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THE BLOOD FLOW IN THE HUMAN ARM DURING SUPINE LEG EXERCISE

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It is commonly taught that the redistribution of blood flow which occurs during leg exercise involves a reduction of blood flow to resting regions of the body. The circulation to the resting arm is considered to share in this redistribution, but the evidence for this is fragmentary. Few previous studies have been specifically concerned with this problem, and much of the available information is in the form of incidental findings.

A number of workers have studied the oxygen content of venous blood from the arm, usually sampling from the basilic vein and always after the completion of exercise. Lundsgaard & Moller (1923*a*, *b*) showed a reduction of the oxygen content of basilic venous blood sampled within 1 min after 1½ min of exercise. They found that this reduction did not persist more than 1 min after exercise had stopped, and that subsequently the oxygen content approached arterial levels. Similar results after short periods of exercise were obtained by Barr, Himwich & Green (1923) and by Weiss & Ellis (1935). Weiss & Ellis concluded that this finding indicated a reduction of blood flow to the arm. Harris & Lipkin (1931), however, found no change in oxygen saturation of basilic venous blood after 4 min of exercise, and Ellis (1932) demonstrated an increased oxygen saturation after 15 min of exercise.

It is very difficult to obtain plethysmographic measurements during exercise, but Christensen, Nielsen & Hannisdahl (1942), using a finger plethysmograph, were able to show a reduction of finger blood flow at the beginning of exercise. Unless exercise was severe this reduction did not persist and blood flow rose above resting levels later in exercise. Christensen & Nielsen (1942) showed that in a cool environment when finger blood flow was low there was no reduction of blood flow with exercise, but during the later part of exercise

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the blood flow increased as had been found in warm environments. Grant (1938), using a forearm plethysmograph, showed a transient increase of blood flow to the forearm together with a transient vasoconstriction in the hand, when the opposite arm was exercised. Lowenthal, Harpuder & Blatt (1952), making similar observations within 30 sec of the cessation of exercise which had lasted for 15 min, found that the forearm blood flow was unchanged, while the blood flow to the hand was increased.

Stewart (1911), when describing his method of hand calorimetry, reported that exercise of one hand resulted in a diminished heat elimination from the opposite hand, and concluded that exercise of one hand was associated with a reciprocal diminution in flow in the resting hand.

Skin temperature changes lag behind changes in skin blood flow, especially when blood flow is decreasing, and are also liable to be unpredictably affected by the onset of sweating. Despite these disadvantages the relative simplicity of the method has resulted in its use by a number of workers. Adae (1876) recorded a decrease in the temperature of the closed hand during walking. Benedict & Parmenter (1929) and Talbot (1931) found a reduction of skin temperature immediately after exercise particularly in the trunk. Most of these experiments involved fairly prolonged exercise and sweating may well have interfered with their results. Christensen *et al.* (1942) and Barger, Greenwood, Di Palma, Stokes & Smith (1949) observed a transient early fall in temperature of the hand during leg exercise.

None of these investigations have provided information about changes in the blood flow to the whole arm during leg exercise. In the first group of experiments described in this paper changes in the arteriovenous oxygen content difference of the whole limb have been studied during and after exercise. Two further groups of experiments have been carried out. Hand calorimetry has been used to give a measure of blood flow changes to skin, while the rate of clearance of intramuscularly injected radioactive sodium has been used to measure changes in blood flow to muscles.

METHODS

The subjects for these experiments were healthy adults, of both sexes, predominantly males, and aged from 20 to 35. All were members of the team or colleagues who understood the nature and purpose of the procedure. They wore light indoor clothing or a cotton operation gown. The room temperature varied from 18 to 23° C and the relative humidity from 40 to 60% but environmental conditions changed little during the course of any one experiment. The subject lay on an X-ray table, and rested for ½–1 hr before the study commenced. Exercise in the supine position was performed on a constant-speed, variable-load bicycle ergometer attached to the foot of the table, and was continued in each case for 10 min.

