AN INFRARED THERMOGRAPHIC AND LASER DOPPLER FLOWMETRIC INVESTIGATION OF SKIN PERFUSION IN THE FOREARM AND FINGER TIP FOLLOWING A SHORT PERIOD OF VASCULAR STASIS

5.årsoppgave

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1. Contents

2. Summary

The use of Infrared Thermography to diagnose circulatory problems in the hands is based upon the assumption that a change in skin temperature can be related to a change in skin blood flow. In this study 7 healthy volunteers were exposed to a 3 min period of vascular stasis of the right arm. The resultant reactive hyperaemia with associated skin erythemia was monitored on the forearm and finger tip of the 2nd digit with Infrared Thermography (IR) and with Laser Doppler Flowmetry (LDF). Following vascular stasis clear increases in skin perfusion as measured with LDF were seen at both the finger tip and forearm. However, a concomitant increase in skin temperature was only seen at the finger tip. This finding indicates that changes in skin blood flow associated with skin reactive hyperaemia and its associated erythemia may not be the same as that used for thermoregulatory purposes. It is concluded that caution should be applied when using IR thermal imaging to monitor blood flow changes associated with induced changes in skin perfusion associated with erythemia.

Keywords: Infrared Thermography, Skin blood flow, Laser Doppler Flowmetry, Vascular stasis

3. Introduction

Infrared thermography (IRT) and Laser Doppler flowmetry (LDF) are two methods commonly used for measuring skin perfusion when diagnosing circulatory problems in the hands and feet, such as Raynaud's phenomenon (1-5). LDF provides a more direct technique for measuring skin blood flow and normally involves the attachment to the skin surface of individual measuring probes with low spatial resolution (1 mm^2). Although non-contact scanning laser Doppler flowmetry permits measurements of skin blood flow over larger skin areas, the available systems are not able to scan the skin surface quickly enough to measure rapid changes in skin blood flow (6). On the other hand, IRT has the advantage of being able to instantaneously measure the skin surface temperature over a large area without direct contact with the skin (7). Conclusions from previous studies in which comparisons have been made in the use of these 2 techniques have confirmed that IRT is a reliable indirect method for measuring skin perfusion, especially in the peripheral appendages (8, 9).

In examining skin perfusion thermal provocations are often used where, for example, the time course and thermal pattern on the skin surface resulting from the cooling and recovery protocol provides useful information concerning skin perfusion, including the functional status of autonomic control. Another approach for measuring the status of skin perfusion in patients is to examine circulatory responses following a short period of venostasis. This has previously been examined using both IRT and LDF (8, 10-15). Hanssler et al using IRT and LDF before and after arterial occlusion of the upper arm concluded that both techniques provided useful tools for the assessment of physiological and pathophysiological functions of the cutaneous circulation (8). On the other hand Seifalian et al using an older type of imaging system concluded that skin perfusion measurements using LDF did not correlate well with IRT following a thermal provocation (15, 16).

Since LDF is regarded as being a more sensitive technique for measuring small changes in peripheral circulation we were interested to see whether our high sensitive IR-camera (see methods for details) could register small invoked changes in skin perfusion associated with erythemia that we know can be detected by LDF (11, 17). In this study we have used IRT and LDF to monitor skin perfusion in the forearm and finger tip following a short period of venous stasis in healthy subjects who were not subjected to any form of pre-heating. Since the magnitude of changes in skin blood flow is known to be greater in fingers compared to the forearm we have used these two sites in our comparison of these 2 techniques.

4. Methods

Subject recruitment

Eight volunteers were recruited among students at the University of Tromsø. All the subjects were non-smokers without any chronic diseases and none were on current or permanent medication. Four male and four females were included in the study. The mean age was 24.1 year, average height 171.6 cm, average weight 68.7 kg, and average BMI 23.2. Prior to the experiments blood pressure and tympanic ear temperature (EXERGEN LightTouch LTX-1, Newton, MA, USA) were measured. All subjects had normal ear temperature (35.9-37.7 °C, average 37.0°C) and normal blood pressure (105/60-130/70 mmHg, average 118/72 mmHg). Participants were asked to abstain from alcohol, caffeine, physical activity and cold exposure in the 12 h preceding the study. The volunteers were also asked neither to drink hot liquids nor to wash their hands in cold water less than two hours before the experiments.

Permission to carry out the experiments was granted by the Norwegian Regional Committee for Research Ethics.

Experimental protocol

The experiments were performed at room temperature (21.4 ±0.4 °C) in a draught

free room. During the experiments the lightly clothed volunteers sat in an upright position in a chair with their hands resting, palm down, on a grid made of thin nylon strung on a wooden frame (Fig 1). The purpose of the nylon grid was to minimize skin contact with the surface supporting the hands. An electrically heated plate was placed 5cm below the grid in order to provide a uniform background with a constant temperature of ca. 39 °C. (Fig 1)

To occlude blood supply to the test arm (right arm), an inflatable cuff was attached around the right upper arm. Skin surface temperature was measured by infrared thermography using a Flir ThermaCAM S65HS IR-camera (Flir Systems, Boston, MA, USA). The HS version of this camera has a temperature sensitivity of 0.06°C. Images were analyzed with the ThermaCam Researcher Pro 2.8 software (Flir Systems AB). Four circular regions of interest (ROI) were selected for temperature measurements, one on each forearm (diameter = 2 cm) and one on each index finger (diameter = 1 cm) (Fig 2). The regions of interest were placed adjacent to the attachment points of the laser Doppler probes (see below).

