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THE EFFECT OF THE POSITION OF THE ARM ON THE OXYGEN SATURATION OF THE EFFLUENT BLOOD

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It has recently been suggested (Gaskell & Burton, 1953) that when a limb is lowered the resulting distension of the veins causes a local reflex vasoconstriction. The evidence put forward in support of this suggestion consists of plethysmographic records of blood flow in the digits. An alternative explanation of the phenomenon of 'after-drop' seen in such records has since been proposed by Gaskell (1955) and Allwood (1955).

The relationship between the posture and the blood flow of a limb has been studied by other methods. Roth, Williams & Sheard (1938) found that the skin temperature of the toes and fingers decreased when the extremities were elevated and increased when the extremities were pendent. Reports of the effect of tilting the whole body on the skin temperature of the digits have been conflicting (Youmans, Akeroyd & Frank, 1935; Mayerson & Toth, 1939; Nielsen, Herrington & Winslow, 1939), but in these experiments the local response to change of posture has been complicated by central reflexes.

Proger & Dexter (1934), using Gibbs's (1933) heated thermocouple, found that the velocity of the blood in the superficial veins of the forearm and in the median basilic vein increased when the arm was lowered. Since, in addition, the veins were distended, this indicated an increase in the volume flow.

A further approach to the problem, and the one employed in the present work, is by way of the oxygen saturation of the venous blood. Wilkins, Halperin & Litter (1950) found that the arterio-venous oxygen difference in both the arm and the leg decreased when the limb was lowered, and thought that the decrease must be attributed to vasodilatation. A similar conclusion was reached by Goldschmidt & Light (1925), who took samples of blood from the dorsal veins of the hand. The present experiments have already been briefly described (Rosensweig, 1955).

METHODS

The subjects (seven healthy young men) sat comfortably in a laboratory at 17·5 – 21·5° C. Ordinary clothing, except jacket, was worn.

The abducted right arm was fully supported by a metal frame, attached to the chair in such a way that it could be swivelled in a frontal plane about an axis through the shoulder joint. The frame could be fixed either in a nearly horizontal position, with the subject's wrist 0–15 cm below the level of the sternal angle, or in a dependent position, with the wrist 43–59 cm below this level. Movement from one position to the other was passive and smooth, and took 10 sec.

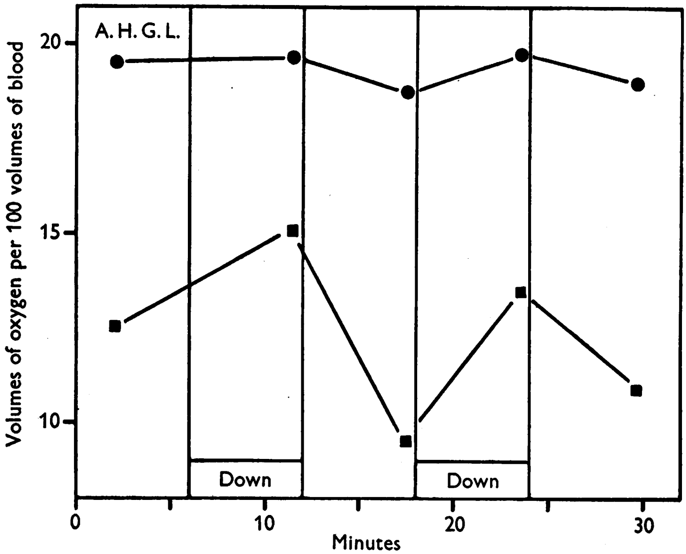

Fig. 1. Oxygen capacity (●) and oxygen content (■) of blood withdrawn from the median cubital vein while the arm was supported alternately in the nearly horizontal and dependent ('Down') positions.

Samples of blood were usually withdrawn through an in-dwelling needle inserted under local anaesthesia ('Novutox', Pharmaceutical Mfg. Co.) into either the median cubital vein or a superficial vein of the forearm. In one case the samples were withdrawn from a deep tributary of the median cubital vein through a nylon catheter, the position of which was determined by palpation. The needle (or catheter) was kept clear by infusing sterile saline (0·9% (w/v) NaCl solution) at 4 ml./min. Before each sample was taken, the infusion apparatus was disconnected and the saline in the 'dead space' was expelled by allowing some blood to run out from the vein.

The samples were drawn into syringes sealed with 1 ml. of sterile paraffin and immediately transferred under paraffin to glass tubes containing potassium oxalate. They were stored at 4° C, and analysed within 8 hr by the volumetric method of Peters & Van Slyke (1932).

