Original Article

JHSMR Journal of Health Science and Medical Research

Impact of Diabetic Retinopathy on Ocular Surface Temperature: Insights from Medical Thermography

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Received 24 November 2024 ● Revised 26 February 2025 ● Accepted 12 April 2025 ● Published online 25 June 2025

Abstract:

Objective: This study aimed to investigate the impact of diabetic retinopathy on the ocular surface temperature (OST) profile, exploring potential links between temperature variations and the inflammatory processes associated with the condition.

Material and Methods: Medical thermography, a non-invasive technique that captures thermal radiation emitted from body organs, was employed to measure OST and lacrimal sac temperature in patients with diabetic retinopathy (DR) compared to healthy controls. Statistical analyses were conducted to assess temperature differences between the 2 groups.

Results: The analysis revealed a significant difference in OST and lacrimal sac temperature between eyes affected by DR and healthy eyes, with a p-value of 0.006. This finding indicates notable temperature deviations in the presence of diabetic retinopathy.

Conclusion: The observed temperature variations support the hypothesis that inflammation may play a significant role in the pathophysiology of diabetic retinopathy, highlighting the potential of thermography as a valuable diagnostic tool in understanding ocular surface changes in this condition.

Keywords: diabetes mellitus, diabetic retinopathy, FLIR Camera, infrared thermography, ocular surface temperature

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J Health Sci Med Res 2026;44(2):e20251234
doi: 10.31584/jhsmr.20251234
www.jhsmr.org

Introduction

Diabetes mellitus is an important public health concern that is characterized by a high blood sugar level for a prolonged period. Diabetes mellitus interferes with the function of almost all parts of our body, including the eyes. One-third of the diabetic population has been affected by DR. It remains silent for many years, and by the time symptoms occur, it may have already progressed through advanced stages. Proliferative diabetic retinopathy (PDR) and diabetic macular edema (DME) are both serious complications of diabetic retinopathy, especially for individuals with type 1 diabetes[1]. While DME is commonly seen in individuals with type 2 diabetes, it is not exclusive to them and can also be present in those with type 1 diabetes. The presence of DME in PDR can vary depending on the individual and the progression of their diabetic retinopathy, which requires careful management. Hence, the need for early detection of DR was a motivation for this research. DR damages the blood vessels in the retina for years, without showing any symptoms that may lead to preventable vision loss. The Color Doppler assessment shows that blood flow in ocular circulation is decreased in type 2 diabetes patients when compared to normal eyes[2]. Ocular blood flow can be indirectly evaluated by measuring the variations of the OST by infrared thermography[2]. Ocular thermography creates an image based on the temperature distribution of the ocular surface. Thermography and image processing are useful tools because they facilitate a noninvasive technique and fast diagnosis. Ocular thermography as a diagnostic tool detects ocular blood flow in the management of ocular diseases[3]. Thermography is used in the detection of various eye diseases such as dry eye, glaucoma, meibomian gland dysfunction, and diabetic eyes. Various studies exist in the literature on the application of infrared thermography for measuring OST in the analysis of eye diseases. The results across different studies on the application of infrared thermography for measuring OST can indeed be influenced by several factors, such as methodologies, sample sizes, patient characteristics, study design, and data analysis. Considering these factors, it is essential to interpret the results of diverse studies on OST measurement in different eye diseases while considering their unique methodologies and limitations.

Several studies have examined the correlation between posterior eye diseases and OST. A comprehensive review and survey on ocular surface temperature is reported in the literature[4–6]. Sodi et al.[3] found that OST was lower in non-proliferative (NPDR) diabetic retinopathy than in healthy eyes, suggesting that infrared thermography could be a useful tool for evaluating ocular blood flow in patients with diabetic retinopathy. Naidorf-Rosenblatt et al.[7] conducted a subgroup analysis on DR and found that eyes with diabetic macular edema had significantly higher OSTs than DR eyes without diabetic macular edema. The literature survey shows that all the findings were based on the OST of the medial cantus, cornea, and lateral cantus, and none of them discussed the temperature in the surrounding regions of the eye. B. Chandrasekar et al.[8] studied the effects of eye dilation on OST and found that the increase in OST is less in eyes with DR than healthy eyes after dilation.

