Evaluating the Potential of Infrared Thermography in the Study of Peripheral Arterial Occlusive Disease

[1]M.G. Sowa, [1]J.R. Friesen, [2,1]M. Hain

[1]Institute for Biodiagnostics, National Research Council Canada, Winnipeg, Canada,
[2]Institute of Measurement Science, Slovak Academy of Sciences, Bratislava, Slovakia
Email: mike.sowa@nrc-cnrc.gc.ca

Abstract. *The diagnosis of peripheral vascular disease is not an easy one to make. It typically begins with an in office assessment that commonly includes reporting of presenting symptoms (with questioning) followed by inspection and palpation (physical examination). This in-office assessment is followed by vascular lab testing and may include Doppler ultrasound, ultrasound scanning, transcutaneous oxygen monitoring, x-ray, CT or magnetic resonance angiography. However, not all technologies can be used reliably in all patients. Because this disease can be difficult to stage, challenges designed to alter blood flow to the extremity (whether they be exercise-induced, occlusion-induced, or supine/dependency states) are occasionally used for additional insight. We investigate the potential of infrared thermography in the evaluation of peripheral arterial occlusive disease and compare a conventional challenge with no challenge at all.*

Keywords: Infrared thermography, peripheral vascular disease, nonlinear fitting

1. Introduction

Peripheral arterial occlusive disease (PAOD) is characterized by poor circulation of blood to the extremities and most generally the lower leg and foot. The disease carries a significant patient morbidity and it is generally the leading cause of amputation in adults [1]. Atherosclerosis exacerbated by the vascular consequences of diabetes and/or smoking is usually the underlying cause of the disease. Narrowing or blockage of the vessels impedes blood flow to the extremities. Starved for blood, fingers or toes are often the first tissue to suffer leading to open, chronic wounds that can be further infected; left unchecked the entire limb may require amputation. At the outset the symptoms of the disease usually consist of the patient developing pain in the calf muscles of the leg when they walk with the pain subsiding on resting. This is known as intermittent claudication and patients are usually treated conservatively at this stage. As the disease advances, pain persists at rest, non-healing wounds may appear and gangrene may develop. At this stage, known as critical ischemia, more aggressive treatment intended to restore blood flow to the extremities is necessary: bypass surgery or less invasive procedures such as angioplasty or atheroectomy can be carried out to restore blood flow.

Treatment is based on the severity of the disease therefore accurate diagnosis and the ability to monitor its progression is essential. Angiographic methods are difficult and costly to carry out routinely and are typically reserved to determine if and what type of revascularization procedure should be used and if a revascularization procedure was successful. More commonly ankle pressure, ankle brachial index (ABI; ankle pressure/arm (brachial) pressure), toe pressures, and transcutaneous oxygen measurements are used to help assess the disease. Each measurement technique has drawbacks or limitations and often more than one of these various measurement methods is used to provide an understanding of the severity of the disease. For example, toe pressures which measures the magnitude of the pulse of blood at the toe using photoplethysmography are an important measure in diabetic patients who generally show falsely elevated or incompressible ankle pressure readings due to extensive vascular calcification [5]. The reproducibility of some of the measurements has also been criticized. For instance, the variability of ankle-brachial pressure index measurements made by trained staff has been reported as 15% [6]. Simple and reliable methods to measure peripheral perfusion that could be used routinely could enhance our ability to diagnose PAOD and result in improved clinical management of the disease. In this paper we examine infrared thermographic measurement of perfusion to the extremities to help study PAOD.

2. Subject and Methods

Infrared Thermography

For the contactless temperature measurement a ThermaCAM SC 3000 (FLIR Systems AB) thermographic camera equipped with GaAs quantum well infrared photon detector Stirling cooled to 70 K was used. The detector has a spectral range between 8-9 μm, providing 0.03 ^{o}C thermal sensitivity at 30 ^{o}C and an accuracy of 1% of the measured value or ±1 ^{o}C (for measurement range up to 150 ^{o}C).