Axillary vein blood sampling. The relaxed arm lay supinated and abducted about 60° and at the same level as the heart. A cardiac catheter was introduced into a tributary of the median basilic vein under local anaesthesia and its tip was advanced until it lay 1 cm lateral to the thoracic cage as judged by radioscopy. In this position venous blood, including that from the cephalic vein and representative of the whole arm, could be sampled. An indwelling arterial needle was inserted in the brachial artery of the opposite arm. In experiments performed at rest on patients with rheumatic heart disease (Donald, Bishop & Wade, 1955), it has been established that no change in oxygen saturation of axillary venous blood resulted from the presence of the catheter in the vein or from the frequent sampling of blood.

Two or three samples of blood, each 2–3 ml. in volume, were drawn from the catheter and from the arterial needle at rest over a period of 2 min, and the subject was then exercised. Venous samples were taken at the rate of 1–3/min throughout exercise and subsequent recovery, while arterial samples were taken less frequently. All samples were drawn steadily over a timed period. Expired air was collected between the fifth and eighth minutes of exercise for determination of the level of oxygen uptake. The percentage oxygen saturation of each blood sample was estimated in duplicate by a modification of Gatman's spectrophotometric method (Wade, Bishop, Cumming & Donald, 1953). Blood oxygen capacity was estimated by the manometric method of Van Slyke & Neill (Peters & Van Slyke, 1932) on samples taken both at rest and during exercise and which had been rotated in contact with air in a sealed flask for 20 min.

Hand calorimetry. The calorimeter used was a vacuum flask as described by Greenfield & Scarborough (1949). Correction was made for a slight heating effect due to the electrically driven mixing paddle, which was measured before and after each experiment. The hand volume was measured by water displacement at the end of the experiment. It was assumed that the temperature of blood entering the hand was 37° C and the heat elimination was standardized to a calorimeter temperature of 32° C, in the manner described by Cooper, Cross, Greenfield, Hamilton & Scarborough (1949). The subject's shoulders were supported by a bed rest so that the sternal angle was about 30 cm above the table. The hand was allowed to hang over the table, care being taken to avoid compression of the arm against the edge of the table. Observations were made for 20 min before exercise and were continued for up to 60 min after the end of exercise.

Clearance rate of radioactive sodium from forearm muscle. The technique described by Kety (1949) was followed. From 5 to 10 μc ^{24}Na as 0·5 ml. of normal saline were injected into the muscle of the common extensor group of the forearm. The injection was made at a site one-third of the distance from the olecranon process to the radial styloid process, and at a depth of 2·5 cm. With the needle used there was very little leaking back along the needle track and any trace of the injected fluid was carefully removed from the skin. A Geiger–Müller counter of the type described by Myant, Pochin & Goldie (1949) was placed against the site of injection. Minute counts were recorded for 10 min at rest and then during the 10 min of exercise, and the results plotted on semi-logarithmic paper.

RESULTS

Axillary venous blood sampling

Nine subjects were studied, and they have been divided into three groups according to the level of work performed. The subjects in group A (NA 1–3) had a mean oxygen uptake during exercise of 1157 ml./min/m^2 (range 1089–1201), the subjects in group B (NA 4–6) had a mean oxygen uptake of 718 ml./min/m^2 (range 682–758) and the subjects of group C (NA 7–9) had a mean oxygen uptake of 567 ml./min/m^2 (range 483–618). Details of the subjects with their oxygen uptake, the mechanical work performed during exercise, the blood oxygen capacity, arterial oxygen saturation and brachial arterial pressure at rest and during exercise are given in Table 1.

The changes in oxygen saturation of axillary venous blood in each subject are shown in Fig. 1. The changes in arterial oxygen saturation were as found in previous studies (Donald, Bishop, Cumming & Wade, 1955), a slight fall occurring in most subjects during exercise, with a larger fall in two of the three subjects performing the heaviest work.

Axillary venous blood oxygen saturation

This will be considered before, during and after exercise.

At rest the oxygen saturation varied from 71 to 87% with a mean value of 80%.