Machado et al.[9] observed in their thermographic study that applying cold drops did not result in the cooling of the lacrimal sac in the affected eye. Shu H et al.[10] found the lacrimal sac's maximum temperature to be a reliable indicator of eye temperature, particularly useful for assessing heat stress in dairy cows. This could be because changes in eye temperature can indicate physiological stress, and the lacrimal sac region may be more indicative of such changes compared to other parts of the eye. This study attempted to incorporate lacrimal sac temperature along with OST for the analysis of diabetic retinopathy.

The outline of the paper is as follows: Section 2 describes the dataset and image acquisition process. Section 3 presents the statistical analysis and discusses the experimental results. Section 4 concludes the paper.

Material and Methods

Data description

A total of 160 images from 40 participants were included in this study. It covers 3 distinct categories: 16 healthy, 15 diabetes mellitus with diabetic retinopathy, and 9 diabetes mellitus without diabetic retinopathy. It comprises 160 ocular thermal images, with 64 images classified as healthy, 60 as diabetes mellitus without diabetic retinopathy, and 36 as diabetes mellitus with diabetic retinopathy. These images are stored in JPEG format, with a resolution of pixels. Pseudo-color code was used to represent the temperature variation of the eye and its surrounding regions in the image.

Experimental design

The FLIR A35sc thermal imaging camera, placed on a bench, and the Dell Latitude Laptop (5th Gen/8GB/1TB with Windows 8) were connected to a PoE injector (16 W, with multi-plugs) using CAT6 ethernet cables (2m /6.6 ft). This particular camera, featuring an uncooled microbolometer and mounted on a tripod, captures emitted infrared energy within a spectrum spanning 7.5–13 µm wavelength, with a detector pitch of 25 µm[11]. The thermal imaging device features a pixel IR resolution and boasts exceptional thermal sensitivity with a Noise Equivalent Temperature Difference (NETD) of less than 0.05 °C at +30 °C (+86 °F), corresponding to 50 mK. It offers a field of view (FOV) of 48° × 39° and is equipped with a 9-mm (0.35 in.) focal length. The device has a spatial resolution (IFOV) of 2.78 mrad and operates at an image frequency of 60 Hz. It covers a wide standard temperature range from –40 °C to +550 °C, with an accuracy of ±5 °C, making it suitable for various thermal applications.

The experiment took place within an ambient room temperature ranging from 24 to 26 °C, with a relative humidity between 65 and 75.0%. Throughout the acquisition process, all windows and doors remained closed[12]. The background temperature served as the reflective temperature, while the room temperature was deemed the atmospheric temperature, the intermediary temperature between the sensor and the object. The acquisition process incorporated a human skin emissivity value of 0.98, assuming near-ideal radiation[13]. The distance measured between the camera and the participant's eyes was 20 cm[14]. Ethical approval for this study was obtained from the Human Ethical Committee of SSN Institutions, Kalavakkam (Ref: IHEC/SSN CE/Pr.No.01/28.09.2019).

The acquisition was conducted at the Department of Ophthalmology, Tagore Medical College Hospital, Chennai. Individuals aged 40 and above, carefully selected for eye examinations, were included in this study. Prior to image acquisition, written informed consent was obtained from all the participants. Patients with fever and eyes with abnormalities in the lacrimal sac region were excluded from this study. Before the acquisition process, participants spent 15 minutes in the examination room in order to acclimatize to the room's temperature[15–17]. While recording, participants' eyes remained undilated, and they were instructed not to blink for 5 seconds for each recording. Two recordings were obtained for each eye within a two-to-three-minute period.

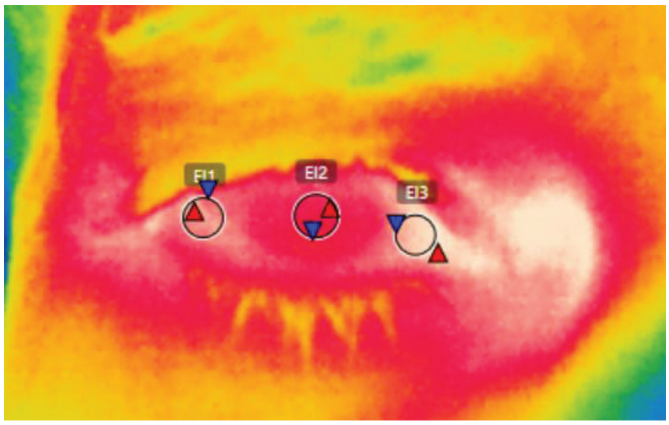
Results

OST measurement

The OST values were derived from the thermal images using FLIR Tools software. The study was conducted through 2 experiments using the same set of images. In the first experiment, the thermographic profiles were analysed from 3 distinct anatomical regions within each ocular thermal image. These regions included: (EI1) the area between the lateral canthus and the temporal limbus, (EI2) the area between the temporal and nasal limbi, and (EI3) the area between the nasal limbus and the medial canthus, as illustrated in Figure 1.

