HÆMODYNAMIC EFFECTS OF SQUATTING DURING RECOVERY FROM EXERTION*

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The hæmodynamic changes that are thought to account for the continuous adoption of a squatting position by patients with cyanotic congenital heart disease have been discussed (Brotmacher, 1957*b*). The present study is concerned with the effects of squatting during recovery from exertion, and was undertaken in an attempt to explain the tendency of these subjects to squat for periods of two to ten minutes when they have become tired and breathless as a result of effort. The effects of squatting on the circulation in the legs and on the anoxia of cyanotic congenital heart disease have been investigated, and the relationship between the two is discussed.

Effect of Squatting on the Circulation in the Legs

The effect of squatting on the venous pressure in the legs was measured in four medical students. A 21-gauge needle was inserted into a vein on the dorsum of the foot and connected to a Southern Instruments Minirack capacitance electromanometer by plastic tubing of 2 mm. internal bore. Another length of plastic tubing, filled with saline, was connected at one end to the manometer and strapped to the ankle at the other, which was open to the atmosphere. It was thus possible to register alterations in the height of the foot relative to the manometer and to apply the appropriate corrections. After control observations had been made with the patient supine, the venous pressure in the leg was measured with the subject in the squatting position. The thighs were passively flexed, slightly abducted and laterally rotated at the hips, and flexed at the knees, the thighs being brought as near as possible to the flanks. Squatting raised the venous pressure on all four occasions, the increases ranging from 10 to 28 mm. and averaging 20 mm. Hg. With resumption of the supine position the pressure fell to about the initial control levels. While in the supine position, one subject was able to raise the venous pressure in his foot by about 16 mm. Hg on three occasions by tensing his leg muscles to the greatest extent possible.

The changes in arterial blood pressure in the legs with squatting were measured by palpation, using the posterior tibial pulse, and by the flush method (Reinhold and Pym, 1955). In order to eliminate the possibility of any underlying general change, control measurements with the legs extended were made both before and after squatting. These measurements were averaged when calculating the pressure changes produced by squatting. Nine squatters and ten control subjects were studied. In both groups the systolic pressure fell by comparable amounts, the decrease ranging from 3 to 58 and averaging 18 mm. Hg. Good agreement between the two methods employed was obtained, the pressures as measured by the flush technique being slightly lower than those measured by palpation.

Blood flow through the leg was measured by venous occlusion plethysmography, the method being essentially that of Grant (1937–8). The subjects rested on the couch for at least half an hour before the first observations were made, the head and shoulders being supported on pillows

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and the legs extended. No attempt was made to regulate the room temperature; in practice it was always between 20° and 24° C.

The squatters were all patients with Fallot's tetralogy, their ages ranging from six to fifteen years. The controls on whom the effects of squatting were measured were children of from five to twelve years of age with acyanotic congenital heart disease or with non-cardiac conditions.

The squatting position was adopted as already described except that full flexion of the knee was not possible when the plethysmograph was on the leg. When the effects of varying degrees of venous occlusion on leg blood flow were being studied, a 12×40 cm. thigh cuff was placed on the upper part of the thigh. Repeat control observations were always made after measuring the effect of any particular manœuvre on blood flow, and the results were only considered acceptable if an increase in blood flow with the manœuvre was followed by a decrease when the final control observations were made, or vice versa. However, an exception was made when the changes with squatting were very small and the two control observations did not differ by more than 1·0 ml./100 ml./min. The mean of the two control observations was used in calculating changes.

Six observations of the effect of squatting on blood flow in the legs were made in squatters. It was reduced on every occasion (Table I), the change varying from 15 to 55 per cent with a mean of

TABLE I

EFFECT OF SQUATTING ON BLOOD FLOW IN LEGS

Case No.	Leg blood flow (ml./100 ml./min.)			Percentage change	Case No.	Leg blood flow (ml./100 ml./min.)			Percentage change
	Supine	Squatting	Supine			Supine	Squatting	Supine	
	1. *Squatters*					2. *Controls*			
22	4·3	3·2	5·0	−32	43	3·0	2·0	4·1	−44
23	9·1	7·4	7·9	−13	44	2·8	1·7	2·9	−41
33	2·7	1·4	3·5	−55	45	6·3	5·2	5·5	−12
40	3·7	3·2	4·1	−18	46	4·3	3·6	5·0	−23
41	3·9	3·1	3·3	−15	47	1·9	1·3	1·3	−19
42	4·0	3·0	4·1	−27	48	2·7	2·0	2·5	−23
					49	3·0	2·4	2·5	−14
					50	4·7	4·5	6·5	−20
					51	3·6	3·1	3·6	−14
					52	6·8	5·7	6·9	−18
Mean change			−1·1	−27	Mean change			−0·9	−23

t=5·90; n=6; 0·01>P>0·001. t=6·45; n=10; P<0·001.

