Infrared Physics & Technology 78 (2016) 105–117

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Review

# Narrative review: Diabetic foot and infrared thermography

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## HIGHLIGHTS

- Advances in diabetic foot care using infrared thermography.
- Revision of different methods for thermogram analysis.
- Temperature variations related to diabetic foot complications.

## ARTICLE INFO

*Article history:*
Received 19 May 2016
Revised 13 July 2016
Accepted 19 July 2016
Available online 19 July 2016

*Keywords:*
Infrared thermography
Diabetes mellitus
Diabetic foot

## ABSTRACT

Diabetic foot is one of the major complications experienced by diabetic patients. An early identification and appropriate treatment of diabetic foot problems can prevent devastating consequences such as limb amputation. Several studies have demonstrated that temperature variations in the plantar region can be related to diabetic foot problems. Infrared thermography has been successfully used to detect complication related to diabetic foot, mainly because it is presented as a rapid, non-contact and non-invasive technique to visualize the temperature distribution of the feet. In this review, an overview of studies that relate foot temperature with diabetic foot problems through infrared thermography is presented. Through this research, it can be appreciated the potential of infrared thermography and the benefits that this technique present in this application. This paper also presents the different methods for thermogram analysis and the advantages and disadvantages of each one, being the asymmetric analysis the method most used so far.



**Contents**



## 1. Introduction

Diabetes mellitus is a chronic and complex disease that requires early and continuous medical care to prevent further complications [1]. The International Diabetes Federation (IDF) estimated

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http://dx.doi.org/10.1016/j.infrared.2016.07.013
1350-4495/

that, in 2015, there were about 415 million people with diabetes, and by 2040 the number increase to 642 million, representing 1 in 10 adults in the world [2]. The complications of diabetes are a major cause of disability, reduced quality of life and premature death caused by problems associated with heart and blood vessels, eyes, kidneys and nerves [2].

Diabetic foot is one of the major complications experienced by diabetic patients and it can be defined as infection, ulceration and/or destruction of deep tissues associated with neurological abnormalities and various degree of peripheral vascular disease in the lower limb [3]. Early identification and appropriate treatment of diabetic foot problems can prevent devastating consequences such as limb amputation. Diabetic foot ulcer is the most common presign of the lower limb amputation, and combined with other foot problems represents the highest number of hospital admissions than any other long-term complication becoming a serious economic issue around the world [4]. For example, in 2007, it was estimated that the cost of the treatment of diabetes and its complications in the United States was around 116 billion in direct costs, and that at least 33% of these costs were for the treatment of diabetic foot ulcers [5].

Patients with diabetes have around 12–25% lifetime risk of developing a foot ulcer [6] which is mainly related to peripheral neuropathy, and often with peripheral arterial disease [7]. This complications can act alone or together with other factors such as microvascular disease, biomechanical abnormalities, limited joint mobility, increased susceptibility to infection, among others [8].

Peripheral neuropathy is a common complication of diabetes that affects the nerves in the extremities especially the feet. It is estimated that about 66% of the diabetic patients have peripheral neuropathy of the lower extremity [4]. The nerve damage can be manifested in different divisions of the nervous system such as motor, sensory and autonomic [4].

Peripheral sensory neuropathy is the main factor in the development of an ulcer [9]. The damage in the sensory nerves involves a loss of feeling in the limb, leading the formation of neuropathic ulcers due to different external factors such as inappropriate footwear or excessive pressure [4]. It is estimated that 45–60% of all diabetic ulcers are purely neuropathic [9]. Motor neuropathy is another form of neuropathy that alters the ability of the body to coordinate movement. Also causes muscle atrophy that can result in foot deformities such as foot drop, equinus, hammertoe, prominent plantar metatarsal heads, and charcot foot [4,9]. Moreover, the atrophy in the foot muscles adds alteration in the foot anatomy causing osteomyelitis [4]. Finally, autonomic neuropathy causes impairment in the functions of the sweat and sebaceous glands making the foot more vulnerable to fissures and development of infections [4].