The average OST values for both the DR and healthy control subjects were compared to the forehead

temperature, which was recorded as 37.18±0.5 °C. The data presented in Figure 2 demonstrate that the average ocular surface temperature for diabetic retinopathy eyes was significantly lower than that of healthy eyes. This finding is consistent with the research conducted by Andrea Sodi et al.[3], which also indicates a notable decrease in ocular surface temperature in individuals with diabetic retinopathy compared to healthy controls.



OST=ocular surface temperature

Figure 1 Measurement of OST at specific regions

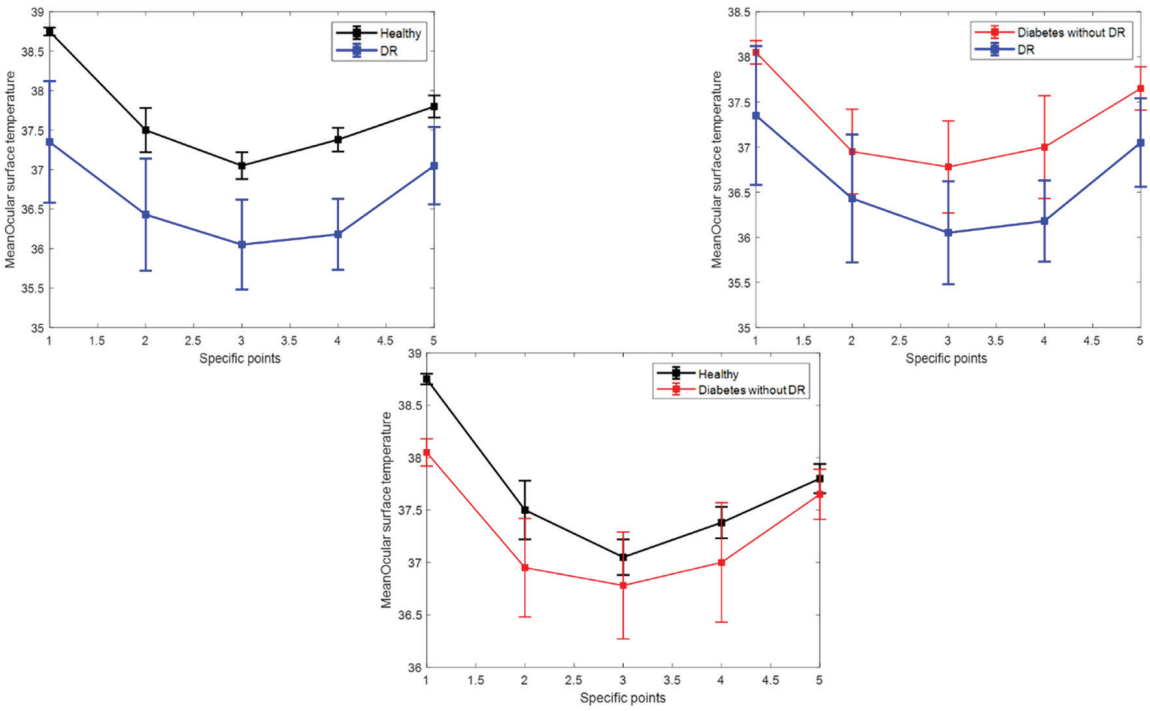


Figure 2 Comparison of mean ocular surface temperature among the study groups

It was observed that the cornea exhibited the most consistent temperature readings, even forehead temperature was externally cooled[18]. However, relying solely on forehead temperature cannot serve as an adequate baseline for the OST analysis of DR. Therefore, the second experiment of this study incorporated the assessment of OST and lacrimal sac temperature for comprehensive analysis. For each image, a thermal line was positioned along the diameter of the eye, where the minimum temperature was recorded, while another thermal line was positioned along the length of the lacrimal sac, where the maximum temperature was recorded, as seen in Figure 3. The other glands, like the lacrimal duct, were discarded from the discussion due to the presence of eyelashes and folds of skin in different patients.