TABLE 1. Axillary vein sampling in normal subjects. Personal data, exercise oxygen uptake, blood oxygen capacity, arterial oxygen saturation and brachial arterial blood pressure

Subject	Age (years)	S.A. (m^2)	Work (kg m/min/ m^2)	O_2 uptake (ml./min/ m^2)	Blood O_2 capacity (vol. %) Rest	Exercise	Arterial O_2 saturation (%) Rest	Exercise	Brachial artery pressure (mm Hg) Rest	Exercise
NA 1	26	1·94	870	1089	18·7	21·9	97·6	97·0	102/68	178/106
NA 2	31	2·14	910	1180	20·0	20·6	97·5	93·0	130/76	220/92
NA 3	30	2·05	870	1201	20·1	21·9	97·0	93·6	112/60	260/126
NA 4	29	1·94	605	758	22·5	23·3	97·7	96·2	132/80	176/80
NA 5	29	1·98	485	682	20·0	20·7	96·7	94·6	128/74	180/84
NA 6	31	1·87	393	714	21·8	22·5	96·0	96·0	148/80	168/80
NA 7	28	1·57	340	600	18·1	19·0	97·0	95·7	136/76	168/94
NA 8	29	1·88	310	483	21·0	21·5	97·2	96·4	110/60	152/78
NA 9	35	1·67	320	618	18·6	17·8	94·3	94·7	114/82	148/100

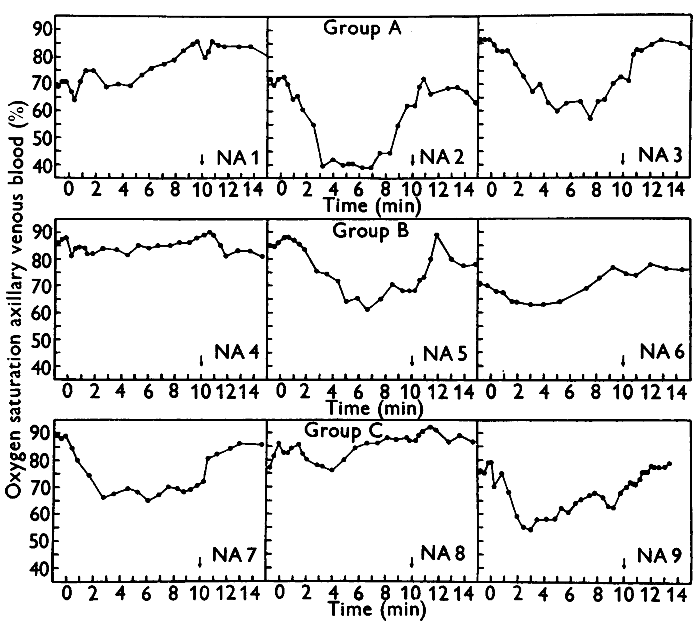

Fig. 1. The axillary venous blood percentage saturation at rest and during exercise and subsequent recovery. Work commenced at zero time and stopped at signal. Subjects grouped according to level of work performed.

During exercise a fall in oxygen saturation was found in all subjects, but this was slight and of short duration in four subjects, particularly in subjects NA1 and NA4. The extent of this fall varied from 3 to 31 %, with a mean value of 16 %, but there appeared to be no relationship between the fall in saturation and the severity of work performed. The lowest oxygen saturation during exercise varied from 40 to 83 % with a mean value of 64 %, and again this was not correlated with the amount of work performed. A slight delay at the beginning of exercise, before a fall in saturation occurred, was observed in two subjects, NA5 and NA8, where the delay was 1·0 and 1·7 min respectively.

The time taken to achieve the lowest oxygen saturation varied greatly and was unrelated to the degree of work performed. The lowest mean minute saturation occurred between the first and eighth minutes of exercise. The four subjects in whom the fall in oxygen saturation was small (NA1, NA4, NA6 and NA8) reached this level earlier (mean 2·0 min) than the subjects in whom there was a larger fall in saturation (mean 4·4 min).

A subsequent rise of saturation was seen in all subjects while exercise continued, but the time of onset and degree of this rise varied considerably. It occurred as early as 0·2 min and as late as 7·5 min. The rise was observed early in the four subjects in whom there had been only a small fall in saturation, and in three of these the final exercising saturation exceeded the resting value, while in the fourth it was equal to the resting value.

