

EARLY DIAGNOSIS OF DIABETIC FOOT USING INFRARED THERMOGRAPHY AND CHECKING IT'S EFFICIENCY AGAINST CONVENTIONAL DIAGNOSTIC TECHNIQUE

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Technology degree in Biotechnology

By

AMRIT WILKHU (Reg.No - 39230002)

ASWINI SAI BALAJI (Reg.No – 39230004)



DEPARTMENT OF BIOTECHNOLOGY

SCHOOL OF BIO AND CHEMICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade “A” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI

CHENNAI - 600119

MAY - 2023



SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with —All grade by NAAC

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119

www.sathyabama.ac.in



DEPARTMENT OF BIOTECHNOLOGY

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Amrit Wilkhu (39230002)** and **Aswini Sai Balaji (39230004)** who carried out their Final Year Project, entitled “**EARLY DIAGNOSIS OF DIABETIC FOOT USING INFRARED THERMOGRAPHY AND CHECKING ITS EFFICIENCY AGAINST CONVENTIONAL DIAGNOSTIC TECHNIQUE**” under my supervision from June 2022 to May 2023.

Internal Guide

Dr. M. Masilamani Selvam, Ph.D.

Head of the Department

Dr. V. Ramesh Kumar, M.Phil., Ph.D.

Submitted for Viva Voce Examination held on 10/05/2023

Internal Examiner
External Examiner

DECLARATION

I, Amrit Wilkhu (Reg. No- 39230002), hereby declare that the Final Year Project Report entitled "EARLY DIAGNOSIS OF DIABETIC FOOT USING INFRARED THERMOGRAPHY AND CHECKING IT'S EFFICIENCY AGAINST CONVENTIONAL DIAGNOSTIC TECHNIQUE" done by me under the guidance of Dr. M. Masilamani Selvam, Ph.D. is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology in Biotechnology.

DATE: 10/5/2023

PLACE: Chennai

SIGNATURE OF THE CANDIDATES

1. Amrit Wilkhu

2. Asin Sai Balaji

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ABSTRACT

Diabetic neuropathy is a frequent long-term complication of diabetes. In simple words, diabetic neuropathy is nerve damage which usually affects the feet and legs of patients suffering from diabetes. It causes dangerous and costly medical symptoms such as ulceration of foot, amputation of leg and pain in extremities of the body. Sadly, diabetic neuropathy diagnosis is mostly delayed and till then a nerve injury which is irreversible has already happened. Early diagnosis of neuropathy is crucial for preventing complications associated with diabetes mellitus. However, conventional diagnostic techniques are only effective when neuropathy symptoms are evident. In this context, the efficacy of thermography as a diagnostic tool for neuropathy is being evaluated and compared to traditional methods. The focus is on early detection of diabetes using thermography and its effectiveness compared to standard diagnostic methods.

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LIST OF ABBREVIATIONS

S.no	ACRONYM	EXPANSION
1.	ROI	Region of interest
2.	IR	Infrared
3.	DFU	Diabetic foot ulcer
4.	LPL	Low- density lipoprotein
5.	IRT	Infrared thermography
6.	PAD	Peripheral artery disease
7.	VPT	Vibration perception threshold
8.	MFT	Mean foot temperature
9.	MFTD	Mean foot temperature Difference
10.	BMI	Body Mass Index

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1. INTRODUCTION

Diabetes mellitus is an emerging global pandemic. The chronic hyperglycemia caused due to diabetes causes innumerable life-threatening complications, including Diabetic foot disease also known as Diabetic neuropathy or diabetic peripheral neuropathy to be more specific. A disorder of the peripheral nerves is Diabetic neuropathy. It is commonly observed in patients suffering from diabetes mellitus. Both Type 1 and type 2 diabetic patients observe the complication of diabetic peripheral neuropathy. It is prevalent and more than 90% of the people suffering from diabetes are diagnosed with it. In the 21st century, one of the biggest global health concerns is diabetes. It is estimated that 422 million people around the world were diagnosed with diabetes in the year 2021 ,by the year 2040 these values are projected to become 642 million people.

Diabetic peripheral neuropathy is found to develop in 50% of the people who suffer from diabetes. The definition of diabetic peripheral neuropathy is “presence of symptoms and/a sign of peripheral nerve dysfunction in people with diabetes after exclusion of other causes”. The everyday life of the patient gets majorly disrupted when they have a condition like this. Pain in the lower limbs of the body are the first signs of diabetic neuropathy. The pain may be of various kinds like the sensation of burning, some have explained it to feel like the sensation of electric shock, or even in some cases, pricking of needles etc. There have also been cases reported where the patients suffer due to loss of sensation in their feet.

The blood supply decreases to micro vasculopathy along with-it people experience decreased immunity which predisposes to foot infections and wound formation. The small wounds, thus, often go unnoticed and get intensified due to peripheral neuropathy, causing intense ulceration. The projection in risk of physical disability and a threat of amputation demonstrates the need for more competent ways for management of neuropathy arising due to diabetes and early detection of the same. Diabetic peripheral neuropathy remarkably affects the daily life of the patients.

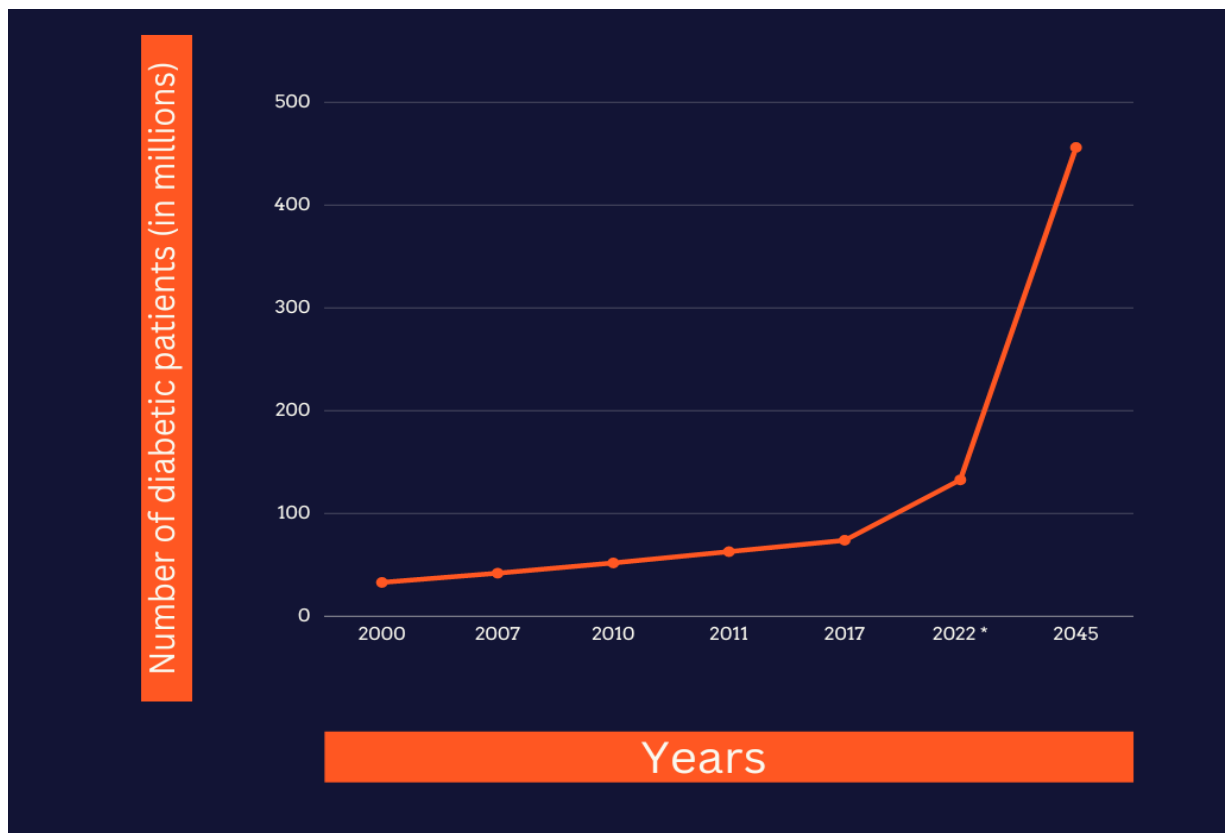


Fig 1.1 - A graph showing the number of people suffering with diabetes (in millions) and the increase in numbers with passing year

In most of the cases, the development of foot disorders due to diabetes can be omitted or considerably delayed by giving treatment that is appropriate and must be provided at a nascent stage. It portrays the necessity of diagnosis of diabetic foot, especially at an early stage. The typical management approach for diabetic foot involves using therapeutic footwear, educating the patient on diabetic foot care, and conducting regular foot examinations. Nevertheless, diabetes specialists suggest that the risk of severe complications, such as foot ulcers, could be further minimized.

Most of the research associated with diabetic foot are on par with two main aspects:

1. To improve the preliminary diagnosis of diabetic foot in hospitals, and

2. To reduce ulcers incidence and related amputation in diabetic foot

Viewing the severity of the condition, the necessity of a rapid and novel procedure for detecting diabetic neuropathy grew extremely critical.

To aid in such tasks, temperature is a significant characteristic to consider. In the past, medical practitioners have relied on body temperature as a diagnostic tool for various illnesses, as it fluctuates depending on the disease. Devices like thermistors, thermocouples, and thermopiles are commonly used to measure temperature and require contact with organs to take accurate readings.

From the use of clinical thermometers to modern thermal imaging technology, many developments have opened up new features in the elucidation of body temperature. These temperature variations generally mirror the underlying changes in the blood supply system.

Infrared thermometers provide means that are non-invasive. This helps detect in a manner for the detection of temperature of organs for metabolic disorders and disease diagnosis.

The infrared thermometer measures temperature, it is a non- contact device that gives us the temperature of a very specific area of the skin or body part. This facilitates the process of getting the temperature reading without the unwanted area around it getting targeted. An infrared thermometer not only helps check the extent to which a condition such as inflammation or neuropathy has damaged the patient. This device particularly is of great interest as it helps recognise areas that are prone to ulceration and inflammation before it's occurrence. The temperature difference when recorded can be analyzed to get a better understanding of the patient's status.

The practice of using infrared dermal thermometry has been proven to be highly reliable in the past few years especially for early detection of neuropathy in a research

setting. In confidence it is said to have high reliability of testing the temperature of the foot. Being cost effective and accurate, these instruments play a role that is vital in the future of how foot care is visualized in the future.

2. REVIEW OF LITERATURE

Audrey Macdonald *et. al.* (2017) conducted a thermal study on pre- ulcerous diabetic feet prior to skin breakdown. It was based on the concept of “hotspot” which is defined as areas which are at least 2.2 °C warmer than corresponding parts of the foot. It established the usage of Infrared spot thermometers which measures spot temperatures of small ROIs.

Studies conducted by Anke Wijlens *et. al.* (2017) concluded that measurement of foot but its authenticity improves with constant re-confirmatory measurements in the subsequent day. The foot temperature difference is not dependent on the walking activity, surrounding temperature and time of the day.

In 1986, Edmonds discovered the cause of elevated temperature in diabetic foot patients. This rise in temperature can be attributed to the elevated blood flow resulting from arteriovenous shunting, with the peripheral arteries becoming dilated and stiff.

Audrey Macdonald *et al.* (2019) conducted research that analyzed numerous hotspots on the feet of patients with a high likelihood of developing ulcers. The aim was to measure the temperature variation during each visit.

The studies done by Machin *et. al.* (2017) concluded that healthy feet are thermally symmetric; the difference in temperature due to thermal transients usually goes away in 10 minutes. The fitting of the footwear worn by the subject also has an effect on the temperature of the feet.

According to Rogers *et al.* (2011), the research conducted revealed that Charcot's foot disorder is a significant complication of diabetes and neuropathy. Early detection is crucial for effective treatment, as failure to diagnose or neglecting the condition can result in catastrophic consequences.

In 2019, Andrea Roskopf *et. al.* employed X-rays and MRI scans to identify neuropathy in individuals with diabetes mellitus who had been affected for at least a

decade. Their findings revealed that untreated neuropathy can cause significant foot deformity.

Thermography and ultrasonography were utilized by Nagase *et al.* (2011) to detect inflammation. Physicians, medical staff not specialized in wound and foot care, and even patients themselves, can easily overlook the inflammation present underneath a seemingly dry callus.

The research conducted by Kerstin Roback in (2014) revealed that a rise in temperature can be identified at a point where a possible diabetic foot complication is still reversible.

Vanessa Houghton, Virginia Bower, and David Chant's research in (2013) also supported the idea that daily monitoring of skin temperature can aid in preventing the onset of diabetic foot ulcers. Although liquid crystal thermography is considered less precise than infrared thermography, their findings confirmed the efficacy of comparing temperature between corresponding anatomical sites on each foot.

Hernandez-Contreras *et al.* (2016) conducted a review of various types of temperature analyses that are associated with diabetic foot complications. The most commonly used analyzes were found to be asymmetric and external stress analysis, while temperature distribution analysis was the least utilized. Independent limb temperature analysis is a simple approach that facilitates the comparison of temperature ranges among different study groups; however, it is not capable of identifying specific areas with the potential to develop into ulcers. In external stress analysis, an external stimulus is applied to the patient, and the plantar temperature's response to this stimulus is analyzed. Asymmetrical analysis is a study that compares the plantar temperature of one foot with respect to the temperature of the contralateral foot.

Kaynak *et al.* (2013) observed that the incidence of neuropathy in individuals with Diabetes Mellitus is 28%. In addition, they outlined the pathway involved in the

development of neuropathy.

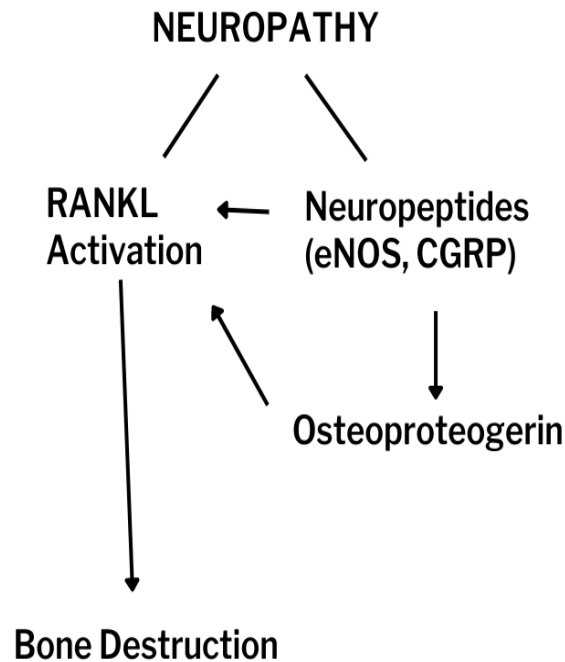


Fig 2.1 - Pathway followed by Neuropathy pathophysiology

Source - Kaynak G, Birsel O, Güven MF, Oğüt T, 'An overview of the Charcot foot pathophysiology' , *Diabet. Foot Ankle*, Vol. 4 ,(2013) , pp. 3

Bus *et al.* (2015) provided evidence of the clinical importance of plantar pressure measurements in reducing the risk of foot ulcer recurrence in patients with diabetes. However, additional technical and clinical validation is needed for this method of monitoring. Daily monitoring of foot temperature can aid in detecting an increase in skin temperature as a potential sign of foot ulceration, which can significantly decrease the incidence of foot ulcers in high-risk patients.

