Early Detection of Peripheral Neuropathy using Thermography: A Review

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ABSTRACT
Neuropathy means damage to nerves .Peripheral neuropathy is the most common form of diabetic neuropathy. In diabetic neuropathy feet and legs are firstly affected, followed by your hands and arms. Possible signs of peripheral neuropathy include Numbness or reduced ability to feel pain or changes in temperature, especially in your feet and toes. In diabetic patient the ulcer is most detecting problem and there early detection is important. For that, many researchers work on this topic. Ulcer is due to the high temperature. Thermography is useful for early detection of ulcer, because using thermography temperature can be measure and abnormal area can be easily detect.

Keywords
Diabetic neuropathy, Ulcer, Thermography, Noninvasive, Angiosome

1. INTRODUCTION
The prevalence of type 2 diabetes is worldwide increasing rapidly. It has been recognized that the main causes of ulceration is diabetic neuropathy Because of uncontrolled diabetes eyes, kidneys, heart, nerves and feet are affected. And in those foot complications is one of the indeed problem. In diabetes patients 50% patients are admitted due to the foot complications. There are two main causes of diabetes that are decreased blood supply and loss of sensation in the feet (neuropathy). High temperatures under the foot coupled with reduced or complete loss of sensation can affect the patient to foot ulceration [1].The heel is the second most common site which is affected due to the ulcer. The areas that ulcer cause, it increase temperature of that areas due to inflammation and enzymatic autolysis of tissue. Redness, pain, swelling, loss of functions, and heated tissue these five signs are mainly characterize of inflammation [2]. The temperature is good parameter which indicates that person is healthy. Temperature reflects our body condition, if the temperature within some area becomes higher or lower than other areas unnaturally, then it will be considered to have some problem such as infection, necrosis, etc. Core body temperature can be easily measure using mercury thermometer and electronic thermometry but in the extremity, the temperature distribution is widely varied and hardly measured using traditional thermometry [3]. So the thermal camera can be useful for measuring the temperature. Thermal imaging is a technique that uses infrared radiation. By remote temperature sensing, the thermal camera is merely receiving the natural thermal energy which is emitted by the body. So no harmful energy is used in the imaging process. And thermography is noninvasive, it does not directly contact with our blood [4]. Thermometry is an effective way for access the risk of ulcer problem in diabetic feet's. It monitoring foot skin temperature and provides the clinical information before other clinical signs of injury can be identified [5]. For calculating foot temperature in diabetic neuropathy using thermal imaging the main parameters are mean foot temperature, temperature difference and recovery index after cold stress testing [6]. Study of this topic is important because in diabetes patient ulcer is most serious and common problem and its early detection is important.

2. METHOD FOR DATA COLLECTION
Normally our human body temperature has 37℃ , and a patient who suffering from diabetic neuropathy, the skin temperature varies according to the atmospheres temperature. So when we measure the feet temperature using thermal camera it does not give the appropriate output. For avoiding these problem, researcher's have some requirements,

1) Room temperature must be constant
2) Subject must remove their shoes, shocks and seated or lay down relax up to 15-20 min.
3) And subject must be in idol position.

3. COMPARITVES STUDY

Table 1: Comparative Study

Ref. No.	Methodology	Database	Method	Result
[1]	1)Mean foot Temperature 2)Temperature difference 3)Normalize Temperature	Own Database	112 subjects with type 2 diabetes selected from a tertiary diabetic center in south India	Patient with diabetic neuropathy had a higher foot temperature (32-35℃) compare to patient without neuropathy (27-30℃). Subject with diabetic neuropathy had higher mean foot temperature (MFT)($\rho = .001$)than non-neuropathy.MFT also show a positive correlation with right great toe (r=0.301,p=.001) and left great toe VPT values(r=0.292, p=.002)