27 per cent. Ten observations were made in control subjects, in all of whom there was a reduction in blood flow, varying from 12 to 44 per cent, the mean reduction in this group being 23 per cent (Table I). In both groups, the difference between the squatting and the supine levels is highly significant. The difference between the effects of squatting on the leg blood flow observed in the squatters and the control group is very small and not significant (difference between mean changes =0·2 ml./100 ml./min., t=0·87, n=16, 0·4>P>0·3), or in their variability (variance ratio (F)= 1·02, 10% level of F=2·9).

In order to determine whether the reductions in leg blood flow with squatting were the result of general or local changes, the effect of putting the left leg into the squatting position on the blood flow in the right one was measured. Five observations were made in squatters and five in control subjects. The changes were inconstant: the blood flow increased on three occasions in the squatting group and decreased twice. There were increases in two control subjects and decreases in three. The mean blood flow *increased* slightly with one leg in the squatting position.

The effect of varying degrees of obstruction to the venous return from a limb was next measured, a cuff proximal to the venous occlusion cuff being inflated to a pressure of 25 mm. Hg, corresponding approximately to the increase in venous pressure in the legs associated with squatting. Four observations were made in control subjects. Inflating the cuff produced falls in blood flow of 31, 33, 45, and 59 per cent. The mean fall was 39 per cent, which is over 15 per cent more than the mean fall in leg blood flow produced by squatting in the control subjects and the squatters when considered jointly (Table I). Although the group studied was very small, the reduction in blood flow produced by the cuff inflated to 25 mm. Hg is significant($t=4{\cdot}3$, $0{\cdot}05>P>0{\cdot}02$).

Effects of Squatting on Arterial Oxygen Saturation

By means of ear oximetry it is possible to measure the percentage oxygen saturation of arterial blood continuously without subjecting the patient to the discomfort of arterial puncture. The instrument employed in the present investigation was the Stanco oximeter, based on the design of Stott (1953).

Observations were made on nine squatters aged five to twenty and on three patients aged five to nine who had cyanotic heart disease but did not squat. Control observations were made with the patients standing until conditions were stable. The effects of squatting or exercising were then observed. The patients exercised by climbing on and off a step six inches high.

The patients were exercised until their arterial oxygen saturations had fallen by ten per cent, or until they felt that they could not continue without discomfort. They then stood still and the arterial oxygen saturation was noted every quarter of a minute during recovery. After an adequate rest the exercise was repeated, and the arterial saturation during recovery was observed with the patient in a squatting position. No attempt was made to standardize quantitatively the amount of work done, but to ensure that the two tests were comparable, the exercise on the second occasion was continued until the arterial oxygen had fallen to the level reached at the end of the first period of exercise.

The arterial oxygen saturation was little changed in nine squatters when standing and when squatting, ten observations being made in all; no differences of more than two per cent were seen, and in five subjects there were no differences at all (Table II). In contrast, the effect of squatting

TABLE II

Effect of Squatting on Percentage Oxygen Saturation of Arterial Blood

Oximetric observations on squatting

Case No.	Percentage saturation of arterial blood		
	Standing	Squatting	Standing
22	61	61	62
23	94	93	95
27	86	86	86
34	95	95	95
35	92–93	90–91	92–93
	92–93	90–91	92–93
36	74	75	75
37	90	90	90
38	74	74	74
39	87	85	87

on the saturation during recovery from exercise was quite dramatic in the patients who were habitual squatters (Fig. 1). When they stood at the conclusion of the exercise, the arterial oxygen saturation continued to fall, reaching its nadir about half a minute afterwards. Only then did it start to rise, reaching the level observed at the moment of conclusion of the exercise after the expiry of about a further half minute; it was, therefore, a minute after the exercise before it began to rise above the level at the end of exercise. When the patient squatted at the end of the exercise, the rate of recovery of the arterial oxygen saturation was no greater than when standing; but it no longer fell after the exercise ended and started to rise from the moment when it ended. The arterial oxygen saturation reached at any point in time with the patient squatting was reached only about a minute to a minute and a half later when standing during recovery. Between a quarter of a minute and two minutes after ending the exercise, the saturation with the patient squatting was anything up to twelve per cent higher than while standing. Ten observations were made and the differences were apparent in all but one.