Skin blood flow was measured with laser Doppler probes using a Periflux 4001 Master (Perimed, Sweden). Two probes were attached to the right arm. Probe 1 was attached to the tip of the index finger, just proximal of the nail. Probe 2 was attached to the center of the forearm, halfway between the styloid process of the radius and the lateral epicondyle of the humerus (Fig 2). Data from the laser Doppler recording was processed with the PhysAqu and PhysAna software (Knut Steinnes, Faculty of Medicine, University of Tromsø). Heart rate was continuously measured telemetrically (Polar Advantage Interface System, Kempele, Finland).

Following baseline recordings of blood pressure, tympanic ear temperature, body weight and height, the subjects were subjected to a 15 min equilibration period. Skin temperature and blood flow measurements commenced during the last 2 min of the equilibration period. At the end of the equilibration period the cuff was inflated to supra-systolic pressure (230 mmHg). After 3 min the cuff was rapidly

deflated. A 3 min occlusion time was selected to give a significant reactive hyperemia without causing to much discomfort for the test persons (18). LDF and IRT recordings continued during the occlusion period and for a further 5 min during the recovery period.

IR images were recorded at a rate of 3 images/second, and laser Doppler measurements were recorded at 4 readings/sec. The experimental protocol was repeated 3 times in each subject. Experiments that showed unstable skin temperatures during the pre occlusion period or where the subject was showing symptoms of a Raynaud like phenomenon was excluded from the study.

5. Results

Fig 3 shows the typical results from a single experiment. As expected there is a much higher level of blood flow in the finger tip than in the forearm (19). Inflation of the cuff caused an almost complete cessation in blood flow, as shown in the LDF measurements. When the cuff was released a reactive hyperaemic response was observed (upper panel), with a clear, short lasting overshoot before returning to base line level. This hyperaemic response was evident on both the fingertip and forearm and was associated with short-lasting skin erythemia.

In the lower panel of Fig. 3 the corresponding skin surface temperature measurements are shown. During cuff inflation there was a 1.8°C decrease in temperature in the fingertip of the test arm (Fig. 3, ROI-3). In the forearm of test arm there was very little change in temperature (Fig. 3, ROI-1).

Although 24 experiments were conducted, eight of them were discarded due to unstable skin temperatures during the pre occlusion period or due to the subject having symptoms of a Raynaud like phenomenon (see below). 16 experiments have been included in the results presented in Fig. 4. The time courses of both the blood flow and temperature values shown in Fig. 4 were very similar to those seen in the single experiment (Fig. 3), with a clear reactive hyperaemic response seen for both ROI's in the test arm as well as a clear change in finger tip temperature.

Skin temperature in the test forearm showed no change.

Figure 5 shows the result from one of the subjects who exhibited symptoms of a Raynaud's like phenomenon. The data from this subject was not included in the group mean, but are presented separatly. Skin temperature on the fingertips of both hands were just below 26°C at the start of the recording, which was ca 7°C colder than the average value of 32.7 °C seen in the other subjects. Skin blood flow was also much lower than that seen in the other subjects (Fig. 4). In this subject fingertip temperature decreased slightly during the occlusion period, but to a much lesser degree than in the other subjects. Despite the clear reactive hyperraemic response following release of vascular stasis as shown in the LDF measurements (upper panel), there were no corresponding changes in skin temperature (lower panel).

6. Discussion

In this study we have used two non-invasive methods for measuring skin blood flow, Laser Doppler flowmetry and infrared thermography. Neither method give a direct measurement of the blood flow, but it is clear from the results that there were occasions where LDF was able to monitor changes in skin blood flow that could not be detected as changes in skin temperature by IRT. The experiments showed that the skin temperature on the forearm did not decrease during an ischaemic period, and furthermore, did not increase when blood flow returns. This is consistent with other studies, who have shown that it is only in the digits, palm and toes that skin temperature can be clearly related to perfusion (20). This observation is most likely related to local differences in skin vascular anatomy. Arterio-venous anastomoses (AVA) in the skin are present in high numbers in the face, hands and feet, areas well known as thermoregulatory windows. In these locations the vessels in the skin are organized in three layers, with AVA's that are controlled by the autonomic nervous system. When the AVA's are open they allow a higher level of blood flow by shunting some of the blood flow directly into the venous plexus to facilitate heat loss. The skin blood flow in the forearm is mainly

a nutritional flow, and not thermoregulatory as in the hand and digits, and there are fewer AVA's (21). The smaller number of AVA's present in the forearm may explain why the infrared camera did not detect any change in temperature in ROI-1 and -3 (Fig 2). The same explanation may be used to explain the results in the subject with Raynaud like symptoms. In this subject it is assumed that there is a malfunction in the autonomic control of blood flow in the digits, resulting in the lower than normal skin temperatures. The increased finger tip blood flow registered with LDF in this subject is presumably a superficial, nutritional flow, of insufficient magnitude to cause a change in temperature.

