

SUPERFICIAL THERMAL GRADIENTS DURING MILD BODY COOLING AND ITS RELATIONSHIP TO FOREARM BLOOD FLOW

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Abstract: Forearm and fingertip temperature gradients were related to simultaneously measured forearm blood flow in eleven adult subjects at rest and during a mild cold stimulus. The change in temperature gradients were converted into a percentage change of the potential capacity for heat exchange and this was found to correlate well ($r = 0.73$; $P < 0.001$) with the absolute reduction in forearm blood flow.

Key words : forearm-fingertip temperature gradient forearm blood flow
thermal gradient

INTRODUCTION

Surface skin temperature recordings in the form of finger tip temperatures, core body to peripheral temperature gradients and forearm to finger tip temperature gradients have been used as indicators of peripheral vascular change in response to a thermal stress (4, 5, 7). Temperature gradients are easy to measure, inexpensive and can be used in certain specialised situations like the peri anaesthetic period (1), unlike more direct methods of blood flow measurement such as venous occlusion plethysmography. While earlier studies have utilised surface temperature gradients to determine directional changes in blood flow response to cold stress (2, 3, 4), no attempts have been made to determine whether these thermal gradients can be used to quantitate absolute reduction in regional blood flow. The present study was carried out with the intention of exploring the relationship between surface skin thermal gradients and simultaneously measured peripheral blood flow through the forearm to determine whether the measurements of the former could be used to predict the latter when the core temperature is constant. The inclusion of ambient temperature as a variable of the surface thermal

gradients is an additional feature which may be beneficial in studies carried out under changing ambient temperatures.

METHODS

The skin surface temperature gradients and the forearm blood flow was measured in eleven healthy male volunteers. They had a body mass index (wt in kg/ht in m²) ranging between 17 and 25. They abstained from smoking and caffeinated beverages for at least 12 hours prior to the start of the experiment. All the subjects were studied in a fasted state after a mandatory rest period of at least 45 minutes. Height, weight and skinfold measurements (biceps, triceps subscapular and suprailiac) were taken as part of anthropometric assessment. The sum of these four skinfold thicknesses were used to estimate the body composition in terms of fat and fat free mass, applying the age and gender specific equations of Durnin and Womersley (13). The cold stimulus was delivered through 40 m of plastic tubing, would round the trunk of the subject. Cold water was pumped into the tube at a rate of 1500 ml/min from a cooling reservoir (colora, West Germany). In each study, the tubing was left unperfused for 30

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min to obtain basal measurements. The average of three measurements taken 5 min apart was taken as the basal value. The tube was then perfused with water at 13°C for 40 min, and blood flow and skin temperatures were recorded every 5 minutes. Right forearm blood flow was determined by venous occlusion plethysmography, using a mercury-in-rubber strain gauge. A pediatric wrist cuff of width 6 cm was applied and inflated to high pressure, (200 mm Hg) for 1 min before the recording of blood flow to isolate volume of the hand, from the forearm. A tourniquet around the upper arm was rapidly inflated to 60 mm Hg for 10 s by connecting it to a cylinder of compressed nitrogen through a pressure valve. The output from the plethysmograph was amplified and recorded using an ink jet recorder (Polyrite recorder, Ambala). The strain gauge was calibrated for a unit change in circumference and the rate of increase in forearm volume is used to compute the blood flow in ml/minute.

Thermal measurements were made using IC thermal sensors (LM 335) with a sensitivity of 0.1°C. The responses were linear between 50°C and 125°C and were calibrated using a single point calibration. Superficial temperatures were measured on the fingertip and the extensor aspect of the forearm. The deep body temperature was obtained using a plastic aural probe, fitted into the ear, insulated with cotton and fixed with an elastocrepe bandage.