According to the research conducted by Arjaleena Ilo *et al.* (2019), infrared thermography (IRT) is effective in identifying local temperature differences, mottled coloration, and higher mean temperatures in high-risk diabetic feet with neuropathy and neurochemicals. It can also detect angiosome disorders in feet, specifically distal

angiopathy and distal peripheral arterial disease (PAD), which are prevalent among diabetic patients. The findings suggest that IRT can serve as an additional screening tool for early detection of diabetic foot complications.

Peregrina-Barreto *et. al.* (2014) studied the temperature difference in the plantar region of the feet of diabetic patients. In this temperature differences in symmetric regions between feet and inside of the same foot was taken into account. The methodology adopted was that the plantar area was divided into four main regions (angiosomes) and the temperatures inside those regions were grouped in classes which helped them to analyze if there is an abnormal difference or not. The other methodology adopted was that the temperatures inside the angiosomes were studied with the aim of detecting the presence of small abnormal areas (hot spots).

Astasio-Picado *et. al.* (2018) conducted a study where they discovered that the highest temperature in both feet was centered around the head of the 5th metatarsal bone, with a temperature difference of 0.21°C higher on the right foot, which is higher than the standard temperature difference of 2.2°C observed in other studies. They also found that the lowest temperature was located in the area of the pulp of the big toe. The study suggests that the position of this body segment, which is located at the distal part of the lower limb, could be a possible scientific explanation for these findings.

Elena-Rodica Perciun *et. al.* (2020) conducted studies that highlighted the importance of measuring temperature changes to detect underlying problems. The studies underlined the use of handheld Infrared Thermometer which is a cheaper, user-friendly instrument than other Infrared rays as the medium. An intense neuropathic foot generally has higher skin temperature throughout, but particularly on the dorsal part of the foot. This is likely due to increased blood flow to the area, which has thinner skin and subcutaneous tissue. The thinner the subcutis layer, the higher the skin surface temperature is likely to be.

The studies conducted by Vanessa Houghton *et al.* (2013) suggested that daily skin temperature monitoring could be an effective way to predict and prevent diabetic foot ulceration. They found that comparing skin temperature between the same anatomical sites on each foot can help predict foot ulceration, and the use of temperature monitoring can contribute to the prevention of diabetic foot ulceration.

Muhammad Adam *et. al.* (2017) utilized the asymmetric temperature analysis technique in their study as it has been proven to be effective and easy to implement in previous research. This method helped to detect temperature differences between the feet which may indicate inflammation or the potential development of foot ulcers. Additionally, they discussed the use of computer-aided diagnosis (CAD) systems in detecting inflammation and other abnormalities in the foot.

The review done by Nisha Charkoudian (2003) showed that the local cutaneous microvascular responsiveness is affected in patients suffering from Diabetes mellitus. They also have decreased cutaneous vasodilation which leads to increased temperature in the feet which eventually leads to pain.

The study by Takashi Nagase *et. al.* was published in (2011), and it investigated the relationship between thermography and angiosomes in diabetic patients. The authors concluded that infrared thermography can be useful for early detection of foot ulcers in diabetic patients by identifying changes in temperature in specific angiosomes. The study also suggests that using the angiosome concept can help in selecting appropriate treatment options, such as revascularization surgery, for diabetic foot ulcers. Overall, the study highlights the potential of thermography and angiosome concepts for improving the management and prevention of diabetic foot complications.

In their study, Petrova *et. al.* (2018) found that measuring 5 ROIs in the feet of diabetic patients using both a thermal camera and a hand-held infrared spot thermometer resulted in no significant difference between the two methods.

In their study, Alfred Gatt *et. al.* (2018) observed that there were no noticeable differences in mean temperatures of the toes and forefoot between healthy subjects

and diabetic patients without any foot related complications. Similarly, there were no significant differences in mean temperatures of the same areas between patients who have other complications like neuropathy, neurochemical and PAD. However, they found a rise in temperature in the feet of diabetic patients with complications, indicating that diabetic foot complications have started to develop. They also compared temperature differences between possible categories of complications in diabetic patients to those in healthy adults.

Here, Armstrong *et. al.* (1997) had to look into patients having neuropathy and foot ulcers. The main objective was to observe the temperature between before, during and after wound healing. The patients were treated accordingly and the temperatures were measured at a regular interval. Temperatures in the ulcerated foot was higher than in the contralateral feet at each stage.

According to a study conducted by Van Netten *et. al.* (2013), patients without any symptoms or complications displayed only minor temperature differences between their feet. However, patients with foot ulcers showed a localized increase in temperature of more than 2°C when compared to the contralateral foot. Patients with diffuse complications, such as a foot ulcer with osteomyelitis or a Charcot foot, showed a mean temperature increase of more than 3°C compared to the contralateral foot. These findings suggest that thermography can be used as a non-invasive, automated diagnostic tool for detecting signs of diabetic foot disease, facilitating early detection and timely management of diabetic foot complications, and ultimately helping to prevent severe consequences.

The experiment conducted by Asfandiyar Mufti *et. al.* (2015) analyzed 108 patients with diabetes and with wounds. They collected demographic data from all the patients. The feet of all the patients were measured using 5 different infrared thermometers and they found out that there was no noticeable difference between the 5 infrared thermometers. However, the results demonstrate that industrial grade non-contact infrared thermometers that are less expensive can provide reliable temperature readings and can be used to identify and quantify temperature gradients

in the periwound skin.

Petrova *et. al.* (2019) conducted studies on diabetic patients who were in the high risk group for developing DFU or who had been previously treated with DFU. They found out that monthly intervention with an infrared thermometer showed no significant reduction in recurrence of foot ulcers. But there are no side effects of using thermal devices so it can be used for detection of ulcers in clinical setup. It also ruled out the previous studies that said that recurrence of ulcers only happens in the plantar regions of the foot whereas ulcer recurrence is found out to be equally there in non-plantar regions as well.

In the experiment conducted by Lavery *et. al.* (2004) worked with 85 patients with neuropathy or some kind of foot amputation wherein they segregated the patients into 2 groups , first group was subjected to standard therapy and second group were assessed using infrared thermography. The occurrence of further complications were seen less in those subjected to infrared thermography than those in standard therapy.

Papana *et. al.* (2008) worked with 60 patients, Group A - consisted of 30 diabetic patients and peripheral neuropathy and Group B consisted of 30 diabetic patients but without peripheral neuropathy. The temperature of the feet from all the 60 patients were measured using a hand held thermometer. The temperature difference in Group A was found out to be more in Group B. Thus, confirming the temperature increase in neuropathy patients

Gary Sibbald *et. al.* (2015) conducted experiments with 22 patients with foot ulcers and validated that a temperature difference of 2 degree celsius exists between the wound and the surrounding and corresponding area. They also introduced the concept of STONEES -The acronym STONEES stands for the following indicators of wound deterioration: increased Size, increased periwound Temperature, Os (probing to bone), new areas of breakdown, Erythema and/or edema (cellulitis), increased Exudate, and Smell. These are signs that a wound is not healing properly and requires further medical attention for patients with diabetic having wound . If 3 or more of the above symptoms are present then the wound has spread considerably and thus

needs immediate intervention. Another concept of NERDS which stands for Non Healing wound status which is not 30% smaller in 4 weeks, increased Exudate, Red and friable granulation tissue, necrotic Debris, and/or Smell was established for superficial temperature increase. It is important to note that the use of topical antiseptics should be based on the underlying cause of the wound and the patient's overall health condition. While an increase in temperature along with other symptoms may suggest the need for treatment with topical antiseptics, this should be determined by a healthcare professional. The choice of the specific antiseptic agent should also be based on various factors, including the type and severity of the wound, patient preferences, and the healthcare provider's clinical judgment.



Fig 2.2 - 10 points on foot being measured

Source - Gatt A., Falzon O., Cassar K, Camilleri K. P., Gauci J., Ellul, C., Formosa, C. ,The Application of Medical Thermography to Discriminate Neuroischemic Toe Ulceration in the Diabetic Foot, The International Journal of Lower Extremity Wounds, Vol. 17,(2018), pp. 40

In a study conducted by Alfred Gatt *et al.* (2018), temperatures were measured in 43 non-ulcerated neuroischemic feet (from 30 subjects), 21 healthy feet (15 subjects), and 12 feet (12 subjects) with ulcers on one toe. The results showed that the temperatures in healthy feet were significantly lower than those in neuroischemic ulcerated and non-ulcerated toes. Additionally, there were no significant differences

between the temperatures of toes in patients with non-ulcerated toes and those with neuroischemic ulcerated toes of the same foot, indicating that all toes in the same foot could potentially be at risk of developing complications.

32 patients were examined by Bijan Najafi *et al.* (2012) wherein 15 had Charcot foot disorder and rest didn't have Charcot disease. Patients with Charcot foot disorder showed significant disorder and patients with no disorder did not show any difference. The plantar foot temperature in individuals with Charcot foot disorder showed a sharp increase after walking more than 50 steps for both feet, while no significant difference in temperature was observed in individuals without Charcot foot disorder between 50 and 200 steps.

In a study conducted by Eduardo Borba Neves *et al.* (2015), 17 healthy male volunteers were divided into two groups of 9 and 8 members, respectively, to investigate the effect of the subcutaneous fat layer on skin temperature variation. The results of the experiment indicated that volunteers with a lower subcutaneous fat layer had a higher rate of skin temperature variation during exercise compared to those with a higher subcutaneous fat layer.

Wouter aan de Stegge *et al.* (2018) conducted a study to determine the cost-effectiveness and cost-utility of at-home monitoring of plantar foot temperature in high-risk diabetes patients for preventing foot ulcer recurrence. The study involved patients who had previously undergone amputations and focused on six predefined regions of interest on the foot. If a patient detected a temperature difference above 1.5 °C for two weeks, they were instructed to consult a physician for further investigations. The study found that foot ulcers typically develop in the plantar region, apex of toes, interdigital spaces, and lateral and medial forefoot due to repetitive mechanical stress.

Kerstin Roback (2010) conducted two trials in 2007 with diabetes patients at high risk for ulceration. Patients were randomly assigned to either standard therapy or standard therapy with the addition of IR thermometry. In both trials, patients in the standard therapy group were more likely to develop ulcers within the study period

(15-18 months) than patients in the intervention group. The study results showed a reduction of over 60% in foot ulceration in the intervention group compared to the standard therapy group.

In the study by David Armstrong *et. al.* (2007), 225 patients were divided into two groups: standard therapy and thermometry groups. Both groups received therapeutic footwear, diabetic foot education, regular foot care, and performed a structured foot inspection daily. The Thermometry Group subjects used an infrared skin thermometer to measure temperatures on 6 foot sites twice daily. If the temperature difference was found to be >4 degrees F between corresponding sites on the left and right feet, the patients had to contact the study nurse and reduce activity until temperatures normalized. After 18 months, the incidence of foot ulcers was significantly lower in the thermometry group compared to the standard therapy group, suggesting that thermometry could be a useful tool for preventing foot ulcers in patients with diabetes.

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In a study by Anke Wijlens *et. al.* (2017), 28 patients with diabetes and neuropathy had their feet examined four times a day for six days using an infrared thermometer. Foot temperature was monitored alongside environmental temperature and walking activity to determine a threshold value of greater than 2.2°C difference between left and right foot temperatures, which was found to be a reliable warning signal for impending ulceration.

Armstrong *et. al.* (2003) conducted a study on 1588 patients with diabetes and assessed 6 plantar regions. They found no significant temperature differences in patients with neuropathy but did find differences in patients with Charcot arthropathy. Additionally, regional variations were observed, with Mexican Americans and Blacks exhibiting higher mean skin temperatures than non-Hispanic Whites at baseline..

Anita Skafjeld *et. al.* (2015) studied the viability of temperature measurements for DFU among European Caucasians. They found out that there is no noticeable difference in temperature measurement on the basis of demography. But it was found out that patients having high levels of HbA1c, LDL-cholesterol, blood pressure and urine albumin /Creatinine ratio are at a greater risk for diabetic foot recurrence. So, the patients who are at high risk should start monitoring the foot skin temperature from early stages. The need of wearing customized footwear by the high-risk patients was underlined.

3. AIM AND SCOPE

AIM OF THE PROJECT -

- ❖ The aim of this project is Early Diagnosis of Neuropathy (Diabetic feet) using Infrared Thermometer and to check the efficiency of this technique against Conventional diagnostic techniques

SCOPE OF THE PROJECT -

1. Diabetes is an emerging pandemic which is going to affect every 3rd person across the globe.
2. Diabetes has numerous complications which includes neuropathy which needs immediate concern.
3. Neuropathy is loss of sensation in the extremities of the body.
4. Infrared dermal thermometry has been proven to be highly reliable in the past few years especially for early detection of neuropathy in a research setting.
5. Infrared dermal thermometry has been applied to diabetic patients to detect inflammation in their feet

4.MATERIALS AND METHODS

4.1 PLACES OF WORK



Fig 4.1 - Tata Motors Hospital



Fig 4.2 - Sathyabama General Hospital

4.2 INFRARED THERMOMETERS

The data collection was held in two separate locations. Data was collected from patients from Jamshedpur, Jharkhand and Chennai, Tamil Nadu. Two different infrared thermometers were used for the data collection in the respective locations.

The infrared thermometer used in Jamshedpur, Jharkhand was an AXLmed Infrared Thermometer AMT001. It has the capacity to check the temperatures ranging from 32 °C to 42.9 °C.

The device used to collect data in Chennai, Tamil Nadu was an infrared thermometer tushti model Tx-21. It is equipped to check the temperatures that range from 32 °C to 42.9 °C.

These tools were selected specifically to help give accurate and reliable readings for the data collection. Apart from the infrared thermometers giving accurate and precise

results, they are also easily portable and do not need prior calibration. Their wide temperature range helps get a more broader data set. These tools were also more economically viable and suitable for the research.

4.2.1 Application of Infrared thermometers

An infrared thermometer is specifically used for the diagnosis of a condition termed as neuropathy. This is done as the skin's temperature is indicative of the patient suffering from the condition or not. This skin temperature difference can be recorded using an infrared thermometer. People who suffer from the condition of neuropathy face symptoms such as reduced blood flow towards the extremities of their body. When the blood flow is reduced, this is in turn reflected onto the temperature of said area. With lesser blood flow, the temperature will decrease. The temperature decrease indicated the lack of blood flow which suggests that the person can be suffering from neuropathy.

