The Effect of the Dependent Position upon Blood Flow in the Limbs

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The blood flow, as reflected by the arteriovenous oxygen difference, in the arms and legs is greater in the dependent position than in the horizontal position. The physiologic and clinical significance of this finding is discussed.

The relationship between the blood flow in and the position of the limbs is a matter of some clinical and physiologic interest. Clinically, it is important to know in cases of ischemic arterial disease whether the limbs have a better blood flow when they are kept horizontal on a level with the body, or are allowed to be dependent. Physiologically, it is known that when a horizontal limb is lowered into a dependent position there is an increase in local arterial (hydrostatic) pressure which is opposed (except early after dependency) by an equal increase in hydrostatic venous pressure. The arteriovenous pressure gradient, therefore, is unaltered. Nevertheless, it is possible that changes may occur in the caliber of the vessels in the dependent limb which may affect the vascular resistance and alter the blood flow. Thus, there may be passive dilatation consequent to the increased intravascular pressure, or there may be active constriction, either as a reflex or a local response to increased blood pressure or flow, or there may be complicated effects that cannot be predicted.

The measurement of changes in blood flow when a limb is lowered entails considerable technical difficulty. The use of a venous occlusion plethysmograph does not seem feasible because the veins of a dependent limb are so distended by hydrostatic pressure that they are not suitable for the further quantitative trapping of blood. Skin temperature measurements are of limited applicability because they do not reflect accurately the blood flow in the deeper tissues; they cannot be related quantitatively to blood flow in the skin; and, even as an index of directional change, they are relatively crude. Indeed, several studies of this problem by the skin temperature method have yielded conflicting results,1-3 although all the experiments were concerned with tilting of the entire body rather than with lowering of the limb. Quantitatively reliable methods involving the use of radioactive substances for determining blood flow were not available to us at the time of this study.

The method employed in this investigation consisted of determining the arteriovenous oxygen differences. This method is based on the Fick principle that when the oxygen consumption is constant the blood flow in an extremity varies inversely as the A-V oxygen difference.

METHODS

The subjects, who were hospital patients with normal circulatory systems, were studied in the basal state. The room temperature remained constant within ±0.5 degree during any given test, being between 24°C and 27°C on different days. Blood was obtained from the antecubital, femoral, or popliteal veins, on one or both sides, when the limb was horizontal, then when it was dependent, and when it was in the horizontal position again. In order to avoid repeated venipunctures with possible concomitant reflex disturbances in circulation, indwelling needles (gage 18) were employed. These were inserted under local procaine anesthesia, and were kept patent with a slow infusion of isotonic saline solution. A manometer attached to this system through a Y tube allowed frequent determinations of venous pressure to be made by the method of Morita and von Tabora.4

Before each sample was collected, the infusion was disconnected and the needle was cleared of saline by withdrawing 2 cc. of blood into a separate syringe. The samples were then drawn into oiled, heparinized syringes, and immediately transferred

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to special containers for anaerobic storage over mercury in a refrigerator. They were analyzed for oxygen within a few hours by the technic of Van Slyke and Neill. Duplicate analyses, carried out on two machines, were required to agree within 0.10 volume per cent. The arterial oxygen content was estimated from the oxygen capacity of the first venous blood sample, assuming a saturation of 96 per cent. Hematocrit determinations were done on each sample by the method of Wintrobe in triplicate analyses and required to agree within 0.3 per cent. The oxygen content of each blood sample was corrected for changes in hematocrit by direct proportion to the hematocrit of the first venous sample. This excluded changes in venous oxygen content due to factors unrelated to blood flow such as hemoconcentration when the limb was dependent.

![Graph of A-V Oxygen Difference](image)

**Fig. 1.** The effect of the dependent position upon the arteriovenous oxygen difference in the arm. When the test arm was lowered, the arteriovenous oxygen difference increased. This was attributed to an increase in blood flow.

The procedures and results of the studies on the arms (antebrachial veins) and on the legs (femoral and popliteal veins) differed in certain details, and are described separately below.

**Procedures and Results**

**Studies on the Arms**

In these experiments, the subject lay on his back in a semirecumbent position. He was close enough to one edge of the bed so that one arm could be dangled. Initially, his arms were supported on Mayo tables so that the antecubital veins were approximately at the same level as the zero reference point for systemic venous pressure. Blood pressure cuffs were applied to the wrists so that the circulation to the hands could be occluded. This was done to exclude the rather large, "spontaneous," reflex vasomotor changes which might occur in the hands and mask the desired observations in the arms. Needles were inserted into the antecubital veins, pointing distally into deep branches. The saline infusions and manometers were connected, and the patient was allowed to rest quietly for about ten minutes while measurements of venous pressure were made. The wrist cuffs were then inflated to a pressure considerably exceeding the subject's systolic arterial pressure. Three minutes later the venous pressures were measured and blood samples were collected from both arms, after which the wrist cuffs were deflated. The experimental arm was then allowed to hang down beside the edge of the bed so that the fingertips were about twenty-two inches and the antecubital fossa about eight inches (depending on the length of the arm) below their original levels. When the arm had been dependent for two to four minutes the wrists were occluded. Three minutes later venous pressures and blood samples were again obtained. Finally, the arm was replaced to its original position, and the same procedure was carried out five to seven minutes later. Great care was taken at all times to keep the muscles free of tension, so as not to increase their metabolism.

