

**5th Academic Biomedical Engineering  
Research Group  
(ABERG)  
Workshop**



**10 February 2005**

**Bournemouth University**

## Liquid crystal thermography (LCT) in biomechanical assessment of diabetic foot

M. Bharara and J.E. Cobb

Academic Biomedical Engineering Research Group,  
School of Design, Engineering & Computing, Bournemouth University  
mbharara@bournemouth.ac.uk, jcobb@bournemouth.ac.uk

### Abstract

*The study of thermal patterns under the foot can be useful in clinical management of the diabetic foot. Progressive degeneration of sensory nerve pathways is thought to affect both thermoreceptors and mechanoreceptors. Recent improvements in the technology combined with low cost, fast video acquisition and reduced pressure insensitivity now offer potential for routine thermographic assessment of the diabetic foot. An important advance offered by the proposed system is feature extraction and temporal measurements from full field plantar images using novel image processing algorithms. This paper describes development of the LCT system, in vitro calibration and initial in vivo results from healthy subjects.*

### 1. Introduction

Diabetes is a metabolic disorder leading to retinopathy, nephropathy, cardiac problems, neuropathy and diabetic foot. Table 1, provides information about types of diabetes mellitus. 2-3% of the UK population (1.8m approximately) is affected by diabetes and uses 5% of the NHS resources. 5% of the diabetic patients in UK are affected by diabetic foot complications. 50% of the diabetics have some degree of neuropathy resulting in at least one foot ulcer during lifetime in 15% of the cases. Foot complications alone cost £252m annually to the NHS.

#### 1.1 Diabetic Foot: Complications and risk factors

Primary etiologic factors of diabetic foot disease include diabetic peripheral neuropathy (Section 1.2) and peripheral vascular disease. These may act alone, together or in combination with other

contributory factors such as microvascular disease, biomechanical abnormalities, previous history of ulceration/amputation, low educational status, impaired vision, limited joint mobility, glycaemic control, ethnic background, cardiovascular complications, genetic factors and environmental factors. Foot ulcers can be classified as neuropathic, neuroischaemic and ischaemic. Figure 1 and 2, show neuropathic ulcer of the great toe and neuroischaemic ulcer of the little toe respectively [4]. Rate of occurrence for neuropathic ulcers is the highest and rate of occurrence for ischaemic ulcers is the lowest [2]. It is important to distinguish between the neuropathic and neuroischaemic foot as their complications are entirely different and so are the respective therapeutic strategies. Three important parameters used to distinguish neuropathic or neuroischaemic foot are skin temperature, pain and Ankle Brachial Index (ABI)<sup>2</sup>. Neuropathic foot ulcers are a major complication of type 2 diabetes mellitus. Classic neuropathic ulcers occur frequently on the plantar surface, but may occur on medial and lateral surfaces. Intrinsic or extrinsic trauma triggers foot ulceration. Consequently, the foot becomes prone to ulceration especially at sites of abnormal pressure such as the prominent metatarsal heads.

#### 1.2 Diabetic Neuropathy

Neuropathy<sup>3</sup> is divided into sensory neuropathy, motor neuropathy and autonomic neuropathy. Sensory neuropathy affects one's ability to sense pain, thermal or vibratory stimuli [5]. Motor neuropathy affects muscle control (imbalance of

<sup>2</sup> This test is done by measuring blood pressure at the ankle and in the arm while a person is at rest.

<sup>3</sup> Neuropathy refers to metabolic changes and poor blood supply in nerve cells as a result of altered blood glucose in diabetes.

flexor and extensor muscles) and involuntary bodily functions. Autonomic neuropathy is characterized by sympathetic dysfunction in which blood flow in most of the microcirculation increases.