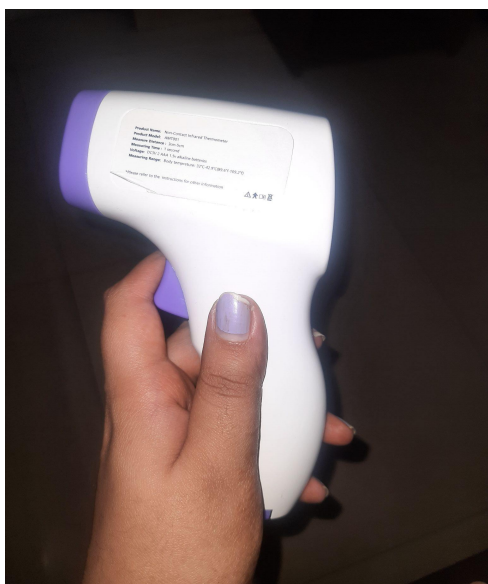


Fig 4.3 - Infrared thermometer used for Jamshedpur patients



Fig 4.4 - Infrared thermometer used for Chennai patients

4.3 REASONS FOR CHOOSING INFRARED THERMOMETERS OVER OTHER INFRARED DEVICES

Infrared thermometer is preferred over other Infrared devices for the following reasons:

1. Accuracy in measurement - Infrared thermometers are usually designed to measure temperatures with high accuracy, which broadens its range of applications. On the other hand, other infrared devices doesn't provide the same level of accuracy
2. Portability - Infrared thermometers are mostly compact, small and lightweight, making it easy to carry and use for various applications. Other infrared devices are mostly larger and thus difficult to carry.
3. Non-contact - Infrared thermometers can measure the temperature from a distance, which makes it ideal for situations where we don't want to make

contact with the object/person whereas the infrared devices require us to make contact with the object.

4. Quick and ease to use - Infrared thermometer provides the temperature readings instantly and accurately. Other infrared devices require more time to measure accurately.
5. Cost effectiveness - Infrared thermometers are more affordable than other infrared devices.

4.4 EXPERIMENTAL WORK - MEASUREMENT OF FASTING AND POSTPRANDIAL SUGAR LEVELS

4.4.1 Fasting sugar

Fasting sugar refers to the level of glucose present in the bloodstream after an interval of fasting, typically for 8 hours or more. Fasting blood glucose test is a blood test which measures the fasting blood sugar levels. Fasting blood glucose levels should be between 70 and 99 mg/dL, this is considered as the normal range. People having their blood sugar level between 100 and 125 mg/dL are considered prediabetic, while those having their blood sugar levels above 126 mg/dL on two distinct occasions, are typically considered diabetic. Factors such as medications, stress, illness, and physical activity can also affect fasting blood sugar levels.

4.4.2 Postprandial sugar

Postprandial sugar refers to the amount of glucose present in the bloodstream after a meal. Postprandial glucose test is a blood test which measures the postprandial sugar levels. Normally, postprandial glucose levels should be less than 140 mg/dL, 2 hours post eating. However, in patients suffering from diabetes, postprandial glucose levels can be elevated due to the inability of the body to properly manage levels of

glucose. For patients suffering from diabetes, the postprandial glucose levels are usually below 180 mg/dL , 2 hours post eating. Postprandial glucose levels in people suffering from diabetes can be managed using dietary changes, exercise and medications.

4.4.3 Application of measurement of sugar levels

For this project work, we had to measure blood sugar levels to draw parallel with the temperature of the feet collected from patients suffering from diabetes to check the efficiency of the thermometers used and to also examine its applicability in healthcare setup.

4.4.4 Equipment used for blood sugar measurement

The equipment used for blood sugar measurement was Cobas analyzer.



Fig. 4.5 - Automatic Cobas analyzer

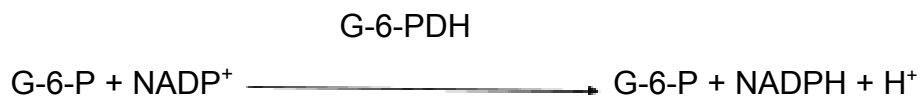
4.4.4.1 Principle involved in the Equipment

Enzymatic method using hexokinase is used.

Hexokinase catalyzes the phosphorylation of glucose to glucose-6-phosphate by ATP.



Glucose-6-phosphate dehydrogenase oxidizes glucose-6-phosphate in the presence of NADP to gluconate-6-phosphate. No other carbohydrate is oxidized. The rate of NADPH formation during the reaction is directly proportional to the glucose concentration and is measured photometrically.



4.5 METHODOLOGY

Methodology describes the complete procedure from surveying of literature to comparative analysis of the results obtained from infrared thermometer and the conventional diagnostic techniques. The given figure shows the methodological framework.

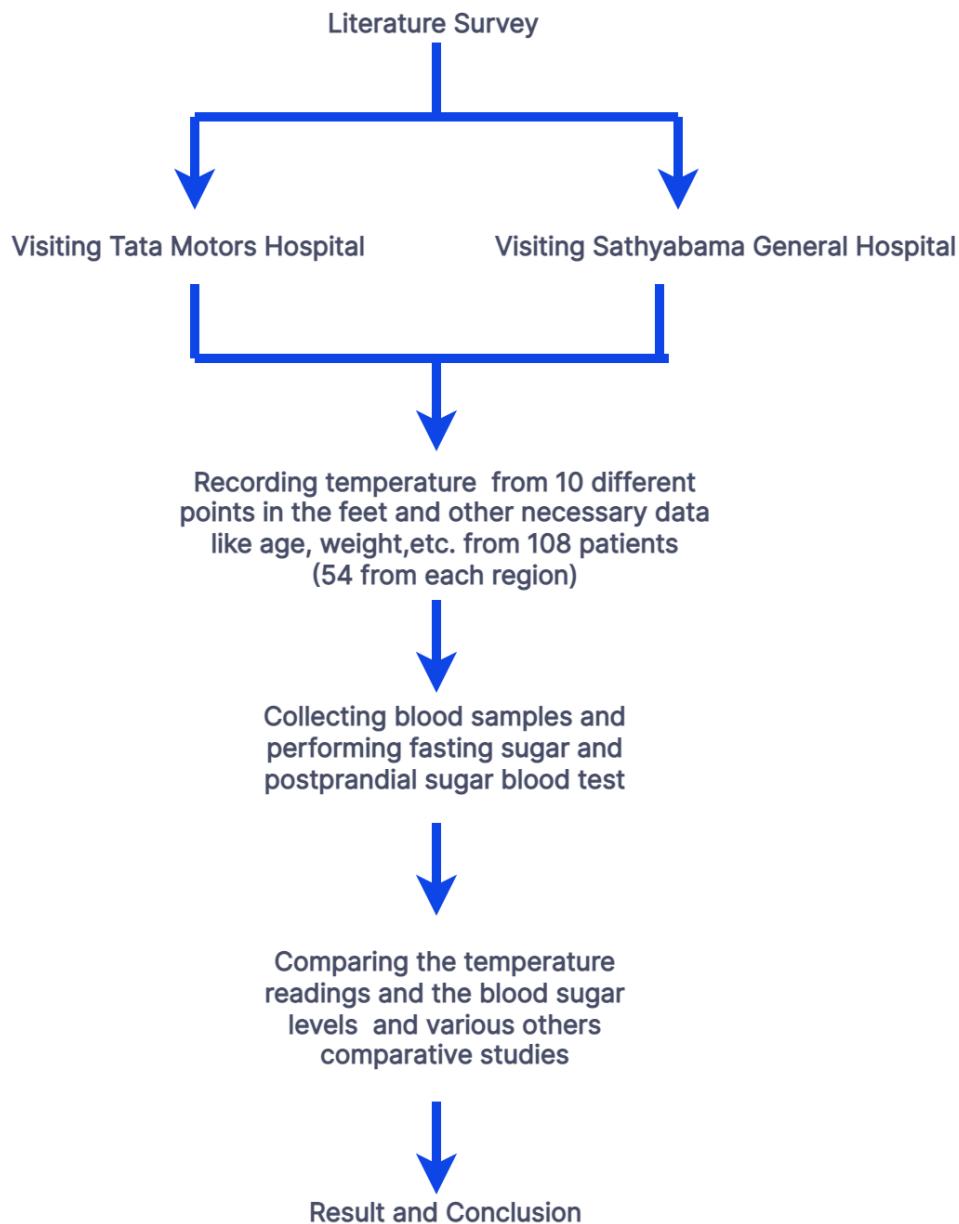


Fig. 4.6 - Methodological framework

4.6 PARAMETERS COLLECTED

01. Age
02. Duration of diabetes
03. Gender
04. Weight
05. Height (in centimeters and meters)
06. The body mass index was calculated using height and weight

4.7 FORMULA USED FOR CALCULATING THE SAMPLE SIZE

For deciding the sample size ,here, the number of patients to be observed, we used a formula , which is as follows,

$$n = N \times \frac{\frac{Z^2 \times p \times (1 - p)}{e^2}}{\left[N - 1 + \frac{Z^2 \times p \times (1 - p)}{e^2} \right]}$$

where:

- n is the sample size,
- N is the population size,
- z is the confidence level (in percent, such as 90% = 0.9),
- p is the sample proportion (in percent, such as 50% = 0.5),
- e is the margin of error (in percent, such as 5% = 0.05).

1. Population size (N) - The population size indicates the total number of people in the population (target audience) we are trying to survey.

2. Confidence level (z) - The confidence level shows the probability that the interval of confidence mentioned contains the true population value, which indicates the number

of times the experiment should be repeated. The accuracy of the results determines how high your confidence interval is. As the confidence level increases, the required sample size also increases.

3. Confidence interval (Margin of error) (e) - The confidence interval is also called the margin of error. It is a range of values that are likely to contain your population value and is expressed in percentage points. For example, a confidence interval of $\pm 2\%$ means that your true population will lie either 2 percentage points above or below where it is shown in your results.

For this project, we took $N = 77$ millions (77000000)

$$z = 90\% = 0.9$$

$$p = 50\% = 0.5$$

$$e = 8\% = 0.08$$

and putting the above values in the formula, n came out to be 105, so we took a sample size as **105**.

4.8 PROCEDURE INVOLVED IN COLLECTING TEMPERATURE FROM PATIENTS

1. The imaging test is carried out in a steady state environment 21 degree celsius.
2. The patient's shoes were removed and it was ensured that the patient was empty stomach.
3. The patient was asked to lay down for 10 - 15 mins before performing the actual measurements to eliminate the external aspects on the temperature distributions of the foot.
4. During this process, we collected the data from the patients like their age, height, weight and the duration of diabetes.
5. After 10 - 15 mins, the temperature from 10 different regions of the feet, covering all the regions like the metatarsal region, midfoot, toes and heels were recorded, as shown in the figure below.

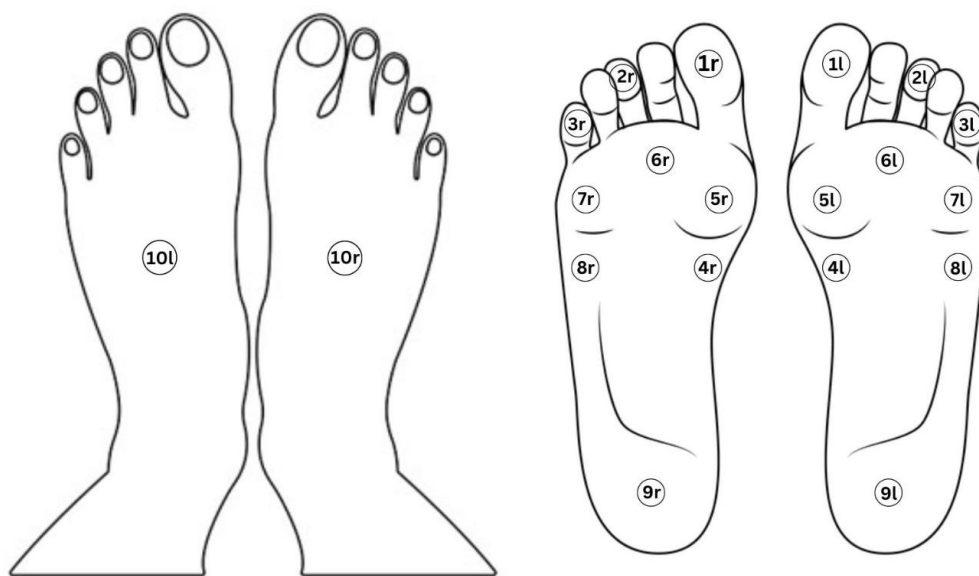


Fig 4.7 - The 10 regions of feet measured.

6. Blood was collected at this point for fasting sugar analysis.
7. Then the patient was allowed to have food and then their blood was collected for postprandial blood test.
8. In order to prevent glycolysis, the blood samples were collected in fluoride tubes (with purple caps).
9. The same procedure was followed in both Chennai and Jamshedpur using two different infrared thermometers for 75 patients in Jamshedpur and 32 patients in Chennai.

NOTE - If the preservative (NaF) is not added, then the sample should be separated from the cells and clots within half an hour of being drawn. Since when the blood is drawn and permitted to clot and to stand uncentrifuged at room temperature, the average decrease in serum glucose is nearly equal to 7 % in 1 hour.

The reagents used for blood glucose testing ,namely , are:

R1 -

- MES buffer : 5.0 mmol/L , pH 6.0 ;
- Mg 2+ : 24 mmol/L ;
- ATP : ≥ 4.5 mmol/L ;
- NADP : ≥ 7.0 mmol/L ;
- preservative.

R2 -

- HEPES buffer : 200 mmol/L , pH 8.0 ;
- Mg 2+ : 4 mmol/L ;
- HK (yeast) : ≥ 300 μ kat/L ;
- G-6-PDH (E.coli) : ≥ 300 μ kat/L ;
- preservative.



Fig 4.8 - Loading the blood sample onto the analyzer



Fig 4.9 - The working of the analyzer



Fig 4.10- Graph showing the calibration of the equipment using the blood test reports



Fig 4.11 - Measuring the foot temperature at Tata Motors Hospital



Fig 4.12 - Measuring the foot temperature at Sathyabama General Hospital

5. RESULTS AND DISCUSSION

For this study , we took temperature readings from n = 105 patients, from which n=75 readings were taken from Tata Motors Hospital , Jamshedpur and n= 30 readings were taken from Sathyabama General Hospital, Chennai .

After that we divided the patients into male and female to get a better understanding of the relationship existing between the temperature readings and different parameters collected.

As we knew from the literature survey , the patients prone to ulcer have a 2.2 ° celsius difference from the contralateral region. So technically the mean of their whole foot region would also be high. We took out the mean/average of all the temperature region differences and correlated it to different parameters collected.

