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Quantitative Radiometric Thermal Analysis of Oral Potentially Malignant Disorders using Portable Infrared Thermography: A Proof-of-Concept Study

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ABSTRACT: Oral potentially malignant disorders (OPMDs) require regular clinical follow up because physiological changes may occur before clear morphological progression is evident during routine examination. This study evaluates the feasibility of portable infrared thermography for obtaining quantitative thermal measurements associated with OPMDs. Thermal images were acquired from five subjects, including the three clinically confirmed OPMD cases and two healthy controls using the four standardized imaging views. Radiometric sensor data were converted into calibrated pixel level temperature values using the embedded Planck calibration parameters. Thermal gradient magnitude, bilateral thermal symmetry, oral-reference temperature difference, temperature percentiles, and thermal entropy were then calculated from the resulting temperature maps. Analysis of 26 thermal images showed that the mean thermal gradient obtained from extraoral views provided the clearest separation between the groups. The OPMD group demonstrated a lower mean gradient of 1.146 °C/px compared with 1.361°C/px in controls, with Cliff's delta of -1.00. one clinically healthy subject also exhibited a thermal profile that differed from the other control across the evaluated features. A visit comparison module was additionally developed to quantify changes between successive examinations. These findings demonstrate the feasibility of calibrated quantitative thermal analysis and support further investigation using larger cohorts, histopathological correlation and prospective longitudinal follow up studies

1. INTRODUCTION

Oral cancer major non-communicable disease and a substantial public-health burden of cancer morbidity and mortality. According to the 2025 National Academy of Medical Sciences task force report, India accounts for approximately 130,000 new

oral cancer cases and more than 75,000 deaths annually, with incidence projected to double by 2040 [1]. A systematic review of Global burden of disease data from 1990 to 2021 reported an age-standardized incidence of 10.1 per 100,000 population, with an increase in age-standardized prevalence rate from 15.71 to 25.46 over the same period (a 62% increase) [2]. According to the Global Oral Cancer Incidence and Mortality database, India accounted for around 83,400 of the 1,20,200 oral cancer cases worldwide in 2022 [3]. This underscores the ongoing burden of oral cancer in India and the requirement for approaches that facilitate earlier diagnosis and appropriate follow-up of high-risk individuals.

The clinical outcome of oral cancer is strongly influenced by the stage at which the disease is identified. A 2024 study on oral cancer cavity cancer incidence and survival trends reported five-year survival rates of approximately 70%-90% for early-stage disease, compared with less than 30% for disease diagnosed at locoregional stages [4]. Hospital-based registry analyses from India have also identified locoregional disease as a common stage at presentation for oral cavity and tongue cancers, indicating that many patients are diagnosed after progression beyond the stage at which early intervention is most effective [5]. Consequently, identification and appropriate monitoring of oral mucosal conditions associated with an increased risk of malignant transformation are important components of oral cancer control.

Oral potentially malignant disorders (OPMDs) comprise a heterogeneous group of oral mucosal conditions associated with an increased risk of malignant transformation. Oral lichen planus (OLP), leukoplakia, and oral submucous fibrosis (OSF) are among the conditions included within the current OPMD classification framework [6]. Oral lichen planus (OLP) is a chronic inflammatory disorder affecting the oral mucosa and may present with characteristic white or mixed red-and-white lesions. Oral leukoplakia is a predominantly white oral mucosal lesion that cannot be characterized as another specific disease or disorder and is recognized as an oral potentially malignant disorder. The risk of malignant transformation varies according to lesion type and clinical characteristics. An umbrella analysis of systematic reviews reported pooled transformation proportions of approximately 1.1%–1.4% for OLP, while a meta-analysis of higher-quality studies reported an estimate of 2.28% [7]. A 2024 evidence-based update involving 101 studies and 38,083 patients further identified tongue localization and atrophic-erosive lesion morphology as important factors associated with malignant transformation [8]. Leukoplakia has been reported to have transformation rates ranging from approximately 3% to 17%, depending on lesion characteristics and population [9].