The measurable changes in forearm skin blood flow, measured with LDF, which did not result in a temperature change large enough to be detected by IRT may also be related to poor camera sensitivity. However, while this may be the case in some studies involving the use of older generation IRT-technology (8, 15), we feel it is unlikely that low camera sensitivity was the problem. Our FLIR S65 camera is the high sensitivity (HS) version of this model, and in other clinical situations we have been able to measure changes in skin temperature related to erythemia coupled to facial blushing (un-published observation). We have also unpublished observations where our IR camera was unable to detect changes in skin temperature associated with a flare (triple) response initiated by a ca 4 cm long linear scratch on the skin with associated erythemia and increases in skin blood flow measured by LDF. However, if a larger area of skin was scratched (ca 2 cm^2) the camera was then able to pick up an increase in max temperature. In addition to the size of the skin area being examined, the region of skin being measured (and the presence of AVA's) may also have an impact on the correlation between IRT and LDF. Bornmyr et al compared the big toe with the dorsum of the foot, and found an exponential relationship between IRT and LDF on the big toe, but a linear relationship on the dorsum of the foot. They explain the different correlation as a result of differences in the vascular geometry (22). Hanssler et al measured the hypothenar eminence, and found a close correlation (8), while Seifalian et al measured at the fingers and at the back of the hand, and found a weak correlation (15).

In this study we have shown that a 3 min period of upper arm vascular stasis results in a clear hyperemic responses in both the forearm and fingertip. This was associated with a reduction in skin temperature on the finger tip during the period of vascular stasis, followed by an increase in temperature and skin erythemia during the resultant hyperemia. There were no concomitant changes in forearm skin temperature. It is concluded that there are situations in which caution must be used even when using high sensitive IR-camera as an indirect method for monitoring skin perfusion.

7. Acknowledgements

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8. Figure text

Figure 1.

Overview of the experimental setup

Figure 2.

IR-image of forearm and hands showing the location of the 4 regions of interest (ROI 1 - 4) used for temperature measurement, and the location of the 2 laser Doppler probes (Arrows)

Figure 3

Time course of changes in skin temperature and skin blood flow before, during and after a 3 minute period of vascular stasis in a single experiment.

Figure 4

Time course of mean changes in skin temperature and skin blood flow before, during and after a 3 minute period of vascular stasis. N=16. Mean values ± SEM

Figure 5

Time course of changes in skin temperature and skin blood flow before, during and after a 3 minute period of vascular stasis in a single experiment in a subject with Raynaud-like symptoms.

