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EVIDENCE FROM VENOUS OXYGEN SATURATION MEASUREMENTS THAT THE INCREASE IN FORE-ARM BLOOD FLOW DURING BODY HEATING IS CONFINED TO THE SKIN

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Barcroft, Bonnar & Edholm (1947) demonstrated that body heating caused a reflex dilatation of the vessels of the forearm, and they concluded that the dilatation was for the most part deep to skin, most probably in the skeletal muscles. Recent and independent experiments by these authors, however, suggest that the dilatation is confined to the skin. Barcroft, Bock, Hensel & Kitchin (1955) found that the muscle blood flow during body heating, as gauged by a thermo-electric needle, remained unchanged or was decreased, and Edholm, Fox & Macpherson (1956) found that the increase in forearm flow could be prevented by the iontophoresis of adrenaline into the forearm skin. These observations are in keeping with the finding that the rate of clearance of ^{24}Na from the muscle is not increased during body heating (McGirr, 1952).

Assuming that the arterial oxygen content and the metabolism of a tissue or organ remains constant, changes in the oxygen content of the venous blood will indicate changes in blood flow. We have applied this principle to the forearm in an attempt to study simultaneously changes in skin and muscle blood flow, and evidence is presented which confirms that the forearm dilatation during body heating is confined to the skin vessels.

METHODS

The subjects were healthy men aged 18–30 years. The room temperature was 17–19° C and the subjects were lightly clad in order to keep them cool. This ensured that their vascular tone was high during the initial part of the experiment. Two nylon catheters were inserted centrifugally via thin-walled needles into veins of one forearm; one was introduced into a superficial vein and the other into a deep vein in the antecubital fossa. For the deep vein catheterization the technique outlined by Mottram (1955) was used, except that after withdrawal of samples the dead space of the catheter was filled with saline containing heparin to prevent clotting, instead of using a continuous infusion of saline. Except for brief periods the circulation was arrested at the wrist by a pneumatic cuff inflated to a pressure of 220 mm Hg. The percentage oxygen saturation of 1 ml. blood samples was determined immediately after withdrawal by a spectrophotometric technique (Roddie, Shepherd & Whelan, 1956*a*). The rapidity with which the samples were analysed enabled the course of the experiment to be adjusted in the light of the blood changes. In most of the experiments the blood flow through the opposite forearm was measured by venous occlusion plethysmography, using the stirred, temperature-controlled plethysmograph described by Greenfield (1954). Body (indirect) heating was carried out by immersing the feet and calves in a water-bath at 43–45° C and wrapping the subject in blankets (Lewis & Pickering, 1931; Gibbon & Landis, 1932).

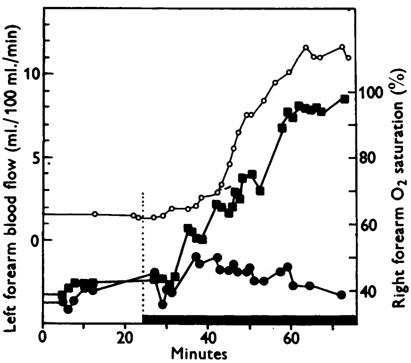

Fig. 1

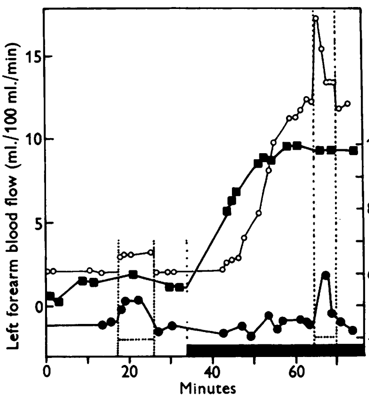

Fig. 2

Fig. 1. The effect of body heating on the oxygen saturation of deep and superficial venous blood and forearm blood flow. The black rectangle represents the period of body heating. ○, left forearm blood flow; ■, oxygen saturation of superficial venous blood (right forearm); ●, oxygen saturation of deep venous blood (right forearm).

Fig. 2. The effect of body heating and of change of posture on the oxygen saturation of deep and superficial forearm venous blood. Conventions as in Fig. 1. The intervals between the dotted lines represent the periods during which the subject's legs were passively raised.