In the remaining five subjects, in whom larger falls in saturation had occurred, the rise in axillary venous saturation occurred later, and although the degree of rise was about the same as in the four other subjects the saturation at the end of exercise was still at least 10 % lower than the resting saturation. The final exercising oxygen saturation in the nine subjects varied from 60 to 88 % (mean 75 %).

After exercise. The rise in oxygen saturation which had been taking place towards the end of exercise in all subjects continued after exercise had stopped, except in the case of subject NA1. In this subject there was a fall in saturation during the first minute of recovery, followed by a further rise so that the saturation remained above the resting level until the study ceased at the fifth minute after exercise. The saturation continued to rise in subject NA6, reaching 7 % above the resting level during the third minute of recovery and returning to resting values only in the twelfth minute after exercise had stopped. In subject NA8 the rise of saturation continued to 92 % in the first minute after exercise: it then fell but remained above the resting level. In the remaining subjects the resting level of saturation was reached between the first and third minutes of recovery, although in two subjects (NA2 and NA5) this was followed by a further fall in saturation.

Axillary arteriovenous oxygen content difference

The axillary arteriovenous oxygen content difference (A–V difference) at rest, its maximum value during exercise and its minimum value during late exercise are given in Table 2.

At rest the axillary A–V oxygen difference varied from 1·8 to 5·3 vol. % (mean 3·1 vol. %). Observations have been obtained at rest in a further four normal subjects in all of whom the value lay within this range. The mean axillary A–V difference in these thirteen normal subjects was 3·1 vol. % (S.D. = 1·3).

TABLE 2. Axillary vein sampling in normal subjects. Axillary A–V oxygen difference and total arm blood flow at rest and during exercise

	Axillary A–V O_2 difference (vol. %)			Total arm blood flow (as % of resting)	
Subject	Rest	Max. in exercise	Min. late exercise	Min. in exercise	Max. late exercise
NA1	5·0	6·6	2·9	76	172
NA2	5·0	11·0	7·1	45	70
NA3	2·1	7·6	5·2	27	40
NA4	2·3	3·3	2·2	71	107
NA5	2·2	6·8	5·1	32	43
NA6	5·3	7·4	4·7	72	114
NA7	1·8	5·7	5·0	31	35
NA8	3·2	4·1	2·0	78	158
NA9	3·2	7·0	4·9	46	66

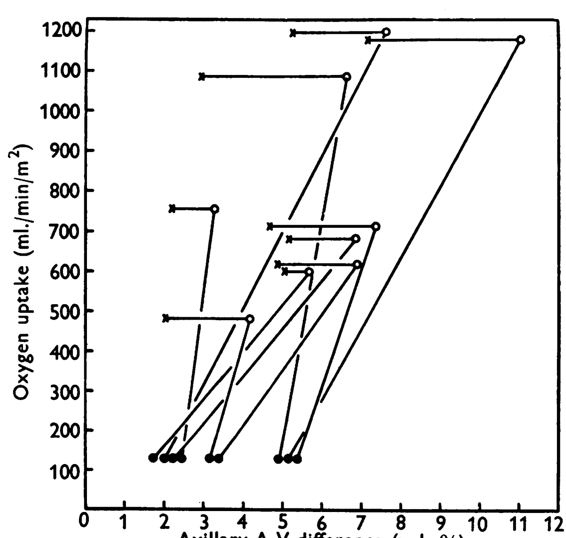

Fig. 2. The relationship of the maximum and minimum axillary A–V oxygen difference to the oxygen uptake during exercise in nine normal subjects. ●, rest; ○, max. in exercise; ×, minimum in late exercise.

During exercise there was an increase in axillary A–V oxygen difference in all subjects, but this increase was transient in several. The relationship of the maximum axillary A–V difference to the oxygen uptake during exercise is shown in Fig. 2. There is a tendency for axillary A–V difference to increase with the amount of work performed, but there is great individual variation. The upper limit of normal resting values was exceeded during exercise in all but two of the subjects.

As exercise continued the axillary A–V difference decreased in all subjects and in four the final exercise value was less than the resting value (Fig. 2). In only one subject did the final exercising value exceed the upper limit of the normal resting range. The tendency for the axillary A–V difference to decrease as exercise continued appeared to be greater in subjects performing the heavier exercise. Thus the mean decrease from the maximum value to the final exercising value was 3·3 vol. % for the subjects in group A, 1·8 vol. % for subjects in group B and 1·6 vol. % for subjects in group C.

