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REFLEX CHANGES IN VASOCONSTRICTOR TONE IN HUMAN SKELETAL MUSCLE IN RESPONSE TO STIMULATION OF RECEPTORS IN A LOW-PRESSURE AREA OF THE INTRATHORACIC VASCULAR BED

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When the legs of a recumbent subject are passively raised the forearm blood flow increases owing to reflex dilatation of skeletal muscle vessels (Roddie & Shepherd, 1956). In this paper evidence is presented that this dilatation is brought about by release of vasoconstrictor tone and that the receptors concerned in the reflex lie in a low-pressure area of the intrathoracic vascular bed.

METHODS

The experiments were carried out on healthy adults aged 19–36 years in a room about 26° C. Changes in posture were brought about by passively raising the legs or the legs and lower trunk of the recumbent subject. Forearm, hand and calf blood flow was measured by venous occlusion plethysmography (Greenfield, 1954). Pressure measurements were made by a capacitance manometer; arterial pressure from a needle in the brachial artery and central venous pressure from a catheter in the right atrium or great thoracic veins. Deep nerve block was performed by infiltrating around the ulnar, median and radial nerves with 3–5 ml. lignocaine with adrenaline 1:50,000 (Whelan, 1952; Roddie, Shepherd & Whelan, 1957*a*). In one experiment venous blood samples from the forearm muscles were withdrawn through nylon catheters (Roddie, Shepherd & Whelan, 1956) and the oxygen saturation determined using a spectrophotometric technique (Roddie, Shepherd & Whelan, 1957*b*).

RESULTS

Evidence that the dilatation of muscle vessels is due to release of vasoconstrictor tone

Effect of atropinization. Human skeletal muscle vessels are supplied with vasoconstrictor fibres (Barcroft, Bonnar, Edholm & Effron, 1943; Roddie *et al.* 1957*a*) and there is some evidence that they also have a vasodilator nerve supply (Barcroft, Edholm, McMichael & Sharpey-Schafer, 1944). Vasodilator nerves to skeletal muscle in dog and cat have been shown to act through a cholinergic mechanism which can be blocked by atropinization of the muscle (Bülbring & Burn, 1935). It was therefore considered that if the forearm

vasodilatation with leg raising was brought about by vasodilator nerves, atropinization of the forearm tissues would abolish or reduce it. Infusions of 0·4 mg atropine sulphate into the brachial artery abolishes sweating and delays the vasodilatation in the forearm during body heating presumably by blocking the action of cholinergic fibres to forearm skin, but it does not affect the release of vasoconstrictor tone in the hand or forearm (Roddie, Shepherd & Whelan, 1957*c*). The infusion of a similar dose in three subjects was without effect on the vasodilatation during leg raising (Fig. 1). In one of these experiments the subject was subsequently heated and forearm sweating was found to be abolished and vasodilatation delayed, indicating that the forearm was effectively atropinized.

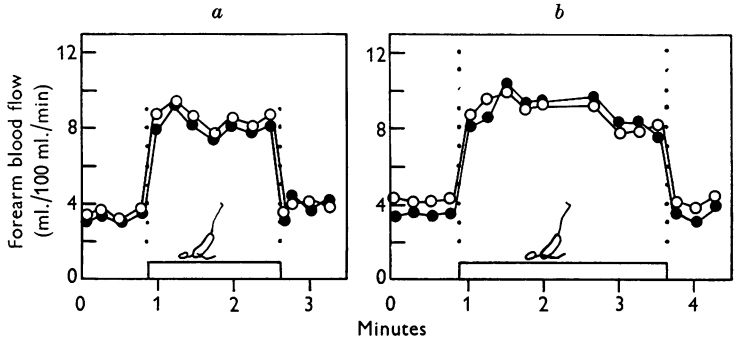

Fig. 1. The effect of atropinization of the forearm tissues on the muscle vasodilatation during leg raising. ○, left forearm blood flow; ●, right forearm blood flow: *a*, before atropine infusion; *b*, after infusion of 0·4 mg atropine sulphate into left brachial artery.

