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ORIGINAL ARTICLE

Medical thermography: a diagnostic approach for type 2 diabetes based on non-contact infrared thermal imaging

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Abstract To test the potential of Infrared (IR) thermography in diagnosing as well as predicting type 2 diabetes and its complications compared with biochemical assay of HbA_{1c} as standard. As per American Diabetes Association criteria, threshold for diagnosis of diabetes was set as $HbA_{1c} \geq 6.5$ % (7.7 mmol L^{-1}). The total subjects ($n = 62$) were studied out of which control ($n = 32$) and diabetic subjects ($n = 30$). IR camera was used to capture the thermal images of the skin for diagnosis of the disease; receiver operating characteristic (ROC) curve was used to set temperature (°C) as threshold for statistically significant body regions under *t* test. In diabetic group, HbA_{1c} showed negative correlation with carotid region ($r = -0.471$, $p < 0.01$) and the mean skin temperature was lower than the normal group at body regions namely knee ($p = 0.002$), tibia ($p = 0.003$), forehead ($p = 0.014$), and palm ($p = 0.019$). The palm region showed highest area under the curve of 0.711 (95 % CI: 0.581–0.842) and the threshold was set as ≤33.85 °C, thereby sensitivity (90 %) and specificity (56 %) was obtained in determining the undiagnosed diabetes with positive predictive value of 65 %, negative predictive value of 85 % and accuracy of 73 %. As HbA_{1c} increases, skin temperature decreases. Skin temperature enables early detection of diabetes as compared to HbA_{1c}. The decrease in skin temperature may be due to the decrease in the basal metabolic rate, poor blood perfusion and high insulin resistance. Thermography can be used as a diagnostic as well as prognostic tool for the diabetes.

Keywords Infrared · Thermography · HbA_{1c} · Diabetes · Skin temperature · Insulin resistance

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Introduction

Diabetes mellitus (DM) is a chronic disease characterized by hyperglycemia with disturbances of carbohydrate, fat and protein metabolism resulting from defects in insulin secretion, insulin action, or both [1]. There is a global predominance of the disease powered by ageing populations, poor diet, and the concurrent epidemic of obesity, physical inactivity and unhygienic environment [2, 3]. The International Diabetes Federation (IDF) [4] estimated the total number of people in India with diabetes to be around 61.3 million in 2011, rising to 101.2 million by 2030.

The American Diabetes Association (ADA), European Association for the Study of Diabetes (EASD), and IDF commissioned an international expert committee, which recommended that HbA_{1c} should be the preferred diagnostic test for diabetes with diagnostic criteria for the disease was set as $HbA_{1c} \geq 6.5$ % (7.7 mmol L^{-1}) [5, 6].

Temperature is a vital and useful indicator of various diseases [7]; there is a resurgence of interest in the

application of infrared (IR) imaging in medicine with improvements in camera technology, which captures the natural thermal radiation emitted by any object above absolute zero [8, 9]. IR imaging allows the representation of the body surface thermal distribution, where it depends on the complex relationships defining the heat exchange processes between skin tissue, inner tissue, local vasculature, and metabolic activity [10].

This imaging modality provides functional information not easily measured by any other methods [11], which is non-invasive, as it passively captures the radiant heat emitted from the human body. Hence, it is risk-free, relatively inexpensive and can be readily used as an adjunct to the other standard imaging methods [12]. Complications affecting the lower limbs are the most common manifestations of diabetes [13, 14]; IR imaging provides the precise level of amputation to be performed and thus prevents re-amputation as seen in conventional methods.

The objectives of the study were: (i) to examine the discriminatory performance of various risk factors and anthropometric indices between the control and diabetic group of subjects as segregated by HbA_{1c} and (ii) to evaluate the potential of thermograph in diagnosis as well as prognosis of the disease from the study group.

Materials and methods

Study population

The screening camp for the diagnosis of the disease was conducted in the month of April 2010 at SRM Medical College Hospital and Research Centre, Kattankulathur, Tamilnadu, India. The institutional ethical clearance was obtained in performing the study. The informed consent form and risk assessment questionnaire was obtained from the total subjects ($n = 75$) and the questionnaire was carefully scrutinized for the subjects with confounding factors namely, fever ($n = 0$), cardiovascular diseases ($n = 13$), and thyroid dysfunction ($n = 0$), from which the subjects reported with known cardiovascular complications were excluded from the study to avoid confounding of the results. Thereby, our study group had $n = 62$ subjects aged between 20 and 80 years with male ($n = 27$) and female ($n = 35$).