Peripheral vascular disease (PVD), in conjunction with a minor trauma, may result in a painful and purely ischaemic foot ulcer [10]; however, leads rarely to foot ulceration [9]. The main problem with arterial disorders is that, once ulceration develops, it can prolong the healing time and increase the risk of amputation [9].

Several studies have demonstrated that temperature variations in the plantar region can be related to diabetic foot problems [11–17]. Among the techniques currently available for temperature measurement, one can find the infrared thermometry [11–14], liquid crystal thermography (LCT) [15–18], and more recently, infrared thermography (IRT) [19–23]. Infrared thermometry is presented as a cheap and easily accessible technique for home temperature monitoring used to obtain the temperature of different points in the feet of the patients [13]. However, if one needs to know the temperature of several points on the foot, this method can be complicated and insufficient. LCT is a technique that provides a color response proportional to the temperature of the surface that is in contact with the thermochromic liquid crystals [24]. Although this technique is cheap and allows to obtain a visual representation of the entire plantar temperature distribution, it is a contact and slow response technique which may limit its use in some applications [25]. IRT also provides a visual representation of the plantar temperature distribution with the advantage that is a rapid, non-contact and non-invasive technique. For this reason, the use of IRT to analyze complications related to diabetic foot has increased significantly in recent years [26].

The aim of this review is to summarize the different proposed studies for the evaluation of complications related to diabetic foot focusing on those using IRT. These studies present different types of techniques for thermogram analysis such as independent limb temperature analysis, asymmetric analysis, temperature distribution analysis and external stress analysis, and each of these techniques are described.

## 2. Methodology

Previous reviews on this subjects [24,26–30] has described the use of different thermal techniques for the evaluation of complications related to diabetic foot, but because of the advantages that IRT can present in this applications, this review only focuses on those that use this technology. The studies presented in this review included only published works of any year with a contribution to determine the relationship between plantar temperature and complications related to diabetic foot. The search for articles was conducted in different databases using the keywords of diabetes, diabetic foot and infrared thermography.

The following part of this paper is organized in 4 main sections. In Section 3, the basic concepts of IRT are described as well as the relation of IRT and diabetic foot complications. In Section 4 different techniques used for thermogram analysis are described. The techniques used in these studies were classified in 4 categories: independent limb temperature analysis, asymmetric analysis, temperature distribution analysis and external stress analysis. Each of these techniques are described in a sub-section where studies using this technique are also presented. The fifth sub-section present several studies using IRT to solve problems that may be related to diabetic foot. In Section 5, it is presented a discussion of the review and, finally, in Section 6 the conclusions of this review are presented.

## 3. Infrared thermography and diabetic foot

Humans are considered homeotherms because they have the ability to maintain their internal temperature despite temperature changes in the surrounding by adjusting the rates of heat production and heat loss [31–33]. This is attained by the human thermoregulatory mechanism, which includes behavioral adjustments to environmental temperature and autonomic nervous responses such as: sweating and cutaneous vasomotor responses for heat dissipation [33]. For this reason, it is that an abnormal variation in the human body temperature can be a sign of a disease.

The origin of IRT dates back to the early 1800s when William Herschel discovered thermal radiation, thanks to the contribution of other scientists, IRT was becoming a very useful technique for temperature measurement [34]. IRT is a rapid, non-contact and non-invasive technique that allows visualize the temperature distribution of the object. Any object with a temperature greater than absolute zero (−273 °C) emits electromagnetic radiation also called infrared or thermal radiation [25]. By definition, a blackbody is one which absorbs all energy that reaches it and reflects nothing [35]. The blackbody spectral intensity was determined by Plank and was defined as:

$$I_{\lambda,b}(\lambda,T)=\frac{2hc_o^2}{\lambda^5\left(\exp\left(\frac{hc_o}{\lambda kT}\right)-1\right)} \quad (1)$$