[2]	1) Asymmetry analysis I) Segmentation II)Geometric transformation, III) Overlapping.	Own Database	140 thermal images. Divided into two sets. First set include 80 Healthy feet with 40 images in different size projection and 40 images with same size projection. Second set include 60 images, images having visibly different sizes of feet projections; the other 30.Images had the same size of feet projections.	The overlapping technique works well only when the feet projections sizes and shapes are the same, the scalable scanning technique works well for all types of feet projections.
[3]	1)Image Analysis 2)Temperature Difference Percentage 3)Karhunen-Loève Transform 4)Thermal Recovery Tendency 5) Image Acquisition	Own Database	1) 9 patients with or without diabetes. Age ranges from 18 to 81. Patients with the diagnosis of diabetes mellitus for 10 to 20 years. 2) For static thermal image analysis, 20 images before and after surgery respectively. 20 images are averaged to obtain the mean temperature	Karhunen-Loève transform is a better way to extract the area of poor circulation and early ulceration,
[5]	1) Gray scale 2) Intermediate segmentation	Own Database	32 healthy volunteers and 129 patients with diabetes mellitus (DM). The DM group participants were recruited from the patients at the Diabetic Foot Outpatient Clinic at the University of Tokyo Hospital	The system objectively found wider variations of the plantar forepart thermographic patterns in the patients with DM compared with those in the control subjects
[6]	1)Temperature Estimated Difference 2)Hot Spots Detection	Own database	Study on patients with diabetes mellitus type 2 in the General Hospital of San Juan del Río, México, with the collaboration of a diabetes expert group. The focus group included male and female patients, in an age range from 35 to 80, with and without neuropathy.	The temperature variation between corresponding regions in both feet usually does not vary beyond 1°C; a difference greater than 2.2°C is considered as abnormal. Diabetes type 2 with and without neuropathy have a plantar temperature of 32.2 $\pm$ 0.94 °C and 30.7 $\pm$ 1.07°C.
[7]	1)ROI 2)Statistical Analysis	Own database	Sample of 15 patients with diabetes mellitus type 1 or 2. Equally divided over three groups: 5 patients without present signs of diabetic foot complications, 5 patients with local signs of diabetic foot complications, and 5 patients with diffuse complications.	Differences in mean temperature between the ipsilateral and contralateral foot in patients with no or local complications were at maximum 1.5 °C. Mean temperature between ipsilateral and contralateral foot of patients with diffuse complications differed at minimum 3 °C, where feet with osteomyelitis and/or Charcot feet were warmer and those with critical ischemia were colder compared with the contralateral foot.
[8]	1) Heart rate variability 2) Plantar thermography 3) Electromyography 4) Statistical analysis	Own Database	Seventy-nine individuals between the ages of 19 and 79 years old (28 males) were evaluated and divided into three groups: control (n = 37), pre-diabetics (n = 13) and type 2 diabetics (n = 29).	Among the diabetic patients, the interdigital anisothermal technique alone performed better than the thermal recovery index alone, with a better sensitivity (81.3%) and specificity (46.2%).
[9]	1) Infrared Images Acquisition 2) Data Analysis 3) Statistical Analysis	Own database	10 type 2 diabetic subjects and 10 non diabetic subjects. subjects were age between 29 and 69 years, both genders	The average temperature pre-cold stress test did not differ between day 1 and day 2 for T2DM subjects, and average temperature post-cold stress was not different in these subjects between days. In nondiabetic subjects both pre and post-cold stress test average temperature were significantly different from day 1 and day 2.

4. RELATED WORK

The Subramnaiam Bagavathiappan et al. have work on diabetic neuropathy. According to their research the temperature of diabetic foot is high as compare to normal feet. For proving these they calculate the mean foot temperature (MFT), temperature difference (ΔT), and normalize temperature (T_N). For mean foot temperature (MFT) they calculate the temperature of Hallux, Lesser toes temperature, arch temperature, lateral sole temperature, forefoot temperature, heel temperature. And they use average hand temperature as a reference temperature which is use for calculating the temperature difference.

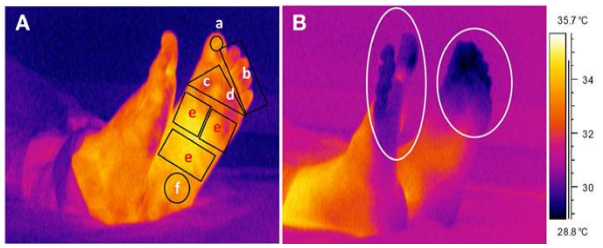

Figure 1: Thermal Image of Feet with (A) hot and (B) Cold region

In figure (A) we see the thermal image of feet with hot spot and six regions which is use for calculating the MFT. In That region a means Hallux area, b means lesser toes area, c means arch area, d means lateral sole, e means forefoot, and f means heel. And in figure (B) we see the cold region.