The completed questionnaire revealed that 29 % ($n = 18$) of the study group were reported with known type 2 diabetes with a mean duration of 4 years in taking the medications. Further, 94 % ($n = 17$) of the known type 2 diabetic subjects were reported with no physical activity during the leisure time or at the work place, who were following a sedentary type of lifestyle.

Physical and physiological measurements

The anthropometrical measurements namely height (cm), weight (Kg), waist and hip (cm) measurements were obtained using standardized techniques. The blood pressure (mmHg) was recorded, in the sitting position, in the right arm using sphygmomanometer.

Biochemical analysis

The blood sample collected from an individual was used to obtain the various biochemical parameters namely HbA_{1c}, which was determined from the whole blood using Olympus auto analyzer, Germany. Estimated average glucose (eAG), a derived parameter from HbA_{1c} is measured in mg/dl. The total cholesterol and high density lipoprotein (HDL) were obtained by enzymatic method using Olympus auto analyzer, Germany.

Thermal measurements and analysis

The IR thermal imaging procedure does not impose any restrictions on diet, exercise or any other physical activity. When compared with other imaging modalities, the requirement for thermal imaging is affordable. It requires an air conditioner of 1.5 ton capacity, waiting and imaging room with a dimension ($15' \times 10'$), 5A socket outlet with 100–240 V AC, 50/60 Hz line frequency, an AC adaptor with 12 V DC output to recharge the Lithium-ion battery. The thermal camera can be operated continuously for 4 h on battery without the need of external power, the imaging room requires no high intensity discharge lamps as thermal camera picks up the naturally emitted IR rays from the body, no harmful radiation is involved, no waiting time in obtaining the report as the captured images can be transferred to the computer through USB (universal serial bus) port, where the report will be generated within few minutes after the image capture.

In a temperature controlled room, the selected body regions to be imaged were disrobed, made free of metallic ornaments and other objects to get equilibrated with the room temperature at about 23 °C for 15 min, where the temperature, humidity, and air circulation was kept under control [15], which allows to capture the skin temperature variations in the range of 0.05–0.1 °C from the affected region to the surrounding body region or the contralateral region of the body, this ensures that the naturally emitted thermal radiation from the human body is neither absorbed nor scattered by any of the objects [16].

The thermal image was captured using ThermaCam (FLIR T400) manufactured by FLIR Systems, Inc., USA. The camera has Focal Plane Array (FPA), Uncooled microbolometer detector, with a thermal sensitivity of 0.05 °C

at 30 °C. The thermal images were captured at a distance of three feet from the various body regions namely face, neck, hand, and leg regions and the images were analyzed using the Quick Report, a thermal software with version 1.2 supported by FLIR T400 camera (www.flir.com). The software provides the settings for object parameters like emissivity (0.98), reflected apparent temperature (23 °C), atmospheric temperature (23 °C), relative humidity (50 %), and distance of measure (3 feet), which can be manually entered in accordance with one's measuring environment. The temperature scale can be set for the various body regions without disturbing the measured temperature, which was fixed as standard for all the subjects and the rainbow palette was chosen to analyze the thermogram in our study.

Measurement

The thermal software provides various measurement tools namely flying spot meter, spot meter, line and area tool. In order to allow repeatability and to minimize the deviations in the measurement of skin temperature, we have chosen the area tool for all the regions of interest (ROI) except at fingers and anterior region of the toes, where the line tool was more compatible when compared to an area tool. From head to toe, the skin temperature for the desired ROI was measured separately for left and right side at the same region approximately. In the measurement panel of the software, the temperature for the measured regions indicate minimum, maximum, and average value, where the average temperature was noted down for all the subjects considered under study.