Deduced changes in total arm blood flow

If it is assumed that the oxygen uptake of the resting arm is unchanged during leg exercise and that arm blood flow is inversely proportional to the axillary A–V oxygen difference, the total arm blood flow during exercise can be expressed as a percentage of its value at rest. In these subjects the lowest flow was always found during early exercise and varied from 27 to 98 % of the resting flow, with a mean value of 53 % (Table 2). There was no close relationship between this flow and the severity of the work performed. Nevertheless, the three subjects in group A who did the hardest work had a mean minimum total arm blood flow during exercise of 39 % (range 17–48 %) of the normal resting blood flow, while the corresponding figure for the remaining six subjects in groups B and C was 60 % (range 43–95 %).

Later in exercise the total arm blood flow increased, and in four subjects it exceeded the resting value before exercise ceased. This increase did not appear to be related to the severity of work performed.

Hand calorimetry

Ten normal subjects were studied. The oxygen uptake during exercise was not measured, but the mechanical work performed by each subject is given in Table 3.

An attempt was made to follow the changes in heat elimination from minute to minute, because the previous studies had suggested that rapid changes in blood flow to the arm occurred early in exercise. The inevitable errors of this method result in considerable minute to minute variations in such measurements even when subjects are at rest, and to minimize the effect of these variations the group of subjects has been considered as a whole whenever possible. The heat elimination at rest has been taken as the mean value for the 10 min period immediately preceding exercise. This value, together with the lowest heat elimination in any minute during exercise, the highest value during later exercise and the greatest heat elimination during recovery are given for each subject in Table 3. All values have been expressed as calories/min/100 ml. of hand. The results are illustrated in a composite manner in Fig. 3, each minute value representing the mean of the corresponding observations on the ten subjects.

TABLE 3. Heat elimination for hand at rest and during exercise and recovery in normal subjects, with deduced changes in hand blood flow

		Heat elimination. (cal/min/100 ml. hand)				Hand blood flow		
Subject	Work (kg m/min/m²)	Rest	Lowest exercise	Highest late exercise	Highest recovery	Min. exercise (% rest)	Highest exercise (% rest)	Highest recovery (% rest)
NC1	470	42·5	16·5	36·0	65·5	39	85	150
NC2	400	3·8	10·4	80·5	74·4	340	2100	1960
NC3	385	33·3	14·1	46·1	60·4	42	140	180
NC4	375	9·4	5·8	27·8	52·8	62	300	560
NC5	340	7·8	5·4	35·6	63·5	69	460	810
NC6	320	26·2	10·3	32·2	44·0	39	120	170
NC7	320	11·0	5·4	50·4	52·4	49	460	480
NC8	320	19·3	5·0	40·8	78·5	26	210	410
NC9	230	7·7	3·2	4·9	6·5	42	65	85
NC10	190	12·6	6·6	14·6	30·2	52	120	240

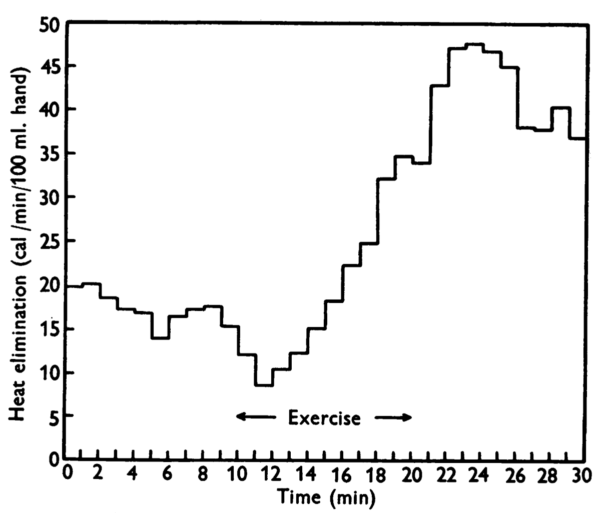

Fig. 3. Heat elimination from the hand at rest, during exercise and subsequent recovery. A composite diagram, each minute value representing the mean of the corresponding observations on ten normal subjects.