Progressive degeneration of sensory nerve pathways is thought to affect both thermoreceptors and mechanoreceptors. Important consequences due to diabetic neuropathy are thermal trauma, bony deformities, great toe lesions, plantar ulcers and heel ulcers. Diffuse polyneuropathy leads to loss of protective sensations of the feet; both small and large nerve fibres are affected. Bone deformities result as a consequence of sensory and motor neuropathy and significantly reduce the total weight bearing area of the foot, increasing plantar pressure [4]. For a neuropathic foot, it leads to hyperkeratosis and callus formation with eventual ulceration. The elevated blood supply due to autonomic neuropathy supports callus formation. In the neuroischaemic foot increased pressure leads to direct tissue damage and ulceration.

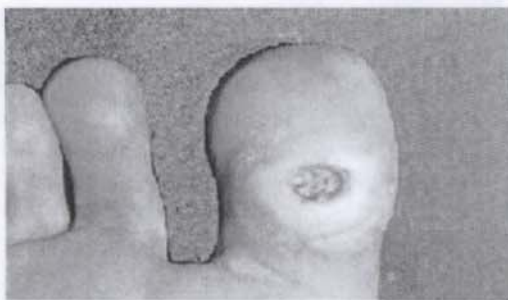


Figure 1: Neuropathic foot ulcer on the great toe

Parameters	Type 1	Type 2
<b>Aetiology</b>	Genetically inherited; infections	Multifactorial; Obesity, genetically inherited
<b>Description</b>	Beta cell destruction; Absolute insulin deficiency	Insulin resistance in peripheral tissue; Reduced beta cell function.
<b>Rate of occurrence</b>	10%	90%
<b>Age groups</b>	Before 25 years of age	Middle to old age
<b>Treatment</b>	Regular insulin injections	Diet; anti-hyperglycaemic drugs and physical exercise.

Table 1: Types of diabetes mellitus

### 1.3 Liquid crystal thermography

LCT is a non invasive, high resolution technique and shows anatomical temperature distribution as determined by blood flow in superficial tissues. Cholesteric liquid crystals are clinically most significant as they exhibit dichroism<sup>4</sup>. Figure 3, shows the typical hue versus temperature curve. Sequence of colours most commonly observed is red, then yellow, green, blue and finally violet.



Figure 2: Neuroischaemic foot ulcer on the little toe

Full field thermal images of the plantar surface have been obtained using LCT [6; 1]. Liquid crystals used in early research work were in the form of spray paints applied directly onto anatomical site over a black absorbing layer. However, wider adoption of the technology has been limited due to pressure sensitivity and slow response times. Recent improvements in technology combined with low cost, fast video acquisition, improved thermal mapping capability, long term stability, and accurate measurements and reduced pressure sensitivity now offer potential for routine thermographic assessment of the diabetic foot. Such an approach provides quantitative measurements of response thresholds compared to qualitative measurements based on sensory perception.

<sup>4</sup> A phenomenon involving differential absorption of right hand and left hand circularly polarised light due to molecular asymmetry and are the most optically active substances known.

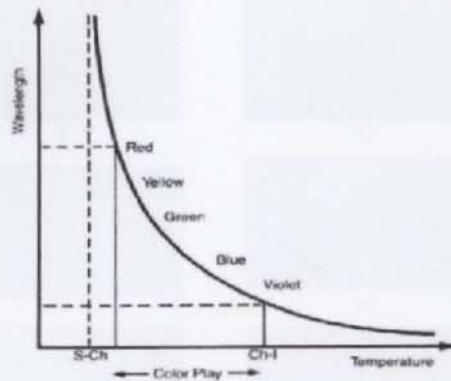


Figure 3: Typical reflected wavelength Vs temperature response of a TLC mixture. Red start represents 25°C and violet represents 30°C (Hallcrest 1960).

## 2. Aims and methods

Three main aims of the research are to develop LCT system capable of dynamically monitoring microvascular response to thermal stimulus, investigate if the results are useful to assess subclinical autonomic neuropathy and obtaining an independent measure of plantar sensory neuropathy.