As per the ADA diagnostic criteria, the threshold for DM was set as $HbA_{1c} \geq 6.5$ % (7.7 mmol L^{-1}) based on which the subjects were classified into control ($n = 32$) and diabetic subjects ($n = 30$). The completed questionnaire revealed that only 60 % ($n = 18$) of the diabetic subjects were previously diagnosed for the disease whereas 40 % ($n = 12$) of the diseased group were unaware of being developed into type 2 diabetic individual.

Statistical analysis

A computerized database was created for all the records. The statistical package for the social sciences (SPSS) (Version 17.0) was used for the analysis. All the data were expressed as mean ± SD. The statistical significance was assumed at $p < 0.05$. The independent samples t test for the clinical, bio-chemical parameters and the skin temperature of the body regions were computed for the entire study group. The Pearson correlation was studied for the DM group to obtain the relation between the measured parameters. The receiver operating characteristic (ROC) curve for the study group was computed to set the optimal threshold in temperature for the statistically significant body regions.

Results

The thermogram obtained from the human subject may vary due to multiple factors such as fever, cardiovascular diseases, and thyroid dysfunction. In order to set the threshold in temperature for diagnosis of DM, the risk assessment questionnaire was carefully analyzed and the subjects with confounding complications were excluded from the analysis to increase the diagnostic accuracy, to study the severity of the disease and its consequences and to envisage the disease at the earlier stage.

Figure 1 illustrates the negative correlation between HbA_{1c} and skin temperature of the carotid region ($r = -0.471$, $p < 0.01$), this can be due the carotid stenosis become prominent when the blood glucose level increases in an uncontrolled manner leading to cardiovascular diseases.

The ROC curve for the body regions where illustrated in Fig. 2, where the curve trajectories of the knee and tibial regions pass closer to the upper left corner indicates the higher accuracy of the test. The vascular disease in the diabetic subjects can occur at the popliteal and tibial region, at which the atherosclerosis tends to be multisegmental rather than involving in a particular region of the artery wall.

The thermogram of the palm region of a control and diabetic subject was illustrated in Fig. 3a, b, respectively. In a control subject, the skin temperature of the palm indicates 35.2 °C, this can be due to the normal metabolic function of the body and good perfusion of the blood, whereas in a diabetic subject, the palm temperature indicates 33.0 °C, which was lower when compared to the control subject, this may be due to poor blood perfusion and decreased metabolism.

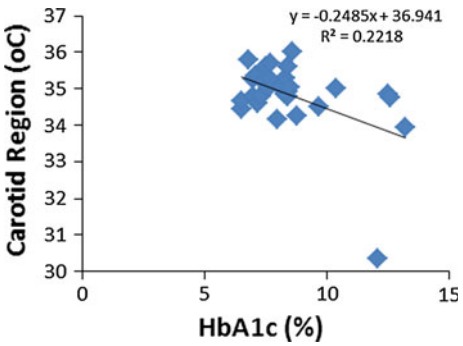

Fig. 1 Pearson correlation between HbA_{1c} and skin temperature of the carotid region in the DM group