5.1 RELATIONSHIP BETWEEN MFTD AND BMI FROM FEMALE DIABETIC PATIENTS

First, of all ,we took MFTD from Female diabetic patients, and their BMI and tried to find out a relationship between them,

Table 5.1 - BMI and MFTD from Female Diabetic patients

BMI of the Patients	MFTD of the Patients (° C)
28.04	1.22
23.805	0.5
24.61	0.53
29.516	1.65
27.757	1.12
29.778	1.77
34.484	1.96

BMI of the Patients	MFTD of the Patients (° C)
29.21	1.5
20.202	0.31
26.892	0.66
21.926	0.39
33.723	1.81
26.635	0.58
22.769	0.47
28.764	1.3
22.222	0.44
24.444	0.52
25.104	0.54
26.062	0.56
27.392	0.98
20.444	0.35
25.806	0.55
27.531	1.07
27.968	1.18
22.827	0.48
20.776	0.36
23.233	0.49
30.043	1.79
25.104	0.28
23.011	0.4
29.432	0.49
27.408	1.06
20.202	0.29
23.495	0.49
26.563	0.57
22.827	0.49
21.403	0.37
26.31	0.57
28.46	1.28

BMI of the Patients	MFTD of the Patients (° C)
32.47	1.7
21.77	0.36
24.25	0.51
27.18	0.75
35.59	2
21.71	0.32
23.28	0.46
24.8	0.47
25.56	0.51
35.71	2.36
26.22	0.51

We, calculated the correlation coefficient (r) as 0.90739959437919, which shows that both the parameters are closely linked as shown in the scatter plot below,

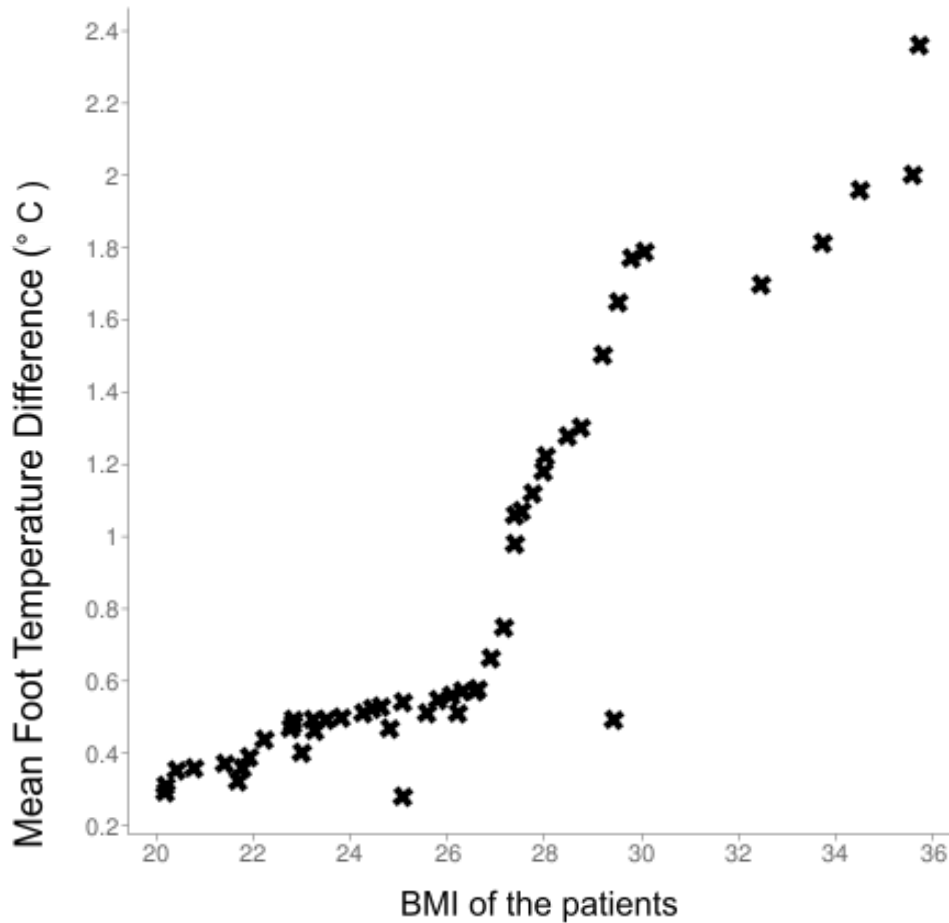


Fig 5.1 - Graph showing MFTD of Female Diabetic Patients VS BMI

As we can see in the graph, as the BMI increases the temperature difference mean also increases.

5.2 RELATIONSHIP BETWEEN MFTD AND BMI FROM MALE DIABETIC PATIENTS

Next, we plotted a graph between BMI and Temperature Difference mean from Male diabetic patients:

Table 5.2 - BMI and MFTD from Male Diabetic patients

BMI of the Patients	MFTD of the Patients (° C)
24.62	1.1
26.04	1.43
20.72	0.41
23.31	0.82
21.78	0.48
23.61	0.86
20.44	0.35
32.47	2
27.55	1.45
24.02	0.89
23.14	0.8
30.43	1.93
28.4	1.54
22.22	0.61
28.33	1.51
25.78	1.4
22.94	0.63
21.91	0.59
29.43	1.79
20.58	0.39
33.15	2.01
24.91	1.3
31.62	1.98
20.98	0.45
28.28	1.49
30.49	0.78
29.02	1.55
24.91	0.33
24.86	1.16
28.23	1.47

BMI of the Patients	MFTD of the Patients (° C)
26.18	0.48
22.99	0.72
19.92	0.35
23.14	0.74
24.49	1.03
25.34	1.39
21.88	0.52
25.73	1.44
26.68	1.42
26.84	1.44
30.19	1.85
24.44	1.02
26.08	1.43
21.16	0.4
29.25	1.63
36.98	2.04
27.59	1.44
24.8	1.15
25.4	1.4
21.5	0.42
28.69	1.5
22.95	0.64
25.76	1.38
21.78	0.46

We, calculated the correlation coefficient (r) as 0.88231539925868, which shows that both the parameters are closely linked as shown in the scatter plot below,

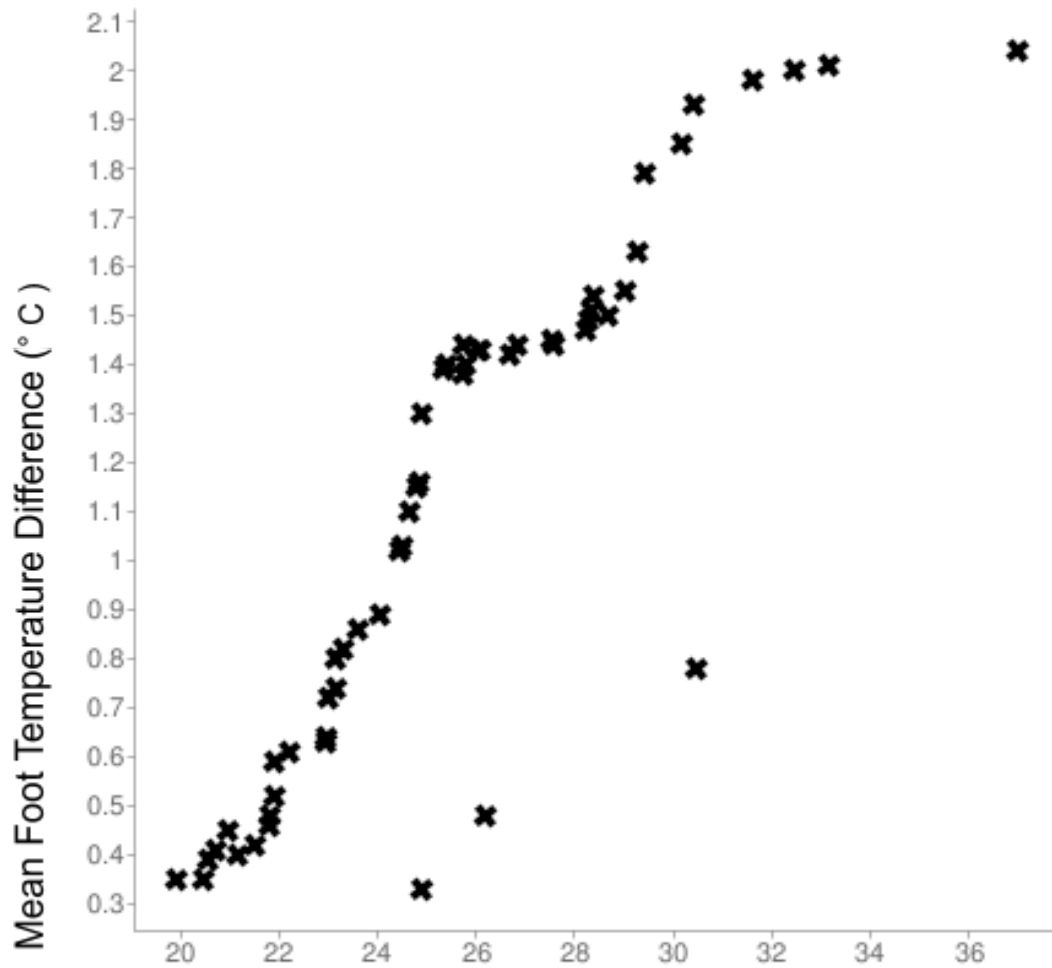


Fig 5.2 - Graph showing MFTD of Male Diabetic Patients VS BMI

5.3 RELATIONSHIP BETWEEN MFTD AND AGE FROM MALE DIABETIC PATIENTS

Next, we tried to find a relationship between age and Temperature difference mean in Male Diabetic Patients,

Table 5.3 - Age and MFTD from Male Diabetic patients:

Age of the Patients (Years)	MFTD of the Patients (° C)
54	1.1
73	1.43
76	0.41
66	0.82
71	0.48
34	0.86
69	0.35
71	2
74	1.45
77	0.89
85	0.8
54	1.93
79	1.54
69	0.61
80	1.51
58	1.4
75	0.63
82	0.59
69	1.79
80	0.39
57	2.01
69	1.3
51	1.98
59	0.45
68	1.49
87	0.78
52	1.55
66	0.33
60	1.16
68	1.47

Age of the Patients (Years)	MFTD of the Patients (° C)
84	0.48
75	0.72
53	0.35
74	0.74
85	1.03
60	1.39
70	0.52
60	1.44
67	1.42
70	1.44
44	1.85
44	1.02
63	1.43
37	0.4
43	1.63
73	2.04
58	1.44
58	1.15
51	1.4
60	0.42
57	1.5
70	0.64
54	1.38
26	0.46

We, calculated the correlation coefficient (r) as -0.14416043695695, which shows that both the parameters are not closely linked as shown in the scatter plot below,

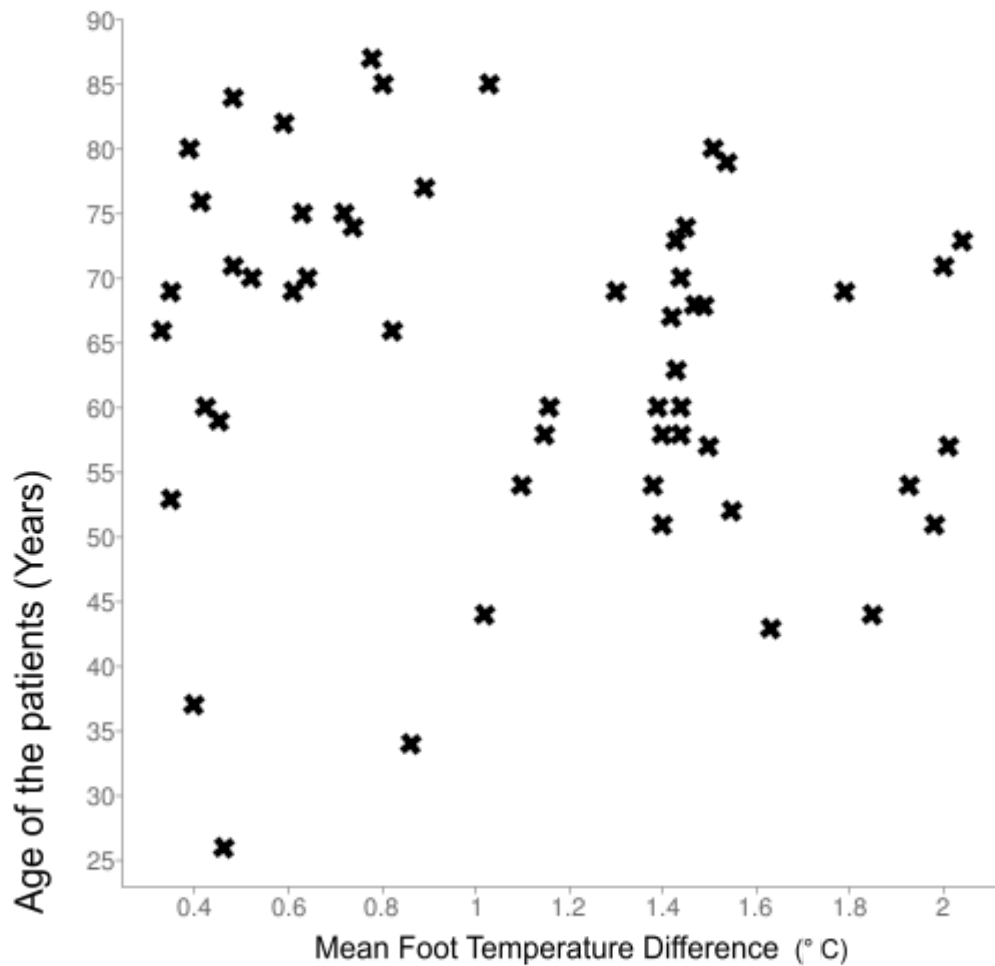


Fig 5.3 - Graph showing MFTD of Male Diabetic Patients VS Age

5.4 RELATIONSHIP BETWEEN MFTD AND AGE OF FEMALE DIABETIC PATIENTS

Next, we tried to find a relationship between age and Foot Temperature Difference mean in Female Diabetic Patients:

Table 5.4- Age and MFTD from Female Diabetic patients:

Age of the Patients (Years)	MFTD of the Patients (° C)
51	1.22
62	0.5
72	0.53
71	1.65
70	1.12
76	1.77
50	1.96
80	1.5
61	0.31
71	0.66
66	0.39
48	1.81
84	0.58
58	0.47
71	1.3
69	0.44
64	0.52
71	0.54
82	0.56
76	0.98
62	0.35
65	0.55
83	1.07
69	1.18
72	0.48
79	0.36
81	0.49
68	1.79
34	0.28
82	0.4

Age of the Patients (Years)	MFTD of the Patients (° C)
80	0.49
74	1.06
70	0.29
87	0.49
70	0.57
68	0.49
63	0.37
62	0.57
38	1.28
77	1.7
69	0.36
50	0.51
46	0.75
35	2
41	0.32
45	0.46
49	0.47
66	0.51
83	2.36
68	0.51

We, calculated the correlation coefficient (r) as 0.0036529781890273, which shows that both the parameters do not have any significant relationship as shown in the scatter plot below,