Table 1 shows that the corneal temperature was slightly lower in individuals with DR (36.4111°) compared to those with diabetes without DR (36.6143°) and healthy controls (36.6933°). The variation, that is, the standard deviation (S.D.) in corneal temperature was higher in the DR (0.858°) group compared to the other groups, indicating more variability. The lacrimal sac temperature was highest in the DR (38.3333°) group, slightly higher in diabetes without DR (38.3071°), and lowest in the healthy (37.9467°) group. The differences in standard deviations were relatively small among groups, indicating less variability in lacrimal sac temperature. The temperature difference between the lacrimal sac and the cornea was highest in individuals with DR (1.922°), intermediate in those with diabetes without DR (1.693°), and lowest in healthy individuals (1.313°). This suggests that the temperature gradient between these 2 sites is more pronounced in those with DR. The standard deviations in the DR group was higher, indicating more variability in this temperature difference. The standard error was highest for the DR group, indicating less precision in the estimate of the mean temperature difference for this group compared to the other groups. This reflects more variability in the data for individuals with DR.

Temperature data were analysed using the online statistical tool Good Calculator and MATLAB R2023b. Figure 4 demonstrates that the corneal temperature in the DR group exhibited a lower range and median compared to the other groups. The Diabetes without DR group showed a broader range and a higher median relative to the DR

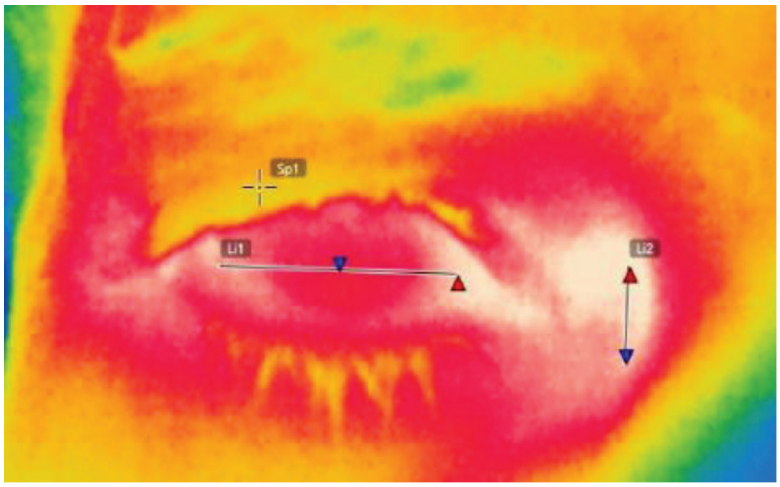


Figure 3 Measurements of ocular surface temperature

group, with some potential outliers. The Healthy Controls group displayed the highest median and a moderate range of corneal temperatures, with some outliers, but these were less extreme compared to those in the DR group.

Figure 5 illustrates that the lacrimal sac temperature in the DR group had a higher range and median compared to both the Diabetes without DR and Healthy Controls groups. The Healthy Controls group exhibited a narrower range and potentially lower-end outliers, indicating generally lower temperatures.

Figure 6 reveals that the temperature difference between the lacrimal sac and cornea was significantly greater in individuals with DR compared to those with diabetes without DR and healthy controls. The DR group showed a wider spread and more potential outliers in this temperature difference compared to the other groups. Conversely, the Healthy Controls group demonstrated the least variability and smallest range, indicating a more consistent temperature difference within this group.

Table 1 Mean temperature of the study groups

Groups	Cornea temperature (Mean±S.D.)	Lacrimal sac temperature (Mean±S.D.)	Temperature difference (Mean±S.D.)	Standard error
DR	36.4111±0.858	38.3333±0.5545	1.922±0.696	0.232
Diabetes without DR	36.6143±0.6359	38.3071±0.5255	1.693±0.405	0.1082
Healthy	36.6933±0.4431	37.9467±0.4779	1.313±0.304	0.0786