In India, smokeless tobacco exposure represents an important risk factor for oral mucosal disease. Preparations such as gutkha and khaini are classified as Group 1 carcinogenic exposures by the International Agency for Research on Cancer [10]. Gutkha users have been reported to have substantially increased risk of developing oral cavity cancer compared with non-users [11]. Prolonged direct contact of these products with the oral mucosa can cause chronic chemical and mechanical irritation and contribute to epithelial changes associated with leukoplakia.

The standard clinical approach to OPMD management involves periodic follow-up examination, typically including assessment of changes in lesion size, colour, texture, and border characteristics. Although conventional oral examination remains fundamental to clinical practice, it provides predominantly qualitative information and does not inherently generate a standardized numerical measurement for comparing tissue characteristics between successive Visits. A 2022 systematic review and meta-analysis encompassing 18 studies reported pooled sensitivity of 71% and specificity of 85% for conventional oral examination in detecting dysplastic or malignant lesion [12].

A 2021 Cochrane systematic review reported sensitivity estimates ranging from 0.50 to 0.99 across screening studies [13]. These findings emphasize the continuing challenge of early detection and importance of complementary approaches that can provide objective information during clinical follow-up. Regular structured follow-up has also been associated with earlier cancer-stage detection and improved five-year net survival among patients who subsequently develop oral cancer, further emphasizing the clinical value of monitoring [14]–[15].

Infrared thermography is a passive, non-ionizing imaging technique that detects thermal radiation emitted from the body surface in the long-wave infrared region. Surface temperature distributions can be influenced by physiological processes including blood perfusion, metabolic activity, inflammation, and heat transfer within tissue. These characteristics have encouraged the investigation of infrared thermography for biomedical imaging and disease assessment [16]–[24]. Previous studies have investigated thermal imaging for oral cancer detection using bilateral temperature distributions and texture-based analysis [25]–[26]. A portable blood-perfusion imaging system was subsequently developed for screening subsurface oral pathology and demonstrated high sensitivity and specificity for distinguishing oral squamous cell carcinoma and oral submucous fibrosis from

normal tissue in a larger clinical study [27]. Infrared thermography has also been investigated for cervical lymph-node metastasis associated with oral cancer [28] and for oral lichen planus, where thermal patterns were evaluated as a complementary indicator of disease activity [29].

While these advancements have been made, current thermal imaging techniques have largely been used for visualizations, classifications, or single-visit assessment. A more specific gap is the lack of calibrated numerical thermal measurements that are designed for reproducible comparison across clinical visits; conventional thermograms primarily give colour-based visual representations, whereas radiometric thermal images retain numerical sensor information that can be converted into calibrated pixel-level temperature values using camera-specific calibration parameters, which allow quantitative thermal characteristics to be calculated and stored for later comparison. The paper also points out the lack of a standardized quantitative framework for longitudinal OPMD assessment as another important research gap.

Hence, this study explores the potential of portable radiometric infrared thermography for quantitative characterization of OPMDs. The proposed framework transforms radiometric sensor data into calibrated temperature maps and extracts quantitative thermal features, such as thermal magnitude, bilateral thermal asymmetry, oral-reference temperature differential, temperature disruption percentile, and thermal entropy. Special attention is given to thermal gradient magnitude as a metric for spatial temperature variation. A computational visit-comparison module is further developed to objectively measure the variation in thermal features between examinations and serves as a foundation for longitudinal assessment. The present work is designed as a proof-of-concept feasibility study involving five subjects and 26 thermal images. The objective is to determine whether calibrated radiometric thermal measurements can provide useful quantitative information for characterizing OPMD-associated thermal patterns and to establish a methodological foundation for subsequent studies involving larger cohorts, histopathological correlation, and repeated longitudinal measurement.

2. MATERIALS AND METHODS

2.1 Study Material

This proof-of-concept feasibility study was conducted at Sibar Institute of Dental Sciences, Guntur, Andhra Pradesh, India. Clinical assessment was performed by a specialist in Oral Medicine and Radiology, and the clinical diagnosis was established through standard clinical examination. The study was approved by the Institutional Ethics Committee of Sibar Institute of Dental Sciences (IEC No. 646/IEC/SIBAR/2025). Written informed consent was obtained from all participants before thermal image acquisition.