Effect of nerve block. In six subjects the maximum forearm blood flow that could be obtained with leg raising approached, but did not exceed, the flow through the opposite forearm to which the deep nerves had been blocked with local anaesthetic (Table 1). In another experiment the deep nerves to one forearm were blocked and the oxygen saturation of the deep venous blood draining the muscle of the two forearms was compared. When the legs were raised the oxygen saturation of the blood from the intact forearm approached, but did not exceed, that from the nerve-blocked forearm (Fig. 2). The results could therefore be explained by release of vasoconstrictor tone and it was not necessary to invoke vasodilator nerve activity in skeletal muscle to account for the findings.

Evidence that the reflex muscle vasodilatation with leg raising is due to stimulation of receptors in a low-pressure area of the intrathoracic vascular bed

The vascular response in muscle to passively raising the legs depends on the shift of blood from the legs, since it does not occur when pneumatic cuffs are inflated round the thighs to prevent the return of blood when the legs are raised (Fig. 3). The dilatation is greater when the legs and lower trunk are

raised which suggests that the response does not depend on the pooling of blood in the splanchnic area. Neither is it a result of venous congestion in the head since inflation of a pneumatic cuff round the neck does not affect forearm flow. It seems therefore that the response depends on the shifting of blood to the intrathoracic vascular bed.

Simultaneous measurements of arterial pressure and forearm blood flow were made on eight subjects. Fig. 4 shows the effect of leg raising on two consecutive occasions in one subject. The dilatation was similar on both occasions; on the first the mean pressure increased slightly but the pulse

TABLE 1. The effect of blocking the deep forearm nerves on the forearm vasodilatation when the legs are passively raised.

(Blood flow, ml./100 ml./min.)

	Nerve-blocked forearm		Normal forearm	
Subject	Legs horizontal	Legs raised	Legs horizontal	Legs raised
H.McK.	11·5	11·5	5·0	11·5
R.S.C.	14·5	15·0	6·0	13·0
P.A.	16·0	15·0	5·0	9·5
G.B.	9·0	9·5	5·0	9·5
S.M.	12·2	12·0	5·0	10·0
I.C.R.	6·5	6·0	3·3	5·6

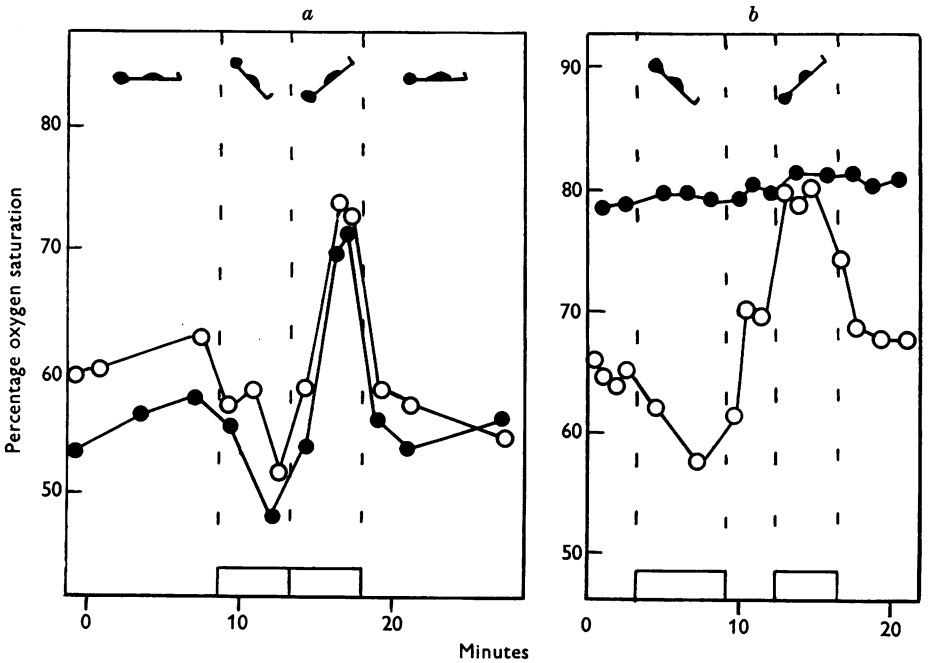

Fig. 2. The effect of body tilting on oxygen saturation of deep forearm venous blood in the normal and nerve-blocked forearm. ●, left forearm deep venous blood; ○, right forearm deep venous blood: *a*, before nerve block; *b*, after block of deep nerves to left forearm.