9. Figures

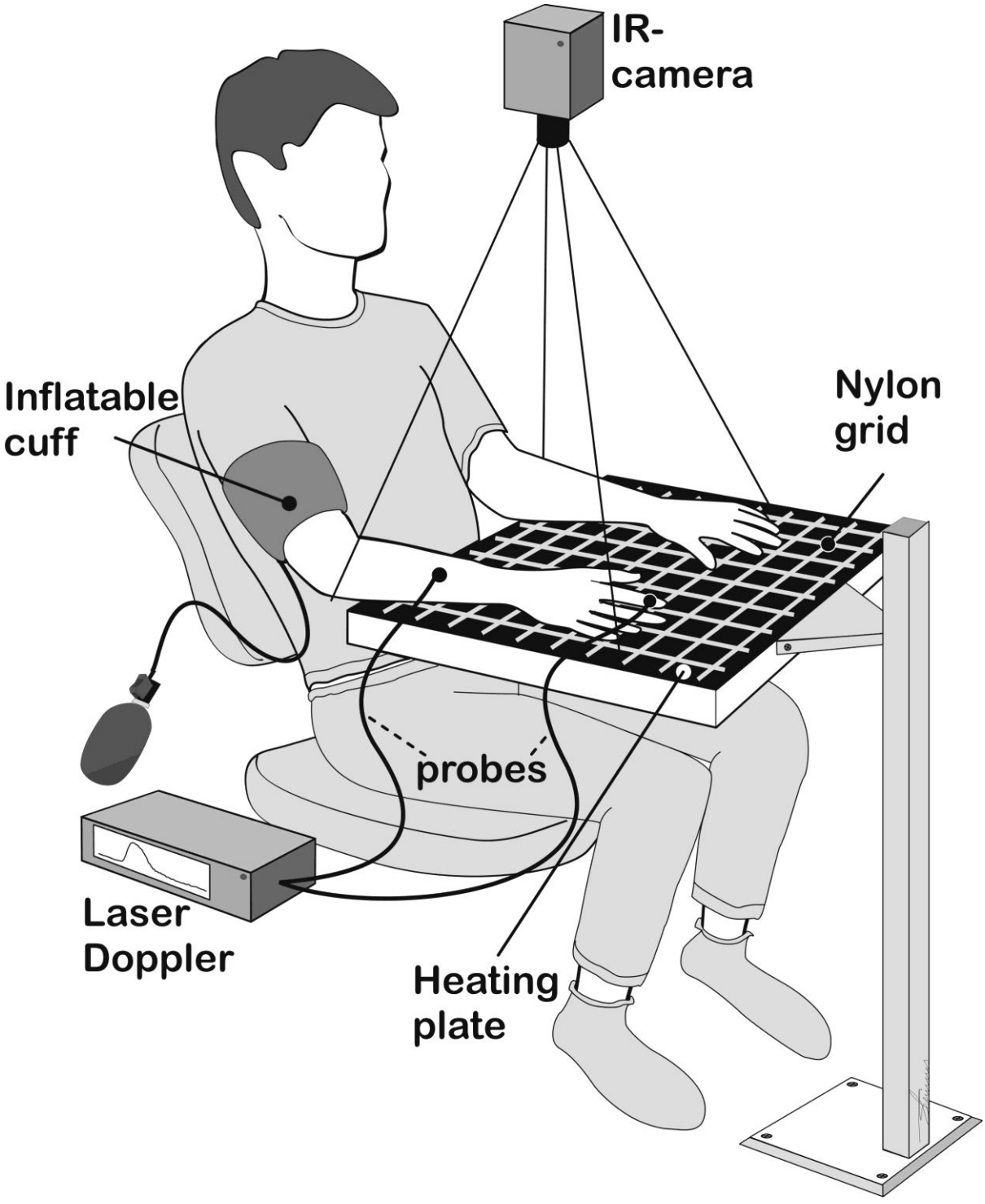

IR-
camera
Inflatable
cuff
Nylon
grid
probes
Laser
Doppler
Heating
plate

Figure 1