A low cost LCT system has been developed for thermographic measurements. Three sensor plates are used corresponding to three different temperature ranges i.e. 20-25° C, 25-30° C and 30-35° C. Four fluorescent bulbs (20 watts each) are used, colour temperature 6500K. Fluorescent bulbs have a homogeneous illumination field and provide temporally constant illumination over whole area of interest. A mains switch is mounted on the box for local control. The box is painted matt white from inside to diffuse/randomize light distribution. For the measurements, a three chip CCD video camera (Panasonic NV-MX 500) was used. Both static images and videos can be stored on the secure digital (SD) memory card.



Figure 4: Photograph of the box

Static images were acquired showing the temperature on plantar surface of the right foot for four subjects. A set of eight images were acquired for each subject in seated position with two second interval between each image. Images were acquired after 15 minutes of equilibration with ambient temperature. Sensor plate used had colour bandwidth of 5° C (25-30° C) and the ambient temperature was 20° C. Area of interest (255x170 pixels) was extracted from original images, originally acquired as 640x480 pixels. Hue distribution was assessed in different areas of the foot. Using similar setup, static images were acquired showing the temperature on both right and left hands of the same subjects. Similar hue distribution was assessed in the palm region and fingers.

## 3. Results

The scope of study is limited due to lack of calibration data and ethical issues for incorporating more human subjects. Figure 5, shows individual images of the plantar surface of right foot for four subjects. Figure 6, shows the image sequence of the first subject.

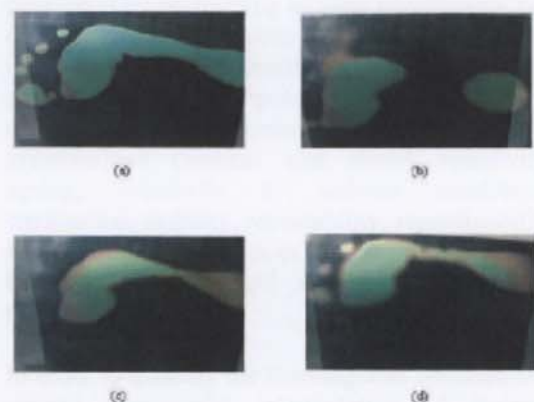


Figure 5: Foot images of four subjects acquired with TLC sheet.

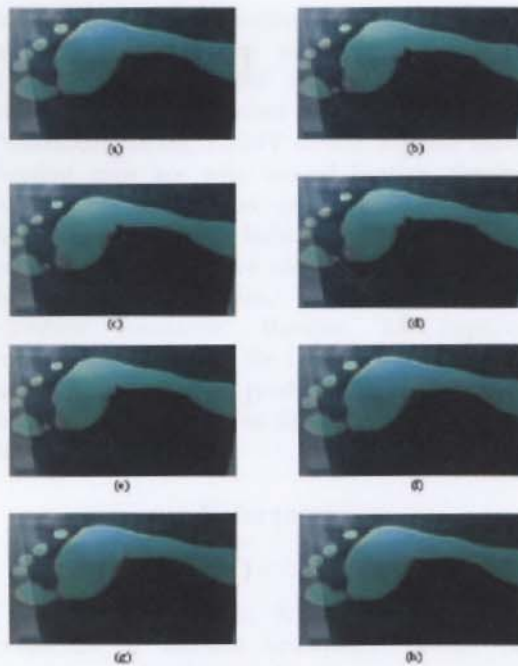


Figure 6: Foot images for first subject

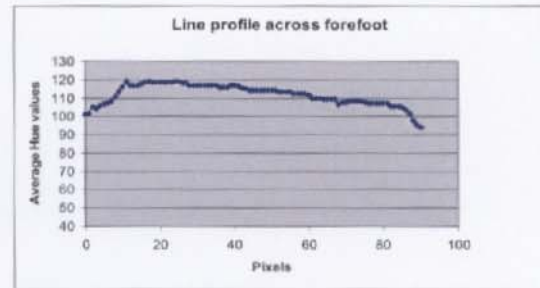
It can be seen that anatomical shape of the foot, especially the foot arches has considerable effect on the acquired images as the contact area is affected. Spatial details can be easily assessed from acquired images. Major anatomical landmarks can be visually assessed for qualitative assessment. Quantification of temperature will be achieved after determination of hue versus temperature calibration curve. Figure 7, shows average hue values (from all eight images) across the line.