S.D.=standard deviation, DR=diabetic retinopathy

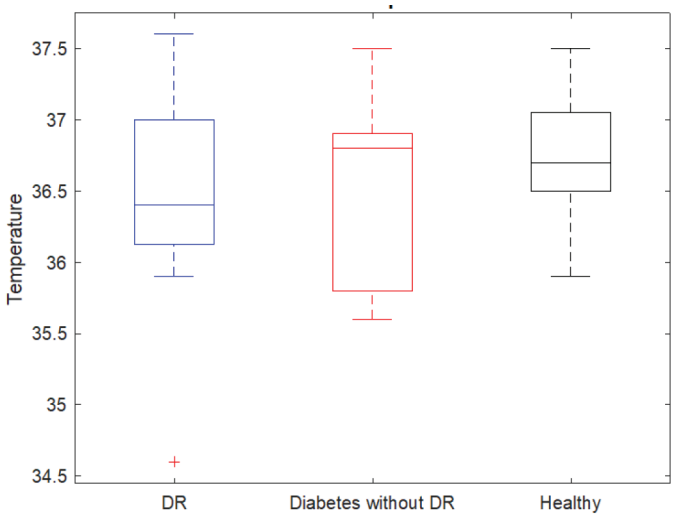


Figure 4 Comparison of mean temperature over cornea temperature

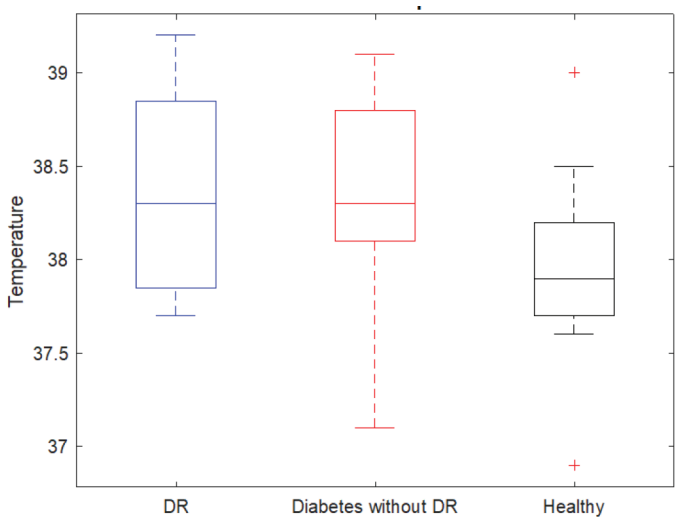


Figure 5 Comparison of mean temperature over lacrimal sac temperature

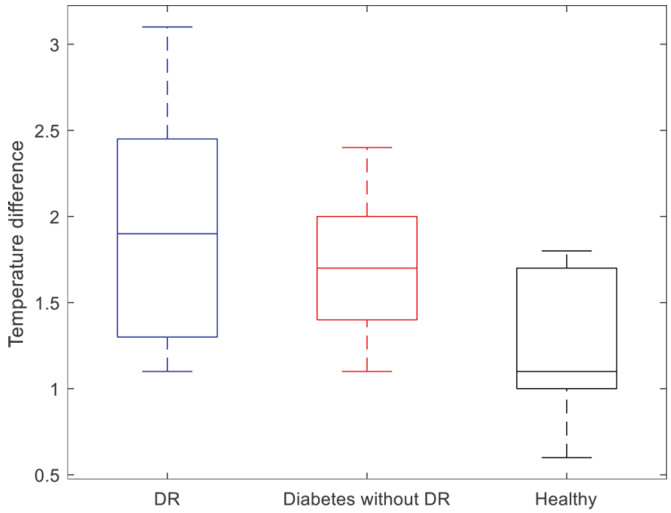


Figure 6 Comparison of mean temperature over average temperature difference between cornea and lacrimal sac temperature

Discussion

Statistical analysis was conducted to test the significance of the hypothesis regarding temperature differences. A one-way ANOVA was performed to compare the temperatures at the cornea and lacrimal sac, as well as the temperature difference between these 2 sites, with respect to healthy eyes and diabetic eyes. The hypothesis of statistical significance was set as p-value<0.05. The

p-values from the ANOVA test are presented in Table 2. The study that compared DR and healthy eyes revealed that the p-value for corneal temperature was greater than 0.05, indicating no statistically significant difference between the DR and healthy groups. Although the p-value was slightly above the threshold for temperature in the lacrimal sac region, it did not reach statistical significance. However, the p-value for the temperature difference between the lacrimal sac and cornea was less than 0.05, indicating a statistically significant difference between the DR and healthy groups.