The parameter described below was derived in order to correlate the blood flow with the thermal gradient in relation to the ambient temperature:

At rest, the forearm and fingertip temperature do not differ significantly from each other, and both are considerably higher than the ambient temperature. The potential capacity for heat exchange is taken as the temperature difference between the forearm and the ambient temperature. With cooling there is a decrease in the capacity for heat exchange because of vasoconstriction in the forearm and in the fingertip. Vasoconstriction in the fingertip is more than the forearm, causing a greater fall in the fingertip temperature as well as creating a forearm fingertip temperature gradient. As the duration and the intensity of the cold stimulus increases, this gradient also increases. At any point in time the ratio of this gradient

to the forearm - ambient temperature gradient (potential capacity) would give the degree of vasoconstriction. This gradient is converted into a percentage of the resting forearm ambient gradient as shown below:

$$\text{Reduction in thermal gradient} = \frac{(\text{FA} - \text{FN}) \text{ at } T}{(\text{FA} - \text{AMB}) \text{ at } T} \times 100$$

FA - FN = Forearm temperature - finger temperature.

FA - AMB = Forearm temperature - ambient temperature

T = Time

If the forearm - finger tip temperature gradient equals the forearm - ambient temperature gradient, then the reduction in the capacity for heat exchange is 100 percent. The percent reduction in forearm - fingertip temperature gradient derived as described above will be henceforth referred to as the thermal gradient.

Ethical approval :

This study was approved by the Ethical Committee of St. Johns Medical College and all the subjects gave fully informed consent to participate in the study.

Statistics :

Results are expressed as means \pm sem. The paired student 't' test was applied to compare the blood flow and thermal gradients before and after cooling. $P < 0.05$ was considered a significant difference. The pooled data from the subjects was used to assess the correlation between thermal gradients and blood flow.

RESULTS

Data from 10 subjects are included in the analysis, as the thermal gradient could not be calculated in one subject.

The mean age of the subjects was 22 ± 5.5 years, weight was 56 ± 13.0 kg and height was 1.66 ± 0.07 m. The average ambient temperature was 28.3°C and did not vary more than 1°C during any experiment.

Core temperature: The basal core temperature was $36.6^\circ + 0.3^\circ\text{C}$. There was no significant fall in

core body temperature with cooling.

Forearm blood flow: On exposure to cold, the forearm blood flow decreased by a variable amount i.e. 20% - 80% from a resting forearm blood flow of $3.73 \text{ ml} \pm 2.26 \text{ ml } 100 \text{ gms min}$.

Thermal gradient and its relationship to forearm blood flow: Thermal gradient refers to the forearm - fingertip temperature gradient derived as shown above.

between the two parameters ($r = 0.73$; $P 0.01$) and the percent reduction in thermal gradient (mean = 39.53; range 0-78%) was not significantly different from the percent reduction in forearm blood flow (mean = 39.31; range 0-83%. The correlation is better for the later half of the cooling period ($r = 0.81$; $P 0.01$). During the initial part of cooling, both thermal gradients and blood flow are in a non steady state and a difference in the rate of change