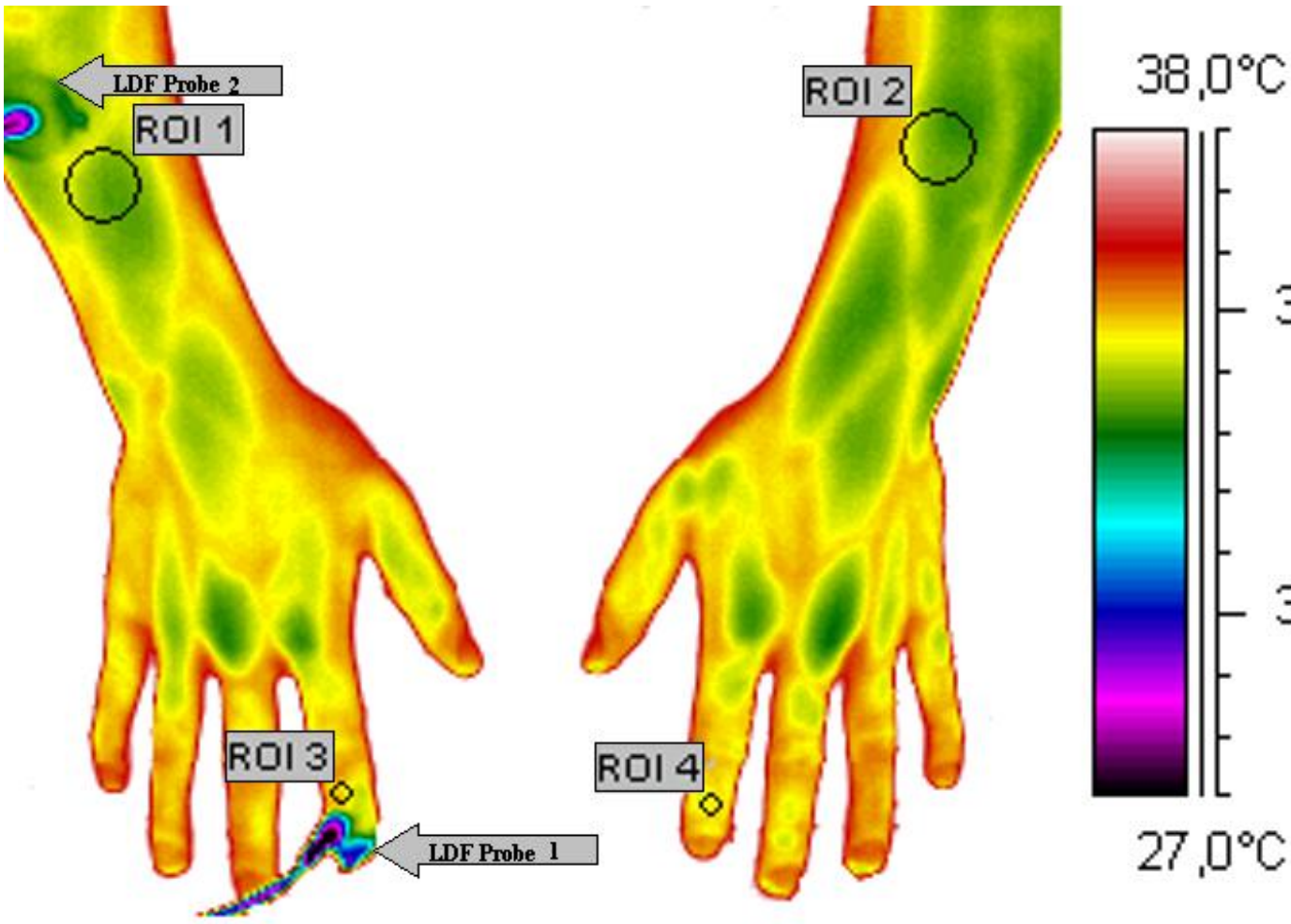


Figure 2

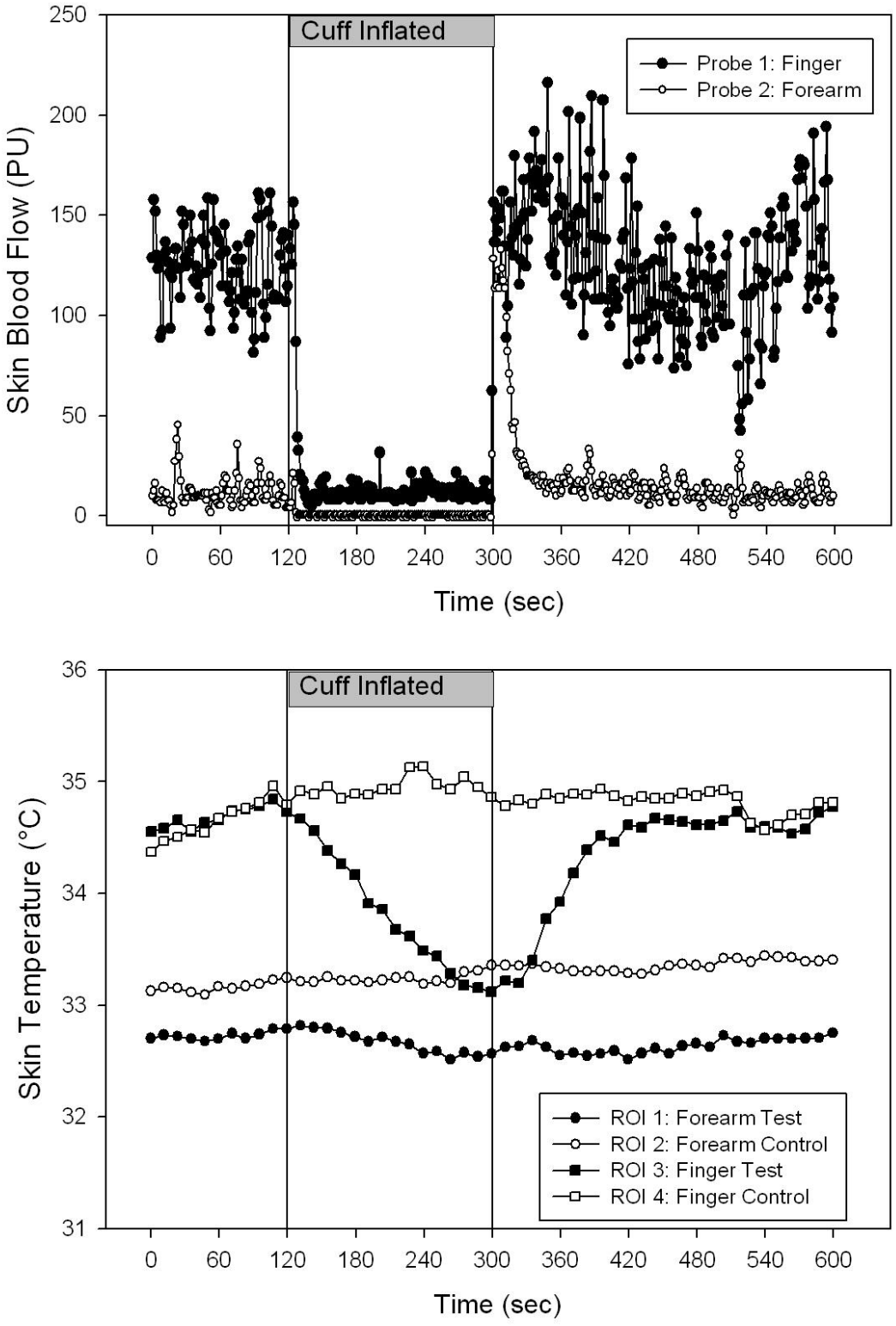
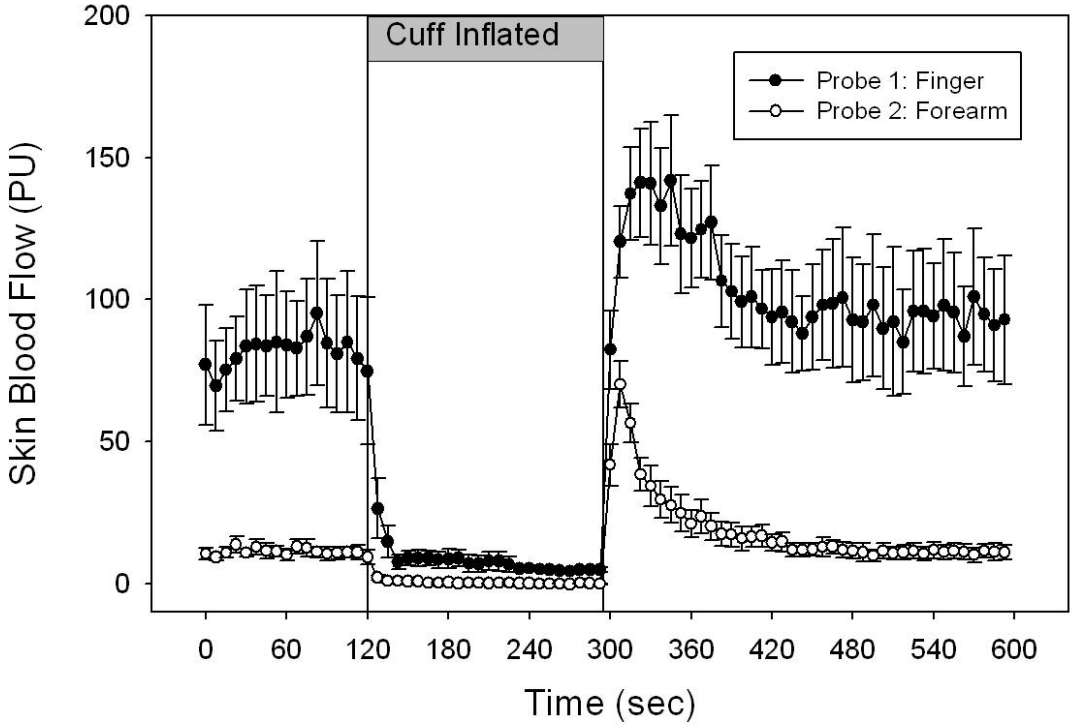

