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THE DISTENSIBILITY OF THE BLOOD VESSELS OF THE HUMAN CALF DETERMINED BY GRADED VENOUS CONGESTION

By B. S. L. KIDD and S. M. LYONS
From the Department of Physiology, The Queen's University of Belfast

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It has been well established that the veins in the human subject react to general and local stimuli (Doupe, Krynauw & Snodgrass, 1938; Duggan, Love & Lyons, 1953; Connolly & Wood, 1954; Burch & Murtadha, 1956). Of importance, however, to the general economy of the circulation is whether these reactions can influence the amount of blood held in the capacity vessels of a part under conditions of normal life. A recent study of the capacity vessels of the human calf has suggested that some of the stimuli which are known to dilate the blood vessels chiefly concerned with providing resistance to blood flow through the calf do not alter the ability of the calf blood vessels to hold blood (Coles, Kidd & Moffatt, 1957).

The present investigation was designed to study the reactions of the capacity vessels of the calf under similar circumstances using a simpler method of wider application.

METHODS

The subjects were eight healthy young men; the subject lay on a couch with one thigh supported so that the hip and knee joints were slightly flexed. The calf was enclosed in a plethysmograph (Greenfield, 1954), containing, unless otherwise stated, stirred water at 35° C, and the axis of the calf was 16 cm above the phlebostatic level (Burch, 1950). Pneumatic cuffs surrounded the leg immediately distal to the plethysmograph and just proximal to the knee joint. When a congesting pressure was applied to the thigh cuff, the calf increased in volume and displaced water from the plethysmograph, through a constant temperature reservoir which stood in the outer jacket of the plethysmograph, into a burette calibrated in ml. The water level in the burette was adjusted to be read at a constant reference level 12 cm above the upper surface of the calf and 28 cm above the phlebostatic level.

When the subject had rested for 30 min, the pneumatic cuff distal to the plethysmograph was inflated to 200 mm Hg and the blood flow through the calf was recorded by conventional venous occlusion plethysmography. The plethysmograph was then connected to the burette and direct readings of the water level were made at 30 sec intervals, while the thigh cuff was inflated successively to pressures 10, 20, 30, 40, 50, 60, 70 and 80 mm Hg above atmospheric. At the lower pressures the volume changes were slight and irregular. At the higher pressures the rate of volume increase was rapid for the first 2–3 min and then gradually diminished, eventually becoming very slow. The distended volume at any congesting pressure was taken as the volume attained when the rate of increase fell below 0·13 ml./100 ml. calf tissue/min, and the cuff pressure was then returned to atmospheric. The calf volume at the end of the congestion never differed from that at the beginning by more than 0·15 ml./100 ml. of tissue. The observed volume increase was expressed in ml./100 ml. of calf tissue and a pressure–volume curve was constructed.

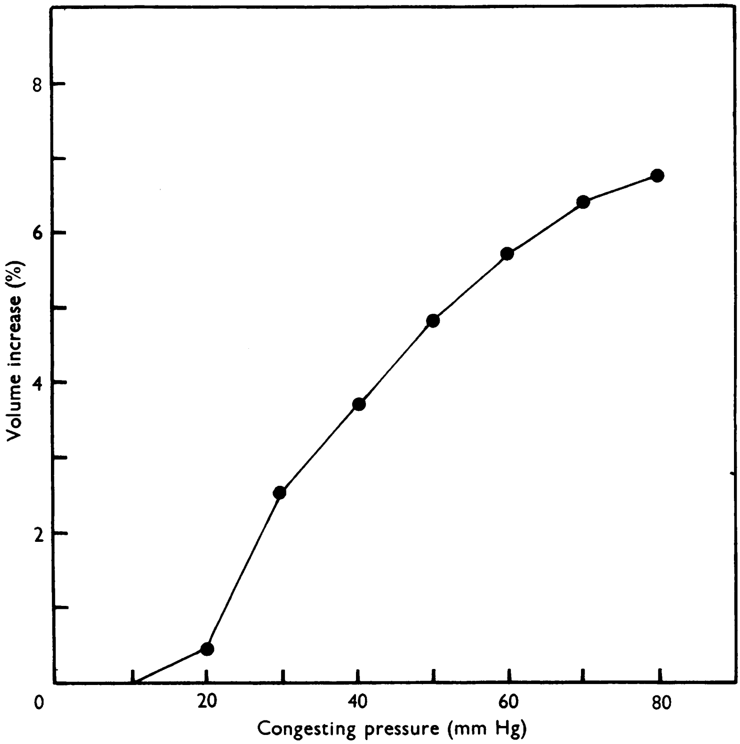

Fig. 1. A typical pressure–volume curve, demonstrating the percentage increase in calf volume with increasing calf pressure.