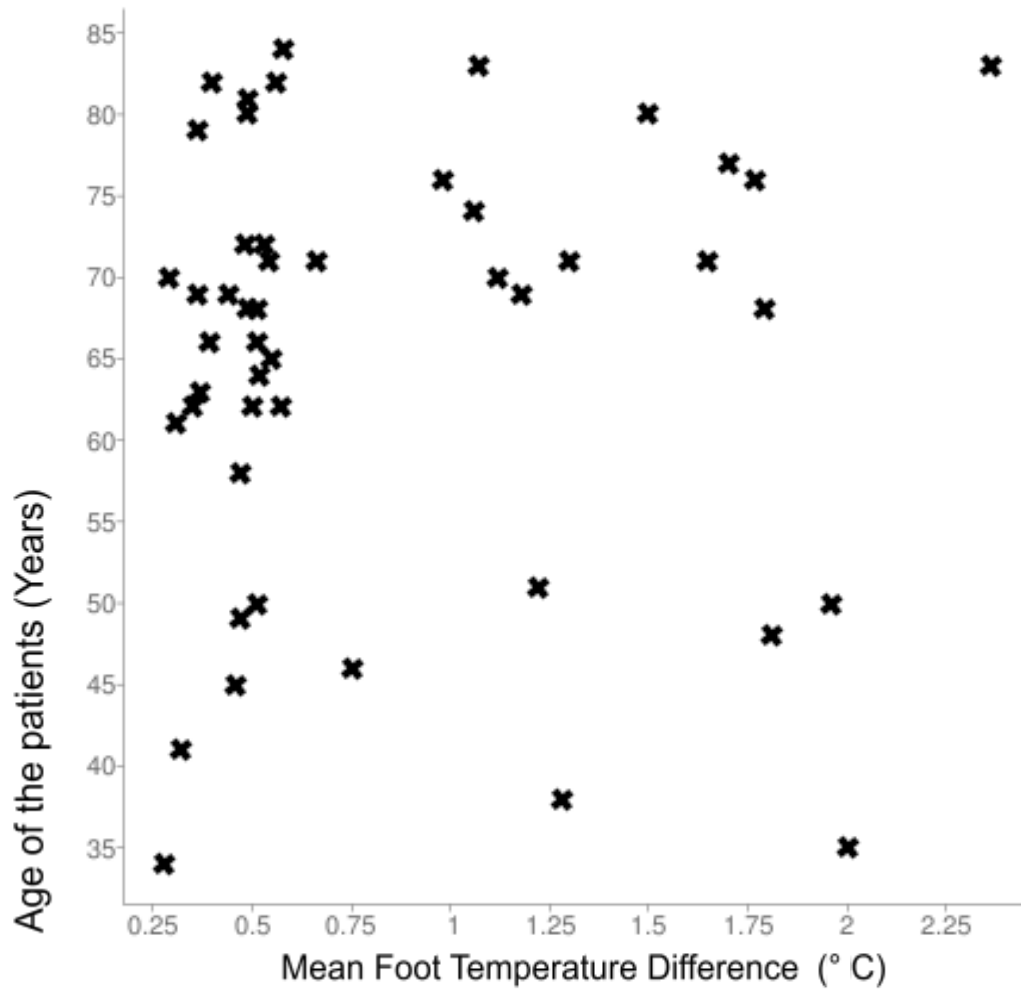


Fig 5.4 - Graph showing MFTD of Female Diabetic Patients VS Age of the Patients

5.5 RELATIONSHIP BETWEEN MFTD AND GLUCOSE LEVELS FROM FEMALE DIABETIC PATIENTS

Here we tried to find the efficiency of the infrared thermometer readings with respect to the diagnostic technique (Glucose level) from Female Diabetic Patients:

Table 5.5- Glucose levels and MFTD from Female diabetic patients

Glucose levels of the Patients (mg/dL)	MFTD of the Patients (° C)
155	1.22
102	0.5
105	0.53
177	1.65
184	1.12
184	1.77
238	1.96
170	1.5
99	0.31
145	0.66
104	0.39
224	1.81
134	0.58
110	0.47
167	1.3
107	0.44
80	0.52
91	0.54
125	0.56
150	0.98
69	0.35
122	0.55
145	1.07
169	1.18
81	0.48
70	0.36
85	0.49
210	1.79
55	0.28
75	0.4

Glucose levels of the Patients (mg/dL)	MFTD of the Patients (° C)
92	0.49
147	1.06
90	0.29
104	0.49
112	0.57
103	0.49
90	0.37
124	0.57
158	1.28
181	1.7
108	0.36
120	0.51
149	0.75
243	2
109	0.32
112	0.46
116	0.47
123	0.51
252	2.36
125	0.51

We, calculated the correlation coefficient (r) as 0.94484746748975 which shows that both the parameters are closely linked as shown in the scatter plot below,

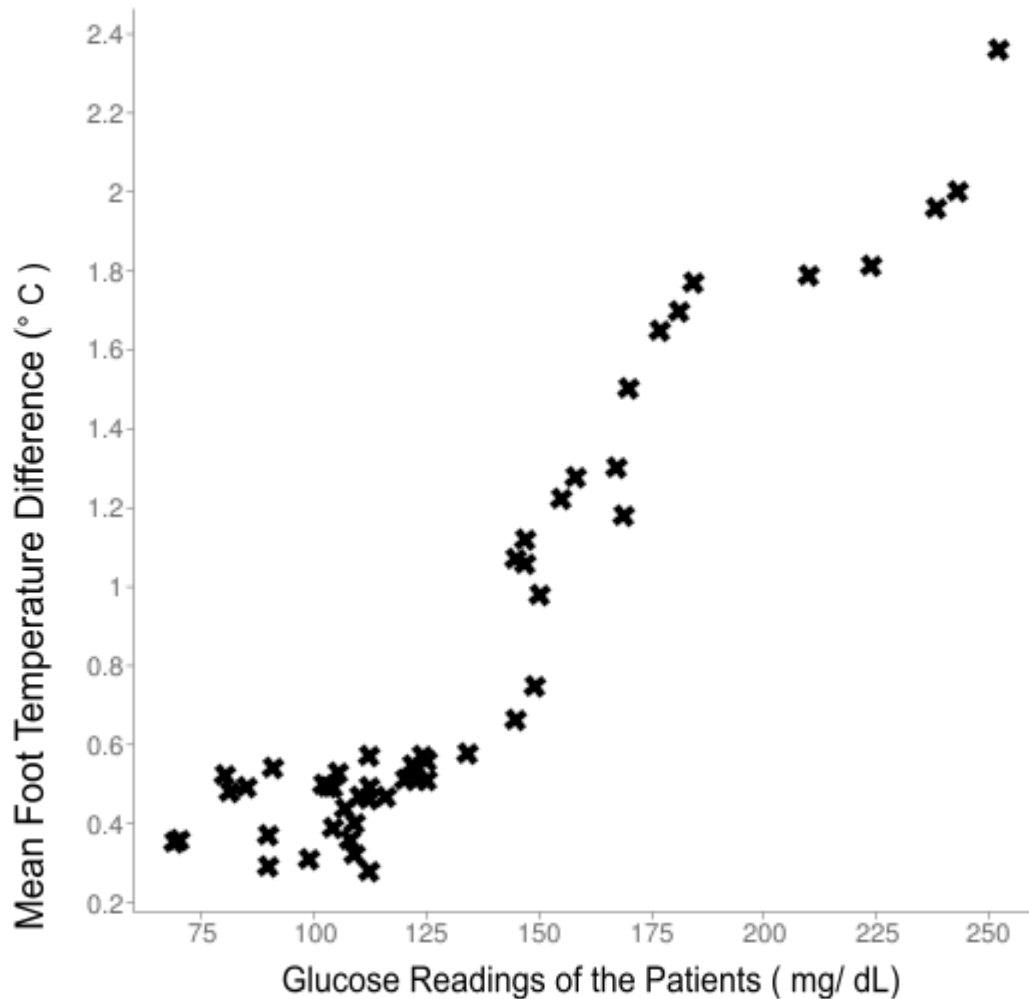


Fig 5.5 - Graph showing MFTD of Female Diabetic Patients VS Glucose Readings of the Patients

5.6 RELATIONSHIP BETWEEN MFTD AND GLUCOSE LEVELS FROM MALE DIABETIC PATIENTS

Here we tried to find the efficiency of the infrared thermometer readings with respect to the diagnostic technique (Glucose level) from Male Diabetic Patients:

Table 5.6 - Glucose levels and MFTD from Male diabetic patients

Glucose levels of the Patients(mg/dL)	MFTD of the Patients (° C)
144	1.1
152	1.43
99	0.41
138	0.82
103	0.48
141	0.86
92	0.35
214	2
155	1.45
142	0.89
130	0.8
207	1.93
182	1.54
113	0.61
170	1.51
150	1.4
118	0.63
108	0.59
198	1.79
98	0.39
216	2.01
146	1.3
212	1.98
101	0.45
165	1.49
122	0.78
185	1.55
251	0.33
146	1.16
161	1.47

Glucose levels of the Patients (mg/dL)	MFTD of the Patients (° C)
100	0.48
294	0.72
103	0.35
121	0.74
140	1.03
146	1.39
104	0.52
151	1.44
151	1.42
156	1.44
203	1.85
141	1.02
150	1.43
98	0.4
188	1.63
250	2.04
153	1.44
144	1.15
149	1.4
168	0.42
166	1.5
119	0.64
148	1.38
102	0.46

We, calculated the correlation coefficient (r) as 0.62762634933851 which shows that both the parameters are closely linked as shown in the scatter plot below,

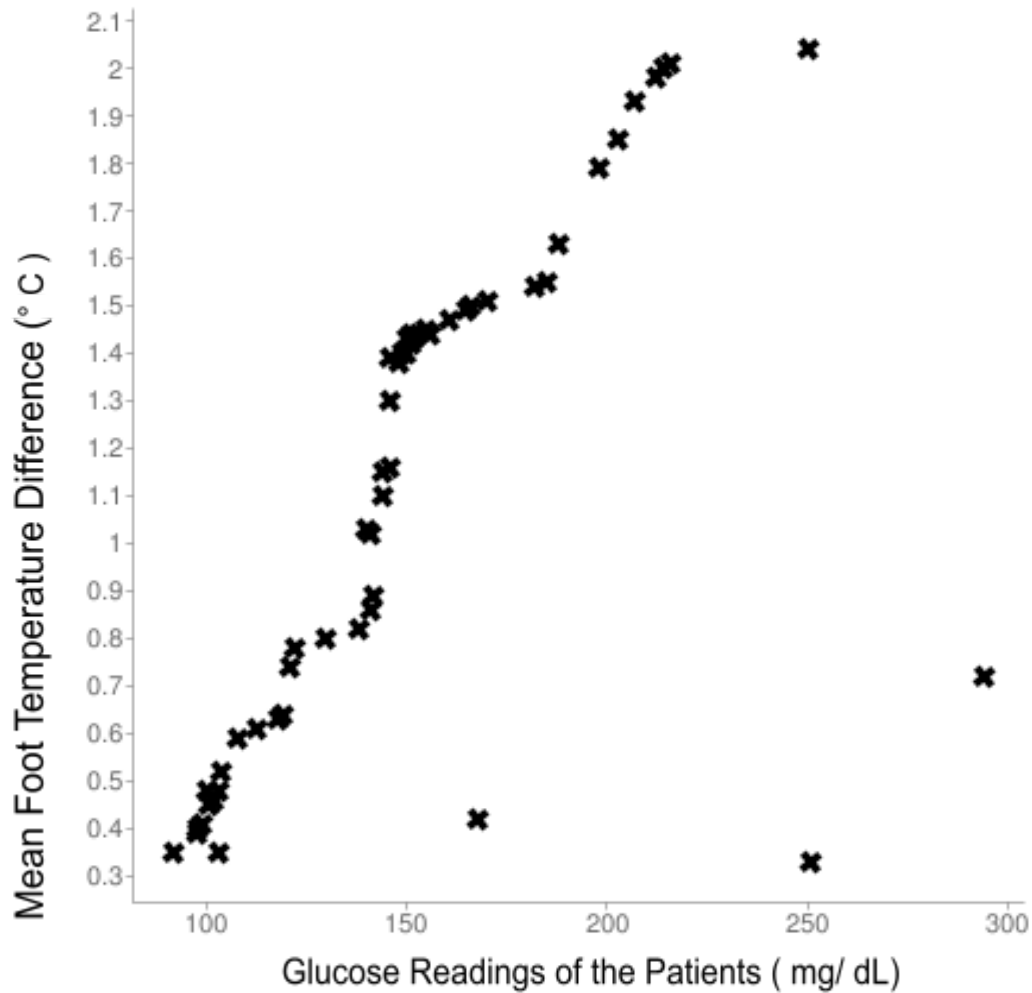


Fig 5.6 - Graph showing MFTD of Male Diabetic Patients VS Glucose Readings of the Patients

5.7 RELATIONSHIP BETWEEN MFTD AND DURATION OF DIABETES OF MALE PATIENTS

Next, we tried to find if the Duration of diabetes has an effect on Mean Foot Temperature Difference in Male Patients.

Table 5.7 - Duration of Diabetes and MFTD from Male diabetic patients

Duration of Diabetes of patients (Years)	MFTD of the Patients (° C)
6	1.1
10	1.43
2.5	0.41
5	0.82
4	0.48
5	0.86
1	0.35
26	2
10	1.45
4	0.89
4.5	0.8
27	1.93
12	1.54
4	0.61
10	1.51
7	1.4
4	0.63
1.22	0.59
14	1.79
2	0.39
30	2.01
5	1.3
28	1.98
4	0.45
11	1.49
5	0.78
11	1.55
1	0.33
6	1.16
10	1.47
5	0.48

Duration of Diabetes of patients (Years)	MFTD of the Patients (° C)
4	0.72
1	0.35
5	0.74
5	1.03
6	1.39
3	0.52
10	1.44
8	1.42
9	1.44
15	1.85
5	1.02
10	1.43
2	0.4
12	1.63
30	2.04
7	1.44
4	1.15
5	1.4
2	0.42
12	1.5
4	0.64
8	1.38
1.5	0.46

We, calculated the correlation coefficient (r) as 0.83944538083312, which shows that both the parameters are closely linked as shown in the scatter plot below,

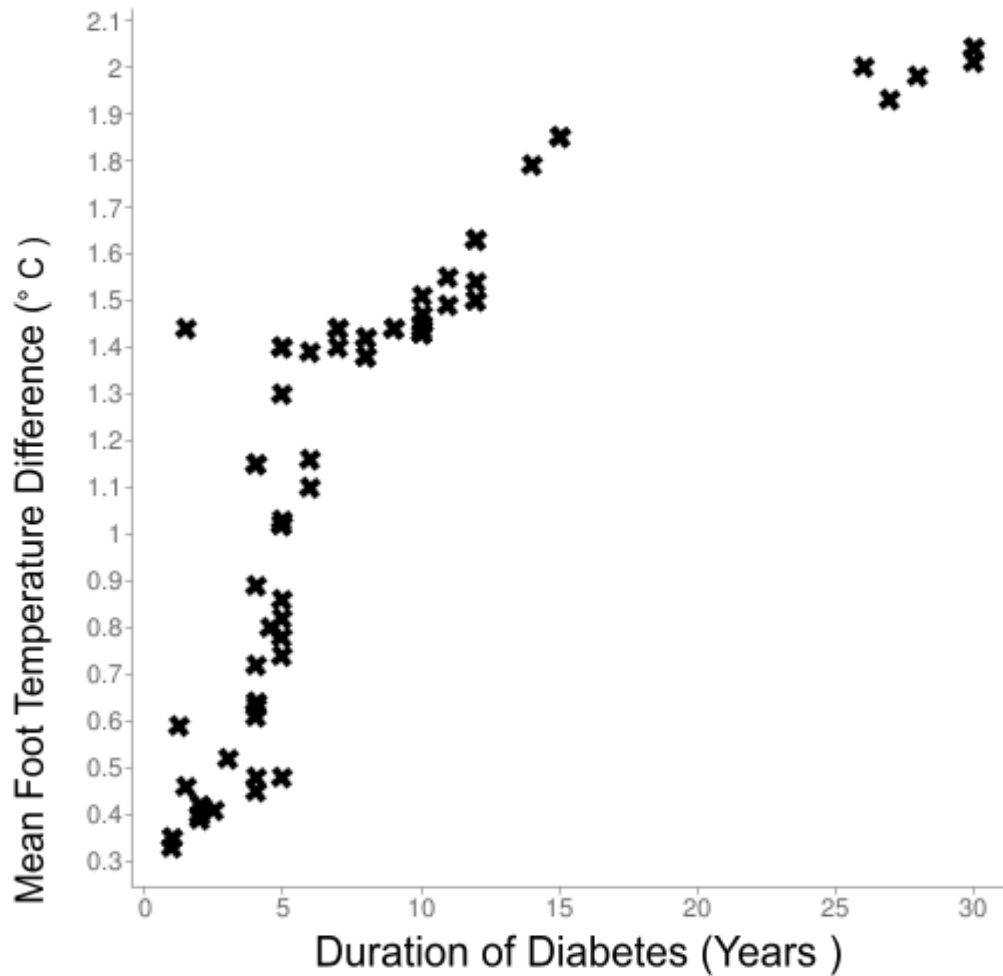


Fig 5.7 - Graph showing MFTD of Male Diabetic Patients VS Duration of Diabetes

5.8 RELATIONSHIP BETWEEN MFTD AND DURATION OF DIABETES OF FEMALE PATIENTS

Next, we tried to find if the Duration of diabetes has an effect on Mean Foot Temperature Difference in Female Patients.