2.2 Study Participants

Five subjects were enrolled in this proof-of-concept feasibility study. Three presented with clinically confirmed oral potentially malignant disorders and two served as healthy controls. Table 1 presents the complete demographic and clinical profile.

Table 1: Subject demographics and clinical profile

ID	Diagnosis	Age	Sex	Habits	Comorbidities	Views
P1	Oral Lichen Planus	80	M	None	Stress	4
P2	Control	37	F	None	None	4
P3	Oral Lichen Planus	31	F	None	Stress	8
P4	Leukoplakia	30	M	Gutkha, Khaini	Alcohol use	5
P5	Control	36	M	None	None	5

The OPMD group consisted of two subjects with oral lichen planus (P1 and P3) and one subject with leukoplakia (P4). The subjects were identified as P1–P5 for analysis.

P1 was an 80-year-old male with oral lichen planus. P2 was a 37-year-old female without a clinically apparent oral lesion and served as a healthy control. P3 was a 31-year-old female with oral lichen planus. P4 was a 30-year-old male with leukoplakia who reported gutkha and khaini use and alcohol consumption. P5 was a 36-year-old male control.

2.3 Imaging Equipment

Thermal images were acquired using a FLIR E6 Pro portable infrared thermal camera (Teledyne FLIR LLC, Wilsonville, OR, USA), operating in the long-wave infrared (LWIR) spectral range of 7.5–13 μm . The camera was used to capture high-resolution thermal images of the oral cavity under standardized imaging conditions. The technical specifications of the thermal imaging system are summarized in Table 2

Table 2. Thermal imaging equipment specifications

Parameter	Value
Thermal sensor resolution	180 × 240 pixels
Spectral range	7.5 to 13 μm (LWIR)
Thermal sensitivity (NETD)	< 60 mK
Temperature range	−20°C to +250°C
Image format	R-JPEG (Radiometric JPEG)
Visual camera resolution	640 × 480 pixels
Field of view	45° × 34°

The Radiometric JPEG format is central to this work. Unlike a standard JPEG, which stores only the visible colour palette representation, an R-JPEG embeds the raw 16-bit radiometric sensor data as a binary payload within the image metadata alongside camera specific Planck radiation formula calibration constants (R1, R2, B, F, O), the configured emissivity value, and the reflected apparent temperature. This enables recovery of actual per pixel temperature in degrees Celsius through the Planck formula without reliance on colour to temperature approximation.

2.4 Acquisition Protocol

The acquisition protocol follows established clinical thermography practice [22, 23, 27]:

1. The subject was seated on a dental chair with the head resting against the headrest for stabilization.
2. A stabilization period of three minutes was observed before imaging commenced, allowing facial tissue temperature to reach equilibrium with the ambient environment [27].
3. All imaging sessions were conducted between 9:00 AM and 11:00 AM to minimize diurnal physiological variation.
4. Ambient temperature and relative humidity were recorded for each session.
5. Four standardized views were acquired per subject: (a) Right lateral, capturing the right buccal mucosa and mandibular region where OLP and Leukoplakia commonly present; (b) Left lateral, capturing the corresponding left sided anatomy; (c) Frontal, capturing the perioral region and both cheeks simultaneously for bilateral symmetry analysis; and (d) Intraoral, a direct thermal image of the oral mucosal surface acquired with the mouth open and dental mirror retraction where required.
6. A corresponding RGB visual image was captured for each thermal acquisition.

A total of 52 images were acquired: 26 thermal and 26 paired RGB. Subjects P1 and P2 each contributed the standard four views. P3 contributed eight views (standard four plus two neck views and two additional intraoral angles). P4 and P5 each contributed five views (standard four plus one additional intraoral angle). All 26 thermal images were included in the analysis.