Irrespective of whether the patient stood or squatted during recovery, the rate of increase in arterial oxygen saturation lessened as the resting level was approached, but the percentage was occasionally slightly greater after recovery than it had been before starting the exercise (Fig. 1).

The continued decline in the arterial oxygen saturation when the patient stood at the end of the exercise—a feature that has often been demonstrated by Campbell in such patients—and the relative

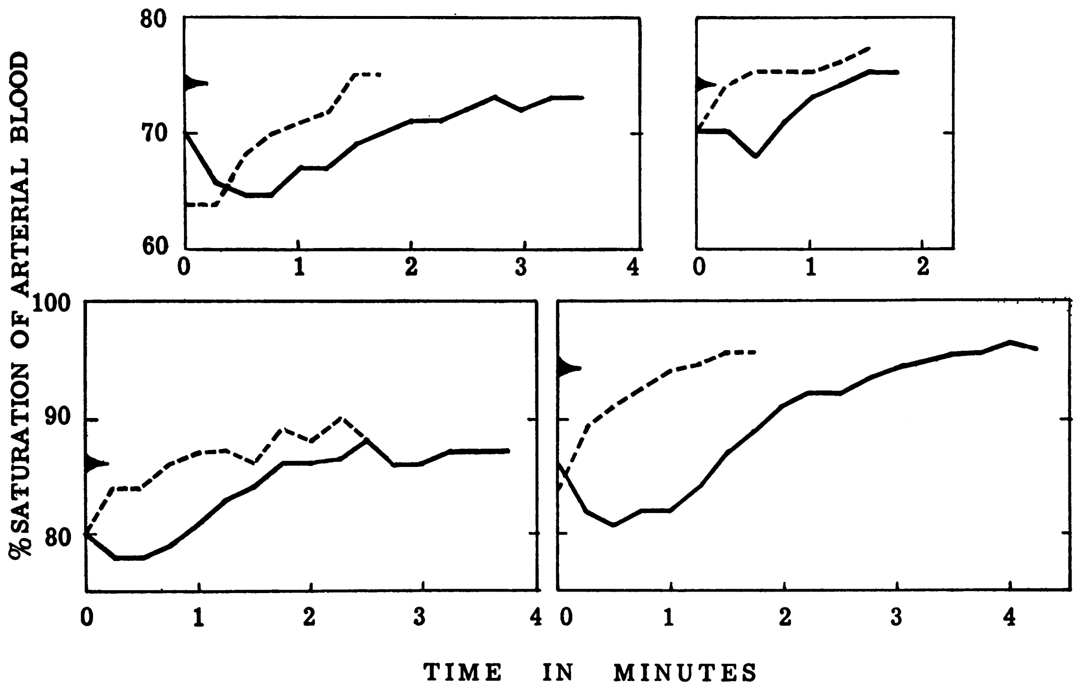

FIG. 1.—Effect of squatting on arterial oxygen saturation in four patients during recovery from leg exercise. Oximetric observations on squatters.

The continuous lines indicate the changes with standing. The interrupted lines indicate the changes with squatting and show an immediate rise and a quicker return to normal.

The arrow heads on the ordinates indicate the initial resting levels.

increase in saturation associated with squatting could often be detected clinically. The patients themselves, when questioned, admitted to greater discomfort when standing than when squatting.

The effects of standing and squatting during recovery from exercise were compared in three non-squatters with cyanotic congenital heart disease. The differences that have been described in the case of the squatters were not observed (Fig. 2a). Irrespective of whether the patients stood or squatted after exercising, the arterial oxygen saturation continued to fall during the first half minute or so of the rest period, and did not rise to the level that was present at the end of the exercise until after about another half minute. Squatting did not appear to have any effect on the arterial oxygen saturation during any part of the recovery period.

In two squatters in whom arterial oxygen desaturation was produced by vigorous upward and downward movement of the arms, the rate of recovery from the moment of ending the exercise was not affected appreciably by squatting (Fig. 2b). Additional observations could not be made, as the remaining subjects were unable to continue the exercise owing to muscular fatigue, even though their arterial oxygen saturations had not fallen appreciably.