Clinical Study & Experimental Protocol

The PAOD study took place at St. Boniface General Hospital in Winnipeg, Manitoba and was approved by the Winnipeg Research Ethics Board of the Institute for Biodiagnostics, the Research Review Committee of St. Boniface General Hospital and the Research Ethics Board of the University of Manitoba, Faculty of Medicine. A total of 60 subjects were enrolled in the study; age range was (47-88), mean age was 71. Based on clinical examination of presenting symptoms and patient history, pressure and transcutaneous oxygen measurements, subjects were divided into three groups, 20 with claudication or rest pain (without tissue loss), 20 with critical ischemia (possible tissue loss, ulcers, and/or gangrene) and 20 controls with normal peripheral blood circulation. All subjects provided written informed consent.
Perfusion in the feet of patients was assessed with infrared thermography in combination with ankle pressure, ankle brachial index, toe pressures, and transcutaneous oxygen measurements. A pressure – cuff challenge was used to invoke changes in perfusion to the foot and examine perfusion recovery times. The challenge consisted of three phases: 1. Rest; 2. Ischemia where a pneumatic cuff on upper thigh was inflated to pressure of 30 mmHg above thigh systolic pressure for 3 minutes to occlude arterial flow; 3. Reperfusion where cuff pressure was released. Infrared thermographic measurements were made throughout this protocol. Figure 1 outlines the expected results from such a challenge.

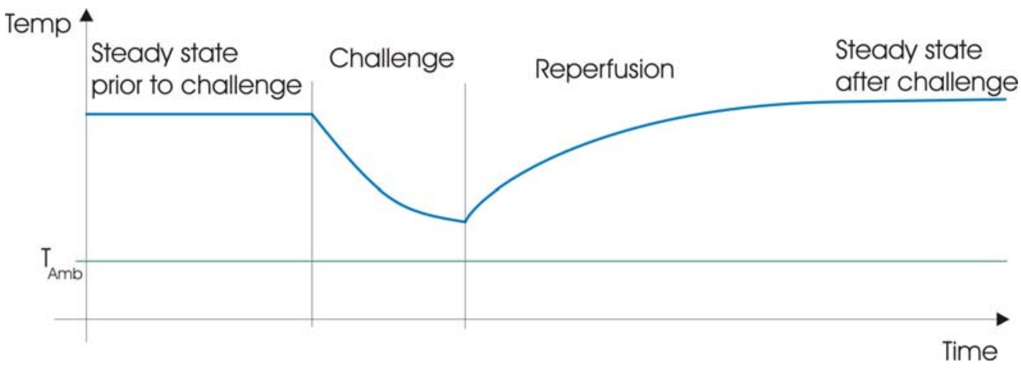


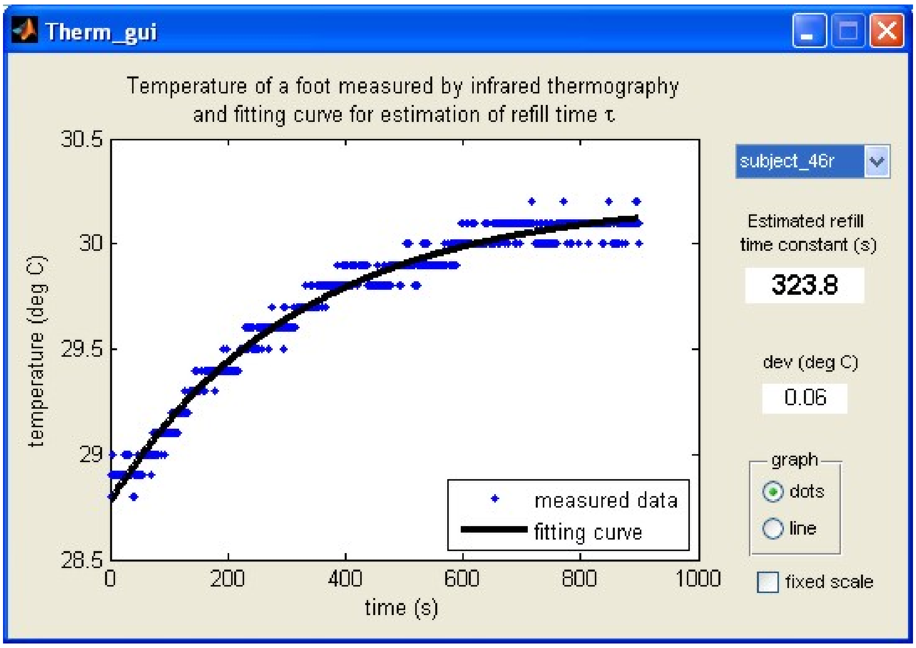
Fig. 1. Schematic of the expected change in the temperature of the foot over the experimental protocol.

Data Analysis

The time dependence of the change in temperature, $T(t)$, of the foot as a result of the challenge was fit a function

$$T(t) = T_0 + \Delta T.\left(1 - e^{-\frac{t}{\tau}}\right)$$

where T is temperature of the foot at the selected point, T_o is steady state temperature of the foot prior to challenge, t is time, ΔT is temperature difference prior and after challenge, and τ is the time constant. The unconstrained multivariable nonlinear optimization method



supported by the MATLAB function *fminsearch* was used to estimate the parameters of this model.

