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ARTERIAL BLOOD FLOW IN THE LOWER EXTREMITIES

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Disturbances in the flow through various anatomically important sections of the arteries in the lower extremities, caused by closing or narrowing them were examined with the cadaver artificial circulation method. Particular attention was devoted to the intensity of the flow through collaterals, the amount of artery flow and to arterial pressure below the closed parts.

A surgeon who relieves the arterial obstruction or performs a by-pass grafting, frequently observes that arteriosclerotic changes in large vessels, which can be clinically stated at the periphery, may cause an important, mechanically produced constriction of arterial lumen.

It is possible, that mechanical factors affect circulatory conditions occurring at the place of the obstruction or below it. The results of clinical observations conducted for 2—3 years, concerning patients, operated on with good results, support this view.

The feeling of pulsation in the foot artery after mechanical recanalization of arterial obstruction or after grafts prompted an analysis of the physical laws governing the circulation in the lower extremities.

This problem requires the explanation of certain circulatory disturbances on the basis of the principles of the fluid flow in a closed tubular system.

The development of the corresponding experimental model (7) afforded a series of experiments which can elucidate the influence of mechanical factors on the intensity and direction of the flow of fluid to the periphery through obstructed or semiclosed major arteries.

The aim of the present research work could be summarized as follows:

1) determining the volume of the fluid, flowing to the periphery after arterial closure at various height,

2) estimating the percent of fluctuations in the peripheral blood flow, depending on the cross section or extent of the collateral branches,

3) determining the influence of the length of the obstruction on the distal flow,

4) investigating, if there is a direct relation between the degree of arterial narrowing and the flow into the periphery,

5) investigating, if the pulse wave can be transferred to the distal segment of the artery, by collaterals,

6) revealing the physical factors, exerting an influence on the peripheral pulse.

EXPERIMENTAL METHODS

There were 37 corpses investigated in three groups, using the cadaver artificial circulation method (c. a. c.).

In the first set of experiments the amount of the fluid flowing from the posterior tibial artery was determined after closing the main arterial trunk

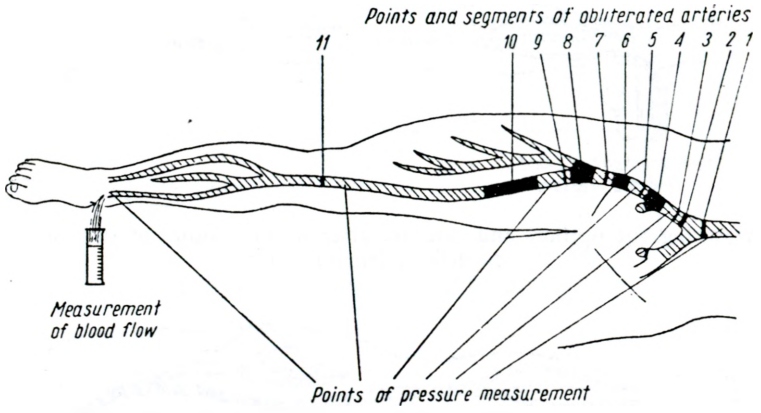

Fig. 1. Measuring the outflow and pressure after obliteration of lower extremity arteries at various heights.

at the places shown in Fig. 1. In each experiment pressures and pulse amplitudes were measured distally to the place of obstruction (Fig. 1). Since with arterial trees in various corpses the liquid outflow differed, percent relations were determined of the outflow from a given point of closure to the control outflow before closure in order to eliminate differences and make the results comparable. The data obtained were statistically elaborated.

The second set of experiments consisted in gradual reducing the lumina of common iliac and superficial femoral arteries and measuring the outflow, mean pressure and pulse amplitude, in the posterior tibial artery. The aim of the investigations was to find a critical value of the lumen at which severe circulatory disturbances appeared. The stricture of the arteries was obtained by introducing polyethylene tubes of various length and diameter (Fig. 2).

The third set of experiments consisted in determinations of the limiting value of the pressure, at which the finger of the experimenter could still feel

the pulse through the skin or at the place of the surgically exposed artery. Using pressures ranging from 120 mm Hg to 20 mm Hg, the pulse amplitude was gradually reduced and the limiting value at which the pulse could no more be felt, when touched with hands in very thin gloves was estimated by palpation.