Table 5.8 - Duration of Diabetes and MFTD from Female diabetic patients

Duration of Diabetes of patients (Years)	MFTD of the Patients (° C)
6	1.22
3	0.5
3	0.53
8	1.65
6	1.12
10	1.77
12	1.96
8	1.5
3	0.31
4	0.66
3	0.39
11	1.81
4	0.58
4	0.47
7	1.3
3	0.44
4	0.52
6	0.54
5	0.56
6.5	0.98
1	0.35
5	0.55
6	1.07
6	1.18
3	0.48
3	0.36
3	0.49
9	1.79
0	0.28

Duration of Diabetes of patients (Years)	MFTD of the Patients (° C)
2	0.4
3	0.49
5	1.06
0	0.29
3	0.49
5	0.57
3	0.49
3	0.37
5	0.57
7	1.28
10	1.7
3	0.36
3	0.51
5.5	0.75
15	2
2	0.32
3.5	0.46
4	0.47
4	0.51
18	2.36
3	0.51

We, calculated the correlation coefficient (r) as 0.87092778607049, which shows that both the parameters are closely linked as shown in the scatter plot below,

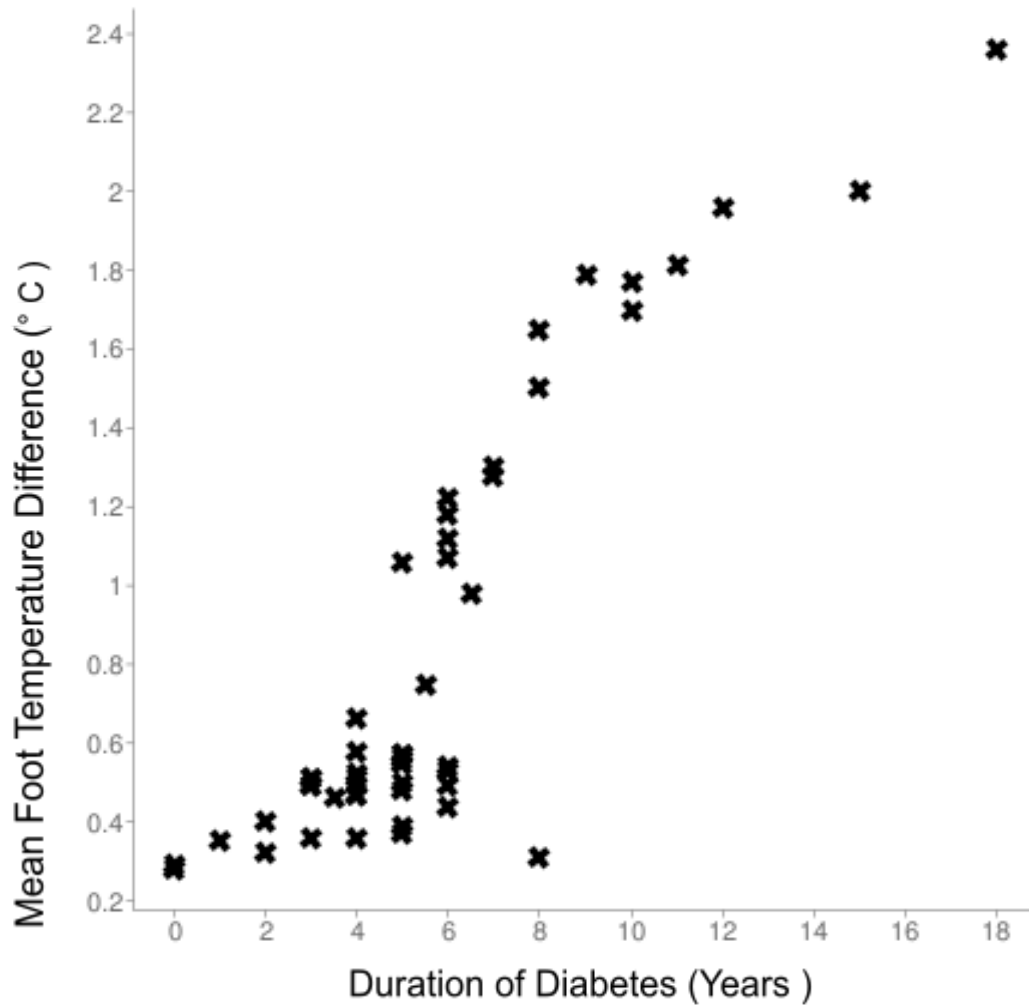


Fig 5.8 - Graph showing MFTD of Female Diabetic Patients VS Duration of Diabetes

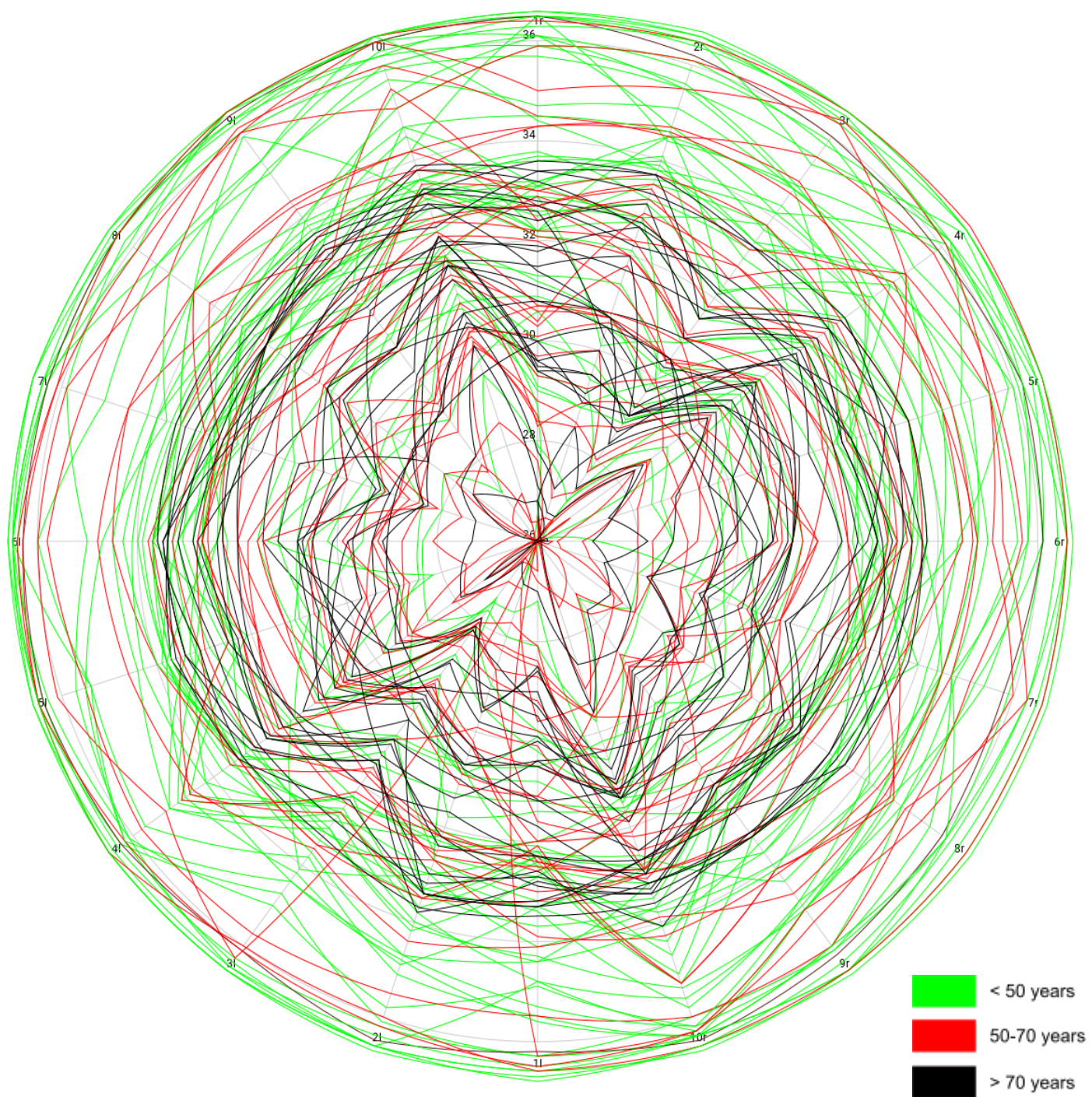


Fig 5.9 - Radar chart showing the foot temperature with respect to age of the diabetic patient

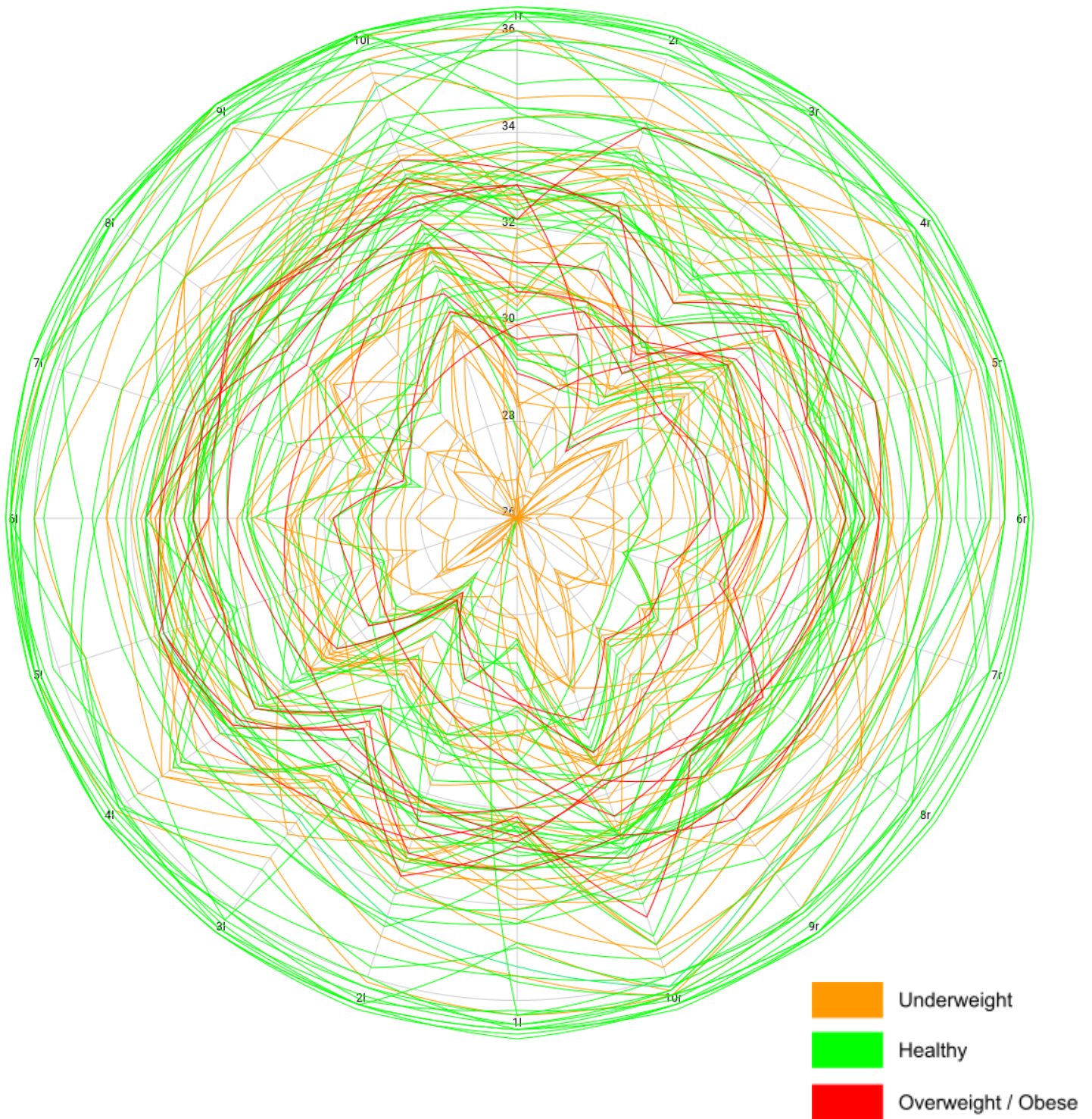


Fig 5.10 - Radar chart showing the foot temperature with respect to the body mass index of the diabetic patients