Heat elimination at rest. The heat elimination in individual subjects at rest ranged from 3·8 to 42·5 cal/min/100 ml. hand, with a mean value of 17·4 cal/min/100 ml. hand.

Heat elimination during exercise and recovery. During the early part of exercise there was a reduced heat elimination from the hand. The extent of the fall in heat elimination at the beginning of exercise was roughly proportional to the heat elimination at rest (Table 3). The lowest value occurred during the second minute of exercise, and thereafter the heat elimination increased until the resting level was regained during the sixth minute of exercise. The heat elimination continued to increase till the end of exercise and reached a value in the last minute of exercise which was twice the mean value at rest. After stopping exercise there was a still further increase in heat elimination and the highest levels were attained during the third, fourth or fifth minutes after exercise.

Certain individual variations from the mean behaviour were observed. Subject NC2, whose resting heat elimination was the smallest of the group, did not show any further reduction of heat elimination with exercise, and although the value in the second minute was the lowest during exercise, it nevertheless exceeded the resting value.

The increase of heat elimination during the later minutes of exercise was observed in all subjects, but was least in subject NC9 and NC10 who performed the lightest work. In subject NC9 the heat elimination did not exceed the resting value at any time during exercise, and this was also the case in subject NC1 whose resting value was the highest of the group. The resting level of heat elimination was regained at times ranging from the fifth to the tenth minute of exercise.

Deduced changes in hand blood flow

If it is assumed that the blood flow to the hand is proportional to its heat elimination, the blood flow during any minute of exercise may be expressed as a percentage of the resting flow by relating the heat elimination in the two states. The lowest blood flow found in each subject during exercise is given in Table 3. It varied from 26 to 69% of the resting blood flow (mean 50%) if subject NC2 whose resting value was the lowest of the group was excluded.

The mean hand blood flow during the last minute of exercise was twice that at rest before exercise. In individual subjects the range of hand blood flow during this minute was from 2100% of the resting hand blood flow in subject NC2 to 65% in subject NC9. After exercise had ceased, higher levels of blood flow were reached in most subjects, the highest mean value for the group being 274% of the resting hand blood flow in the fourth minute of recovery. The values in individual subjects varied from 1950% in subject NC2 to 150% in subject NC1, while in one subject, NC9, the resting level was not exceeded during recovery.

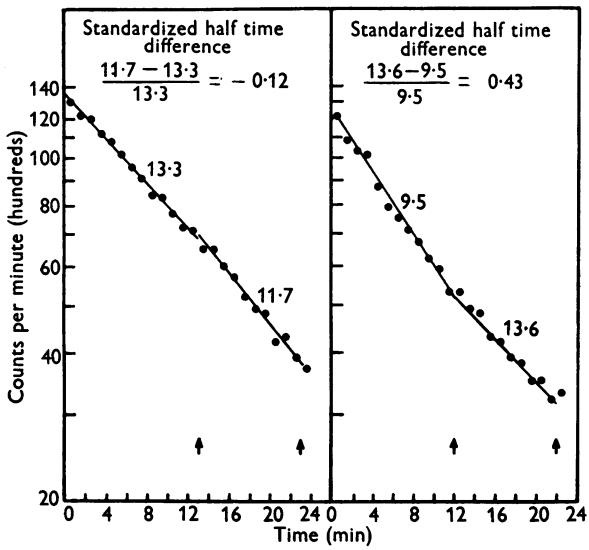

Fig. 4. Clearance of radioactive sodium from forearm muscle. Examples of the decline in minute counts during rest and exercise, indicated by the signal markers, following the injection of 5–10μc ^{24}Na.

Clearance of radioactive sodium from forearm muscle

Twenty-five normal subjects were studied at rest and during exercise. The oxygen uptake was not measured but the mechanical work was recorded and varied from subject to subject. Examples of the results obtained are given in Fig. 4. From these graphs an estimate was made of the slope of the decline in counting rate, this slope being considered proportional to the muscle blood flow. The gradient of the decline has been expressed by the half time of decay and a value for this has been calculated for the resting and exercising states. Frequently the first 2–3 min following the injection gave variable readings, and observations in this period have been disregarded. The fitting of lines to the points on the graphs was difficult, and each graph was therefore examined by different observers on a number of occasions. Each value for the half time represents the mean of several of such examinations. The half time varied greatly from subject to subject at rest and changes in the half time that occurred during exercise were best expressed as a proportion of the resting half time and the term so derived has been called the standardized half time difference (Fig. 4).