Cuff Inflated
Probe 1: Finger
Probe 2: Forearm
Skin Blood Flow (PU)
250
200
150
100
50
0
0
60
120
180
240
300
360
420
480
540
600
Time (sec)
Cuff Inflated
ROI 1: Forearm Test
ROI 2: Forearm Control
ROI 3: Finger Test
ROI 4: Finger Control
Skin Temperature (°C)
36
35
34
33
32
31
0
60
120
180
240
300
360
420
480
540
600
Time (sec)

Figure 3


Cuff Inflated
Probe 1: Finger
Probe 2: Forearm
Skin Blood Flow (PU)
200
150
100
50
0
0
60
120
180
240
300
360
420
480
540
600
Time (sec)

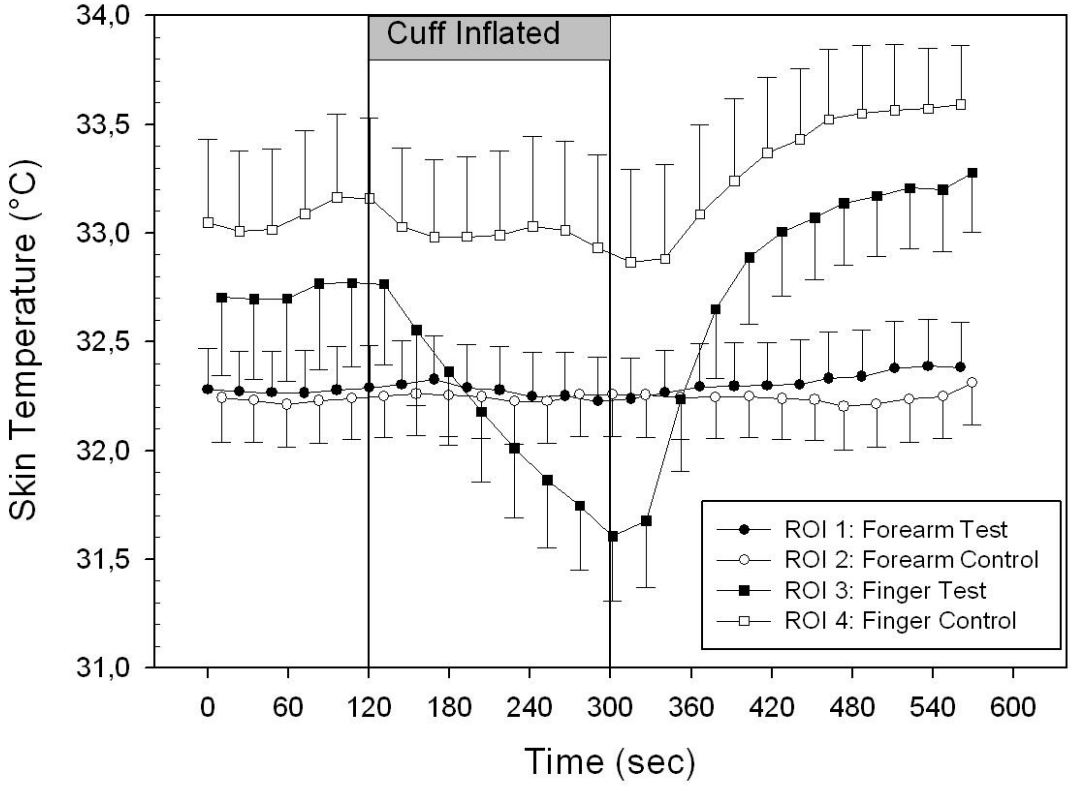
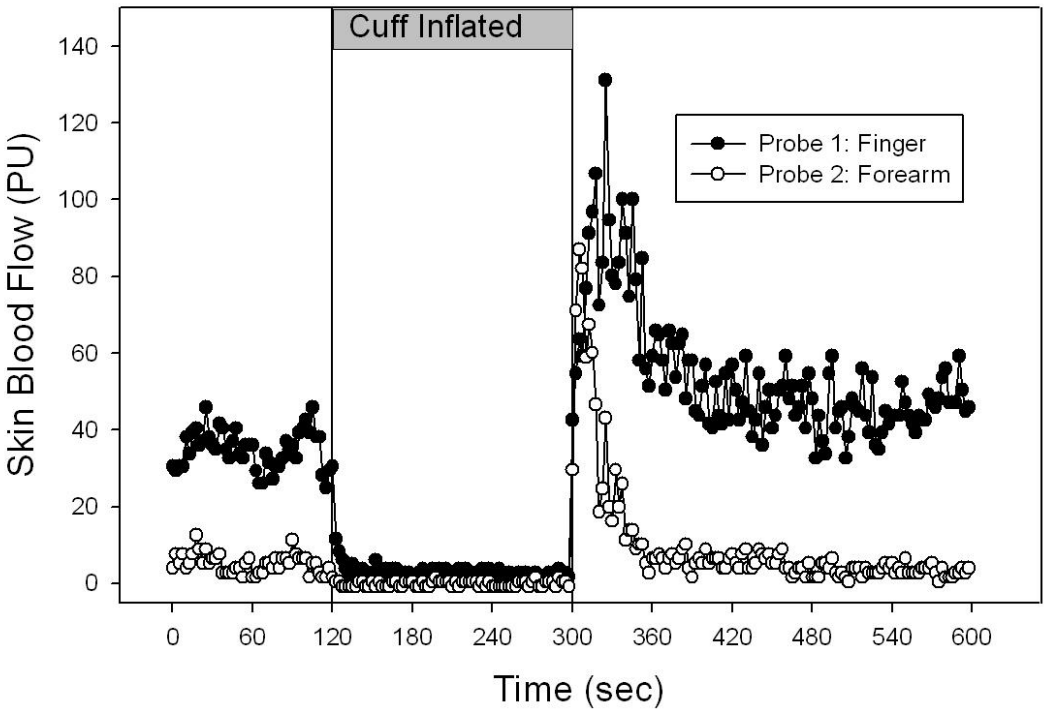