#### 4. Discussion and Conclusions

Prevention by identifying individuals at high risk represents the most effective way of reducing rates of ulcer formation and leg amputation in diabetic patients. Current focus is on a nutritious diet, patient education, collaborative research and early diagnosis of the high risk patients to control disease complications.



(a)



(b)

Figure 7: Hue variation across the line drawn in forefoot region for subject 1.

Presently, clinicians evaluate risk of ulceration routinely by measurement of plantar pressure using pedobarography or gait analysis and determination of extent of sensory neuropathy using Semmes-Weinstein monofilament technique and vibration perception threshold (Biothesiometer). However, these techniques cannot be used to establish the mechanisms that lead to tissue damage and initiate ulceration. It is suggested that diabetes disturbs unmyelinated nerve fibre function prior to and more severely than large fibre function [3; 7]. LCT can be used to dynamically monitor temperature distribution on the plantar surface and obtain informative parameters such as temperature magnitude and temporal response. Dynamic measurements may be sensitive for detection of perfusion abnormalities owing to neuropathy in diabetic subjects.

#### 4.1 Improvisation of the current system

Drawbacks of the current system include noise, hysteresis, thermal conductivity of tissue and physiological factors. A prototype system will be developed incorporating remedies for the above and appropriate test methodologies will be developed by performing in vitro experiments and determination of system specifications which include accuracy, sensitivity, response times, spatial resolution, temporal resolution, operating range, dynamic response, linearity, hysteresis, pressure/load (vertical and shear) sensitivity, ageing, sensitivity to ambient conditions, sterilisation, stability, repeatability, reproducibility and potential noise sources. Image processing will be done using ImageJ and image processing toolbox in MATLAB.

In order to quantify the thermograms obtained and present meaningful interpretation of thermal patterns, it is essential to calibrate the LCT system.

It is envisaged to use isothermal calibration<sup>5</sup> using silicone rubber heating mats (80mm diameter, 12V/20W) with inbuilt thermocouple (J-type) controlled via independent temperature controller (thermocouple I/p, 12-24V ac/dc). Silicone rubber heating mats are wire wound heating elements with even distribution of wires for uniform heating. These offer advantages such as fast response to temperature control, flexibility, rapid heat up characteristics, precise heating and moisture resistance. Besides, an improved mechanical design for the light box will be made which will be robust, portable and will contain better optics as well as light sources free from heating effect.

### References

- [1] Benbow, S., Chan, A., et al. (1994). "The prediction of diabetic neuropathic plantar foot ulceration by liquid-crystal contact thermography." *Diabetes Care* 17(8): 835-839.
- [2] Grunfield, C. (1992). "Diabetic foot ulcers: Etiology, treatment and prevention." *Advances in Internal Medicine* 37(19): 103-132.
- [3] Guy, R., Clark, C., et al. (1985). "Evaluation of thermal and vibration sensation in diabetic neuropathy." *Diabetologia* 28: 131-137.
- [4] Pendsey, S. (2003). *Diabetic foot: A clinical atlas*. New Delhi, Jaypee Brothers - Medical Publishers (P) Ltd.
- [5] Shaw, J. and Boulton, A. (1997). "The pathogenesis of diabetic foot problems: An overview." *Diabetes* 46(Supplement 2): S58-S61.
- [6] Stess, R., Sisney, P., et al. (1986). "Use of liquid crystal thermography in the evaluation of the diabetic foot." *Diabetes Care* 9(3): 267-272.
- [7] Ziegler, D., Mayer, P., et al. (1988). "Assessment of small and large fibre function in long term type 1 (insulin dependent) diabetic patients with and without painful neuropathy." *Pain* 34: 1-10.

<sup>5</sup> Determine hue versus temperature characteristics within the usable bandwidth of TLC sheets.