Ten other subjects were investigated at rest only, the half time of decay being calculated for the first and second 10 min periods. It was hoped in this way to eliminate any confounding effect resulting from the exercise period occupying a later period in time than the resting period.

Studies at rest only. The half time at rest in these ten subjects varied from 7·6 to 16·6 min and the difference between the half time for the first and second 10 min periods varied from −0·8 to +5·5 min. The standardized half time difference had a mean value of +0·182 (S.D. 0·222).

Studies at rest and on exercise. The half time at rest in these twenty-five subjects varied from 6·9 to 19·8 min and the difference between the half time for the resting and exercise states varied from −4·2 to +17·6 min.

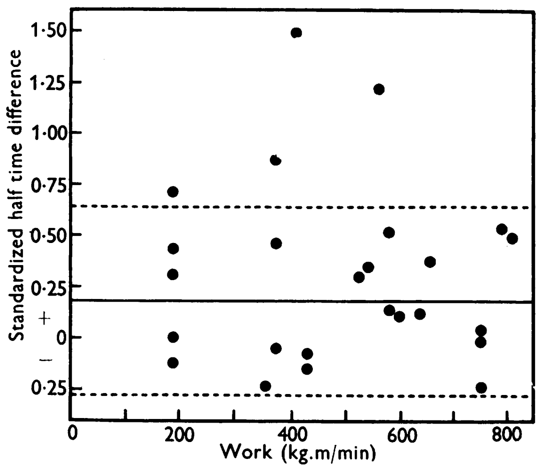

Fig. 5. Relationship of the differences between the standardized half times for the resting and the exercising states to the level of mechanical work performed in twenty-five subjects.

The standardized half time difference is plotted against the mechanical work performed in Fig. 5. There was no evidence that the magnitude of this difference was related to the severity of the work performed, and the group of subjects has therefore been considered as a whole. The mean value for the standardized half time difference between the resting and exercising states was +0·304 (S.D. 0·433). This is not significantly different from the changes found between the first and second 10 min period of the ten resting subjects ($t = 0{\cdot}25$, $P = 0{\cdot}8$).

Thus, although the group of subjects as a whole showed an increase in half time, and presumably a decrease of muscle blood flow during exercise, there is no evidence that this change was greater than would be expected if during the period under observation the subjects had rested throughout. It will be noted in Fig. 5, however, that in four subjects the standardized half time difference fell outside the range defined by twice the standard deviation of the mean difference derived from the studies at rest. The finding of four out of twenty-five observations above the upper limit of this range, whereas only one out of twenty would be expected, is statistically significant ($P = 0{\cdot}027$).

DISCUSSION

If the assumption that there is no significant change in the resting arm oxygen uptake during leg exercise is accepted, these studies of oxygen saturation of axillary venous blood suggest that there is a reduction of total arm blood flow during the early part of exercise, that later in exercise the blood flow increases, and that after exercise it is frequently greater than the resting blood flow. These changes in total arm blood flow represent a summation of changes taking place in the two major circulations of the limb. It has been recently shown that the skin and muscle circulations react quite independently to reflex body heating and to changes in posture (Roddie, Shepherd & Whelan, 1956; Edholm, Fox & Macpherson, 1956). Hand calorimetry and the measurement of the rate of clearance of radioactive sodium from forearm muscle were performed in an attempt to determine the separate response of skin and muscle circulation in the resting arm during leg exercise.

The studies of radioactive sodium clearance provided no definite evidence that the muscle blood flow was altered during exercise, but further information is required on this point, and studies with retrograde catheterization of deep muscle veins of the forearm are in progress. It will be noted that the brachial arterial pressure rose considerably during exercise, particularly at the highest levels of exertion. The lack of any significant change in muscle blood flow, as judged by sodium clearance, despite a raised perfusion pressure, would suggest that there was in fact vasoconstriction in the resting muscle of the forearm during leg exercise.