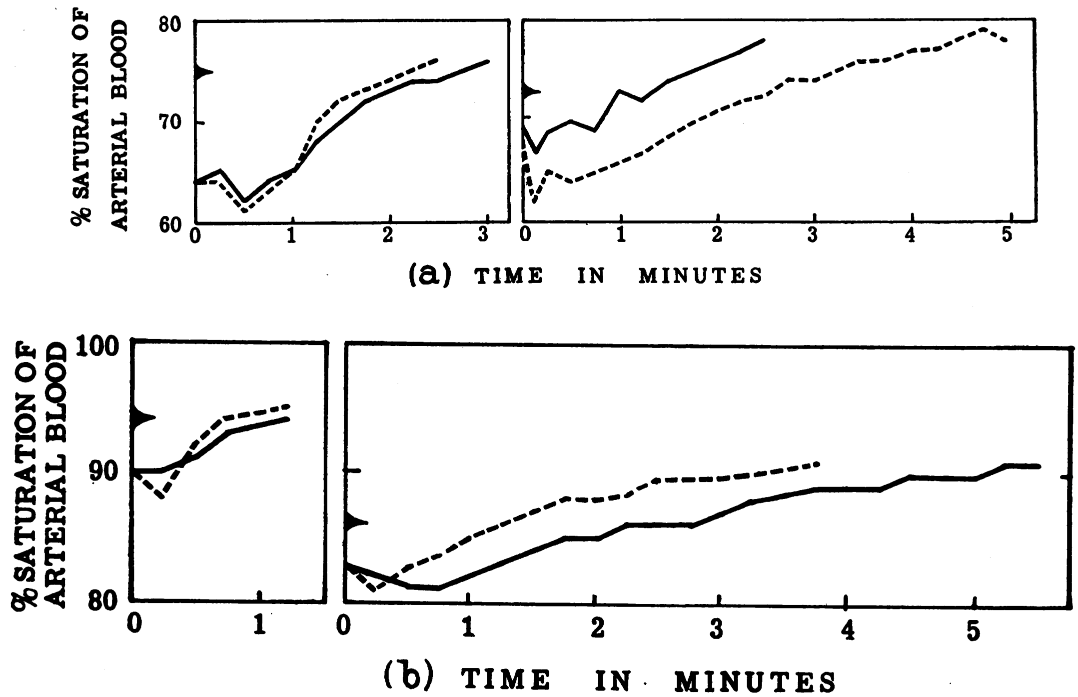

FIG. 2.—Effect of squatting on arterial oxygen saturation. Oximetric observations during recovery from exercise.
(a) Two control subjects with cyanotic congenital heart disease. Leg exercise.
(b) Two squatters. Arm exercise with patients standing.

The continuous lines indicate the control observations. The interrupted line indicates the changes with squatting and fail to show the improvement that was seen in Fig. 1.

The arrow heads on the ordinates indicate the initial resting levels.

DISCUSSION

When a patient squats, the femoral arteries and the femoral veins become angulated acutely in the groins, where they pass between the inelastic inguinal ligaments and the superior pubic rami. The popliteal arteries and veins are similarly angulated in the popliteal fossæ. The muscles of the legs are in tonic contraction and there is some increase in the tone of the muscles of the anterior abdominal wall, against which the thighs are pressed. The slight fall in arterial pressure in the legs observed in the present investigation is thought to be secondary to such kinking of the main arteries of the legs in the groins and behind the knees. The rise in venous pressure could be due to venous kinking in the groins and popliteal fossæ, or to pressure on the veins by muscles in tonic contraction. Kinking of the veins is probably the more important, as voluntary tonic muscle contraction produces rises in venous pressure comparable with those associated with squatting only when the leg muscles are tensed to the greatest possible extent.

The reduction in the blood flow in the legs with squatting is an expected consequence of the reduction in the arterial and the increase in the venous pressures. Obstructing the venous return from a limb by inflating a cuff to 25 mm., which is about the average increase in venous pressure observed with squatting, produced falls in limb blood flow comparable to those produced by squatting. This indicates that the increase in venous pressure with squatting can, by itself, bring about the reduction in leg blood flow. Once a local cause for the change in leg blood flow with squatting is accepted, the absence of any difference between the changes observed in the squatters and in the control subjects becomes quite understandable. As far as the anatomy of the great vessels in the legs is concerned, patients with cyanotic congenital heart disease do not differ from others.