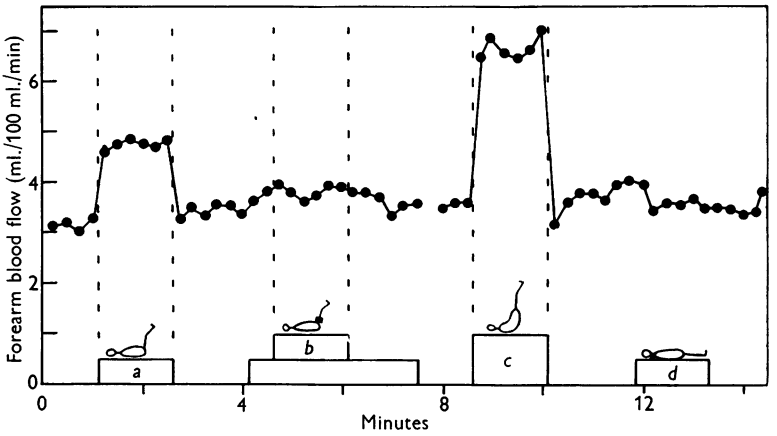

Fig. 3. Evidence that the forearm vasodilatation depends on the shift of blood to the intrathoracic vascular bed. (*a*) legs alone raised; (*b*) legs alone raised with pneumatic cuffs inflated to 180 mm Hg round the thighs; (*c*) legs and lower trunk raised; (*d*) pneumatic cuff inflated to 30 mm Hg round the neck.

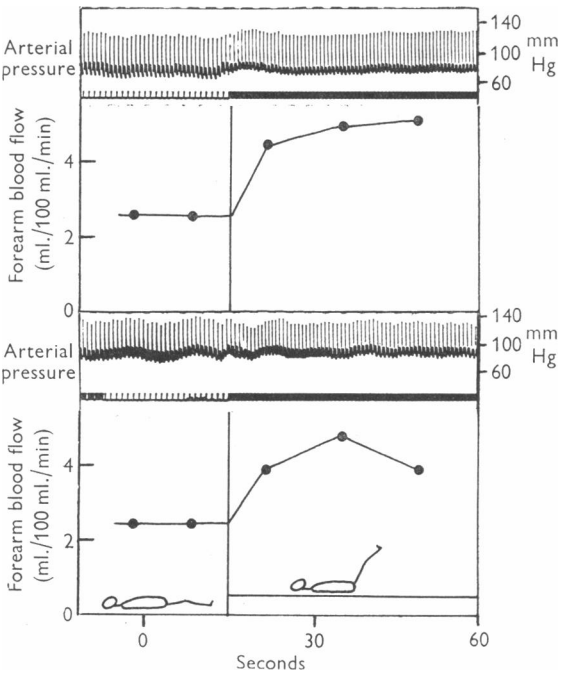

Fig. 4. The effect of leg raising on brachial arterial pressure and forearm blood flow on two consecutive occasions on one subject.

pressure remained unchanged, and on the second the mean pressure was little altered whereas the pulse pressure fell slightly. Typical results on two other subjects are shown in Figs. 5 and 6. It was not possible in this series of experiments to correlate the magnitude of the dilatation with changes in arterial mean or pulse pressure.