The study that compared diabetes without DR to healthy controls shows that the p-value for corneal temperature, as well as for lacrimal sac temperature, was well above 0.05, indicating no significant difference between these groups. However, the p-value for the temperature difference between the lacrimal sac and cornea was <0.05, indicating a statistically significant difference between individuals with diabetes without DR and healthy controls.

The study comparing individuals with DR to those without DR shows that the p-value was >0.05. This indicates that there was no significant difference in corneal temperature, as well as lacrimal sac temperature, between the DR group and without DR. Furthermore, there was no significant difference in the temperature difference between the lacrimal sac and cornea between these 2 groups.

The study comparing individuals with DR, without DR, and healthy controls shows that the p-value for both corneal temperature and lacrimal sac temperature was >0.05. This indicates no significant difference in these temperatures across the 3 groups. However, the p-value for the temperature difference between the lacrimal sac and cornea was <0.05, indicating a significant difference across the 3 groups. In comparing individuals with DR and without DR, no significant differences were observed in corneal and lacrimal sac temperatures (p-value>0.05). This finding suggests that this temperature difference could serve as a valuable indicator for distinguishing between diabetic retinopathy and other diabetes-related conditions.

Earlier studies on the statistical analysis of OST in diabetic eyes have revealed significant findings. Sodi et al.[3] conducted pioneering research, analysing the OST differences between DR-affected eyes and healthy eyes. In temperature analysis specific to DR, B. Chandrasekar et al.[8] explored the OST in both NPDR and PDR cases compared to the controls. The findings indicate that OST was consistently lower in NPDR and PDR under both dilated and normal conditions, highlighting the thermal changes associated with diabetic eye complications. Moreover, this research shows that the temperature difference between the lacrimal sac and cornea was low in healthy eyes and high in eyes affected by DR. The analysis of corneal and lacrimal sac temperatures, as well as their differences, reveals distinct patterns across different groups. These findings suggest that the temperature metrics can effectively differentiate between DR, Diabetes without DR, and the Healthy Controls group, with the DR group showing greater variability and extremes in temperature differences.

Table 2 P-values from one-way ANOVA for ocular temperature comparisons

Study	p-values		
	Cornea	Lacrimal sac	Temperature difference
DR in comparison with healthy	0.2971	0.0842	0.0069<0.05
Diabetes without DR in comparison with healthy	0.6992	0.0636	0.0079<0.05
With DR in comparison with without DR	0.5210	0.9101	0.327>0.05
All three groups compared (DR, without DR, healthy)	0.5695	0.1085	0.0085<0.05

DR=diabetic retinopathy

Conclusion

This study highlights significant differences in ocular temperature regulation across 3 groups: individuals with diabetic retinopathy (DR), those with diabetes without DR, and healthy controls. The temperature difference between the cornea and lacrimal sac was quantitatively higher in individuals with DR compared to both those with diabetes without DR and healthy controls, with an average temperature differential of 38.33 °C (p-value=0.0085). Healthy eyes showed a minimal temperature difference (average differential of 37.94 °C, p-value=0.0069), which was statistically significant when compared to the DR group. These findings indicate that diabetic retinopathy and diabetes (without retinopathy) influence ocular temperature regulation in distinct ways, with DR exhibiting more pronounced variations. Temperature metrics, particularly the differential between the cornea and lacrimal sac, may therefore serve as valuable diagnostic indicators for differentiating DR from other diabetic eye conditions. Further studies should focus on temperature thresholds across the various stages of DR—mild, moderate, and severe NPDR, as well as early and advanced PDR. Quantitative measurements of ocular surface temperature (OST) at these stages could offer a clearer, more objective tool for monitoring disease progression. This investigation would further strengthen the utility of OST as a diagnostic tool for diabetic eye conditions and provide deeper insights into the mechanisms behind ocular temperature regulation in diabetic patients.

Acknowledgement

The authors would like to thank Tagore Medical College, Rathinamangalam, Chennai, for providing the dataset for this study. The authors also wish to acknowledge the management of Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam, Tamil Nadu, India, for providing the thermal camera, and the Vellore Institute of Technology, Chennai, Tamil Nadu, India, for providing facilities to carry out this work.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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