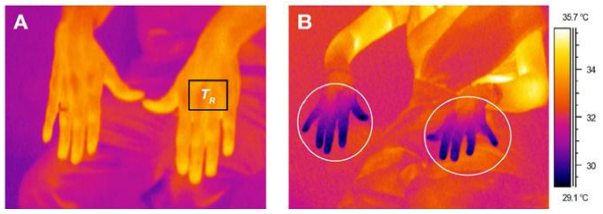

Figure 2: (A) Thermal Image of dorsal view of hands of patients and (B) Thermal image of patients with cold spot in both hands. [1]

Naima Kaabouch et al. work on diabetic feet for ulcer examination. For that they use an Asymmetry Analysis technique. They say that, there is no standard distribution for the skin-surface temperature of a healthy foot because that temperature can be affected by many factors, such as ambient and internal thermal conditions, age, sex, weight, etc. for eliminate this variability they compare the temperature of both feet's and this comparison is called as asymmetry or symmetry analysis. Segmentation, geometric transformation, and overlapping are the three steps of this technique. Segmentation remove the noise as possible, Geometric transformation-adjust the same position of both foot in, and Asymmetry analysis-subtract the intensity level of each pixel in the left foot from the intensity level for the symmetric pixel of the right foot to detect abnormal areas. Using this technique abnormal area is detected if the intensity of this area is higher than a specific designated threshold. Also using this technique they shows when the feet present as the same shape and size in an image, it tends to detect false abnormal areas when the feet are not the same shape or size in the image [2].

Kuo-Sheng Cheng et al. design one GUI for diagnosis of diabetic feet. For diagnosis of diabetic feet first they select the area of image using ROI then using geometric transformation correct the image before subtraction then spatial-Temporal representation is used to represent the variation of thermal image with time. Using these represent temperature difference in percentage. This method is not very effective in diagnosis of poor circulation area [3].

Taketoshi Mori et al. proposed a classification method for plantar thermographic patterns according to angiosome concept they distinguished five different patterns in the distal area and four patterns in the heel area and obtained the conceptual 20 different categories.

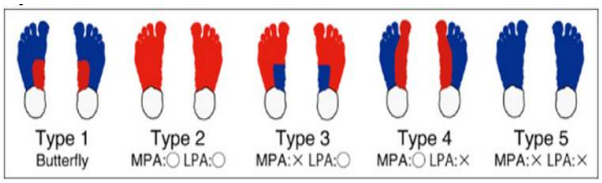

Figure 3: Variations of the thermographic patterns of the distal part of the plantar found in Nagase and coauthors. Red color indicates higher temperature and blue color indicates lower temperature [5].

H. Peregrina-Barreto et al. has work on diabetic feet for early detection of abnormal area. There work is based on the angiosome concept using this concept analyzes temperature differences. Each pixel of a thermogram has a specific temperature value, and the image contrast is derived from the skin surface differences (gradients) in temperature. They divide thermal image of each foot is into four sub images, like angiosomes, and then all the pixels are classified according to their temperature. And division of image is manually performed [6].

Jaap J. van Netten et al. study on diabetic foot for detection of foot complications. For that they design a one matlab tool, in this tool using ROI they detect signs of diabetic foot complications (e.g., callus, ulcer). Also using ROI they select the only foot area and calculate the mean temperature and the standard deviation (SD) automatically of only this selected area [7].

Luciane Fachin Balbinot et al. study on Heart rate variability, plantar thermography, Electromyography for early diagnosis of diabetic neuropathy. According to their study in diabetic patient interdigital anisothermal test perform best when used alone. For study of plantar thermography they use a cold stress test.

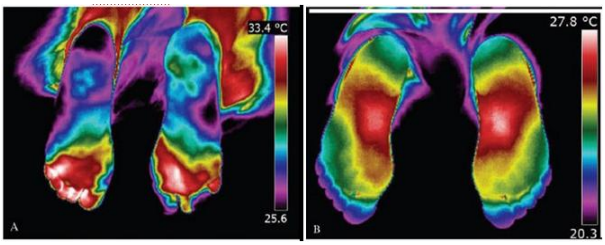

Figure 4: (A) Plantar thermographic image in a diabetic patient, showing Interdigital Anisothermal (the white arrow shows the different colors in toes meaning ΔT ≥ 0.4°C). (B) Plantar thermographic image in a control subject, with regular [8].

Luciane Fachin Balbinot et al. study on Infrared Plantar Thermography in Diabetes Patients. For that study they apply pre and post cold study on plantar region and see the temperature difference between days [9].

5. COCLUSION

Thermography is a noninvasive imaging technique that is useful to measure temperature distribution in organs and tissues. And it is useful tools in the medical field applied to the study of diseases such as diabetes. Using the thermal images we can detect the abnormalities of diabetic feet .And also useful for early detecting the ulcer problem.

6. REFERENCES

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