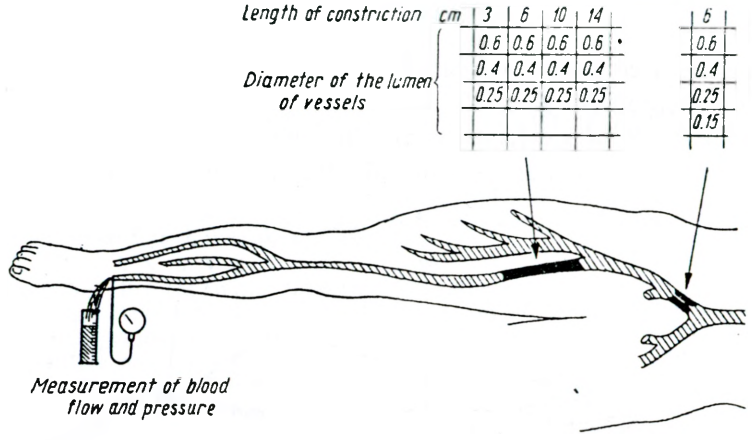

Fig. 2. Measuring the outflow and pressure after partiel closure of the common iliac and superficial femoral artery.

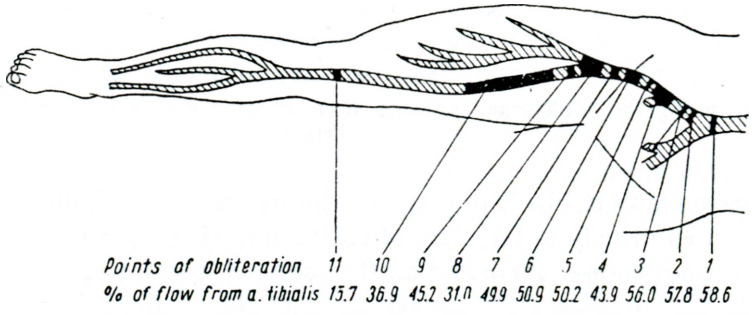

Fig. 3. Results of the first set of experiments.

RESULTS

The results obtained in the first set of experiments are presented in Fig. 3. Mean percent values of outflow from the posterior tibial artery in different places of its closure are given. The volume of the liquid, flowing out of the posterior tibial artery, within one minute, at a mean pressure 120/80 mm Hg, ranged within limits of 64—260 ml, on average of 164·6 ml.

The mean percent values of outflow diminished with the lowering of the point of arterial closure, except in two cases vz: when either all the branches of the common iliac artery or the branches of the common femoral artery were

closed. The value of the mean outflow was in these cases far lower than in the cases where the obstruction appeared above or below this level. The posterior tibial outflow was not influenced by the length of the obstruction in the external

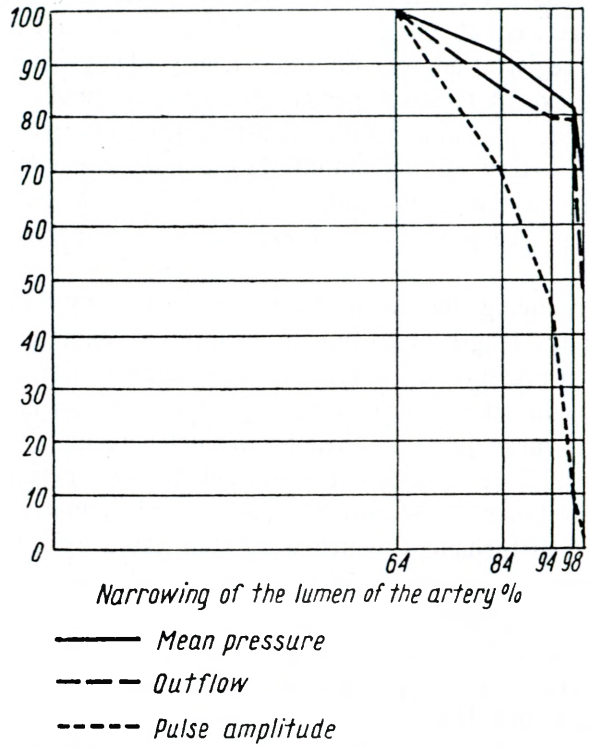

Fig. 4. Changes in mean pressure, outflow volume and pulse amplitude in the posterior tibial artery on gradual constriction of the common iliac artery.

