Infrared Thermal Imaging for Interpreting Complications of Diabetic Foot Ulcers: A Case Control Study

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ABSTRACT

Introduction: Diabetic foot ulcer is one of the most frequent complications of diabetes. The inevitable need for early detection and effective management is essential, with increasing hospitalizations worldwide. This study proposes usage of Infra-red thermal imaging technique as a pre-diagnostic tool for early interpretation of the temperature variations of diabetic foot ulcers.

Material and methods: We conducted a three month retrospective case-control study using a high resolution Infra-red Thermoscan. A total of hundred subjects were recruited and divided into Diabetic and Control groups. The study involved collecting plantar thermal images of all subjects, which were analyzed and compared to interpret the temperature variations during ulceration.

Results: The results showed lower average foot temperature in most of the diabetic subjects, indicating the higher incidence of vasculopathy. It also showed a few high risk ulcer prone areas with a temperature gradient of 1.5oC and above, in some of the diabetic subjects.

Conclusion: The active inflammatory areas of diabetic foot disease were significantly detected even before the clinical manifestation, by accurate mapping of the temperature patterns of foot.

Keywords: Infra-red thermal imaging, Diabetic foot ulcer, Vasculopathy, High risk ulcerative zones, Screening tool, Pre-diagnostic tool

INTRODUCTION

Diabetes mellitus is an emerging global epidemic. The chronic hyperglycemia of diabetes manifests many life threatening complications, including Diabetic foot disease.[1] The compromise of blood supply from micro vasculopathy and decreased immunity predisposes to foot infections and wound formation. The small wounds thus formed go unnoticed and intensified due to peripheral neuropathy, causing intense ulceration. As per 2015 estimates, of the 415 million diabetics, 8% suffered foot ulcers and 1.8% of them underwent amputation[2] due to delayed management. This high risk of physical disability and a threat of amputation demonstrate the necessity for more effective approaches for early detection and management of diabetic foot disease.[3]

From usage of clinical thermometer to modern thermal imaging technology, many advances have opened up new perspectives in the interpretation of body temperature. These temperature variations generally reflect the underlying changes in the blood supply. The hyper perfusion of blood as seen in inflammatory, neogenic and neoplastic conditions causes hyperthermia where as hypo perfusion due to degeneration of tissue or dead tissue causes hypothermia. Assessing these pathological temperature variations early could be beneficial in identifying the primary pathogenesis and check future damage.

The main aim of this study was to ventilate the usage of Infra-red (IR) thermal imaging as an efficient screening technique to interpret the temperature variations of diabetic foot ulcers. The principle of infrared imaging technique involves the detection of emitted infrared radiation that can be directly correlated with these temperature variations in the body. The revelation of minute changes in temperature is done at micro vascular level, which identifies high risk ulcer prone zones.[4] In the past few decades, there has been a promising development in application of infra-red thermal imaging technique in the field of medicine. Some include evaluation of breast cancer[5], cutaneous and vascular diseases[6], neurological disorders[7], coronary artery diseases and open- heart surgery[8], urology problems[9] and mass fever screening[10], complex regional pain syndrome[11], and arthritis. Some studies were also done in the field of injury management in athletic animals.[12,13]

The primary objectives of this study include - Identifying high risk ulcer prone areas in the affected foot and differentiating the plantar temperature patterns of diabetic group from the control group

MATERIAL AND METHODS

Assuming that there are no major plantar thermal variations between diabetic and non diabetic subjects, a pre diagnostic screening was conducted. Some of the diabetic subjects who were totally unaware of the condition showed high risk ulcer prone zones in the plantar surface. A lower mean temperature was found in diabetic patients indicating angiopathic vascular compromise.

Method

We conducted a retrospective case-control study in an urban hospital setup in Davangere, Karnataka, India, with the approval of ethical committee of associated medical institutions. It was started in the month of August, 2014 and extended for three months. A total of hundred subjects were recruited from CG and Bapuji Hospitals, Davangere and divided into Diabetic and Control (normal) groups, with 50 subjects each, using random sampling method. The selection criteria of diabetic group included subjects aged 40 to 60 years, with no clinical diabetic foot signs, trauma or cellulitis and those with a 5 to 10 years history of diabetes (for diabetic group). The control group eligibility criteria included subjects aged 40 to 60 years, with no

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history of diabetes and with none of diabetic foot like symptoms or any wounds. The cases were matched with controls using variables like age and sex.