RESULTS

Fig. 1 shows the results of a preliminary experiment in which large (10 ml.) samples of blood were withdrawn. The oxygen content of a part of each sample was determined; the remainder of the sample was equilibrated with air and the oxygen capacity was determined. It can be seen that the oxygen content varied considerably, the oxygen capacity only slightly. The values of oxygen saturation of the five samples are 64·3, 76·8, 50·9, 68·2 and 57·5 % respectively. If the oxygen saturation is calculated on the assumption that throughout the experiment the oxygen capacity was equal to that of the final sample, the results are 66·2, 79·7, 50·2, 71·1 and 57·5 %. The difference is very small, and in the main series of experiments the oxygen content of each sample (single estimation) has been expressed as a percentage of the oxygen capacity of a large final sample. The capacity was estimated in duplicate, and on only one occasion did results disagree by as much as 1·25 vol. of oxygen per 100 vol. of blood.

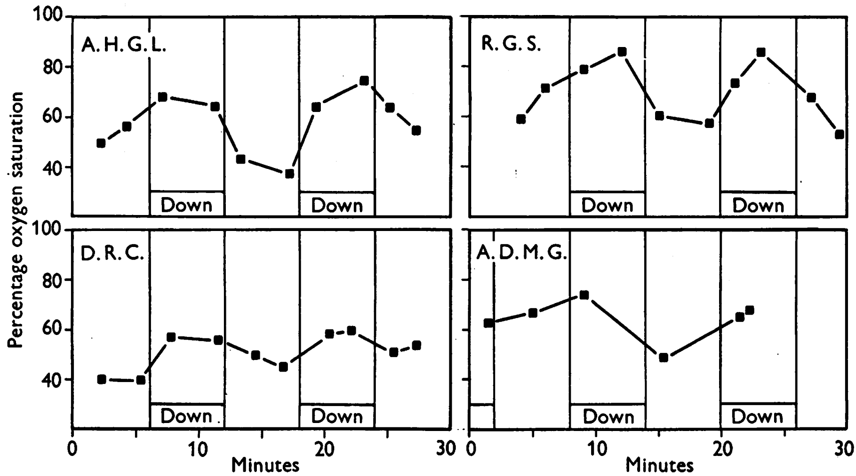

Fig. 2. Percentage oxygen saturation of blood withdrawn from the median cubital vein while the arm was supported alternately in the nearly horizontal and dependent positions.

Fig. 2 shows the results of the four experiments of the main series in which the needle was placed in the median cubital vein. With one exception, the values of oxygen saturation in each period when the arm was dependent were higher than those in the preceding and following periods when the arm was horizontal.

Fig. 3 shows the results of the experiments in which the needle was placed in a superficial vein of the forearm. The effect of the change of position was not so consistent as before. It was sometimes difficult to obtain adequate samples of blood in these experiments, particularly when the arm was horizontal. Where the collection of the sample lasted longer than an arbitrary time of 36 sec, the actual period of collection has been indicated in the figure by the length of the symbol. Occasionally, it was necessary to 'milk' blood proximally along the vein to the needle.

Fig. 4 shows the results of the single experiment in which samples of blood were withdrawn from a deep vein, as described earlier. Here, the oxygen saturation clearly increased when the arm was lowered.

It thus appears that, in general, lowering the arm caused an increase in the oxygen saturation of blood in the veins. The increase was maintained for several min; in one experiment (Fig. 5) it was shown to persist for at least 14 min.

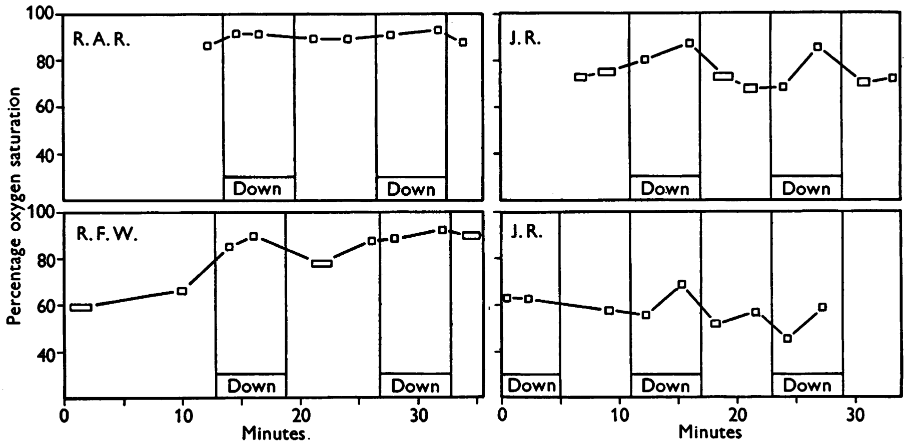

Fig. 3. Percentage oxygen saturation of blood withdrawn from a superficial vein of the forearm while the arm was supported alternately in the nearly horizontal and dependent positions.