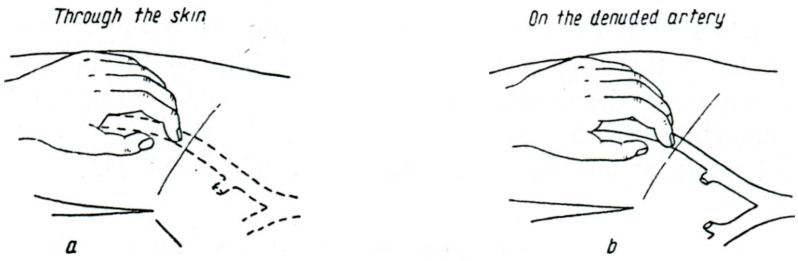

Fig. 5. The pulse amplitude at which the pulse could be felt with the palpation method

iliac artery. On the other hand when the superficial femoral artery was closed over a length of 15 cm the outflow was lower than in the case when the artery was closed at a single point.

As follows from the analysis of intraarterial pressure curves, the mean pressure occuring distally to the point of closure, was always lower than that in the unobstructed arterial tree. In the whole vascular tree, distally to the obstruction, the pressures were equal. The pulse wave was, as a rule, not transferred through collaterals. A registration was obtained nearly always in the form of rectilinear tracing, except for two special situations. At unobstructed branches of the common iliac or common femoral artery the pulse wave appeared in the posterior tibial artery but its amplitude did not exceed 5 mm Hg. In these cases the pulse on the medial ankle of the body could not be felt.

The results of the second set of experiments are presented in a diagram (Fig. 4).

As is seen, reducing the lumen of a femoral artery by 64 percent (10 mm in diameter over the length of 60 mm to an internal diameter of 6 mm) did not affect the mean pressure, pulse amplitude or outflow. Marked changes occured only after reducing the arterial lumen by 84 percent (to an internal diameter of 4 mm). The mean pressure then fell by 8·4 percent, on the average pulse amplitude by 30·2 percent, and the outflow by 14·2 percent.

Reducing the lumen to 94 percent (the internal diameter equalling 2·5 mm) caused marked disturbances, which were manifested by a fall of 15·0 percent in mean pressure, a decrease of 54·8 percent in pulse amplitude and a decrease of 21 percent in outflow.

The narrowing of the lumen by 98 percent caused the fall of pressure distally to the constriction by 18·7 percent, the pulse amplitude and the outflow decreased by 92·7 and 21·6 percent respectively.

After the artery had been completely closed the decrease in pressure amounted to 31·2 percent and those of the pulse amplitude and of the outflow were 99·0 and 52·6 percent respectively.

Similar changes were observed after superficial femoral artery closure.

The results obtained in the third set of experiments are presented in Fig. 5. They indicate that feeling the pulse depends only on the pulse amplitude. The pulsation in the common femoral artery, examined through the intact skin could still be felt at a pulse amplitude of ± 15 mm Hg and in the surgically exposed artery at an amplitude not lower than ± 5 mm Hg.

DISCUSSION OF RESULTS

The present results may be considered as valuable only for comparison purposes. They do not provide an answer to the question how much blood is necessary to ensure sufficient perfusion to the distal parts of the extremity. The results of the outflow measurements certainly do not correspond to the outflow of the blood in living subjects. All the results represent only relative values, which express percent ratios of the changes in the outflow from an obstructed

system as related to the wholly unobstructed system. The body perfusion permits to explain only some of the physical laws of flow, because with the method used we had to consider the major vessel system as composed of stiff tubes, neglecting the influence of the nervous system.

The assumption may arouse some controversion, in the light of the fact that the nervous system influences the peripheral circulation considerably. It seems, however, that the flow through major peripheral arteries primarily obeys the physical laws of circulation. Hence the mechanical factors are of particular importance for the analysis of the blood flow in major vessels, treated by means of surgery for obstruction.

In the available domestic and foreign literature (1, 11), we have met with only two papers dealing with a corpse's artificial circulation. Neither of them provides an answer to the questions put by the authors at the beginning of this work.

Using the body perfusion method the outflow changes depending upon the anatomical location of the arterial constriction, which could be expressed quantitatively. Generally the outflow from the posterior tibial artery gradually diminished according to the lowering of the place of arterial obstruction.

A striking finding was nearly the same outflow in the following three situations:

1) when the aorta was closed above the bifurcation,

2) at the unilateral closure of the common iliac artery,

3) when simultaneously at one side the common iliac artery and on the other side the internal iliac artery were closed.

This might suggest that in these situations the common iliac and collateral iliac internal artery played a secondary role in the development of the collateral circulation.

The cadaver artificial circulation method proved that the internal iliac and deep femoral arteries exerted a most important influence on the collateral circulation. As our calculations have shown it is through either of these that 10 to 20 percent of the whole fluid flows.