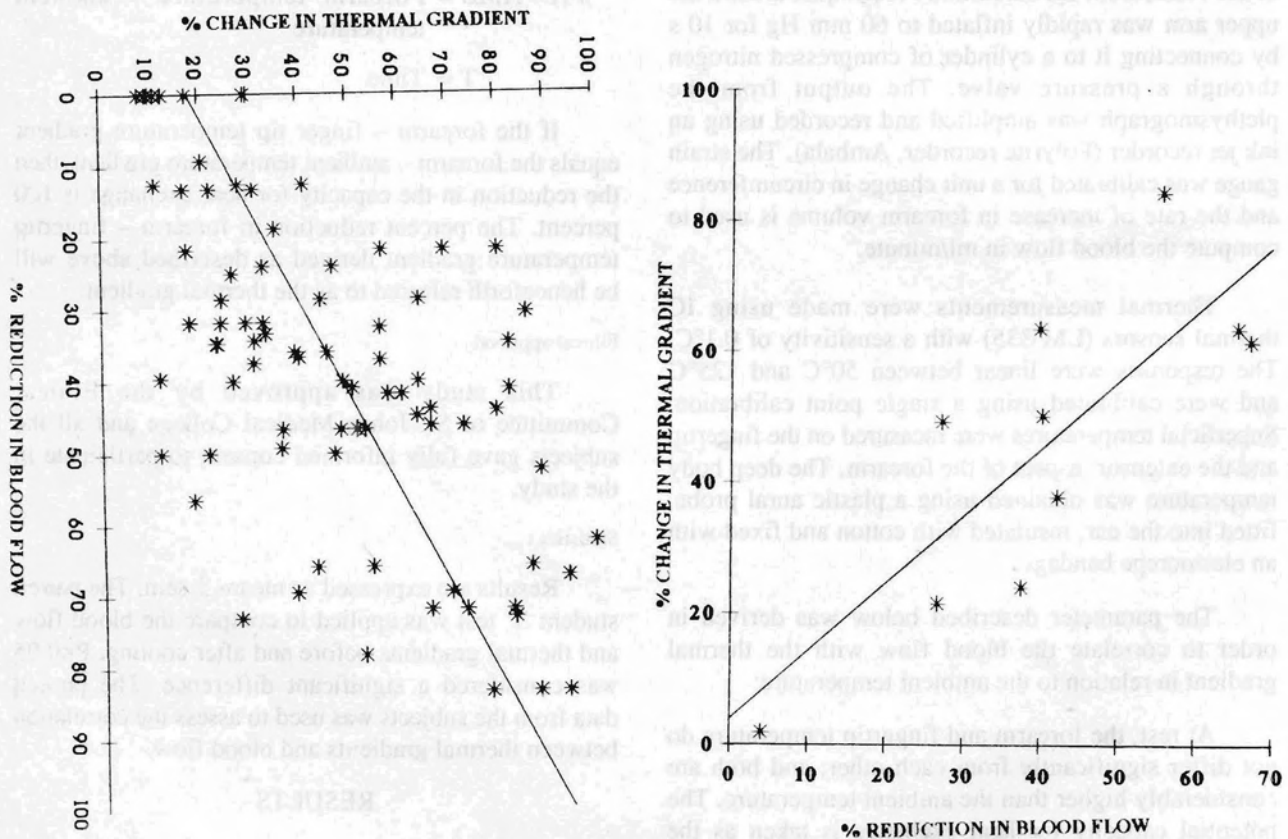


Fig. 1: Correlation between thermal gradient expressed as the percentage reduction in the potential capacity for heat exchange and the percentage reduction in blood flow.

Fig. 1a - pooled data points over 40 minutes, $r = 0.73$

$P < 0.01$.

Fig. 1b - 10 subjects. $r = 0.78$; $P < 0.001$.

Fig. 1 correlates the percent reduction in thermal gradient to the percent reduction in forearm blood flow. There was a significant overall correlation

might account for the poor correlation in the initial phase (Table I). Though the values form a homogenous set throughout the duration of the experiment, the

TABLE I : Correlation between thermal gradients and blood flow during cooling.

Time	Corr
5	0.37
10	0.55
15	0.57
20	0.48
25	0.83*
30	0.80*
35	0.77*
40	0.90*

*P < 0.001

correlation is better in the later half where both the parameters reach a near steady state (Fig 2).

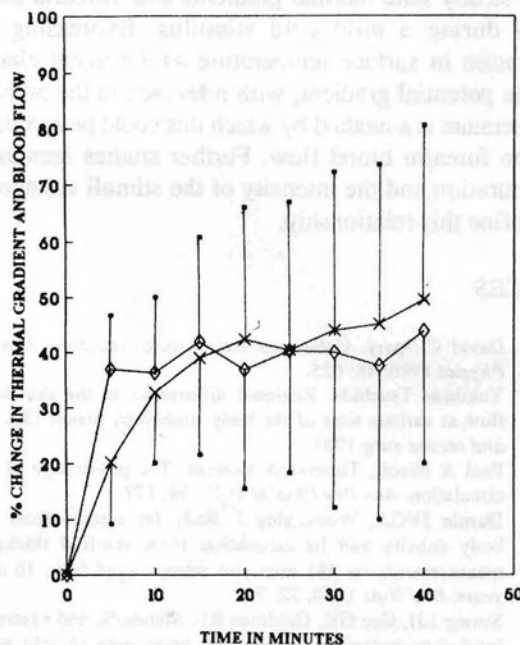


Fig. 2 : The percentage change in thermal gradient and forearm blood flow (mean + sd) for the duration of cooling (40 minutes).

Forearm blood flow.

Thermal gradient.