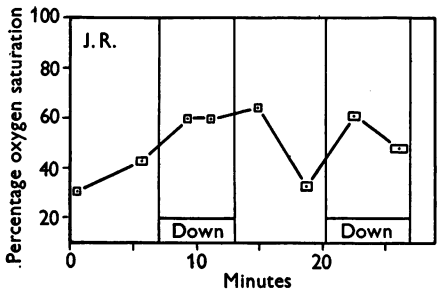

Fig. 4.

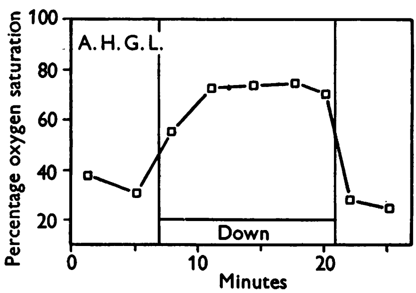

Fig. 5.

Fig. 4. Percentage oxygen saturation of blood withdrawn from a deep vein of the forearm while the arm was supported alternately in the nearly horizontal and dependent positions.

Fig. 5. Percentage oxygen saturation of blood withdrawn from a superficial vein of the forearm before, during and after 14 min in the dependent position.

However, not all the variations in oxygen saturation seen in Figs. 1–5 were due to changes of posture. The oxygen saturation of the venous blood varied appreciably even when the arm remained in one position. This is illustrated in Fig. 6.

The experimental and control results are summarized and compared in Table 1. In the case of the experimental results, 'number of observations' refers to the observations of oxygen saturation while the arm was dependent; 'mean difference' is the average of the amounts by which these observations

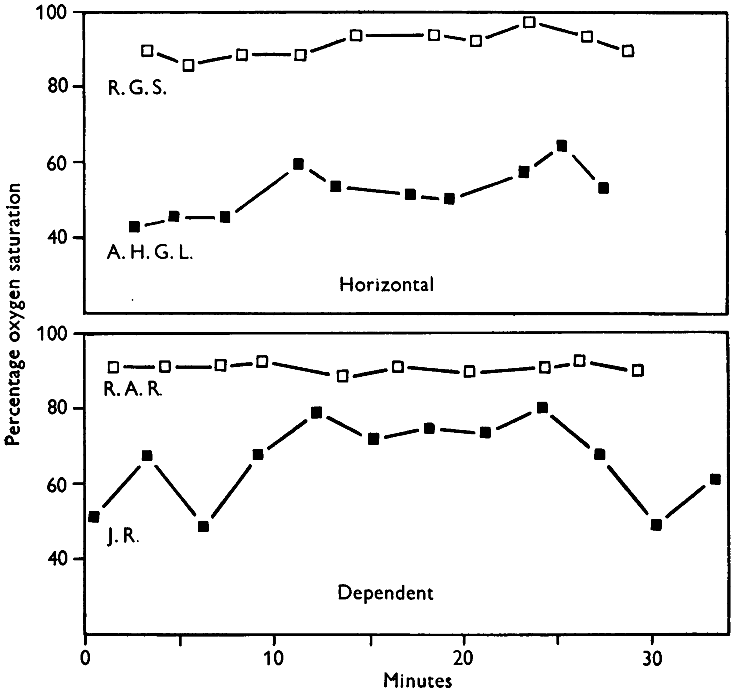

Fig. 6. Changes in percentage oxygen saturation of blood withdrawn from a superficial vein of the forearm (□) or the median cubital vein (■) while the arm was supported in the horizontal (upper frame) or nearly dependent (lower frame) position.

TABLE 1. Comparison of experimental and control results

'Mean difference (experimental)': mean amount by which the percentage oxygen saturation while the arm was dependent exceeded the mean saturation in the preceding and following periods when the arm was horizontal.

'Mean difference (control)': mean amount by which any observation of percentage oxygen saturation exceeded (+ve) or was less than (−ve) the mean of the two preceding and the two following observations.

'Significance': result of 'Student's' *t* test of significance of difference between means.