RESULTS

Eight experiments were carried out, each on a different subject. The results of a typical experiment are shown in Fig. 1. Initially the oxygen saturation of the superficial venous blood was about 40 % and that of the deep blood 38 %. During body heating the saturation of the superficial blood rose rapidly, reaching 95 % in 35 min, while that from the deep vein showed no tendency to increase and remained between 40 and 50 % throughout. The blood flow through the opposite forearm increased from 1·7 to 11 ml./100 ml./min. A similar experiment is shown in Fig. 2, but in addition to the heating the legs were passively elevated before and at the end of body heating to produce a reflex dilatation in the deep forearm vessels (Roddie & Shepherd, 1956). This caused an increase in the forearm blood flow and a rise in the oxygen saturation of the deep blood samples. The results of all the experiments are summarized in Table 1. It can be seen that in every case during heating the skin blood reached 85–99 % saturation without any corresponding change in the saturation of the deep samples. In one of these experiments the oxygen saturation of the deep venous blood increased gradually from 38 to 53 % during the heating, and this was attributed to some of the blood from the skin veins draining into the deep vein catheterized.

TABLE 1. The effect of body heating on the oxygen saturation of blood from deep and superficial forearm veins

Subject	Vein	Oxygen saturation (%)				
		Before heating	After heating			
			10 min	20 min	30 min	40 min
J. K. N.	Deep	43	42	47	44	42
	Superficial	56	80	94	99	98
J. J. C.	Deep	48	40	42	55	41
	Superficial	56	59	81	93	99
W. F. M. W.	Deep	42	40	45	50	53
	Superficial	50	53	85	95	97
J. Q.	Deep	37	45	46	42	41
	Superficial	42	59	66	75	94
R. A.	Deep	55	49	—	55	—
	Superficial	40	54	—	96	—
D. B.	Deep	49	—	49	43	43
	Superficial	42	—	75	80	88
J. E. B.	Deep	47	—	37	49	—
	Superficial	58	—	69	88	—
D. R. C.	Deep	45	—	—	45	—
	Superficial	72	—	—	85	—

DISCUSSION

In order to interpret changes in venous oxygen saturation in terms of changes in blood flow the assumption is made that (*a*) the arterial oxygen saturation, and (*b*) the local tissue metabolism remain unchanged throughout the procedure. In order to use the method to study simultaneously changes in the flow through forearm skin and muscle it must be shown in addition, (*c*) that the deep and superficial veins catheterized drain mainly muscle and skin respectively, and (*d*) that there is no important degree of mixing between the two streams.

(*a*) In two experiments the oxygen saturation of blood samples withdrawn from the brachial artery showed no significant change during body heating.

(*b*) The following experiment suggests that the body heating did not alter to any important degree the metabolism of the forearm tissues. After infiltrating around the deep nerves to the forearm with local anaesthetic solution the oxygen saturation of the blood samples from superficial and deep forearm veins increased to about 65 % (Fig. 3) owing to release of vasoconstrictor tone (Roddie, Shepherd & Whelan, 1956*b*). Body heating was then carried out and the oxygen saturation of the blood from the two sites remained virtually unchanged.

(*c*) Rhythmic exercise of the forearm muscles during the resting period before nerve block (Fig. 3) resulted in an increased saturation of the deep blood with no increase in that of the superficial. This demonstrated that the deep vein was draining mainly muscle and that the superficial vein was draining mainly skin.

(*d*) The evidence that there was no important degree of mixing between the blood in the superficial and deep forearm veins in the present experiments rests on the fact that the saturation of the deep blood samples remained unchanged during body heating while that of the superficial increased almost to

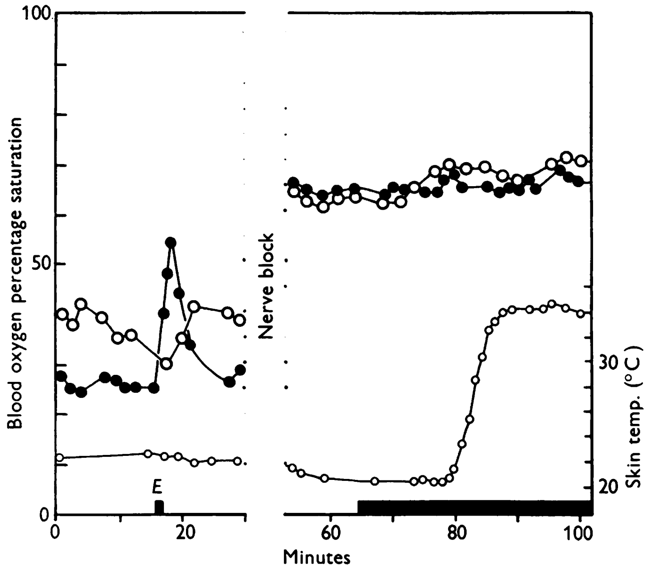

Fig. 3. The effect of body heating on the oxygen saturation of deep and superficial forearm venous blood following blocking of the nerves to the forearm with local anaesthetic. The black rectangle represents the period of body heating. At *E* the subject exercised the left forearm for 1 min. ●, oxygen saturation of deep venous blood (left forearm); ○, oxygen saturation of superficial venous blood (left forearm); o, skin temperature of pulp of the right index finger.

arterial level. The possibility cannot be excluded, however, that the blood flow through the muscle may decrease during body heating (McGirr, 1952; Barcroft *et al.* 1955). If this occurred, the fact that the oxygen saturation of the deep blood did not change could be explained by contamination of the deep blood by the superficial to a degree sufficient to leave the oxygen saturation unchanged. It seems unlikely that such a fine balance could be maintained at a time when the skin vessels were undergoing a rapid change in calibre. It is, evident, however, that heating does not result in vasodilatation in the muscle.