In cases of obstruction of the main vessels the additional closure of the internal iliac artery or the deep femoral artery caused considerable fall in blood pressure in the periphery. This fact is in accord with clinical observations, which proved that the obstruction of these arteries by persistent unilateral closure of the main vessel usually leads to necrosis.

When the external iliac artery had been closed either at a single point or over a small length the inflow of fluid to the periphery diminished in the same way. This might be a consequence of the absence of any important collaterals in the external iliac artery.

On the other hand the closure of the superficial femoral artery at a single place or over a length of 15 cm involved differences in outflow up to 10 percent.

This fact can be ascribed to the presence of a higher number of branches of collateral circulation.

A marked similarity between electromanometric curves obtained from c. a. c. and from clinical investigations permits us to form an idea as to the problem of palpating the pulse in patients suffering from an obstruction syndrome of the iliac or femoral arteries. Judging from c. a. c., it may be accepted, that while liquid is flowing through collateral circulation a marked decrease in pulse amplitude occurs or it may even fall to zero.

Pulse disappearance is directly related to the number of collaterals and inversely related to the size of their common lumen.

It is clear in the light of these facts why a wave of very small amplitude could be transferred to the periphery due to the patency of such wide branches as the internal iliac or deep femoral artery. However, at very small pulse amplitudes (5 mm Hg), the possibility of feeling the pulse becomes hardly likely even with a most benign situation of the stricture near which the collaterals of the common iliac or femoral arteries were patent.

Further c. a. c. experiments were carried out with the aim of establishing the changes in the outflow occuring after artery narrowing. The same investigations were carried out to establish the changes in arterial pressure and in pulse amplitude.

It could be stated that the critical value of the arterial lumen constriction is equal to 20 percent of the previous artery diameter. The outflow rate, arterial pressure and pulse amplitude, which up to this point of gradual reduction of the artery lumen remained unchanged, below this value rapidly fell.

These observations provide an explanation for the sometimes diagnosed clinical syndromes of acute ischemia in the course of arteriosclerosis. A gradually increasing constriction may not be revealed clinically until the critical value of 20 percent lumen closure is reached.

This critical constriction of artery lumen may also be responsible for sudden ischemic signs occuring after artery grafting or after operative artery recanalization. This may be of special importance for the places of anastomosis or vascular sutures.

The interrelation between the outflow rate, mean pressure and pulse amplitude through a reduced artery lumen is also of interest. As follows from the curve in Fig. 7, the outflow mean pressure is maintained on a relatively high level although the pulse has disappeared. This could explain the fact of sufficient perfusion although the pulse could not be felt. This is sometimes observed also in patients after succesfull grafting or surgical artery recanalization, when there is sufficient perfusion and the extremity function is satisfactory although the pulse is absent in the periphery.

The establishing of a c. a. c. model permitted to investigate the factors influencing the pulse in the periphery. It could be stated, that the palpatory

feeling of the pulse in the femoral artery was possible at a pulse amplitude not lower than 15 mm Hg. The investigator's hands were in rubber gloves and the skin was not incised. With a surgically exposed artery the pulse could be felt with amplitudes not lower than 5 mm Hg. The conditions occuring after artery occlusion at various levels, when performing c. a. c. correspond most closely to those existing shortly after sudden obliteration or artery embolism has appeared. It seems, however, that some conclusions could also be drawn for chronic obstruction, in the first place for that occuring in chronic peripheral arteriosclerosis.

CONCLUSIONS

A cadaver artificial circulation may give some ideas as to the physical principles of peripheral circulation in cases of constriction of the lower extremity arteries.

1. With the lowering of the points of artery obstruction in the lower extremity the outflow from the posterior tibial artery decreased.
2. The internal iliac artery and deep femoral artery are the most important ways of collateral circulation. The participation of either of them in peripheral circulation amounts to 10—20 percent.
3. The pulse wave was not transferred through collaterals except for two situations: when simultaneously the common iliac or external iliac artery were closed and the internal iliac artery remained unobstructed, or when simultaneously the common femoral or superficial femoral arteries were closed and the deep femoral artery was free from obstruction. The pulse amplitude did not exceed 5 mm Hg.
4. The critical value of artery lumen constriction was 20 percent, at which point vascular disturbances appeared.
5. The palpatory feeling of the pulse wave depended on the pulse amplitude width, irrespective of absolute values of the arterial pressure.

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