Skin temperatures: At rest, there was no significant difference between forearm and fingertip temperature. With cooling, there was a fall in skin temperature at both sites. The fingertip temperature decreased by 2.41°C (P 0.001), and the forearm temperature decreased by 0.55°C (P 0.05).

The reduction in forearm blood flow correlated inversely with the percent fat tissue of the individual as shown in Fig. 3.

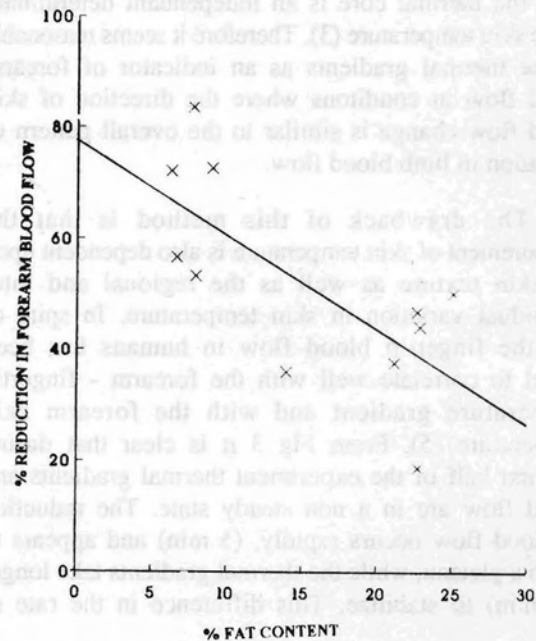


Fig. 3 : Correlation between the percent reduction in forearm blood flow with cooling and fat mass in 11 subjects. r = 0.80 P < 0.01. The fat mass was derived using the equation of Durnin and Womersley.

DISCUSSION

The stimulus that was delivered was a cold stimulus of a mild nature, as evidenced by the absence of a fall in core body temperature. This uniform stimulus was applied to a group of subjects who varied considerably in body composition; who could therefore be expected to vary in their responses (both thermal and vascular) to cold, in keeping with earlier reports relating body composition and responses to cold (14,17).

Total skin blood flow consists of nutrient or capillary flow and arteriovenous (a-v) anastomoses flow. A cold stimulus causes vasoconstriction of arteriovenous anastomosis, so that the a-v shunt flow decreases significantly. The distribution of a-v anastomotic vessels is variable, such that they are numerous in the digits, particularly in the fingertips and minimal in the forearm skin. Therefore, a cold stimulus which primarily

constricts the a-v shunts would be expected to produce a larger temperature drop at the fingertip compared to the forearm. It has been found that in areas where the a-v shunt vessels are absent or minimal, heat conduction from the thermal core is an independent determinant of the skin temperature (3). Therefore it seems reasonable to use thermal gradients as an indicator of forearm blood flow in conditions where the direction of skin blood flow change is similar to the overall pattern of alteration in limb blood flow.

The drawback of this method is that the measurement of skin temperature is also dependent upon the skin texture as well as the regional and inter individual variation in skin temperature. In spite of this the fingertip blood flow in humans has been found to correlate well with the forearm - fingertip temperature gradient and with the forearm skin temperature (5). From Fig 3 it is clear that during the first half of the experiment thermal gradients and blood flow are in a non steady state. The reduction in blood flow occurs rapidly, (5 min) and appears to reach a plateau, while the thermal gradients take longer (20 min) to stabilize. This difference in the rate of

change of the two parameters could explain the initial lack of correlation. It is also possible that the extent of the individual response to the stimulus could determine the strength of this relationship, such that those subjects with a smaller reduction in forearm blood flow could have a poorer relationship with thermal gradient. Though our subjects responded with a wide range of reduction in blood flow this hypothesis could not be tested because their number was not adequate. The measurement of thermal gradients is not a substitute for the measurement of blood flow, but it is useful in situations where it is not possible to measure blood flow directly and the core temperature does not alter.

In summary, there is a good correlation between near steady state thermal gradients and forearm blood flow during a mild cold stimulus. Expressing the alteration in surface temperature as a percent change of the potential gradient, with reference to the ambient temperature is a method by which this could be correlated to the forearm blood flow. Further studies increasing the duration and the intensity of the stimuli are needed to define this relationship.

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