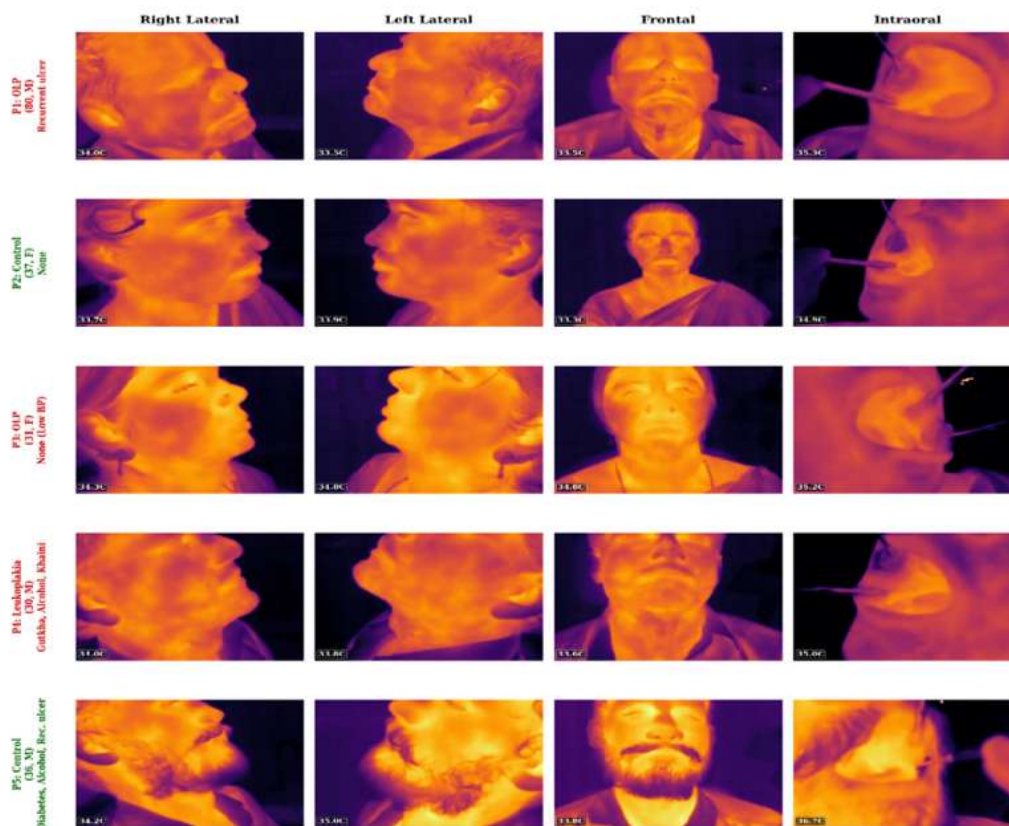


Figure 1: Standardized four view thermal imaging data for all five subjects. Each row represents one subject imaged from right lateral, left lateral, frontal, and intraoral views. Temperature annotations in degrees Celsius. Subject demographics and risk factors shown on the left.

2.5 Radiometric Temperature Extraction

The raw 16-bit sensor data embedded in each R-JPEG image were extracted using the flirimageextractor Python library, which accesses the radiometric thermal data and Planck calibration parameters stored in the image metadata. The calibrated temperature of each pixel was calculated using the Planck radiation equation:

$$T = \frac{B}{\ln\left(\frac{R_1}{R_2} + O\right) + F} - 273.15$$

where T is the calibrated pixel temperature in $^{\circ}\text{C}$, R_1 is the raw 16-bit radiometric sensor value, and R_2 , B , F , and O are the camera-specific calibration parameters. The resulting temperature data were represented as a 180×240 floating-point array, with each element corresponding to the calibrated temperature of an individual pixel.

2.6 Region-of-Interest Selection

For frontal extraoral images, the facial region was divided into predefined zones to distinguish the oral region from surrounding reference tissue. The upper zone corresponded to image rows 10–35%, the middle zone to rows 35–55%, and the oral zone to rows 55–75% within the central 60% of the image width. For lateral images, pixels with temperatures above 30°C were included in the analysis. For intraoral images, a threshold of 33°C was applied to identify the relevant warmer mucosal region.