Hand calorimetry showed a reduction of hand blood flow during the early part of exercise, except in the case of individuals whose hand blood flow at rest was small, a finding similar to that of Christensen & Nielsen (1942) in their finger plethysmographic studies. Later in exercise and during early recovery the hand blood flow was shown to increase to several times that at rest. When the time lag inherent in the calorimetry studies is taken into account, these findings suggest that the initial increase and later decrease in axillary A–V difference could well result from early reduction and later increase in the blood flow to the skin of arm and hand. Towards the end of the exercise period and in the first minutes after exercise the heat elimination from the hand indicated a far greater increase in hand blood flow than was to be expected from the changes in the axillary A–V differences. This was most evident in individuals in whom hand blood flow at rest was small, and it seems not unlikely that the increase in blood flow at this time was far greater in the hand than in the skin of the rest of the arm. Another possibility is that at rest a considerable proportion of the hand blood flow was passing through arteriovenous communications and that during and after exercise this blood passed through the superficial skin capillary or venous plexuses resulting in an increased heat elimination without a proportionate increase in blood flow.

It is worth briefly comparing these findings with those in patients with chronic rheumatic heart disease and mitral stenosis in whom the cardiac output is reduced both at rest and on exercise (Donald, Bishop & Wade, 1955). The most disabled patients with a low cardiac output had at rest a large axillary A–V oxygen difference and small hand blood flow (Abramson, Fierst & Flachs, 1942; Bishop, 1956). Leg exercise caused a marked and sustained fall of axillary venous blood oxygen saturation to levels as low as 20%. In the very disabled patients the level remained low until the end of exercise. In the less disabled patients with some increase of cardiac output on exercise, the axillary venous saturation did not show such a marked fall and a rise towards or even above resting levels occurred as exercise proceeded, as in normal subjects.

It would appear that a reduction of arm blood flow is the initial response to leg exercise in both normal subjects and patients with heart disease, but that this is most marked and sustained in the patients with an impaired cardiac output response. As exercise proceeds, a decrease of axillary A–V oxygen difference, a rise in blood flow and a marked increase of heat loss from the hand occurs in the normal subjects and the less disabled patients with normal or near normal levels of cardiac output at rest and exercise. In the more disabled patients with low and unchanging cardiac outputs this increase of arm blood flow did not occur late in exercise.

The fact that the skin vaso-dilatation and the resultant loss of heat which normally occurs late in exercise appears to be prohibited when the cardiac output is greatly restricted, suggests that the maintenance of blood pressure in the face of increased blood flow to the exercising limbs takes priority over the need for skin vaso-dilatation and heat loss. It is possible that such limits of circulatory economy may occasionally occur in the normal subject and studies of the body temperature and skin circulation of athletes during very violent exercise would be of interest.

SUMMARY

1. Blood flow changes in the resting arm have been studied by the use of three different techniques during and after ten minutes leg exercise in the supine position.

2. In each of nine subjects the axillary arteriovenous oxygen content difference showed an initial increase after the start of exercise, followed after a variable time by a decrease, indicating a reduction of deduced total arm blood flow during the early part of exercise to a mean value of 53% of that at rest.

3. Hand calorimetry in another group of ten subjects showed a reduction

of heat elimination in each case in the early minutes of exercise, indicating a reduction of blood flow to the hand to a mean value of 47 % of the deduced blood flow at rest. This was followed by an increasing heat elimination reaching a peak during the last minute of exercise or the early part of recovery. The increase in hand heat loss at this time was usually of a greater order than that suggested by axillary A–V difference changes.

4. Study of the rate of clearance from forearm muscle of injected radioactive sodium in a further twenty-five subjects showed the mean difference between the resting and exercise values to be not significantly different from the mean difference between pairs of consecutive measurements at rest.

5. It is concluded that the blood flow to the resting arm is initially reduced during leg exercise under these conditions, this reduction usually not persisting after the early minutes of exercise. The change takes place principally in the skin circulation, there being no present evidence of alteration in the muscle blood flow.

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