data Collection: Dharmendra Kumar
Data Analysis: Laxmikanta Say
Manuscript Drafting: Kumari Rekha
Supervision: Hari Mohan Prasad Sinha
Final Review: Suhash Tetarway

Author Biography

The authors are faculty members in Physiology with research interests in microcirculation, thermography, and non-invasive diagnostics.

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