2.7 Quantitative Thermal Feature Extraction

Thermal features were calculated from the calibrated temperature maps: thermal gradient magnitude, bilateral thermal asymmetry, oral-reference temperature differential, temperature distribution percentiles, and thermal entropy

3. RESULTS AND DISCUSSION

In this study, the quantitative results of thermal analysis of all 26 calibrated temperature arrays extracted from radiometric sensor data are presented: thermal gradient magnitude, bilateral asymmetry, oral reference differential, temperature percentiles, and entropy computed from each thermal image across four standardized imaging views, showing consistent attenuation of thermal gradient magnitude in premalignant tissue compared with healthy controls, independently observed in the right lateral, left lateral, and frontal views, which is interpreted in the context of the histopathological characteristics of Oral Lichen Planus and Leukoplakia, where diffuse subepithelial inflammation and epithelial keratinization change the tissue thermal properties in a manner consistent with the predictions of the Pennes bioheat equation

A secondary observation was identified in Subject P5, who was clinically healthy but presented with three systemic risk factors. This participant exhibited a thermal profile that deviated from the healthy baseline across all computed thermal metrics.

Effect sizes were quantified using Cliff's delta, a non-parametric measure appropriate for the small sample size of this feasibility study. The biological significance of the observed thermal patterns is discussed with reference to published histopathological and thermophysical literature. The limitations of the present study are also explicitly acknowledged to provide appropriate context for interpreting the findings.

Table 3 presents the thermal gradient magnitude and face region mean temperature computed from each of the 26 acquired images organized by subject and view.

Table 3. Gradient magnitude and mean temperature across all 26 thermal images

Subject	Group	View	Category	Mean	(°C) Gradient
P1	OPMD	Right lateral	Extraoral	33.95	1.051
P1	OPMD	Left lateral	Extraoral	33.49	1.161
P1	OPMD	Frontal	Extraoral	33.50	1.349
P1	OPMD	Intraoral	Intraoral	35.30	0.662
P2	Control	Right lateral	Extraoral	33.75	1.029
P2	Control	Left lateral	Extraoral	33.90	0.977
P2	Control	Frontal	Extraoral	33.31	1.687
P2	Control	Intraoral	Intraoral	34.94	0.625
P3	OPMD	Right lateral	Extraoral	34.32	1.065
P3	OPMD	Left lateral	Extraoral	34.82	1.065
P3	OPMD	Frontal	Extraoral	34.77	1.235
P3	OPMD	Intraoral	Intraoral	35.23	0.635
P3	OPMD	Neck	Extraoral	33.44	1.204
P3	OPMD	Left neck	Extraoral	34.57	1.077
P3	OPMD	Intraoral (2)	Intraoral	36.47	0.566
P3	OPMD	Intraoral (3)	Intraoral	35.84	0.546
P4	OPMD	Right lateral	Extraoral	34.02	1.012
P4	OPMD	Left lateral	Extraoral	33.84	1.016
P4	OPMD	Frontal	Extraoral	33.60	1.340
P4	OPMD	Intraoral (1)	Intraoral	34.97	0.638
P4	OPMD	Intraoral (2)	Intraoral	35.40	0.639
P5	Control	Right lateral	Extraoral	34.17	1.512
P5	Control	Left lateral	Extraoral	35.02	1.310
P5	Control	Frontal	Extraoral	33.83	1.648
P5	Control	Intraoral (1)	Intraoral	36.67	1.066
P5	Control	Intraoral (2)	Intraoral	36.47	1.112

The average thermal gradient magnitude across all extraoral views was computed for each participant. The results demonstrated a consistent reduction in thermal gradient magnitude among OPMD subjects compared with healthy controls. The aggregated subject-wise thermal gradient values are presented in Table 4

Table 4. Average thermal gradient magnitude across extraoral, intraoral, and all imaging views for OPMD and control subjects.

Subject	Group	Extraoral Avg	Intraoral Avg	All Views Avg
P1	OPMD	1.187	0.662	1.056
P2	Control	1.231	0.625	1.079
P3	OPMD	1.129	0.583	0.924
P4	OPMD	1.123	0.639	0.929
P5	Control	1.490	1.089	1.330

The OPMD group mean for extraoral gradient was 1.146 °C/px compared to 1.361 °C/px for the control group. All six pairwise comparisons between individual OPMD and control subjects yielded the same directional result, corresponding to a Cliff's delta effect size of $d = -1.00$. When computed across all views combined, the pattern remained consistent, with an OPMD mean of 0.970 compared to 1.205 for the control group, yielding $d = -1.00$.