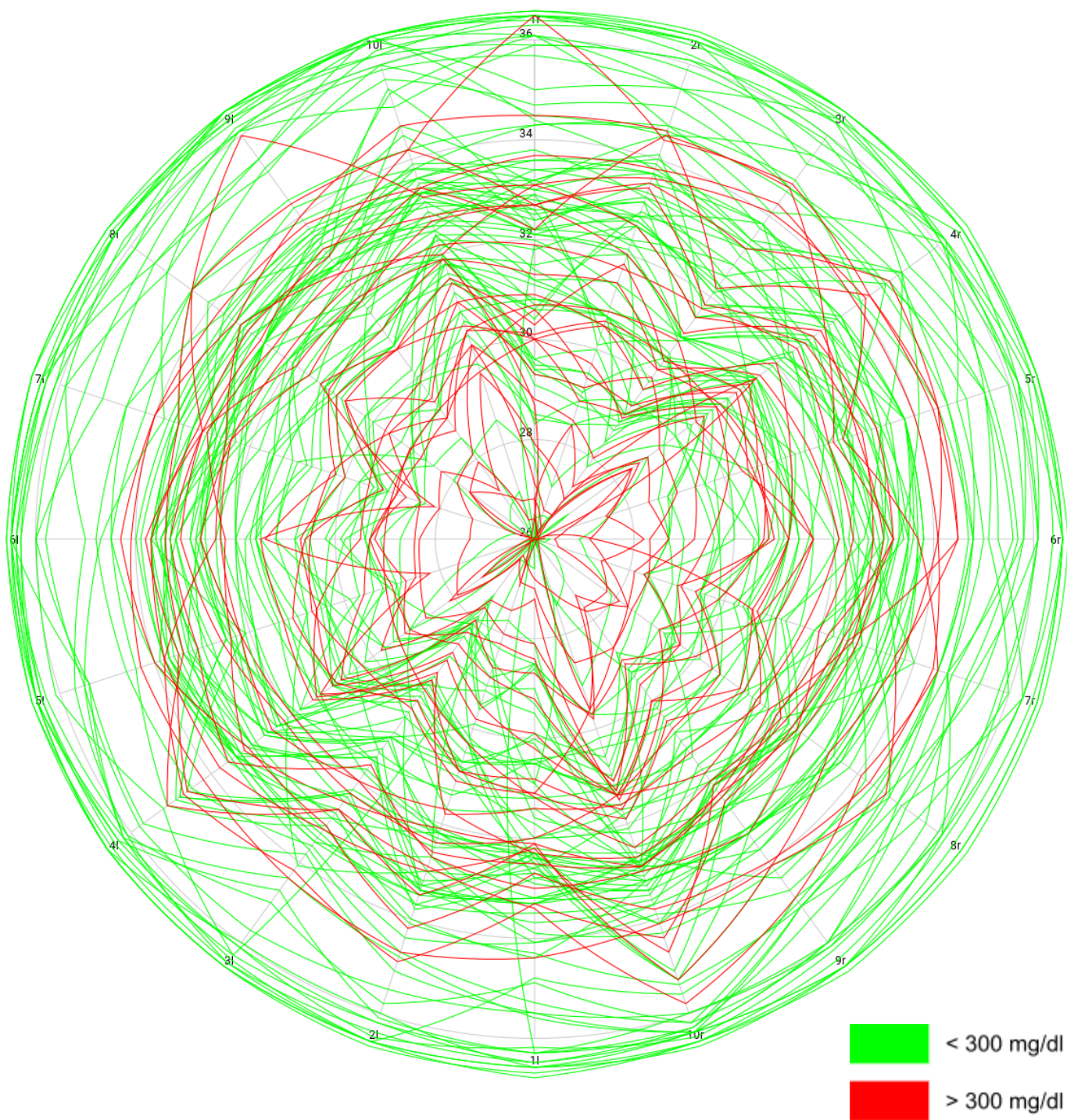


Fig 5.11 - Radar chart showing the foot temperature with respect to the postprandial glucose levels of the diabetic patients

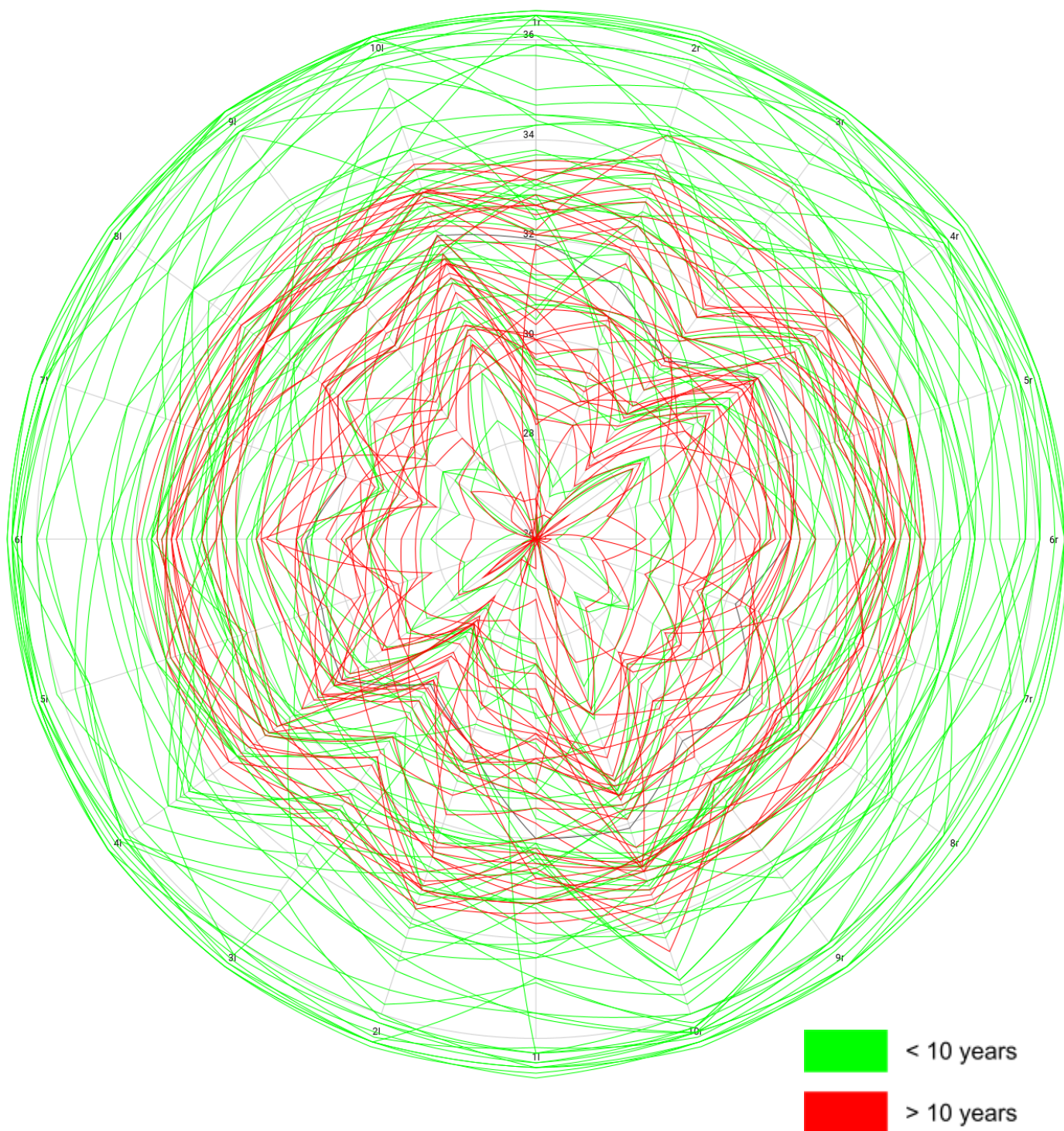


Fig 5.12 - Radar chart showing the foot temperature with respect to the duration for which the patient has diabetes

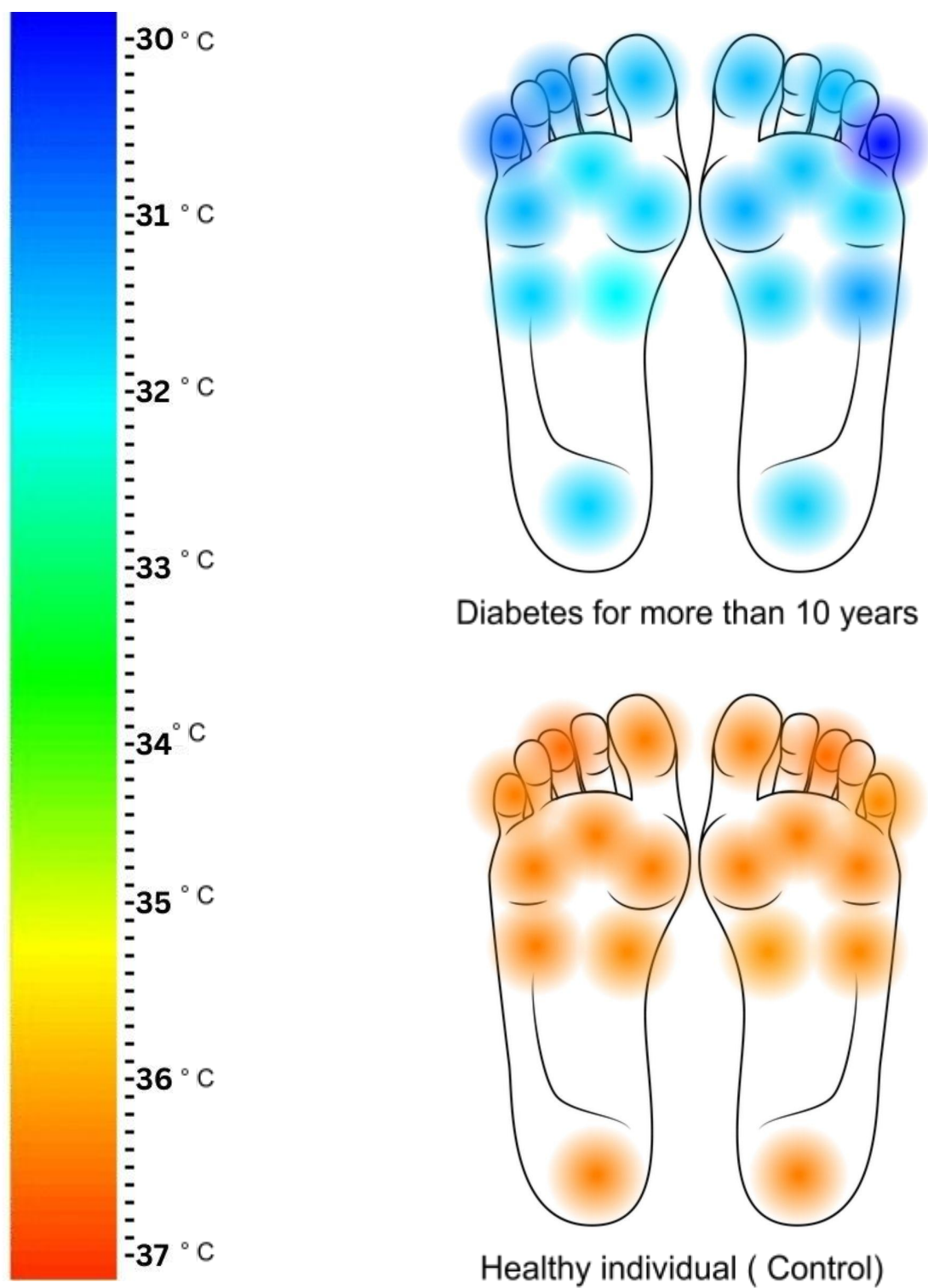


Fig 5.13 - Heat signatures of healthy individual and patients with diabetes for more than 10 years

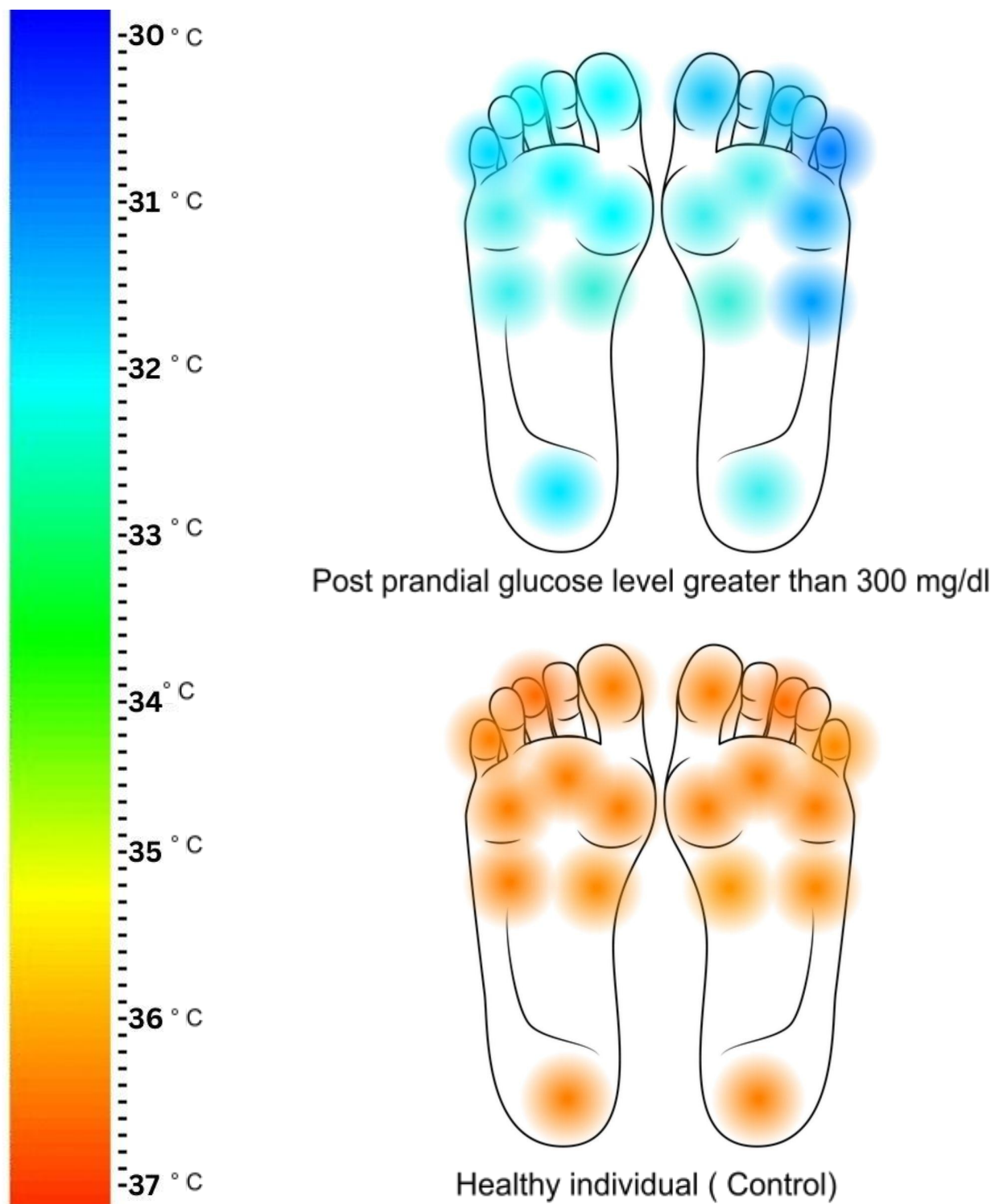


Fig 5.14 - Heat signatures of healthy individual and patients with postprandial glucose level greater than 300 ml/dl