RESULTS

Fig. 1 illustrates the volume increase in ml./100 ml. of tissue in relation to the various congesting pressures used, in a typical experiment. It can be seen that there was no volume increase at 10 mm Hg and only a small increase at 20 mm Hg, but thereafter the increase was considerable for each 10 mm Hg increment in pressure. Two factors may account for the failure of the low pressure to cause any volume increase: first, the pressure in the cuff may not be fully transmitted to the vessels in the deeper parts of the limb, and secondly, the pressure in the veins enclosed in the plethysmograph must increase sufficiently to overcome the hydrostatic pressure acting on the surface of the leg before any blood can accumulate in them. With the lowest pressures results were not always reproducible, but with congesting pressures above 20 mm Hg the pressure–volume curve was reproducible and showed only slight variations from day to day.

Fig. 2 shows one pressure–volume curve from each of the eight subjects studied, and while there was some individual variation, the curves are similar in their general characteristics. The remaining observations all deal with the effects of stimuli known to affect the resistance vessels of the calf.

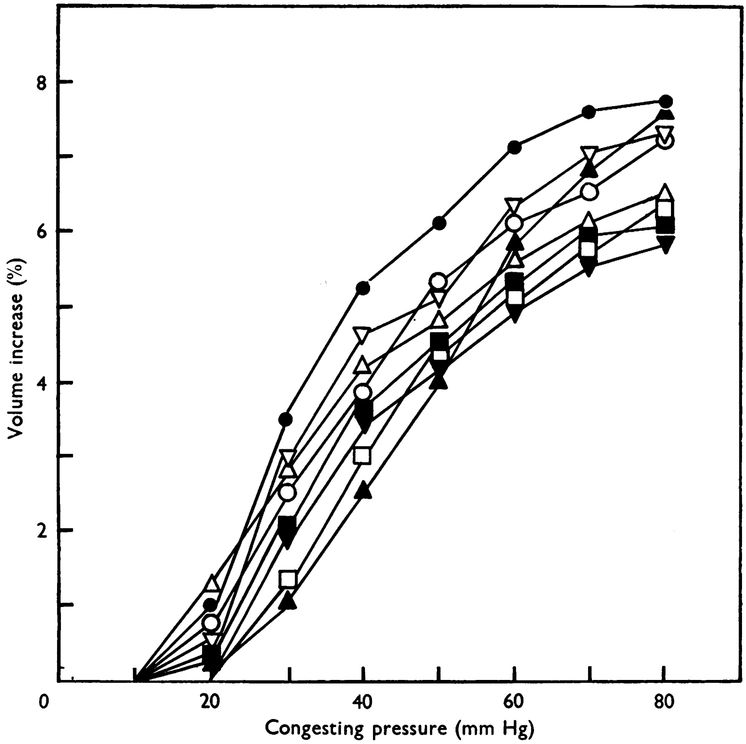

Fig. 2. Pressure–volume curves for each of the eight subjects tested.

Local heating. In these experiments standard pressure–volume observations were first made with the water in the plethysmograph at 35° C, as described above. The water was then rapidly heated to 44° C, and after 30 min further observations were made at 44° C. The blood flow was measured and found to be increased by 2–3 times, indicating dilatation of the resistance vessels. It was found that raising the temperature had very little effect on the amount of blood which could be held in the calf. The results are summarized in Fig. 3*a*.

General heating. After standard pressure–volume observations had been made, the subject was wrapped in blankets, hot water bottles were applied to the trunk and abdomen, and his arms were immersed in water baths at 43° C. This procedure causes a large increase in blood flow; by analogy with the forearm (Roddie, Shepherd & Whelan, 1956), this increase is presumed to be mainly through the skin blood vessels. Despite the observed increase of from 3–6 times in calf blood flow, there was little alteration in the distensibility of the calf blood vessels. The results are as summarized in Fig. 3*b*.

Local cooling. Following the standard observations the water in the plethysmograph was cooled to 6° C for 30 min and the observations were then repeated at this temperature. The blood flow was reduced to between one-third and one-quarter of its resting value, and it was found that less blood could be held in the part at each level of congesting pressure when the limb was cold. The results are illustrated in Fig. 3*c*.