With group sizes of $n_1 = 3$ and $n_2 = 2$, Cliff's delta can assume only seven discrete values. The probability of observing $|d| = 1.00$ under random assignment is approximately 14%. The minimum achievable p value for a Mann–Whitney U test with these sample sizes is 0.10. Accordingly, these results should be interpreted as descriptive findings from a feasibility study rather than confirmatory statistical evidence.

The clinical diagnosis for each OPMD subject was established at Sibar Institute of Dental Sciences, Guntur, through standard oral pathology examination. Histopathological validation through biopsy is the gold standard for confirming OPMD diagnosis and grading dysplasia. In this proof-of-concept study, the clinical diagnosis established at Sibar Institute of Dental Sciences served as the reference standard. A larger validation study would incorporate biopsy-confirmed histopathological grading.

The gradient direction observed here, OPMD lower than controls, is specific to the pre malignant conditions in this cohort. In oral squamous cell carcinoma, focal neo angiogenesis driven by vascular endothelial growth factor creates concentrated zones of elevated perfusion at the tumour site, which would produce steep temperature gradients and higher gradient values relative to surrounding tissue. The thermal gradient feature may therefore carry stage dependent diagnostic significance, a hypothesis warranting investigation through longitudinal monitoring of subjects who undergo malignant transformation.

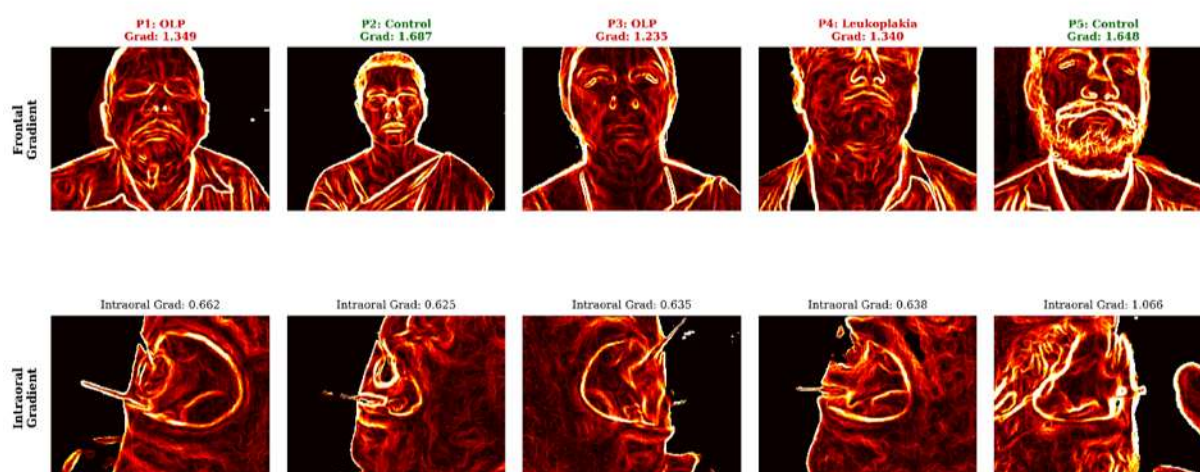


Figure 2: Thermal gradient maps for the five study participants. Top row: frontal views; bottom row: intraoral views. The

same color scale is used across all panels for comparison. OPMD subjects generally show lower and smoother thermal-gradient patterns than controls.

Table 5 presents Cliff's delta for all features computed from the full 26 image dataset.

Table 5. Effect sizes for all computed thermal features

Feature	OPMD Mean	Control Mean	Cliff's d
Gradient (extraoral avg)	1.146	1.361	-1.00
Gradient (all views)	0.970	1.205	-1.00
Gradient (intraoral avg)	0.628	0.857	-0.33
Intraoral P90 (°C)	36.78	36.87	+0.00
LR Lateral Diff (°C)	0.376	0.504	+0.00
Extraoral Entropy (bits)	5.536	5.636	-0.33
Extraoral Mean Temp (°C)	33.95	34.00	+0.00

Among all features examined, only gradient magnitude achieved complete group separation. The remaining features exhibited overlapping distributions between groups at this sample size. This is reported transparently. The value of features such as bilateral asymmetry, oral reference differential, and entropy may lie in within subject longitudinal tracking rather than between group cross sectional discrimination, a distinction evaluable only with repeated imaging of the same individuals over time.