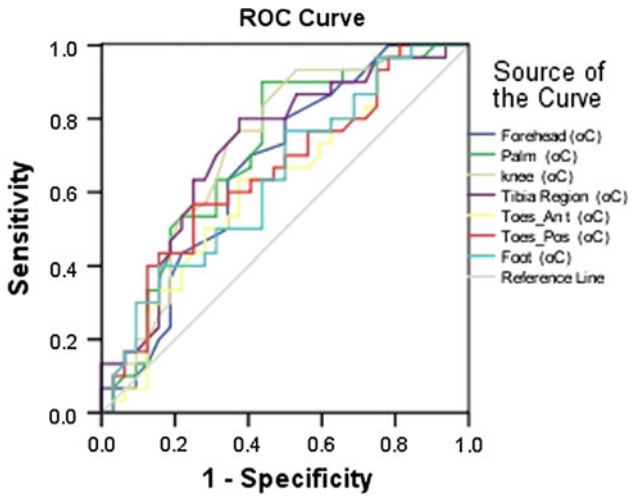

Fig. 2 ROC curve for the statistically significant body regions

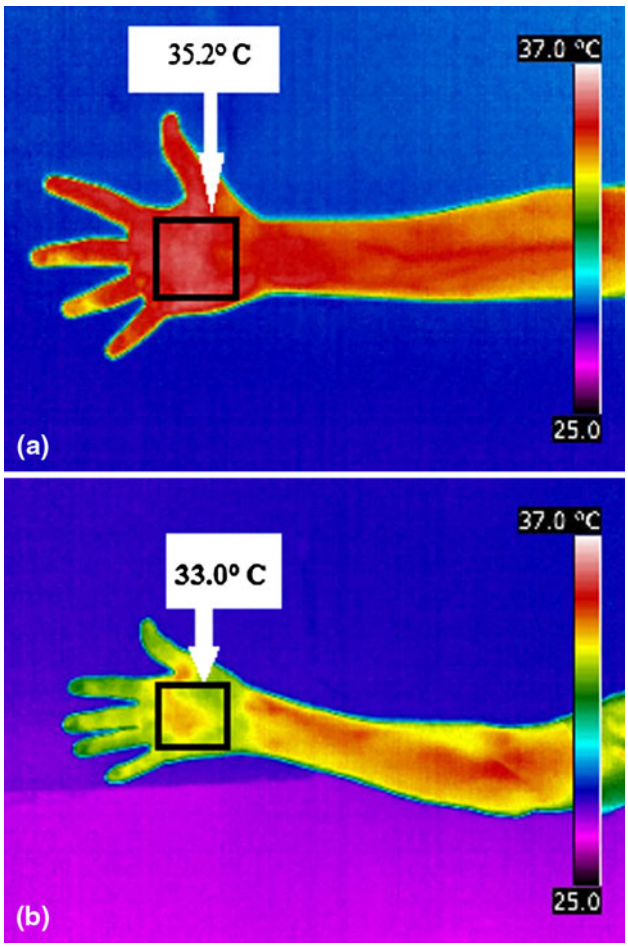

Fig. 3 The thermogram of the palm region in a control subject (**a**) and diabetic subject (**b**)

The thermogram of the foot region was analyzed by measuring the mean skin temperature of the metatarsal, mid foot and the heel regions. Figure 4a, illustrates the foot thermal distribution of a control subject in which the measured temperature lies within the mean ± SD of the control group, whereas Fig. 4b, illustrates the foot temperature of a diabetic subject without the complication of ulceration, where a decrease in temperature of 2 °C was observed in comparison with the control subject, this could be due to the decrease in the basal metabolic rate and the obstruction of blood flow in the minor blood vessels. Figure 4c, illustrates the skin temperature of the diabetic foot with early signs of ulceration, where the average temperature of the base foot was decreased by 0.5 °C when compared with the control subject, whereas the toe regions illustrate higher skin temperature of 3.9 °C and 2.2 °C in comparison with the right and left foot, respectively. Further, the right toe indicated an increase in temperature of 1.7 °C in comparison with contralateral region, which may lead to amputation, if necessary corrective measures are not taken.

Table 1, describes the Pearson correlation coefficient for the DM group, in which the age of the diabetic subjects were positively correlated with HbA_{1c} ($r = 0.379$, $p < 0.01$), this could be due to the sedentary lifestyle and poor diet. The systolic blood pressure (SBP) ($r = 0.555$, $p < 0.01$) of the DM group was positively correlated with age and negatively correlated with skin temperature of the body regions namely forehead ($r = -0.481, p < 0.01$), eye ($r = -0.574$, $p < 0.01$), and ear ($r = -0.403$, $p < 0.05$), this could be due to the decrease in the metabolic rate and endothelial dysfunction, respectively. In contrast, the age parameter was positively correlated with skin temperature of the posterior side of the toes ($r = 0.390$, $p < 0.05$), where this could be the early sign of foot ulceration. The HbA_{1c} was negatively correlated with skin temperature of the ear lobe ($r = -0.440$, $p < 0.05$) and the carotid region ($r = -0.470$, $p < 0.01$), these could be due the atherosclerosis of the arteries. There also exists a positive correlation in the skin temperature between the lower extremities and the upper extremities in the DM group, where most of them are affected; this could be due to the dependency of blood perfusion at the extremities.