The study was done in a closed room with stable room temperature. The feet of the subjects were cleaned dry and rested for 15 to 20 minutes to stabilize blood circulation. Using Infra-red imaging technique, plantar thermal images of both right and left foot of all the subjects were taken and spot temperature assessment of nine marker regions (great toe, 2st toe, 3nd toe, 4rd toe, 5th toe, medial plantar region (MPA), lateral plantar region (LPA), medial calcaneal region(MCA) and lateral calcaneal region (LCA) was done. The obtained images were analyzed using Physiological imaging software after standardizing.

The temperature gradient (left and right foot of same subject) of each marker region was calculated and interpreted to detect inflammatory signs of diabetic foot ulcer. Average temperature of all nine points of a foot was calculated and the resulting mean of all average temperatures of left and right foot of diabetic group was calculated separately and compared with that of control group to demonstrate the phenomenon of peripheral angiopathy.

STATISTICAL ANALYSIS

All data analysis and interpretation was done using IBM SPSS statistics version 20.0 software. The statistical tools like mean, standard deviation and student t-test were used. The data has been presented in the form of tables, pie charts and bar graphs.

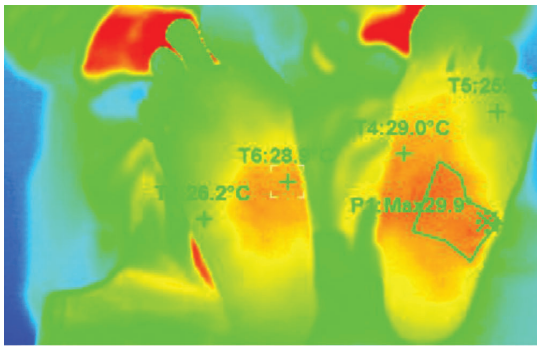
RESULTS

A total of 73 subjects with diabetes were examined for case eligibility criteria and 50 subjects satisfying the above mentioned criteria were selected using random sampling method. Out of the total 90 normal subjects examined for control eligibility criteria, 50 were selected by matching using variables like age, sex and work mode. Subjects with history of fever, injuries to foot, pressure related symptoms, cracks were excluded to avoid false positive results. The causes of ulceration other than diabetic foot like venous ulcers, traumatic ulcers, infectious conditions and chronic scars were eliminated to check potential confounders.

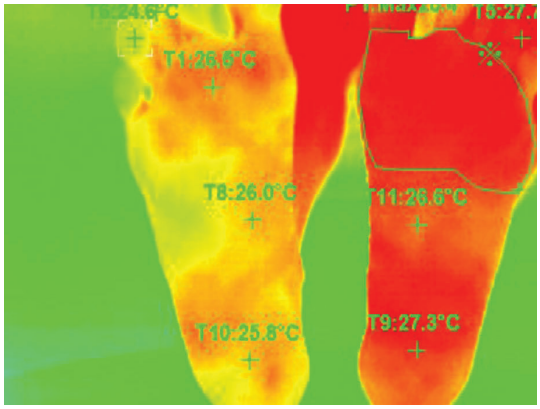
According to the results, seven out of fifty diabetic subjects showed high risk ulcer prone areas, identified with a spot temperature gradient of 2^0C to 4^0C (when compared with contra lateral foot of the same subject) (figures1-3). A total of 79% of diabetic subjects showed a lower average plantar temperature than that of the control group. The mean plantar temperature of the diabetic subjects was lower than the mean temperature of the controls [left foot: $p(T_{49}<1.93)=0.05$; right foot: $p(T_{49}<2.33)=0.05$] (table-1). For convenience, the mean temperature of left foot of the diabetic group was compared with that of the control group and same was followed for the right foot mean temperature.