3. 2 Discussion

The present study investigated the feasibility of using radiometric infrared thermography for quantitative characterization of oral potentially malignant disorders (OPMDs). Thermal gradient magnitude was the most discriminative feature in the present dataset. All three OPMD subjects showed lower extraoral gradient values than both healthy controls, with mean values of 1.146 °C/px and 1.361 °C/px, respectively. When all imaging views were considered, the corresponding mean values were 0.970 and 1.205 °C/px. The Cliff's delta value of -1.00 indicates complete directional separation within this dataset; however, because only five subjects were included, this finding should be considered preliminary feasibility evidence rather than diagnostic validation.

The lower thermal gradient observed in the OPMD subjects may be associated with the pathological characteristics of oral lichen planus and leukoplakia. Chronic inflammatory changes in oral lichen planus and epithelial keratinization associated with leukoplakia may influence local thermal distribution and produce relatively smoother temperature patterns. However, the present study does not establish a direct pathological mechanism, and this interpretation requires confirmation using larger datasets with histopathological correlation.

The other evaluated thermal features showed overlapping distributions between the OPMD and control groups. Therefore, their potential usefulness may be greater for within-subject longitudinal monitoring than for cross-sectional differentiation. This requires repeated imaging of the same individuals over time and cannot be established from the present single-visit dataset.

Subject P5, although clinically classified as a control, showed a thermal profile different from the other control subject. This may reflect the influence of systemic or local physiological factors. Since this observation is based on a single participant, it should be regarded only as an exploratory finding and not as evidence of subclinical OPMD.

The use of radiometric R-JPEG data provides calibrated pixel-level temperature measurements using the camera-specific calibration parameters and Planck radiation equation. This offers a quantitative basis for comparing thermal measurements between examinations. The implemented visit-comparison module calculates absolute change, percentage change, trend direction, and alert indications for the extracted features. However, because actual repeated clinical visits were not available in this study, the module represents a framework for future longitudinal assessment rather than a clinically validated monitoring system.

The principal limitations were the small sample size, single-centre design, absence of actual longitudinal follow-up, and use of specialist clinical examination rather than biopsy-confirmed histopathological grading. Future work should therefore include a larger longitudinal dataset with repeated examinations, balanced representation of OPMD subtypes and dysplasia grades, histopathological correlation, and multicentre validation.

4. CONCLUSION

This proof-of-concept study demonstrated the feasibility of using radiometric infrared thermography for quantitative OPMD assessment. Thermal gradient magnitude showed the clearest separation between OPMD subjects and controls, with mean extraoral values of 1.146 and 1.361 °C/px, respectively, and a Cliff's delta of -1.00 . The radiometric approach provides calibrated temperature measurements and a computational basis for future inter-visit comparison.

However, the findings are preliminary because the study included only five subjects and lacked actual longitudinal and biopsy-confirmed histopathological data. Larger longitudinal studies with repeated measurements, histopathological correlation, and multicentre validation are required to establish clinically meaningful thermal thresholds and determine the value of this approach for OPMD monitoring.

AUTHOR CONTRIBUTIONS

Koteswararao Mallaparapu: Writing—Review & Editing, Data Curation, Methodology

SVL Sowjanya Nukala: Data Curation, Writing—Review & Editing.

Shrivardhini Indla: Data Curation, Writing.

K Kiran Kumar: Data Curation, Formal Analysis, Review

Yalamanchili Samata: Data Curation, Formal Analysis, Review.

K A Sunitha: Supervision, Writing—Review & Editing.

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CONFLICT OF INTEREST

There is no conflict of interest presented in the writing of this article.

ETHICS STATEMENT

The study was approved by the Institutional Ethics Committee of Sibar Institute of Dental Sciences (IEC No. 646/IEC/SIBAR/2025).

DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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