THE EFFECT OF THE APPLICATION OF TOURNIQUETS ON THE HEMODYNAMICS OF THE CIRCULATION

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The treatment of acute left ventricular failure by morphine and venesection frequently produces as dramatic relief of symptoms as does the intravenous administration of glucose in a case of insulin shock. Cases which have not responded to morphine alone may recover promptly after the removal of from 500 to 800 cc. of blood.

Many clinicians (1, 2, 3, 4) believe that pooling of blood in the extremities by means of tourniquets is as effective as phlebotomy in the treatment of left ventricular failure. While this is a widespread clinical impression, experiments demonstrating that a significant quantity of blood is pooled in the extremities by venous tourniquets are lacking. Without this knowledge there is no rational basis for comparing the efficacy of these two forms of therapy. The purpose of this study is, therefore, to measure the amount of blood pooled in the extremities by venous tourniquets and to determine whether this amount is sufficiently large to be of clinical significance. The dye method was used for the determination of the blood volume, and tourniquets were used to separate the blood circulating in the extremities from that of the remainder of the body.

METHOD

Each of the following 3 experiments was performed on 4 normal males and 1 subject with chronic arthritis.

Basal blood volume. The total blood volume was calculated from the proportion of plasma to cells, as shown by hematocrit determinations. The plasma volume was determined by the dye method of Gibson and Evans (5) as adapted to the photoelectric microcolorimeter by Gibson and Evelyn (6).

The blood volume of head, trunk, and arm at rest. On another day the arterial circulation to the extremities was occluded by inflating tourniquets on the right arm and both thighs to a pressure of 250 mm. of Hg. As the pressure was thrown into the cuffs from a large reservoir, the occlusion was rapid. Ten mgm. of dye were immediately injected into the left antecubital vein. Ten minutes after the injection of the dye, a needle was placed in the left antecubital vein and from 4 to 6 samples of blood were taken during the next 10 minutes. The amount of blood in head, trunk, and arm at rest was determined from the concentration of the dye in these samples and from the hematocrit. Twenty minutes after the injection of the dye the tourniquets were released. Samples of blood were taken for 10 to 50 minutes after the release of the tourniquets.

Blood volume of head, trunk, and arm after venous congestion of the extremities. On a third day the three extremities were congested by inflating tourniquets on their proximal portions to diastolic pressure. At the end of 7 to 10 minutes the arterial circulation to these extremities was cut off from the remainder of the body by raising the pressure in the cuffs to 250 mm. of Hg. Ten mgm. of dye were then injected into the left antecubital vein. Ten minutes later a needle was placed in the left antecubital vein and from 4 to 6 samples of blood were taken during the next 10 minutes. The blood volume of head, trunk, and arm was determined from the concentration of the dye in these samples and from the hematocrit. Twenty minutes after the injection of the dye the tourniquets were released. Samples of blood were taken for 20 to 60 minutes after the release of the tourniquets.

The volume of blood normally present in the three extremities was obtained by subtracting the result obtained in experiment 2 from that obtained in experiment 1, and the volume of blood that was removed from head, trunk, and arm by venous congestion was obtained by subtracting the result obtained in experiment 3 from that obtained in experiment 2.

In all the experiments the subjects had fasted for 12 hours. They rested comfortably on a bed for 30 minutes before the experiments started. The room temperature was from 20 to 22° C. In the experiments measuring volume of blood in head, trunk, and arm, the vessels of the extremities were neither contracted by cold nor dilated by heat. In 3 experiments with venous congestion the extremities were heated by immersion in warm water before the tourniquets were applied. However, as warming produced no demonstrable difference in the amount of blood pooled, it was discontinued.

To secure the maximum pooling of blood in the extremities with minimum discomfort to the subject, the cuffs on the thighs should be at least 12 cm. wide and the cloth should be long enough to wrap around the thigh several times. The tourniquets on the extremities were placed as close to the body as possible. Padding was placed under the distal portion of the cuffs to prevent them from sliding down the thighs when they were inflated. Subjects with long, thin limbs were the most suitable.