At rest there is no special difference between the oxygen content of blood from the legs and that from the rest of the body. On five occasions samples obtained from the bifurcation of the inferior vena cava or from a common iliac vein showed a percentage oxygen saturation of from 64 to 85 per cent. Reduction in the extent of its contribution to the mixed venous blood is unlikely, therefore, to affect the oxygen saturation of the latter appreciably. On the other hand, with exercise, the oxygen saturation of iliac vein blood falls precipitously: on four occasions it was found to be between 31 and 51 per cent after only 20 movements of foot pedals against a spring resistance. In patients with a veno-arterial shunt, mixed venous blood with correspondingly low oxygen content passes directly into the arterial stream: Davison *et al.* (1953) have shown that this accounts in very large measure for the fall in arterial oxygen saturation with exercise.

The continued fall after exercise when patients with cyanotic heart disease remain standing is probably due in large measure to the oxygen requirements of the leg muscles remaining high even after contraction has ceased. This is frequently the case when the energy requirements have been met in some measure anærobically during the period of contraction. A small part of the continued fall may also be accounted for by the time taken for blood leaving the muscles at the moment the exercise ends to reach the arteries.

McNeill (1956) has shown that, after exercise, vaso-dilatation of muscle arterioles persists after the excess oxygen requirements have been met, the oxygen content of venous blood from the muscles rising towards arterial levels. This may well account for the arterial oxygen saturation of some of the patients in the present investigation rising to above the initial resting levels at the end of the recovery period.

The present investigation has shown that squatting produces obstruction to the venous return from the legs. It therefore reduces the amount of desaturated femoral vein blood reaching the heart and so minimizes the tendency of the oxygen saturation of mixed venous blood to fall with exercise. This is reflected in the higher arterial oxygen saturation that has been observed, both in the present and in previous investigations (Callebaut *et al.*, 1949; Lurie, 1952, 1953), when habitual squatters squat instead of standing during recovery from exercise. The findings of Dexter (1951) and of Lurie (1953) that elastic bandages applied to the legs can obviate the need to squat can be similarly explained on the basis of obstruction to venous return. The effects of abdominal compression by means of binders, which has also been found to obviate the need to squat (Lurie, 1953) can be explained in the same way. The effect of abdominal compression on cardiac output suggests that it impedes venous return (Brotmacher, 1957*a*). A degree of obstruction to venous return too slight to produce measurable reduction in leg blood flow may well have a measurable effect on arterial oxygen saturation, when femoral venous blood is very desaturated. Callebaut *et al.* (1949) attributed the changes in arterial oxygen saturation that they observed with squatting to diminution in the veno-arterial shunt. This was not measured by them, and recent findings indicate that this shunt is not, in fact, lessened (Brotmacher, 1957*b*).

During recovery from arm exercise, the rate at which the arterial oxygen saturation returns to the resting level is not affected by squatting. This is an expected finding, as squatting cannot have any effect on the venous return from the arms.

In patients with cyanotic congenital heart disease who do not squat, the obstruction to the venous return from the legs tends to raise the arterial oxygen saturation, and the effort required to maintain an unaccustomed position tends to lower it. As a result of the interplay of these opposing factors, the arterial oxygen saturations when standing and when squatting after exercise are not appreciably different in this group.

The changes with squatting after exertion that have been described result in the capillary oxygen tension being raised in the upper part of the body, at the cost of lowering the blood supply to the legs. This is not serious, as muscles that are not actively contracting can tolerate ischæmia well. In fact, partial exclusion of the legs from the circulation is beneficial, as it reduces the amount of work that the heart has to perform at a time when the demands upon it are maximal. The magnitude of the changes that have been observed suggest that the increases in capillary oxygen tension that result from squatting after exertion are much greater than those produced by squatting at other times.

These increases occur in the parts of the body that contain the vital centres and are the most sensitive to anoxia. They are brought about with a relative economy in cardiac work and are thought to be the basis of the subjective improvement with squatting, and to account for the habitual adoption of this position after exertion by patients with cyanotic congenital heart disease.

Summary and Conclusions

Squatting causes kinking of the femoral arteries and veins in the groins and of the popliteal arteries and veins in the popliteal fossæ. Blood flow in the legs is reduced, mainly as a result of obstruction to the venous return.

When patients with cyanotic congenital heart disease exercise, the oxygen content of femoral venous blood falls precipitously. This desaturated blood reaches the right side of the heart and is shunted into the systemic arteries. The oxygen saturation of arterial blood falls in consequence Squatting impedes the venous return from the legs and therefore minimizes the tendency of the arterial oxygen saturation to fall with exercise.

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