Table 2 describes the independent samples *t* test for the whole study group, in which the level of significance and the 95 % confidence interval (CI) measures for the clinical, anthropometrical indices and skin temperature of the body regions were analyzed. Table 2 indicates that the age parameter was significant in control (40 ± 12 years) and DM group (51 ± 15 years) ($p = 0.003$), but the deviation in both the groups were high. The higher range of the control group may be due to the awareness of the disease and lower range of the DM group may be due to the family history, poor diet and sedentary lifestyle. The waist and the hip circumference in the diabetic group was larger than control group by 10 and 9 cm ($p = 0.010$), respectively,

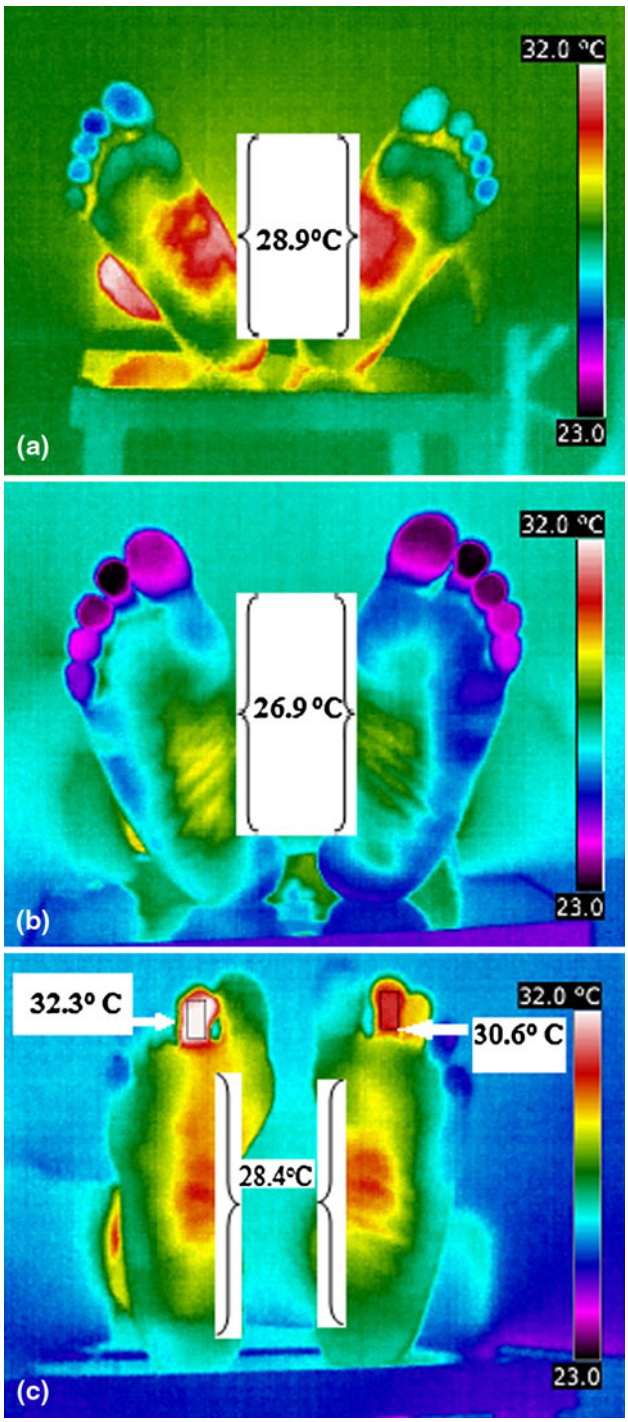

Fig. 4 The thermogram of the foot region in a control subject (**a**), diabetic subject (**b**), and diabetic subject with early signs of ulceration (**c**)

this can be due to poor diet leading to central obesity and lack of regular exercises. Among the body regions considered for IR imaging, there observed a lower skin temperature in the DM group at forehead, palm, knee, tibia, toes, and foot regions, this can be due to decreased metabolic rate. Among the statistically significant body regions, the skin temperature at the knee ($p = 0.002$, 95 % CI: 0.27–1.10) and tibia region ($p = 0.003$, 95 % CI: 0.22–1.01) indicate significance among the study group, this can be due to the atherosclerosis of the arteries in the lower limb.