Cuff Inflated
ROI 1: Forearm Test
ROI 2: Forearm Control
ROI 3: Finger Test
ROI 4: Finger Control
Skin Temperature (°C)
34,0
33,5
33,0
32,5
32,0
31,5
31,0
0
60
120
180
240
300
360
420
480
540
600
Time (sec)

Figure 4


Cuff Inflated
Skin Blood Flow (PU)
140
120
100
80
60
40
20
0
Probe 1: Finger
Probe 2: Forearm
0
60
120
180
240
300
360
420
480
540
600
Time (sec)

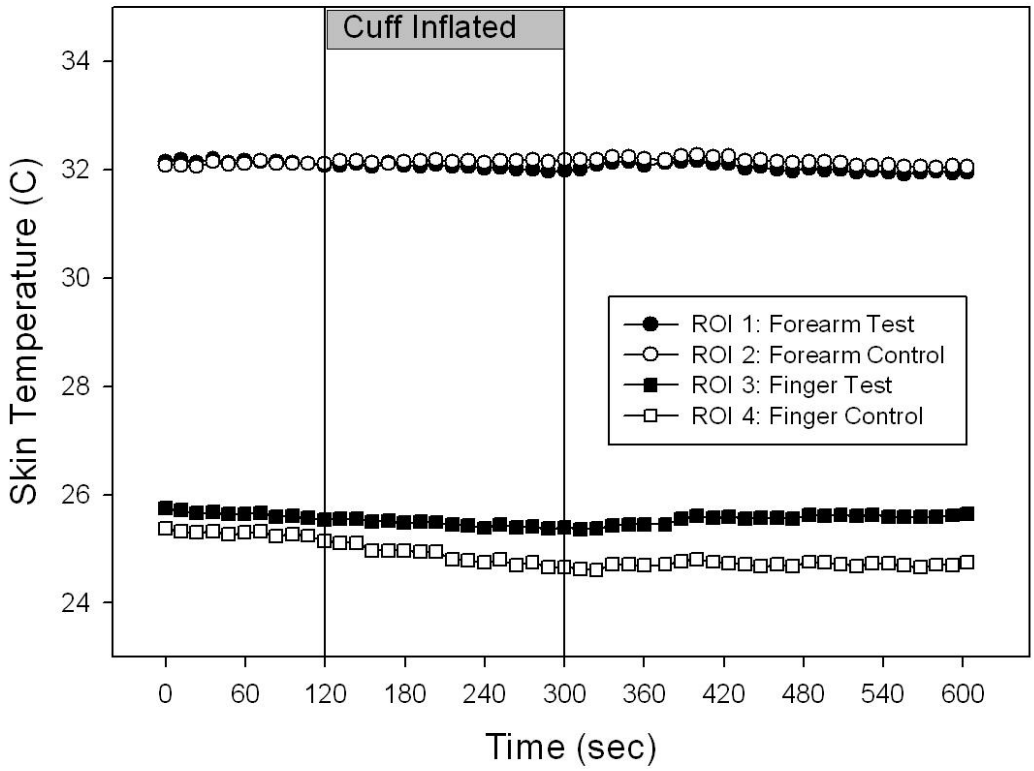

Cuff Inflated
Skin Temperature (C)
34
32
30
28
26
24
ROI 1: Forearm Test
ROI 2: Forearm Control
ROI 3: Finger Test
ROI 4: Finger Control
0
60
120
180
240
300
360
420
480
540
600
Time (sec)

Figure 5

10. References

1. Del Bianco E, Magini B, Muscarella G, Cappugi P, Lotti T. Raynaud's phenomenon (primary or secondary to systemic sclerosis). The usefulness of laser-Doppler flowmetry in the diagnosis. Int Angiol. 2001 Dec;20(4):307-13.