DISCUSSION

In this study, hypothermia from the compromised blood supply of foot due to micro vasculopathy and atherosclerosis[15] resulted in a lower mean temperature in diabetic subjects. It was visualized clearly in the respective plantar thermal images. In association with peripheral neuropathy, the sensations in feet will be reduced or absent in severe conditions.[16] This anesthetic



Figure–1: Plantar thermal image of a diabetic patient showing 'high risk ulcer prone zone' in the left lateral plantar region, just lateral to the arch of foot, with a temperature raise of 40C (29.9-26.20C). The patient is referred for immediate foot care management.



Figure–2: Plantar thermal image showing inflammatory zones in left foot- upper plantar region shows a temperature raise of 20C; great toe shows a raise of 20C; 3rd and 4th toe shows 30C raise and the heel region with a raise of 1.50C.

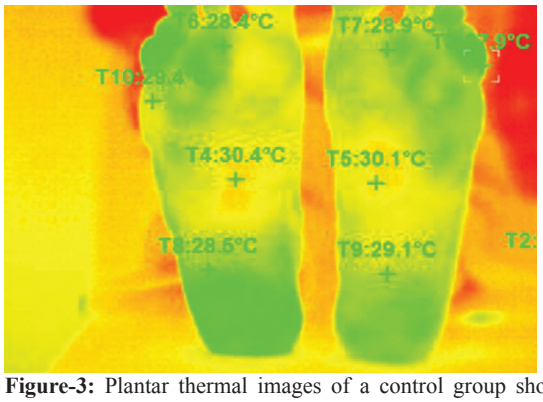


Figure-3: Plantar thermal images of a control group showing glow in arch regions due to pooling of blood and normal temperature distribution over both feet. This pattern is seen in normally arched foot.

state aggravates the unnoticed wounds or cuts, leading to development of infections, secondary to diabetes. It ultimately causes cellulitis[17,18] and ulceration because of poor wound healing capacity.[19] These particular ulcer prone zones showed higher temperature due to active inflammatory status. The raise of 1^0C and more was interpreted as high risk for inflammation. Immediate podiatric and medical care is advised to check further ulcer formation. The high pressure symptoms like callus formation also showed a comparative lesser degree rise in temperature and was differentiated by physical examination. Individual temperature of each ulcer prone area was compared to that of the corresponding areas in normal foot and temperature

	Left foot		Right foot	
	Diabetic group	**Control group**	**Diabetic group**	**Control group**
Sample size	50	50	50	50
Mean	29.302	30.921	29.465	30.920
Standard deviation	5.676	1.697	4.260	1.095
Standard error	1.368	0.240	0.602	0.154
Unpaired-t test	$p(T_{49}<1.93)=0.05$		$p(T_{49}<2.33)=0.05$	

Table-1: t-test of Left and Right foot of two groups:

gradient was calculated.

The thermal imaging technique in this study was carried out using the high resolution device called Thermoscan. Its advantages lie with the easy portability, non-invasive procedure, and early detection of abnormalities and quicker interpretation of obtained results. The study needed a closed room with stable room temperature because of which outdoor services couldn't be provided. It was limited to subjects with no active inflammatory lesions, thus progression of already formed ulcer could not be assessed in this study.

Armstrong and coworkers evaluated the effectiveness of home temperature monitoring involving 225 patients with foot complications. They asked subjects to measure foot temperature for certain period and as per results found that 19 subjects ulcerated over the study period of 18 months.[20] Francis and group disclosed characteristic abnormalities in the thermal imaging patterns over feet of diabetic young patients with and without vascular complications.[21] It showed thermography as an efficient technique for the study of circulation and metabolism in diabetes. This study provided significant results with better sample size and lesser duration.

CONCLUSION

Diabetic foot disease is a debilitating manifestation of diabetes mellitus which hampers the physical activity of the diseased. It need not be thought of a morbid lifelong burden, but something that can be tamed and controlled. This study proposes infra red thermal imaging technique as a simple, non invasive and highly accurate tool for screening diabetic foot disease. It not only evaluates the vascular status of foot, but also acts as a red flag to start appropriate podiatric care long before its clinical diagnosis, checking the formation and further progression of ulcer. It is prudent to extend the application of such screening techniques to other fields for significant health care benefits.

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