Table 3 describes the area under curve (AUC) for the statistically significant body regions of the study group. The skin temperature at the knee, tibia, and palm region has an AUC of (0.727, 0.722, and 0.711 with 95 % CI: 0.598–0.855, 0.594–0.851, and 0.581–0.842), respectively.

Table 4 presents the statistical measures of performance of the binary classification test for the study group, where temperature (°C) was set as a threshold point for the body regions, by choosing an optimal sensitivity and specificity from the coordinates of the ROC curve. The palm region with threshold value $\leq$ 33.85 °C obtains the sensitivity of 90 %, this indicates the percentage of diabetic subjects who are correctly identified as diseased and specificity of 56 % indicates the percentage of healthy subjects identified as control. Also, positive predictive value (PPV) of 65 % indicates proportion of subjects with positive test results who are correctly diagnosed, negative predictive value (NPV) of 85 % indicates proportion of subjects with negative test who are correctly diagnosed and an accuracy of the test for the palm region was obtained as 73 %.

Discussion

This study reported a high prevalence of type 2 DM (48 %), which was consistent with the study reported by Ramachandran et al. [17]. Our study was a preliminary research on the application of thermography in the diagnosis and prognosis of the disease.

The negative correlation between HbA_{1c} and the skin temperature of the carotid region indicate decreased blood flow in the carotid artery of DM subjects; the thermogram of the popliteal (knee) and tibial region of the lower limb indicate a decrease in the skin temperature, these can be due to atherosclerosis, the effect of high blood sugar on the cells lining the blood vessels cause increased production of free radicals, the highly reactive molecules tear the sensitive cell components like deoxy ribo nucleic acid (DNA) which lead to apoptosis. This process also reduces the availability of nitric oxide (NO) which is responsible for dilation of blood vessels [18, 19].

The abnormal increase in the temperature of the specific sites of the foot was observed in comparison with the surrounding regions and with the contralateral region of few of the diabetic individuals, which indicate the early stages of ulceration, this could be due to the elevated levels of glycated hemoglobin; the red blood cells (RBC) become more rigid to pass through the capillaries, thus poor blood

Table 1 Pearson correlation between various variables studied in DM group ($n = 30$)

Parameters		Age (Years)	HbA_{1c} (%)	SBP (mmHg)	Body skin temperature (°C)											
					Fore head	Nose	Neck	Palm	Forearm	Finger tip	Finger whole	Knee	Tibia region	Ankle-toe	Toes anterior	Toes posterior
Age (Years)		1														
HbA_{1c} (%)		0.37**	1													
[a]SBP (mmHg)		0.55**	0.21	1												
Body skin temperature (°C)	Forehead	−0.48**	−0.32	−0.43*	1											
	Eye	−0.57**	−0.33	−0.38*	0.75**											
	Nose	0.02	−0.20	−0.18	0.38*	1										
	Neck	−0.15	−0.25	−0.41*	0.32	0.16										
	Ear	−0.40*	−0.44*	−0.12	0.57**	0.06										
	Carotid	−0.27	−0.47**	−0.29	0.04	0.10	0.23									
	Palm	0.16	−0.05	−0.20	0.15	0.61**	0.29	1								
	Forearm	0.08	−0.25	−0.28	0.34	0.61**	0.51**	0.80**	1							
	Fingers tip	0.27	−0.11	−0.06	0.04	0.58**	0.17	0.92**	0.73**	1						
	Fingers whole	0.25	−0.09	−0.15	0.07	0.61**	0.23	0.95**	0.78**	0.98**	1					
	Knee	0.31	0.02	−0.12	0.00	0.37*	0.15	0.46**	0.48**	0.48**	0.54**	1				
	Tibia region	−0.09	0.01	−0.34	0.17	0.34	0.30	0.59**	0.66**	0.51**	0.56**	0.59**	1			
	Ankle-toe	0.18	0.04	0.01	−0.03	0.38*	−0.04	0.57**	0.51**	0.56**	0.57**	0.57**	0.74**	1		
	Toes anterior	0.34	0.13	0.08	−0.03	0.50**	0.00	0.64**	0.58**	0.62**	0.64**	0.45*	0.48**	0.81**	1	
	Toes posterior	0.39*	0.22	0.09	−0.00	0.47**	0.09	0.63**	0.58**	0.59**	0.62**	0.47**	0.48**	0.75**	0.95**	1
	Foot	0.25	0.15	0.01	0.00	0.54**	0.04	0.61**	0.57**	0.55**	0.59**	0.47**	0.60**	0.82**	0.91**	0.91**