In addition to the blood volume determinations, the subjective sensations, skin color, and respiratory rates of the subjects were noted. The effects of venous tourniquets were also observed in 2 other normal subjects in whom blood volume determinations were not done. In 2 hypertensive subjects the effect of a more prolonged venous occlusion on arterial pressure and heart sounds was studied.

RESULTS

Basal blood volume. In 5 subjects (Table I) the basal blood volume ranged from 5010 to 6100 cc. of blood, with an average of 5580 cc.

Arterial tourniquets. In the same 5 subjects (Table I) the volume of blood circulating in the head, trunk and one arm, when the circulation to the other three extremities had been occluded without venous congestion, ranged from 4040 to

TABLE I

The amount of blood in the head, trunk and arm

Subject	Age of subject	Height	Weight	Basal blood volume			Volume of blood in head, trunk, arm without congestion			Volume of blood in head, trunk, arm, with venous congestion			Volume of blood in three extremities without congestion	Decrease in volume of head, trunk, arm, with venous congestion
				Plasma volume	Total blood volume	Hematocrit	Plasma volume	Total blood volume	Hematocrit	Plasma volume	Total blood volume	Hematocrit		
		inches	*lbs.*	*cc.*	*cc.*		*cc.*	*cc.*		*cc.*	*cc.*			*cc.*
J.W....	24	73	143	3490	6100	42.9	2900	5190	44.1	2490	4300	42.1	910	890
L.T.*...	42	71	152	2750	5010	45.1*	2220	4380	49.3*	1950	3800	48.7*	630	580
R.E....	27	69	143	2950	5220	43.5	2280	4040	43.5	1850	3300	44.0	1180	740
J.R.....	31	73	176	3380	5970	43.4	2930	5080	42.4	2480	4300	42.3	890	780
H.S.....	28	70	170	3080	5600	45.0	2510	4700	46.6	2180	4080	46.6	900	620

* This subject had chronic arthritis. His hematocrit showed a slight fall during his stay in the hospital.

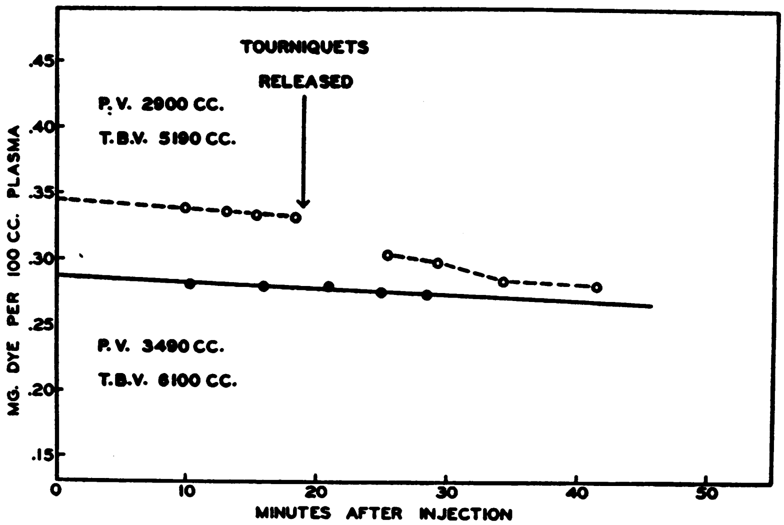

FIG. 1. AMOUNT OF BLOOD NORMALLY PRESENT AT REST IN ONE UPPER AND TWO LOWER EXTREMITIES (SUBJECT J. W.)

Solid line represents concentration of dye (Evans blue) in plasma after the injection of 10 mgm. of dye. On the basis of this curve and the hematocrit, the basal blood volume is 6100 cc. The first portion of the broken line represents the concentration of dye in the plasma of head, trunk, and arm after injection of 10 mgm. of dye. The volume of blood in this portion of the body is 5190 cc. The lower portion of broken line represents the concentration of dye in the plasma after release of tourniquets. Note that plasma volume is decreased after the release of tourniquets and has not completely returned to normal at the end of 20 minutes.