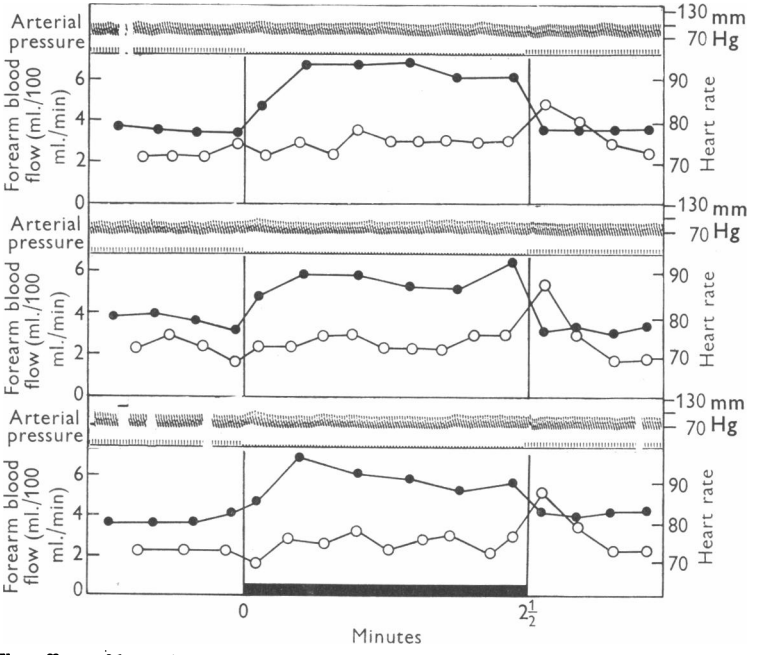

Fig. 5. The effect of leg raising on brachial arterial pressure, forearm blood flow (●) and heart rate (○) on three consecutive occasions on one subject. The black rectangle represents the period of leg raising.

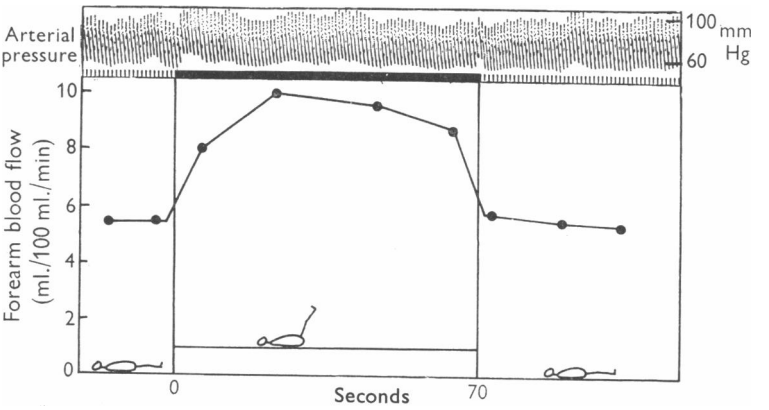

Fig. 6. The effect of leg raising on brachial arterial pressure and blood flow.

The heart rate increased in most subjects when the legs were raised (Fig. 4), but in the subject shown in Fig. 5 the increase in rate was inconspicuous, though a marked increase in forearm blood flow occurred.

In three subjects central venous pressure, arterial pressure and forearm blood flow were simultaneously measured (Figs. 7, 8). Though raising the legs caused no consistent change in arterial pressure there was an increase in mean venous pressure and an increase in the amplitude of the venous pulsations. Raising the subject's legs did not cause these changes in venous pressure if cuffs were first inflated round the thighs to prevent the return of blood to the trunk. Like the increase in forearm blood flow the increases in mean venous pressure and the amplitude of the venous pulsations were greater when the legs and lower trunk were raised than when the legs alone were raised.

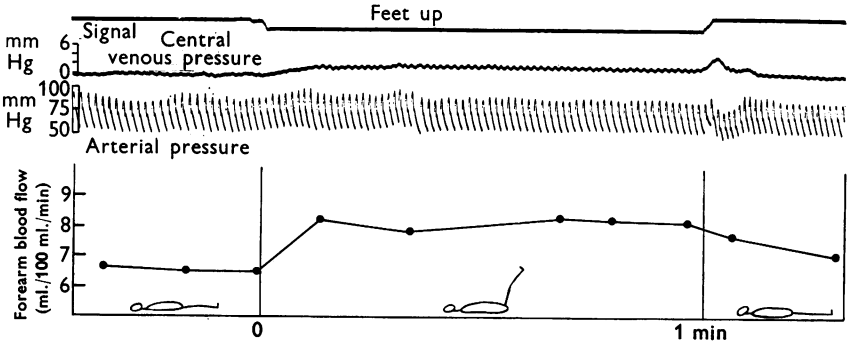

Fig. 7. The effect of raising the legs alone on central venous pressure, arterial blood pressure and forearm blood flow.