The numerous connexions between the superficial and the deep veins of the forearm indicate that mixing of the two streams is possible and the demonstration that there was no important degree of mixing in the present circumstances does not imply that it may not occur in others. Mottram (1954) demonstrated that during the inflation to 60 mm Hg of a pneumatic cuff around the upper arm the oxygen content of the blood from the deep forearm vein increased often by as much as 4 vol. % and in some experiments approached that of arterial blood. Mottram attributed this increase to an opening up of non-metabolic

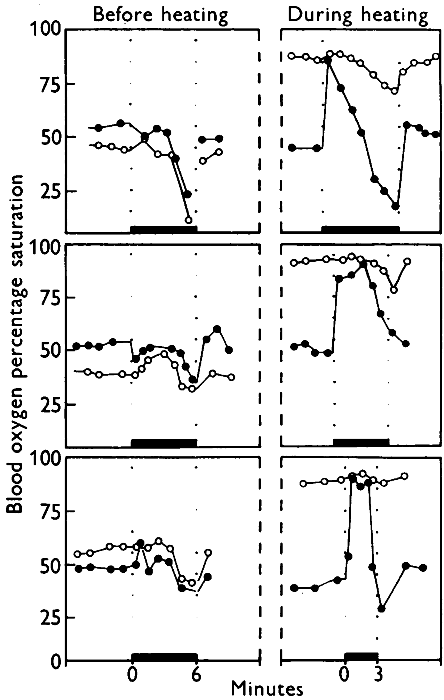

Fig. 4. The effect on the oxygen saturation of blood from deep and superficial forearm veins of inflating to 60 mm Hg a pneumatic cuff on the arm before and during body heating (three subjects). Left, before body heating; Right, during body heating; ●, oxygen saturation of deep venous blood; ○, oxygen saturation of superficial venous blood. The black rectangles represent the periods of cuff inflation.

pathways in the muscle as a result of the application of the cuff pressure. We have studied this phenomenon in three subjects before and during body heating (Fig. 4). Before heating commenced and when the subject was cool the application of 60 mm Hg pressure to the cuff produced a variety of changes. If the oxygen saturation of the superficial blood was higher than that of the deep, the deep samples showed an increase in saturation and vice versa. If the venous occluding pressure was left on for some minutes, both the superficial and the deep saturations decreased. After about 30 min of body heating, when the superficial blood oxygen saturation approached arterial level and the deep was unchanged, application of the venous occluding pressure was followed by a very rapid and striking increase in the saturation of the deep samples, to approach that of the superficial blood. These observations suggest that the phenomenon described by Mottram can be explained by the mixing of superficial with deep venous blood when the venous occluding pressure is applied, and is a consequence of the altered venous haemodynamics during application of such a pressure.

Deductions regarding changes in forearm skin or muscle flow from changes in oxygen saturation of superficial and deep venous blood samples can only be made if there is shown to be no important degree of mixing of the blood in the two streams as a result of the procedure under study.

It is believed that in the present experiments this condition is fulfilled. The finding that the oxygen saturation of blood from superficial veins rose to near arterial level and that from deep veins did not change demonstrates that the increase in forearm flow brought about by body heating can be attributed to a dilatation of skin vessels only. This conclusion is in keeping with the recent observations of other workers using different techniques.

SUMMARY

1. The oxygen saturation of blood samples withdrawn simultaneously from a superficial and a deep forearm vein has been determined before and during body heating in eight subjects.

2. During 30–40 min heating the saturation of the superficial samples gradually increased from 40–72% up to 85–99%. There was no increase in the oxygen saturation of the deep samples.

3. Evidence is presented that the superficial vein was draining mainly skin and the deep vein mainly muscle. The arterial oxygen saturation and the metabolism of the forearm tissues were unchanged by the heating. The changes in the venous oxygen saturation, therefore, reflected changes in blood flow in skin and muscle.

4. It is concluded that the increase in the blood flow through the forearm with body heating is entirely due to an increase in the blood flow through the skin.

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