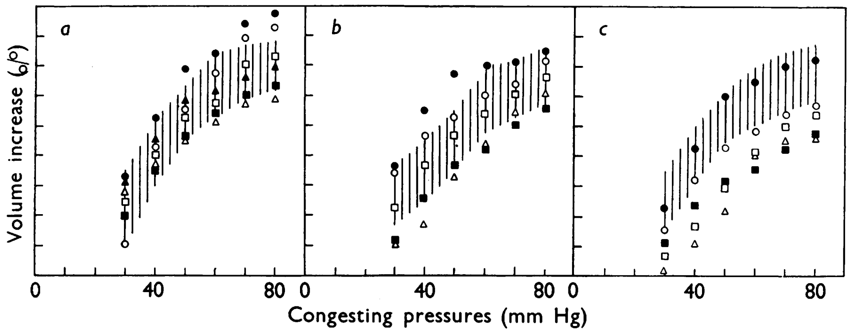

Fig. 3. Pressure–volume observations obtained while (*a*) the temperature of the water in the plethysmograph was raised to 44° C; (*b*) the subject was generally heated; (*c*) the water in the plethysmograph was cooled to 6° C for 30 min.

The hatched area in each case represents the range of observations on the same subjects made immediately beforehand while the subject was comfortably warm. The plethysmograph temperature was 35° C.

Muscular exercise. Cuff pressures of 30, 50 and 70 mm Hg were applied in succession, and at each pressure, when the calf volume had reached a steady level, the calf muscles were exercised by plantar flexion of the foot against a hinged board (Coles *et al.* 1957) 30 times a minute for 1 min. The cuff pressure was maintained for a further period after the exercise before being returned to atmospheric. Control observations were then made, in which the exercise was omitted. Experiments were carried out on six subjects and the results were in all cases similar to those illustrated in Fig. 4. It may be seen that during the exercise there is a reduction in the congested calf volume; when, however, the exercise ceased the volume of the calf rapidly reverted to a level very close to that observed in the control experiments. The calf blood flow at this time was greatly increased, and it is inferred that the vessels chiefly concerned with resistance to flow were dilated.

The recorded reduction in volume during exercise is considered to be reliable since no change in volume was observed in other experiments when the circulation was arrested as completely as possible while the exercise was carried out.

The reduction was presumably due to the action of the muscle pump in expressing blood from the calf.

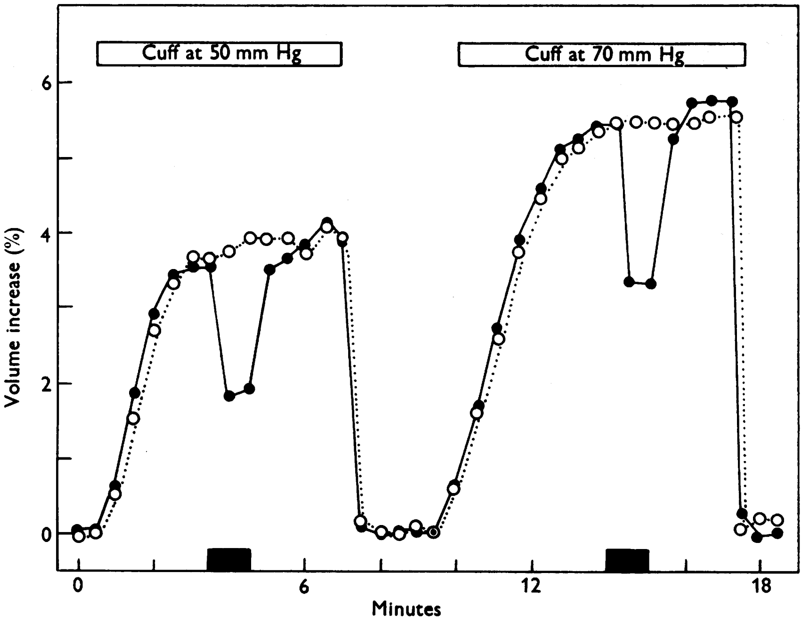

Fig. 4. Records of changes in volume of the calf. Curve ···○··· shows the effects of applying congesting pressures of 50 and 70 mm Hg for the periods shown. The same procedure was adopted in curve -●-, but, in addition, exercise (plantar flexion of the foot against a hinged board 30 times/min) was carried out for the period indicated, ■.