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

[a] Systolic blood pressure

Table 2 Principal characteristics of the study subjects

Parameters	Normal ($n = 32$) mean ± SD	Diabetic ($n = 30$) mean ± SD	Sig. (2-tailed)	95 % CI of the measure	
				Lower bound	Upper bound
Age (years)	40 ± 12	51 ± 15	0.003**	−18	−4
HbA_{1c} (%)	5.7 ± 0.4	8.5 ± 1.8	0.000***	−3.5	−2.1
[a]eAG (mmol L^{-1})	6.54 ± 0.64	11 ± 2.93	0.000***	−5.52	−3.34
[b]TC (mmol L^{-1})	4.69 ± 1.07	4.83 ± 0.97	0.616	−0.67	0.41
[c]HDL(mmol L^{-1})	1.04 ± 0.24	1.02 ± 0.18	0.554	−0.08	0.15
[d]SBP (mmHg)	123 ± 17	131 ± 16	0.088	−16	1
[e]DBP (mmHg)	79 ± 9	84 ± 12	0.155	−9	1
[f]BMI (kg $m^{-2)}$	26 ± 6	28 ± 4	0.157	−4	0.7
[g]WC (cm)	87 ± 13	97 ± 13	0.010*	−17	−2
[h]HC (cm)	96 ± 11	105 ± 11	0.010*	−15	−2
Body regions (°C)					
Forehead	34.98 ± 0.48	34.70 ± 0.40	0.014*	0.06	0.51
Eye	34.88 ± 0.62	34.72 ± 0.40	0.223	−0.1	0.42
Nose	32.55 ± 2.07	31.94 ± 1.76	0.216	−0.37	1.59
Neck	35.16 ± 0.39	34.98 ± 0.45	0.095	−0.03	0.4
Ear	36.50 ± 0.41	36.38 ± 0.40	0.227	−0.08	0.33
Carotid region	35.10 ± 0.51	34.82 ± 0.97	0.166	−0.12	0.66
Palm	33.64 ± 1.42	32.86 ± 1.09	0.019*	0.13	1.43
Forearm	33.33 ± 2.76	33.39 ± 0.64	0.9	−1.1	0.97
Fingers tip	32.40 ± 2.44	31.38 ± 1.98	0.079	−0.12	2.15
Fingers whole	32.71 ± 2.20	31.76 ± 1.74	0.066	−0.07	1.96
Knee	32.34 ± 0.94	31.66 ± 0.65	0.002**	0.27	1.1
Tibia region	32.82 ± 0.75	32.20 ± 0.81	0.003**	0.22	1.01
Ankle-toe	30.80 ± 1.57	30.23 ± 1.26	0.12	−0.15	1.3
Toes anterior	27.27 ± 2.72	26.12 ± 1.59	0.047*	0.02	2.27
Toes posterior	26.59 ± 2.86	25.05 ± 1.74	0.013*	0.33	2.76
Foot	28.43 ± 2.20	27.34 ± 1.65	0.033*	0.09	2.08

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

*** Correlation is significant at the 0.001 level (2-tailed)

[a] Estimated average glucose

[b] Total cholesterol

[c] High density lipoprotein

[d] Systolic blood pressure

[e] Diastolic blood pressure

[f] Body mass index

[g] Waist circumference

[h] Hip Circumference

perfusion lead to starvation of the tissues from the essential nutrients and oxygen and thus the tissue breakdown, leading to ulceration [20]. The ulceration is a condition of inflammation of the foot region. The typical regions of the foot which are more prone to ulceration are the metatarsal region, heel and lower digits of the foot [21, 22], these can be due to the excessive foot pressure resulting from foot deformities like hammer toes, bony prominences and muscle atrophy.

The SBP was negatively correlated with forehead, eye and neck regions, this can be due to increased insulin resistance resulting in decreased skin temperature as blood flow reduces. This can also be due to endothelial dysfunction, a condition in which the inner lining of the blood vessels does not function normally, which develops atherosclerosis [23–25].