2. Clark S, Dunn G, Moore T, Jayson Mt, King TA, Herrick AL. Comparison of thermography and laser Doppler imaging in the assessment of Raynaud's phenomenon. Microvasc Res. 2003 Jul;66(1):73-6.

3. von Bierbrauer A, Schilk I, Lucke C, Schmidt JA. Infrared thermography in the diagnosis of Raynaud's phenomenon in vibration-induced white finger. Vasa. 1998 May;27(2):94-9.

4. Ring EFJ. Raynaud’s Phenomenon: Assessment by Thermography. Thermology 1988;3:69-73.

5. Schuhfried O, Vacariu G, Lang T, Korpan M, Kiener HP, Fialka-Moser V. Thermographic parameters in the diagnosis of secondary Raynaud's phenomenon. Arch Phys Med Rehabil. 2000 Apr;81(4):495-9.

6. Mercer JB, De Weerd L. The effect of water-filtered infrared-A (wIRA) irradiation on skin temperature and skin blood flow as evaluated by infrared thermography and scanning laser Doppler imaging. Thermology Int. 2005;15(3):89.

7. Francis JE, Roggli R, Love TJ. Thermography aas a Means of Blood Perfusion Measurement. Journal of Biomechanical Enginering. 1979;101:246-9.

8. Hanssler L, Hendricks O, Ranft J, Blank M. Reactive hyperemia after arterial occlusion: comparison of infrared telethermography and laser Doppler flowmetry. Vasa. 1995;24(2):148-54.

9. Bornmyr S, Svensson H. Thermography and laser-Doppler flowmetry for monitoring changes in finger skin blood flow upon cigarette smoking. Clin Physiol. 1991 Mar;11(2):135-41.

10. Lorenzo S, Minson CT. Human cutaneous reactive hyperaemia: role of BKCa channels and sensory nerves. J Physiol. 2007 Nov 15;585(Pt 1):295-303.

11. Yvonne-Tee GB, Rasool AH, Halim AS, Rahman AR. Reproducibility of different laser Doppler fluximetry parameters of postocclusive reactive hyperemia in human forearm skin. J Pharmacol Toxicol Methods. 2005 Sep-Oct;52(2):286-92.

12. Watson JC, Gorbach AM, Pluta RM, Rak R, Heiss JD, Oldfield EH. Real-time detection of vascular occlusion and reperfusion of the brain during surgery by using infrared imaging. J Neurosurg. 2002 May;96(5):918-23.

13. Hassan M, Togawa T. Observation of skin thermal inertia distribution during reactive hyperaemia using a single-hood measurement system. Physiol Meas. 2001 Feb;22(1):187-200.

14. Bungum L, Kvernebo K, Oian P, Maltau JM. Laser doppler-recorded reactive hyperaemia in the forearm skin during the menstrual cycle. Br J Obstet Gynaecol. 1996 Jan;103(1):70-5.

15. Seifalian AM, Stansby G, Jackson A, Howell K, Hamilton G. Comparison of laser Doppler perfusion imaging, laser Doppler flowmetry, and thermographic imaging for assessment of blood flow in human skin. Eur J Vasc Surg. 1994

Jan;8(1):65-9.

16. Black CM, Clark RP, Darton K, Goff MR, Norman TD, Spikes HA. A pyroelectric thermal imaging system for use in medical diagnosis. J Biomed Eng. 1990 Jul;12(4):281-6.

17. Morales F, Graaff R, Smit AJ, Bertuglia S, Petoukhova AL, Steenbergen W, Leger P, Rakhorst G. How to assess post-occlusive reactive hyperaemia by means of laser Doppler perfusion monitoring: application of a standardised protocol to patients with peripheral arterial obstructive disease. Microvasc Res. 2005 Jan;69(1-2):17-23.

18. Tee GB, Rasool AH, Halim AS, Rahman AR. Dependence of human forearm skin postocclusive reactive hyperemia on occlusion time. J Pharmacol Toxicol Methods. 2004 Jul-Aug;50(1):73-8.

19. Svensson H, Jonsson BA. Laser Doppler flowmetry during hyperaemic reactions in the skin. Int J Microcirc Clin Exp. 1988 Jan;7(1):87-96.

20. Stoner HB, Barker P, Riding GS, Hazlehurst DE, Taylor L, Marcuson RW. Relationships between skin temperature and perfusion in the arm and leg. Clin Physiol. 1991 Jan;11(1):27-40.

21. Johnson JM, Brengelmann GL, Hales JR, Vanhoutte PM, Wenger CB. Regulation of the cutaneous circulation. Fed Proc. 1986 Dec;45(13):2841-50.

22. Bornmyr S, Svensson H, Lilja B, Sundkvist G. Skin temperature changes and changes in skin blood flow monitored with laser Doppler flowmetry and imaging: a methodological study in normal humans. Clin Physiol. 1997 Jan;17(1):71-81.