Four experiments of this kind were performed. The results of two are presented in figure 1. In the other two, similar results were obtained in the experimental arm, but technical difficulties resulted in failure to obtain the control samples. It was, therefore, deemed best to exclude these experiments because it is known that such fluctuations in A-V oxygen difference may occur spontaneously in the horizontal forearm. It has been shown in this laboratory that such random fluctuations tend to be parallel in the two forearms, with a correlation coefficient as high as +0.93. Therefore, one side can be used as a control for the other, and indeed must be so used when the number of observations is small.

The results of the first experiments, illustrated in figure 1, show that during dependency the A-V oxygen difference in the limb decreased.
from a level of 10.0 to 8.4 volumes per cent, corresponding to a 16 per cent increase in blood flow. When the arm was returned to its original position, the A-V oxygen difference returned to 10.4 volumes per cent. Meanwhile, the control arm showed only small changes, at times opposite to those in the experimental arm. No more experiments were done on the arm since this problem is important principally as applied to the legs, and since the results in the arms and legs proved to be similar.

The venous pressures relative to the fixed (zero) level of reference were not altered appreciably in the dependent position. Relative to the level of the needle, the pressure was, of course, elevated by the hydrostatic difference. The pressures dropped about 1 cm. of saline when the hand circulation was occluded, and rose 4 to 5 cm. during the reactive hyperemia in the hand following restoration of its circulation.

\[ \text{Studies on the Legs} \]

Two groups of experiments were done on the legs, the first being on the femoral veins because of the ease with which they may be punctured. As shown below, this method proved unsatisfactory for our purpose. The second method, utilizing the popliteal veins, was therefore substituted.

1. **Femoral Veins.** In general, the procedure was similar to that in the preceding experiments. The differences as were follows. The subject lay supine on a special bed which had a hinged section under each leg. This allowed either leg to be lowered, flexion occurring at the knee to an angle of about 60 degrees from the horizontal. Needles were inserted into both femoral veins. Blood pressure cuffs, applied on the ankles, allowed the circulation to the feet to be occluded for three minutes prior to each sampling of blood.

At first, experiments were done with the subjects lying flat on the bed. The results of one such test are shown in figure 2. They were contrary to what had been expected on the basis of the results on the arms. When either leg was lowered, the A-V oxygen difference in that leg rose. This indicated that there was either a decrease in blood flow, or an increase in oxygen consumption in the area through which the sample of blood had circulated. A third possibility was that a variable amount of blood from the pelvis had been drawn back into the femoral vein by the sampling syringe, contaminating the samples. Other experiments carried out in this fashion yielded similar results. At this point, it was noted that when a leg was lowered some tension could be felt in the quadriceps muscles of the thigh. Either increased oxygen

consumption or a decreased blood flow in these slightly tense muscles could, therefore, account for the increased A-V oxygen difference, although the magnitude of the change (almost double in some instances) was surprising. The fact that the change in A-V oxygen difference indeed did occur in the horizontal thigh, and not in the dependent leg, was confirmed in an experiment carried out in exactly the same fashion, except that the circulation to the dependent leg was occluded by inflation of a cuff above the knee at greater than systolic pressure.
Further experiments on the femoral vein were carried out with the subjects supported in a semirecumbent position. It was found that in this position there was less tension in the thigh muscles when the knee was flexed, and therefore it was thought that the increased A-V oxygen difference in these muscles might be avoided. Figure 3 shows the results of one such experiment. Here, it is seen that when the test leg was lowered there was a considerable decrease in A-V oxygen difference as compared with the control leg. This would suggest an increase in blood flow in the dependent leg. Several additional tests showed similar results, but tension in thigh muscles could not always be avoided completely and occasional erratic changes in A-V oxygen differences were noted. This method, therefore, was abandoned in favor of studies on the popliteal veins.

2. Popliteal Veins. These experiments were carried out with the patient lying prone on the special bed with his groins over the hingees, so that an entire leg and thigh could be lowered, flexion occurring at the hip. An attempt was made to place indwelling needles in both popliteal veins.

Due to technical difficulties, it was usually possible to place correctly only one needle. Therefore, control observations could not be obtained in the opposite limb during most of the experiments. However, a sufficiently large number of unilateral experiments was carried out to insure that the spontaneous fluctuations in opposite directions would tend to cancel each other.

In general, the procedure was similar to that previously described. In most instances, when only one popliteal vein could be punctured, blood samples were obtained alternately with the leg horizontal, and when it was lowered to about 60 degrees from the horizontal. The leg was lowered and raised three times. When samples were obtained bilaterally, the test leg was lowered and raised only once. Experiments were done with the foot excluded from, as well as included in, the circulation. Five minutes elapsed between each change in limb position and the sampling of blood. Great care was taken at all times to keep the patient comfortable and relaxed.

