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The identification of higher forefoot temperatures associated with peripheral arterial disease in type 2 diabetes mellitus as detected by thermography

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ABSTRACT

Aims: The purpose of this study was to investigate whether heat emitted from the feet of patients with type 2 diabetes (DM) and peripheral arterial disease (PAD) differed from those with type 2 diabetes without complications (DM).

Methods: A non-experimental, comparative prospective study design was employed in a tertiary referral hospital. Out of 223 randomly selected participants (430 limbs) who were initially tested, 62 limbs were categorized as DM + PAD and 22 limbs as DM without PAD. Subjects with evidence of peripheral neuropathy were excluded. Participants underwent thermographic imaging. Automatic segmentation of regions of interest extracted the temperature data.

Results: A significant difference in temperature in all the toes between the two groups was found ($p = 0.005$, $p = 0.033$, $p = 0.015$, $p = 0.038$ and $p = 0.02$ for toes 1–5 respectively). The mean forefoot temperature in DM + PAD was significantly higher than that in DM ($p = .019$), with DM + PAD having a higher mean temperature (28.3 °C) compared to DM (26.2 °C). Similarly, the toes of subjects with DM + PAD were significantly warmer than those of subjects with DM only.

Conclusions: Contrary to expectations the mean toe and forefoot temperatures in DM patients with PAD is higher than in those with DM only. This unexpected result could be attributed to disruption of noradrenergic vasoconstrictor thermoregulatory mechanisms with resulting

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increased flow through cutaneous vessels and subsequent increased heat emissivity. These results demonstrate that thermography may have potential in detecting PAD and associated temperature differences.

1. Introduction

Diabetes is a worldwide health burden which brings about many complications, amongst the most significant being those associated with diabetic foot disease [1]. One of the commonest complications is Peripheral Arterial Disease (PAD) with a prevalence of 3–10% in the general population increasing to 15–20% in individuals over 70 years of age [2]; PAD prevalence in diabetes is estimated at being 29% in people over 50years of age [3]. One method for diagnosing PAD in a clinical setting is the Ankle Brachial Pressure Index (ABPI), however it should be noted that the reliability of this technique has been questioned in literature, especially in the diabetic population presenting with arterial calcification [2]. This raises the need for investigating alternative methods that could possibly detect the presence of PAD, such as thermography, which is the infrared imaging of the human body.

Thermography has been employed in a number of medical applications, including vascular disease, breast disease [4], skin disease [5] and Raynaud Phenomenon [6], amongst others. This technology, which is noninvasive and non-contact, has the potential to measure physiological changes resulting in alteration of emitted skin temperature [7] and skin temperature distribution [8,9]. Medical infrared imaging is a real-time temperature measurement technique used to produce visualization of thermal energy emitted by the measured site at a temperature above absolute zero [10].

Thermography and thermometry have been employed in the study of foot vascular complications and ulceration in diabetes [8,9,11–13]. Thermal changes in the plantar aspect of the diabetic foot may be the result of ischaemia, diabetic neuropathy, infection, or a combination of these factors (22). The neuropathic foot exhibits increased skin temperature indicating increased cutaneous blood flow [14].

Temperature differences between corresponding areas on contralateral feet are clinically significant parameters [15]. It has been suggested that if one foot has a significantly higher temperature than the other, an inflammatory disease process may be suspected. Indeed, a temperature change >2.2 °C in one foot is an indicator of a suspected disease process [16–18].

Van Netten et al. report that whilst no difference >1.5 °C was found between the ipsilateral and contralateral foot of participants without complications, in the affected Region of Interest (ROI) of patients with local complications a temperature of >2 °C was found when compared to the similar ROI of the unaffected foot. Their study, however, was characterized by very small sample sizes of 5 participants per group [19].

In normal healthy feet, temperature patterns are symmetrical in both feet. This has recently been confirmed by Gatt et al. who reported the thermographic patterns of hands and feet of healthy adults [20]. The implication is that asymmetry of temperature patterns between the feet may indicate the presence of pathology [16], which is also a logical conclusion from the findings of Gatt et al., who have demonstrated symmetry in the healthy adult. While this has been shown to be the case in the presence of peripheral neuropathy, there is a lack of studies reporting use of thermography to detect differences between healthy and ischaemic feet in diabetes. When both feet are ischaemic, the temperature difference between the two limbs may not be present, thus making detection utilizing this 'asymmetry' theory difficult.

The aim of this study was to determine whether infrared thermal imaging can detect significant differences in the thermographic images of type 2 diabetes patients with PAD (DM + PAD), compared to those diabetes patients without PAD (DM).

2. Methods

Ethical approval was sought and obtained from the University Research Ethics Committee. All investigations were carried out in accordance with the principles of the Declaration of Helsinki as revised in 2013 and all participants signed informed consent prior to inclusion in the study [21].

Participants with type 2 diabetes were recruited from the patient list of a vascular surgeon at a Tertiary Referral Hospital over a 3 month period. Participants underwent a thorough clinical examination that included validated tests for neuropathy and peripheral arterial disease. Participants with evidence of peripheral neuropathy were excluded for this part of the study. Subjects with active ulceration or other significant co-morbidities that could affect thermographic patterns, such as rheumatoid arthritis and other autoimmune diseases, Raynaud's Phenomenon, Charcot neuroarthropathy, venous disorders including varicose veins and deep vein thrombosis, oedema, dermatological and neurological disorders were also excluded.

Prior to data collection, all participants were rested in a supine position in a room with temperature controlled at 23 °C since ambient temperature is known to affect thermal emissivity of the body. During this period, a detailed medical history was obtained. Following the 15-minute acclimatization period, investigations were carried out to detect or exclude the presence of PAD and neuropathy. The presence of PAD was investigated utilizing two methods: the Ankle Brachial Pressure Index (ABPI) and Spectral Doppler Waveform Analysis [2].

An ABPI was derived as described in literature [2,22,23], according to standard clinical practice. A Huntleigh (Cardiff, Wales) Dopplex Assist was utilized for this purpose. PAD was diagnosed from the ABPI results, with normal values being 0.9–1.3. In order to include only those participants with a defi-

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