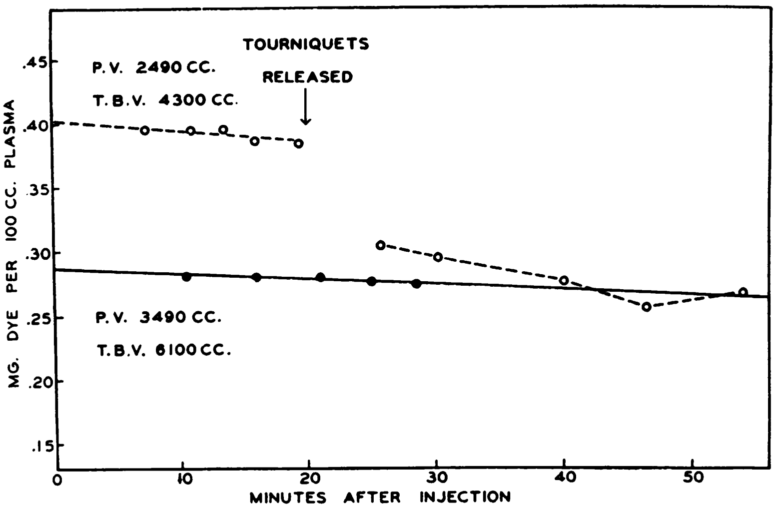

FIG. 2. AMOUNT OF BLOOD WHICH IS REMOVED FROM HEAD, TRUNK AND ARM BY VENOUS TOURNIQUETS (SAME SUBJECT AS IN FIGURE 1)

The basal blood volume (solid line) is 6100 cc. The first portion of the broken line represents concentration of dye in plasma of head, trunk and arm when the extremities are congested. The volume of blood in this portion of the body is 4300 cc. When this volume (4300 cc.) is subtracted from the normal volume of the head, trunk and arm (5190 cc.), as determined in Figure 1, it is found that 890 cc. of blood are removed by congesting the three extremities. The lower portion of the broken line represents the concentration of dye in the plasma after the release of tourniquets.

5190 cc., with an average of 4680 cc. The amount of blood present at rest in the right arm and lower extremities ranged from 630 to 1180 cc., with an average of 900 cc., or 16 per cent of the total blood volume. A typical experiment is shown in Figure 1.

After the tourniquets were released the plasma volume remained lower than the basal volume for 20 to 30 minutes. This was presumably the result of an increase in permeability of the capillaries of the extremities from the prolonged arterial occlusion. In the experiments with venous tourniquets given below, the combined effect of increased venous pressure and anoxia usually resulted in an even greater loss of fluid into the tissues of the extremities.

Subjectively, all 5 persons were conscious of discomfort when the pressure was applied, but after a few minutes the pain subsided. The extremities felt cool to the subject. Sensation and motor power were greatly diminished in the extremities by the end of 20 minutes. There were no other symptoms; the subjects did not develop nausea, sweating, or pallor. After release of the tourniquets, tingling and pain in the extremities were present for several minutes.

Venous tourniquets. In the same 5 subjects (Table I) the volume of blood present in head, trunk and one arm after the other three extremities were congested ranged from 3300 to 4300 cc., with an average of 3960 cc. The congested extremities, therefore, contained from 1210 to 1920 cc. of blood, with an average of 1640 cc. (29 per cent of the total blood volume). A typical experiment is shown in Figure 2.

When the three extremities were congested by venous tourniquets, the volume of blood circulating in the head, trunk and one arm was decreased by 580 to 890 cc. of blood (average decrease, 720 cc.). The volume of blood normally present at rest in the head, trunk and one arm was thereby decreased approximately 15 per cent by pooling blood in the extremities.