	Superficial vein		Median cubital vein	
	Experimental	Control	Experimental	Control
Number of observations	14	12	13	14
Mean difference	+7·04	+0·24	+16·7	+0·06
Standard error of mean	1·63	0·61	1·52	2·1
Significance	$0{\cdot}01 > P > 0{\cdot}001$		$0{\cdot}001 > P$	

exceeded the mean of the observations relating to the preceding and following periods when the arm was horizontal (where only one sample could be obtained during such a period it was assumed that a second sample would have given the same result). The mean difference for the control results is the average of the amounts by which individual observations exceeded (+ve) or were less than (−ve) the mean of the two preceding and the two following observations. As many of the control results as possible were treated in this way (i.e. all except the first two and the last two of each set). The difference between the experimental mean and the control mean is significant in the case of the superficial veins, and highly significant in the case of the median cubital vein.

DISCUSSION

The results show that when the arm was lowered there was a significant increase in the oxygen saturation of the blood in the superficial veins and in the median cubital vein.

The oxygen saturation of venous blood is related to three factors: (1) the oxygen saturation of the arterial blood, (2) the oxygen consumption of the tissues drained by the vein concerned, and (3) the rate of blood flow through these tissues. The relationship is expressed in the equation

$$\text{Blood flow} = \text{oxygen consumption}/(\text{art. satn.} - \text{ven. satn.}).$$

Thus, the increase in the oxygen saturation of venous blood (ven. satn.) on lowering the arm indicates an increase in blood flow, provided that (*a*) the saturation of arterial blood (art. satn.) is constant, and (*b*) the oxygen consumption of the tissues is constant. Variation of factors (*a*) and (*b*) does not invalidate this statement in a statistical sense provided that the variation is random and unrelated to changes in the position of the arm.

It is very unlikely that changing the position of a limb could produce any alteration in the oxygen saturation of the arterial blood. However, it is conceivable that the oxygen consumption of the tissues of a limb might be affected by changes in its position. Mottram (1954) has made observations which suggest that an increase in venous pressure caused by inflating a cuff to 60 mm Hg reduces the oxygen consumption of tissues in the hand and forearm, but it is not known if the effect persists for periods longer than 1 min. A reduction in oxygen consumption as a result of increased venous pressure might explain the increase in oxygen saturation which occurs when the arm is dependent. On the other hand, it is possible that in the present experiments the oxygen consumption in the dependent limb was increased as a result of increased muscular activity consequent upon the necessarily less perfect support in this position.

Because of these uncertainties, one must be cautious in interpreting the results as indicating changes in blood flow. Further, it must be pointed out that the method cannot detect local or transient changes in flow, if these differ from the general changes. Thus, the results do not exclude the possibilities that lowering the arm causes (*a*) an initial decrease in blood flow which lasts a few sec, and then a sustained increase, or (*b*) a sustained decrease in the blood flow through a small volume of tissue, for example the digits, which is obscured by a sustained increase throughout the remaining tissues.

If it is assumed that the oxygen consumption and the arterial oxygen saturation are unaffected by the change in posture, it is reasonable to conclude from the results that lowering the arm produces an increase in the blood flow through most, if not all, of the tissues. An explanation for this effect has been suggested by Tigerstedt (1922). The blood vessels in the arm may be considered as resembling a U-tube of distensible material. When the arm is lowered, the pressure inside the tube increases at each point by an amount equivalent to the height of the column of fluid above it. The increase in pressure is approximately equal in both limbs of the tube, so that the perfusion pressure is unaltered. The pressure in the tissues outside the tube is unchanged (or it may increase slightly), since the fluid in these tissues is not freely mobile. Therefore there is an increase in the effective transmural pressure, and this causes distension of the tube. It is possible that the tension of the muscle fibres in the walls of the resistance vessels increases, but any increase in tension is evidently not sufficient to prevent lengthening of the fibres. The consequent decrease in resistance allows the rate of flow to increase.

The present observations indicate an overall decrease in resistance to flow in the regions contributing to the venous blood samples. A small decrease in resistance to flow through the fingers when the arm was moved to the dependent position has been found by Roddie (1955). Edholm, Moreira & Werner (1954) concluded that the resistance to flow through the forearm was decreased during the application of venous back pressure, and a small decrease in resistance during slight venous congestion of the forearm can be inferred from the observations of Greenfield & Patterson (1954). Thus for the vessels of two of the constituent regions an effect has been reported which is similar to the general effect here described.

SUMMARY

1. Estimations have been made of the oxygen saturation of samples of blood taken from the arm veins when the arm was alternately horizontal and dependent.

2. The oxygen saturation was found to be higher during the periods of dependency.

3. If the oxygen saturation of arterial blood and the oxygen consumption of the relevant tissues are assumed to have been unaffected by the change in posture, the raised oxygen saturation of the venous blood indicates that the

blood flow was greater when the arm was dependent, though the possibility of a local or transient decrease cannot be excluded.

4. The increase in blood flow may be due to distension of the resistance vessels caused by the hydrostatic effect of lowering the arm.

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