Fig. 2. Example of the thermographically measured time dependence of temperature of a lower extremity during reperfusion phase and nonlinear fitting curve with estimated refill time t_{TH}

Correlation analysis was performed to understand the association between the thermographic measurements as well as with the assessment of PAOD disease. An ordinal score, DSI = Disease Seriousness Index, was introduced where 1= control group, 2= claudicant group and 3= critical group. Correlation analysis was performed on the following variables, DSI, t_{TH} the thermographic refill time, T_{TOE} the temperature of the big toe prior to challenge, T_{ANK} the temperature of the ankle prior to challenge and $T_{ANK} - T_{TOE}$ the difference between the temperature of the ankle and temperature of the big toe prior to challenge. Correlation analysis was performed in the MATLAB environment.

3. Results

Correlation analysis demonstrates a strong association ($r > 0.8$) between the static thermographic measurements made at the ankle and toe prior to the challenge with the static thermographic measurement at the toe showing a modest negative correlation ($r = -0.33$) with the disease seriousness index. Static thermographic measurement of the ankle were less correlated with the disease index ($r = -0.19$) but both ankle and toe measurements displayed the expected negative correlation with disease severity. People with more advanced disease showed lower temperatures in general. When examining the difference between the thermographic measurements at the toe and ankle, the difference measure showed a modest positive correlation with the disease index ($r = 0.34$). Surprisingly, the estimate of the refill time from the nonlinear fit to the temperature curve from the challenge, t_{TH}, showed no significant correlation with the disease seriousness index and only a modest positive correlation with the static temperature measurement made at the ankle ($r = 0.39$). Table 1 summarizes the results from the correlation analysis.

Table 1. Correlation analysis examining the association between DSI – disease seriousness index, t_{TH} – thermographic refill time, value of this variable is obtained as a result of mathematical evaluation (estimation of refill time from nonlinear fitting curve) of thermographic assessment of the PAOD disease, T_{TOE} - temperature of the big toe prior to challenge, T_{ANK} - temperature of the ankle prior to challenge, T_{ANK} – T_{TOE} - difference between the temperature of the ankle and temperature of the big toe prior to challenge.

	DSI	t_{TH}	T_{TOE}	T_{ANK}	T_{ANK}-T_{TOE}
DSI	1	-0.06	-0.33	-0.19	0.34
t_{TH}	-0.06	1	0.16	0.39	0.12
T_{TOE}	-0.33	0.16	1	0.80	-0.83
T_{ANK}	-0.19	0.39	0.80	1	-0.33
T_{ANK}-T_{TOE}	0.34	0.12	-0.83	-0.33	1

4. Discussion

The results from this limited clinical study indicate that infrared thermographic measurements can be made at the time of the physical examination of patients suspected of have lower limb PAOD. Static thermographic measurement of ankle and toe temperatures under controlled conditions provide additional information on the state of lower limb perfusion in the patient. These thermographic measurements and their difference showed a modest correlation with the severity of the disease. Thermographic measurements during a pressure cuff challenge and the vascular refill time based on the temperature profiles did not show a correlation with disease seriousness. These preliminary results cast doubt on the value of a pressure cuff challenge to be used in conjunction with infrared thermography in the assessment of PAOD.

Acknowledgements

The authors would like to acknowledge support from the National Research Council Canada, Genomics and Health Initiative.

References

[1] Krupski WC, Skinner HB, and Effeney DJ. Amputation, in Current Surgical Diagnosis and Treatment. Way LW, Editor. Appleton and Lange, San Mateo, CA, 1988.

[2] European Working Group on Critical Leg ischemia. Second European Consensus Document on Critical Leg ischemia. *European Journal of Vascular and Endovascular Surgery*, 6 (Supp A), 1992.

[3] Jacobs MJHM, Ubbink DTh, Kitslaar PJEHM, et al. Assessment of the microcirculation provides additional information in critical limb ischemia. *European Journal of Vascular and Endovascular Surgery*, 6: 135-141, 1992.

[4] Rutherford RB, Baker JD, Ernst C, et al. Recommended standards for reports dealing with lower extremity ischemia: Revised version. Journal of Vascular Surgery, 26: 517-538, 1997.

[5] Raines JK, Darling RG, Buth J et al. Vascular laboratory criteria for the management of peripheral vascular disease of the lower extremities. *Surgery,* 79: 21–29, 1976.

[6] Ray SA, Srodon PD, Taylor RS, Dormandy JA. Reliability of ankle:brachial pressure index measurement by junior doctors. *British Journal of Surgery*, 81:188-190, 1994.