The application of venous tourniquets at diastolic pressure produced symptoms of shock in 4 of 7 subjects tested. These symptoms were nausea, sweating, and pallor. Blood pressure readings were not made as a tourniquet was on

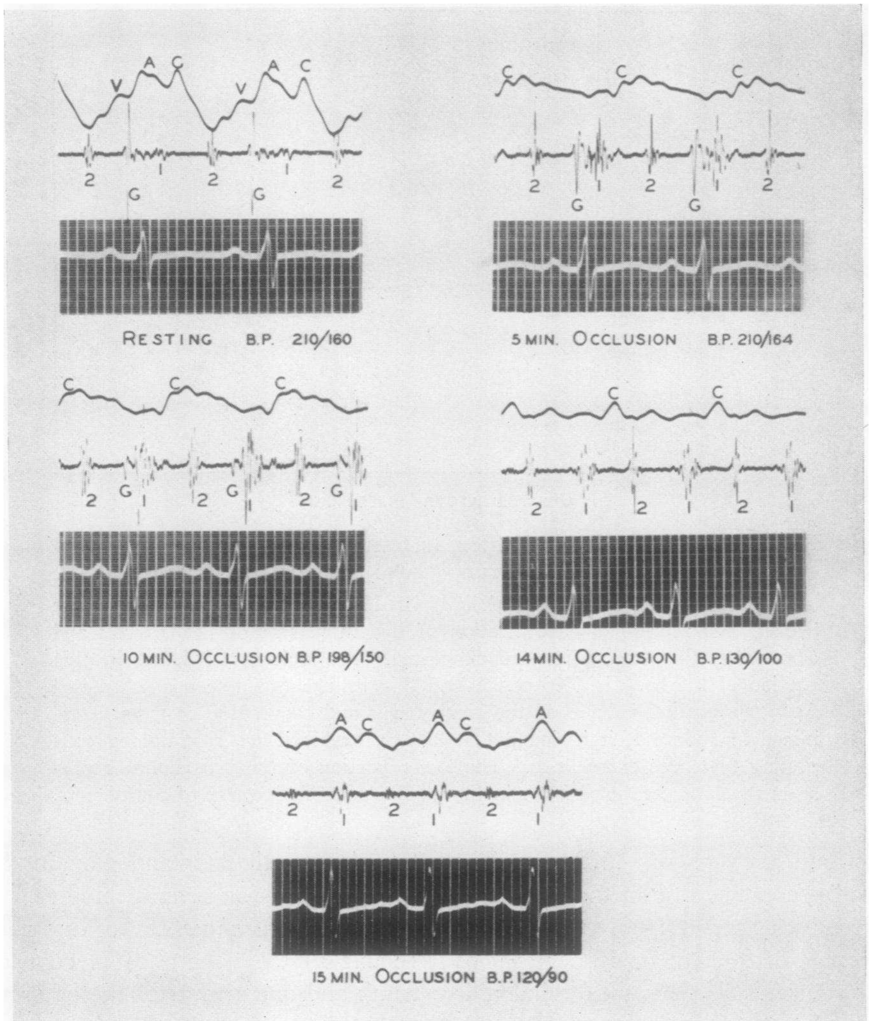

FIG. 3. THE EFFECT OF VENOUS TOURNIQUETS (110 MM. OF HG) ON THE ARTERIAL PRESSURE AND HEART SOUNDS OF A HYPERTENSIVE SUBJECT, F. C.

The pooling of blood in the extremities lowers the pulmonary venous pressure and the gallop (g) disappears.

one arm and a needle in the vein of the other arm. As these same subjects had experienced no generalized reaction to rapid arterial occlusion, a procedure which was as painful as the venous congestion, it was believed that the symptoms of shock were produced by the rapid pooling of blood in the extremities. After release of the tourniquets the subjects experienced more severe tingling than after the simple arterial occlusion. They also showed distinct hyperpnea. Two of the 7 subjects showed a few petechial spots.