The HbA_{1c} indicates negative correlation with upper extremities, whereas with lower extremities it indicates

Table 3 Area under curve (AUC) for the statistically significant body regions

Test result variable(s)	Area	Standard error[a]	Asymptotic sig.[b]	Asymptotic 95 % CI	
				Lower bound	Upper bound
Knee	0.727	0.065	0.002	0.598	0.855
Tibia region	0.722	0.066	0.003	0.594	0.851
Palm	0.711	0.067	0.004	0.581	0.842
Forehead	0.669	0.069	0.022	0.534	0.805
Toes posterior	0.655	0.07	0.036	0.518	0.792
Foot	0.64	0.07	0.058	0.503	0.778
Toes anterior	0.624	0.071	0.092	0.485	0.764

[a] Under the nonparametric assumption

[b] Null hypothesis: true area = 0.5

Table 4 Binary classification test for the statistically significant body regions

Sl. No	Body regions	Threshold for diabetes (°C)	Sensitivity (%)	Specificity (%)	[a]PPV (%)	[b]NPV (%)	Accuracy (%)
1	Palm	≤33.85	90	56	65	85	73
2	Knee	≤32.40	86	53	63	81	69
3	Tibia region	≤32.78	80	62	66	77	71
4	Foot	≤28.41	76	50	59	69	63
5	Toes anterior	≤26.83	73	40	53	62	56
6	Forehead	≤34.93	70	59	61	67	65
7	Toes posterior	≤26.14	70	50	56	64	60

[a] Positive predictive value

[b] Negative predictive value

positive correlation. This seems to be anonymous, may this relationship was due to the sedentary lifestyle of the participants involved in the study [26]. This can also be due to the mechanism of lower limb involved in the ambulation, where the exercising muscle allows the blood glucose to enter the tissue without the need of insulin whereas in the upper extremities insulin resistance predominates due to lack of physical activity. As usage of mixer grinders, washing machines and electric motor for pumping water has become part of the modern lifestyle, which reduces the upper limb activity and the skin temperature of the upper extremities were low in comparison with the lower extremities, due to poor metabolism.

The body mass index (BMI) of the study population was not statistically significant whereas the waist circumference and hip circumference indicate significance among the study group, this indicate that South Indians are prone to central obesity as compared to the western countries where total obesity is the major risk factor for the disease [27]; this can be due to insulin resistance syndrome, a group of risk factors that occur together and increase the risk for the disease. The risk factors include, abdominal obesity, insulin resistance, the sedentary lifestyle of the subjects as revealed in the risk assessment questionnaire of this study, hypertension, dyslipidemia, and elevated fasting glucose [28].

The merits of the IR imaging procedure are non-invasive, risk-free; no diet, age invariant, less time, and inexpensive when compared to other imaging modalities. The measurement procedure had a demerit, that the temperature coefficient was measured by manual selection of ROI, which may result in slight deviation in the skin temperature. To overcome this, an advanced image processing tools may be incorporated to obtain a better result with higher accuracy.

Conclusion

The prevalence of diabetes continues to increase on a global level where most of the people were undiagnosed for the disease. A non-invasive diagnostic method is necessary to eliminate the subject discomfort, to enable early detection and to reduce the cost involved. The IR imaging procedure provided enormous information about the physiological processes through examining the skin temperature distributions, which can be related to the core body temperature and blood perfusion. The test results indicated better sensitivity,

specificity, accuracy in detecting the disease as compared with HbA_{1c}. IR thermograph has achieved the most success in examining the extremities of the body where the minimal temperature changes are more readily detected, because they were separated from the thermal reservoir of the body's core. The early signs provided by the thermogram of the foot can be used as a valid prognostic tool in detecting the ulceration among the individuals who were being developed into diabetic subject and individual who were in the earlier stages of the disease, if unchecked, which may lead to amputation and other series of complications may result in the near future. The thermograph can be used as a diagnostic and predictive tool for the DM and which is the need of the hour to control the severity of the disease globally.

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Conflict of interest The authors declare that there is no conflict of interest associated with this manuscript.

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