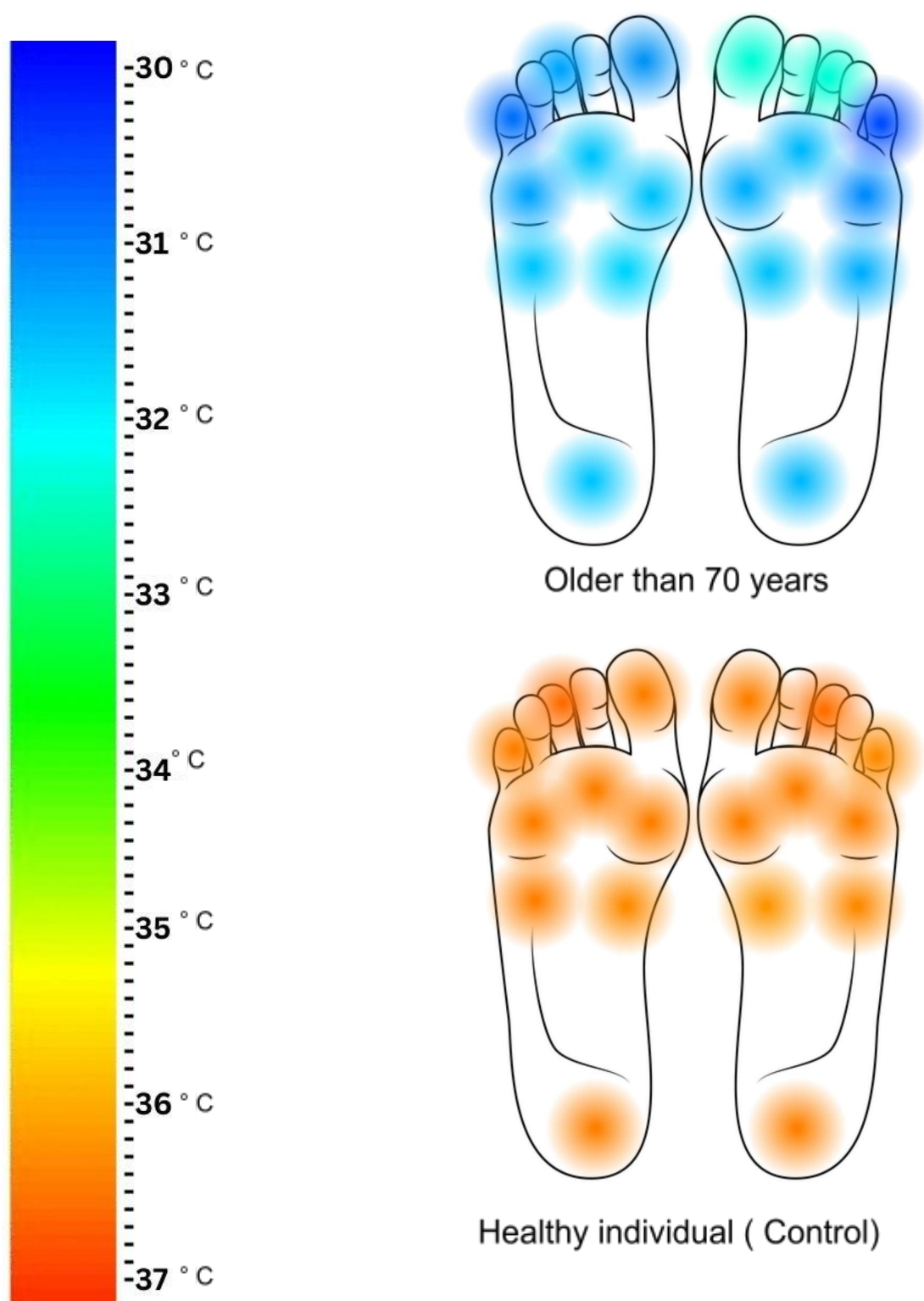


Fig 5.15 - Heat signatures of healthy individual and patients who are older than 70 years

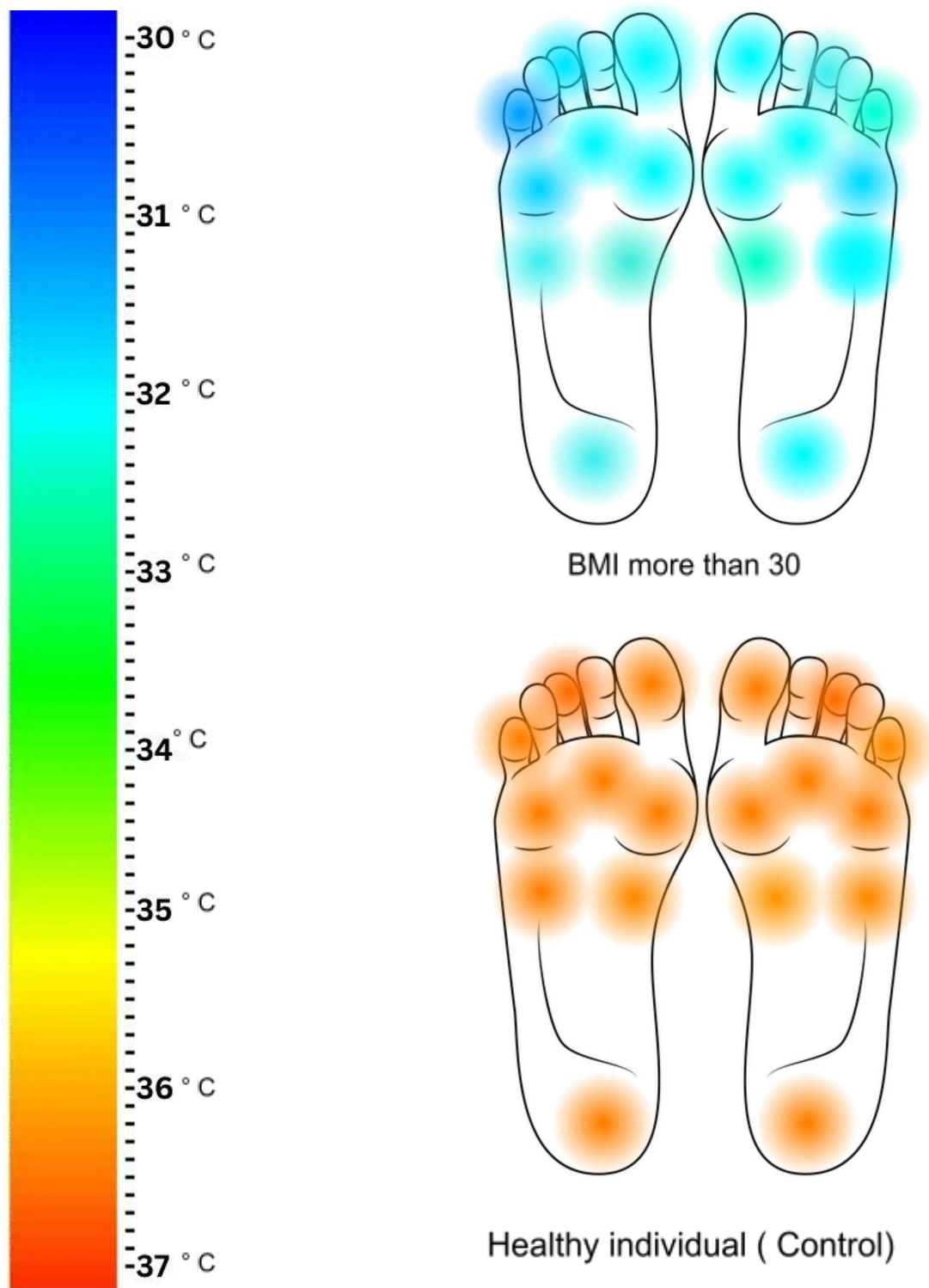


Fig 5.16 - Heat signatures of healthy individual and patients with BMI more than 30

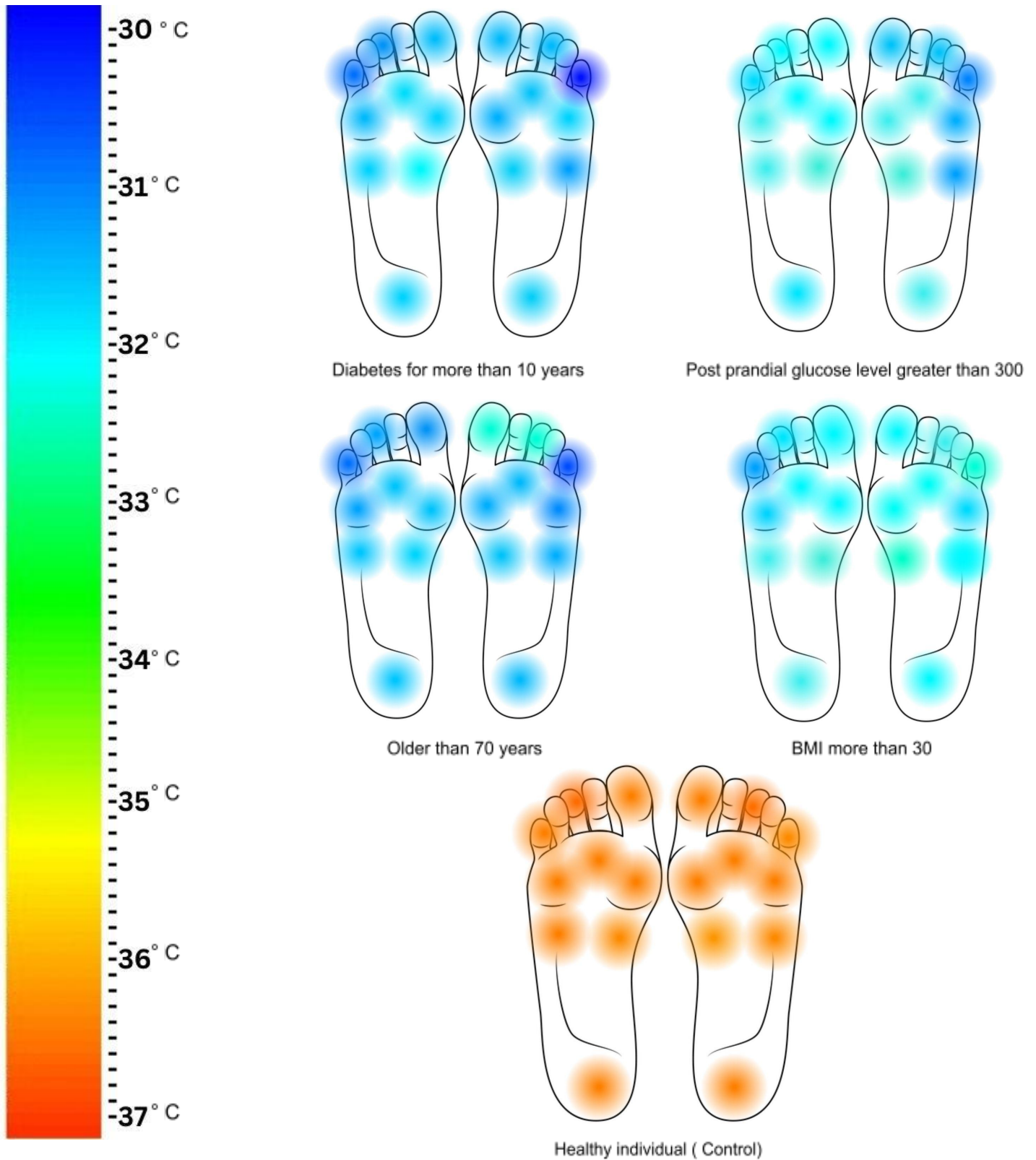


Fig 5.17 - Visual representation of temperature points of specific groups

The study determines the correlation between the foot temperatures of diabetic patients and different parameters such as their BMI, the duration for which they have had diabetes, their postprandial blood glucose level and their age. These parameters were plotted against the mean foot temperature difference. This analysis supported the theory stated by Alfred Gatt *et al.* (2018) in his studies that diabetic complications lead to higher MFTD. The 10 points of each foot which was measured was referred from the work done by Gary Sibbald *et al.* (2015).

The radar graphs were built on the existing evidence established by Armstrong *et al.* (1997), Singh *et al.* (2008) and Paisey *et al.* (2019) where they had highlighted that the foot temperatures were lower for patients who have a higher risk of developing neuropathy. This temperature difference enabled us to plot the radar graph that can help us group the data.. Diabetic patients who suffer from neuropathy have lesser foot temperature than those who do not. This is due to the fact that damaged blood vessels decrease blood flow to the foot therefore decreasing the temperature. Neuropathy is caused due to damaged blood vessels that drastically reduce the blood flow to the extremities of the body (eg. feet)

Fig.5.9 puts forward a visual representation of the temperature data points of all the tested patients. From the radar graph, we can conclude that up to the age of 70, the temperature signatures are random and have yielded inconclusive. But, when observed deeply, the radar graph brings to our attention that all the temperature points of patients who are older than 70 years of age (labeled with black) lie closer to the center or the origin of the radar graph. This helps us to infer that the temperature gradient of patients older than 70 years is lower than of any other age group.

Fig 5.10 is a representation of three BMI levels, namely the underweight, healthy and obese/ overweight categories. In this illustration of the temperature data, we can observe that the majority of the underweight and overweight diabetic patients have their temperature graphs concentrated towards the origin of the graph. The overweight category strictly lies closest to the origin when compared to the underweight and

healthy category. The healthy category has data points that are pretty random and range from near the origin towards the circumference of the radar graph, therefore cannot be drawn conclusions from. This puts into perspective how the body mass index of an individual plays a vital role in the blood flow of that individual therefore being a leading cause of diabetes and neuropathy.

Fig 5.11 is a radar graph that depicts the temperature points of diabetic patients who have the post prandial level of less than 300 and more than 300. Postprandial glucose levels of an individual are the glucose level of an individual after they have had a meal. When postprandial glucose of an individual are high, it can lead to nerve damage. nerve damage is one of the leading factors that proceeds to the reduction of blood which further leads to neuropathy. When the graph is studied, we can clearly conclude that the patients who have postprandial glucose levels that are higher than 300mg/dl, they have low foot temperatures which is a sign of neuropathy. Therefore, when a patients postprandial levels are higher than 300mg/dl, it is important that they frequently get checked for neuropathy and get it diagnosed as early as possible.

Fig 5.12 brings into picture the temperature gradient of diabetic patients who have had diabetes for less than 10 years and more than 10 years. When inferring from the graph we can understand that the duration for which a person has suffered from diabetes in fact does play a role in the temperature of their foot and therefore neuropathy. Patients who have had diabetes for 10 or more years have a temperature gradient that does not surpass 34.4° C. The longer an individual suffers from diabetes, their abnormal blood glucose levels damage the small blood vessels and nerves for a longer time. this leads to severe blood flow reduction to the extremities of the body.

The radar graph data has suggested that there are high risk groups that consist of:

1. Individuals who have unhealthy body mass index (under or overweight).
2. Patients who have suffered from diabetes for more than 10 years.
3. Individuals who have had high postprandial blood glucose level (>300 mg/dl) over a period of time.