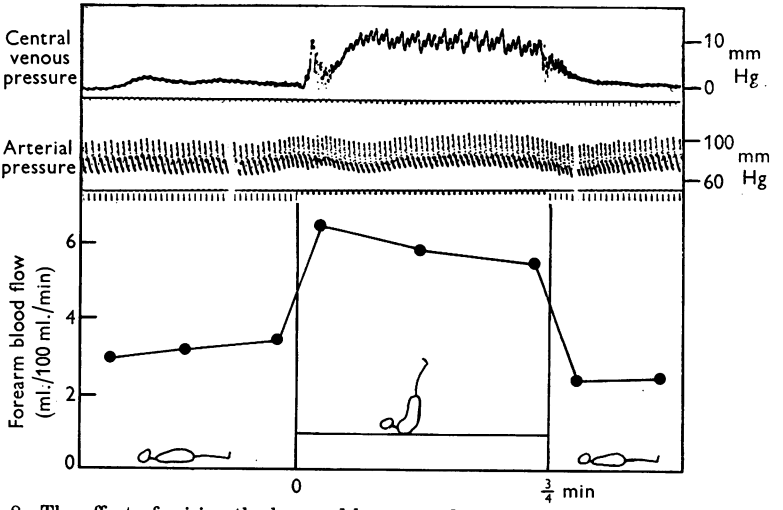

Fig. 8. The effect of raising the legs and lower trunk on central venous pressure, arterial pressure and forearm blood flow.

DISCUSSION

The present experiments show that reflex vasodilatation occurs in skeletal muscle as a consequence of increasing the intrathoracic blood volume. This vasodilatation does not appear to be related to changes in mean arterial pressure, since the latter is often unaltered during the procedure; nor is there an obvious correlation between the vasodilatation and the arterial pulse pressure, since the latter was sometimes unchanged or even reduced at a time when the vasodilatation was marked.

It seems most likely therefore that the cause of the vasodilatation in the forearm muscles is the stimulation of receptors in a low-pressure area of the intrathoracic vascular bed and is not a consequence of arterial baroreceptor stimulation. This suggestion is supported by recent evidence that the activity of the carotid artery stretch receptors in man does not cause reflex changes in the calibre of the limb blood vessels (Ernsting & Parry, 1957; Roddie & Shepherd, 1957).

While in the present experiments changes in the venous pressure and pulsation appear to be related to the forearm flow changes, both being greater when the legs and lower trunk are raised than when the legs alone are elevated, it cannot be concluded that these changes represent the stimulus responsible for the forearm vasodilator response. In view of the numerous receptors described in the intrathoracic vascular bed (Aviado & Schmidt, 1955) and the doubt about the manner of their stimulation, we cannot define the nature of the stimulus nor the exact location of the receptors in the low-pressure system. A vasodilatation in muscle of the type described, if produced by an increase in venous return to the heart, would permit an increase in cardiac output without much change in arterial pressure, thus avoiding arterial baroreceptor stimulation which would tend to slow the heart reflexly.

SUMMARY

1. When the legs of a recumbent subject are passively raised the vessels of forearm skeletal muscle are affected by a vasodilator reflex. The vessels of the hand and forearm skin are not affected.

2. Since the muscle vascular responses are unaffected by atropinization of the forearm and since the vasodilatation that can be evoked is not greater than that obtained by full release of vasoconstrictor tone (produced by nerve block) it is suggested that the dilatation is due to release of vasoconstrictor tone in muscle.

3. Evidence is presented that the response is dependent on the shifting of blood to the intrathoracic vascular bed. It is accompanied by increases in mean central venous pressure and amplitude of venous pulsation.

4. There was no correlation between the forearm vasodilatation and the

mean arterial or pulse presssure, suggesting that the dilatation was not a consequence of arterial baroreceptor stimulation.

5. While the precise nature of the stimulus and the accurate location of the receptors concerned in the reflex have not been determined it seems clear that the vasodilatation in the forearm muscle is due to stimulation of receptors in a low-pressure area of the intrathoracic vascular bed.

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