Figure 4 shows the results of one typical experiment. Each time the limb was lowered, the A-V oxygen difference decreased considerably. Conversely, each time the leg was brought back to the horizontal, the A-V oxygen difference rose. This would indicate that the blood flow was greater when the limb was dependent than when it was horizontal.

Experiments were carried out on a total of
11 subjects. The effects of lowering the limb was observed 25 times, and that of re-elevating it to the horizontal position, 22 times. The individual results are shown in Table 1. The means show a decrease in A-V oxygen difference from 8.8 to 7.6 volumes per cent when the limb was dependent, corresponding to a 13.6 per cent increase in blood flow. Conversely, when the limb was elevated again to the horizontal position the mean A-V oxygen difference rose from 7.7 to 9.0 volumes per cent, representing a 17.5 per cent decrease in blood flow. These changes were highly significant statistically ($P$ less than 0.01).

When the data from the experiments excluding the foot circulation were analyzed
separately from those including the foot (see table 1), the results for the two groups were similar. There was, therefore, no evidence from these experiments that the circulation in the foot behaved differently from that in the leg in response to the changes of position.

Only nine contralateral control observations were made during changes in position of the test leg. These showed no significant alteration in A-V oxygen difference (mean 6.9 volumes per cent before and 7.0 volumes per cent after the test leg was lowered). Thus, the fluctuations on the control side appeared to be of a random nature and cancelled each other.

As in the arm, there were no significant or consistent changes in venous pressure as referred to the fixed reference level. Thus, the rise in local pressure in the veins roughly equaled the hydrostatic difference in level, and did indeed oppose the hydrostatic increase in arterial pressure, at least by the time accurate measurements could be obtained with the method used.

The hematocrit determinations showed an average increase of 1.5 units during dependency, revealing a considerable degree of hemoconcentration in the venous blood issuing from the dependent limb. If this had not been corrected for, the higher venous oxygen contents associated with this hemoconcentration would erroneously have been attributed to a greater increase in blood flow.

**DISCUSSION**

Two significant findings may be noted in these studies. The first is the increase in blood flow which occurs in a dependent limb. It was shown by Scheinberg and his co-workers that if a foot is previously emptied of blood by external pressure, its blood flow during the first few seconds of dependency is greatly increased over that which would have occurred in the horizontal position. In their plethysmographic study the hydrostatic venous pressure normally opposing the increased arterial perfusing pressure in the dependent limb was temporarily eliminated by first emptying the foot of its blood. They noted that the blood flow in the emptied foot was usually *more* than doubled when the mean arterial pressure (and arteriovenous pressure gradient) was doubled, indicating the possibility of vasodilatation (decreased resistance to flow). However, they felt that their methods of recording mean arterial pressure and blood flow were too crude to permit them to attach significance to this discrepancy. The present study shows that even when the arteriovenous pressure gradient is not changed, the blood flow is greater in the dependent limb. This must be attributed to vasodilatation, probably as a passive effect of the increased intravascular pressure. It should be emphasized that in the present study the position of only the limb was changed, not of the whole body, as takes place on a tilt table or a Sanders oscillating bed. It is known that when the body as a whole is tilted into a vertical position reflex vasoconstriction occurs in the lower parts, otherwise the patient shows orthostatic hypotension. The net effect of this reflex vasoconstriction plus the passive dilatation certainly must be different from the results described here.

The second point to be emphasized is the large *increase* in A-V oxygen difference produced by even slight muscular tension, such as occurred in the thigh during dependency of the leg in the femoral vein experiments. This is attributed chiefly to an increased oxygen consumption in the tense muscles, although, of course, a change of blood flow in them cannot be ruled out. This effect outweighs any possible increase in blood flow and results in a considerable decrease in venous and tissue oxygen tensions. To increase the oxygen tension in the tissues would seem to be a most important aim of therapeutic measures in peripheral vascular disease. Any postural maneuver designed for this purpose apparently must be accomplished in such a way as to avoid the slightest muscular tension; certainly active motion as in Buerger's exercises would seem undesirable. Studies of the effects of such maneuvers are not adequate if blood flow alone is measured, without taking into account oxygen consumption. Arteriovenous oxygen differences afford a measure of blood flow in relation to metabolic demand for
oxygen, and hence are of fundamental importance.

It is frequently observed clinically that patients with ischemic vascular disease prefer to lower their limbs into a dependent position. The results of this study offer an explanation for this observation. Other patients, especially those with superimposed infection, have greater pain when the limb is dependent. This might be due to vascular distention in the inflamed area.

**Summary**

The blood flow in a limb (leg or arm) of a recumbent person is about 15 per cent greater in the dependent position than in the horizontal position. This was shown by measuring arteriovenous oxygen differences in the antecubital or in the popliteal vein. If the dependent position is accompanied by muscular tension in the limb, however, the oxygen content of the venous blood may decrease markedly, due presumably to increased local oxygen consumption.

**REFERENCES**