DISCUSSION

When a congesting pressure is applied to a leg raised above heart level, the volume of the calf increases as the previously collapsed capacity vessels fill up. Eventually the venous pressure distal to the cuff exceeds the cuff pressure; blood then escapes under the cuff and further volume increase is slight. This slight increase is due either to filtration of fluid into the tissues or to a relaxation of the capacity vessels. The size of the first rapid volume increase is taken as an index of the distensibility of the calf blood vessels at that particular congesting pressure.

In these experiments no measurements were made of the resting volume of blood in the limb or of the alterations in this under the various conditions studied. Since there were changes in blood flow, which implies that there were alterations in the calibre of the resistance vessels, it is possible that the resting volume of blood in the calf did vary. What is shown by these results is that the distensibility of the vessels which are collapsed in the elevated limb is unaltered by certain stimuli which dilate the resistance vessels. Cold, a stimulus which constricts the resistance vessels, on the other hand, reduces the distensibility of the capacity vessels.

These results are in agreement with those obtained for the calf, using local exposure to subatmospheric pressures as the distending force (Coles *et al.* 1957). Henry (1954) studied the effects of temperature on venous distensibility in the leg using positive-pressure breathing as the distending force. The present results confirm his observation that the amount of blood held in the leg is decreased by cooling. Henry, however, observed an increase on warming while we observed no change. The apparent discrepancy probably arises from differences in the 'normal' conditions in the two sets of experiments, since in Henry's the subject stood in a tank containing water and was exposed to a relatively cooler environment than in our experiments. In support of this explanation, the difference between the capacities of the 'hot' leg and the 'cold' leg was very similar in both sets.

In these experiments, then, evidence is presented that the capacity vessels can reduce their distensibility. This is in broad agreement with studies on functionally isolated though anatomically intact superficial veins in man (Duggan *et al.* 1953; Burch & Murtadha, 1956), which have shown that the pressure in such a segment rises in response to various stimuli. A point of interest is that neither in the isolated segment experiments nor in those here reported was there found any evidence of a relaxation in venous tone in normal subjects; it may well be that, in the comfortably warm subject in the horizontal position, the tone of the smooth muscle in the capacity blood vessel walls is fully relaxed.

SUMMARY

1. The volume increases of the human calf resulting from graded venous congestion have been measured plethysmographically in the raised leg of the recumbent subject.

2. These volume increases were reproducible for any one subject and when expressed as a percentage of the resting limb volume did not vary widely between the subjects tested.

3. Normal pressure–volume curves were determined, and any alteration in this curve was presumed to indicate an alteration in the distensibility of the capacity blood vessels.

4. This distensibility was unaltered by local heating of the limb, general heating or following muscular exercise; in all these conditions the blood flow through the part was greatly increased.

5. The distensibility was reduced by severe local cooling.

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REFERENCES

BURCH, G. E. (1950). *A Primer of Venous Pressure.* London: Henry Kimpton.

BURCH, G. E. & MURTADHA, M. (1956). A study of vasomotor tone in a short intact venous segment of the forearm of man. *Amer. Heart J.* **51**, 807–828.

COLES, D. R., KIDD, B. S. L. & MOFFAT, W. (1957). The distensibility of blood vessels of the human calf determined by local application of subatmospheric pressures. *J. appl. Physiol.* **10**, 461–468.

CONNOLLY, D. E. & WOOD, E. H. (1954). Distensibility of peripheral veins in man determined by a miniature balloon technique. *J. appl. Physiol.* **7**, 239–244.

DOUPE, J., KRYNAUW, R. W. & SNODGRASS, S. R. (1938). Some factors influencing venous pressure in man. *J. Physiol.* **92**, 383–400.

DUGGAN, J. I., LOVE, V. L. & LYONS, R. H. (1953). A study of reflex venomotor reactions in man. *Circulation*, **7**, 869–873.

GREENFIELD, A. D. M. (1954). A simple water-filled plethysmograph for the hand or forearm with temperature control. *J. Physiol.* **123**, 62–64*P*.

HENRY, J. P. (1951). The significance of loss of blood into the limb during pressure breathing. *J. Aviation Med.* **22**, 31–38.

RODDIE, I. C., SHEPHERD, J. T. & WHELAN, R. F. (1956). Evidence from venous oxygen saturation measurements that the increase in forearm blood flow during body heating is confined to the skin. *J. Physiol.* **134**, 444–450.