Effect of venous tourniquets in hypertensive subjects. In 2 subjects with arterial hypertension, tourniquets inflated to a pressure of 110 mm. of Hg were applied to the three extremities. The resting arterial pressures in these subjects were 210 and 150 mm. systolic, and 160 and 110 mm. diastolic, respectively. In the first subject sweating, pallor, nausea and mental confusion developed, and at the end of 16 minutes the arterial pressure had fallen to 90 mm. systolic and 70 mm. diastolic. A marked gallop rhythm (Figure 3), which was present before the tourniquets were applied, had disappeared. On release of the tourniquets the pressure rose rapidly and the gallop gradually returned (Figure 4). In a sec-

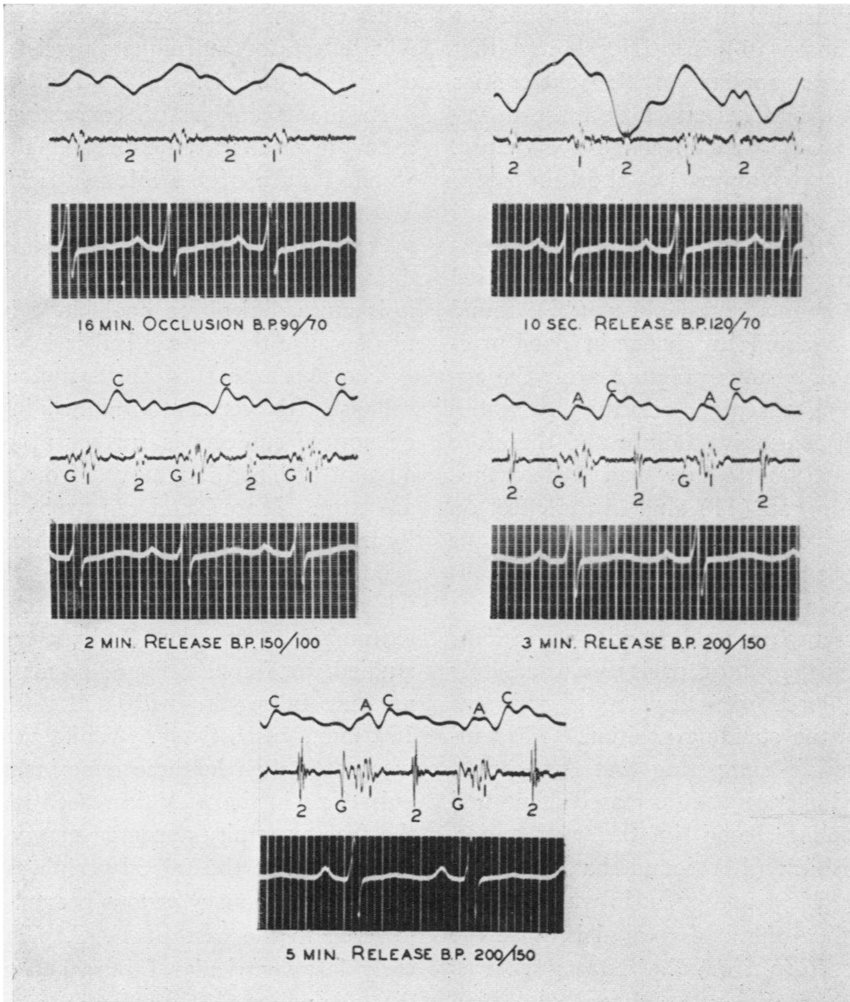

FIG. 4. THE EFFECT OF THE RELEASE OF VENOUS TOURNIQUETS ON THE ARTERIAL PRESSURE AND HEART SOUNDS IN THE SAME SUBJECT

The arterial pressure rises rapidly. The gallop reappears as the pumonary venous pressure increases.

ond subject a similar fall in arterial pressure with symptoms of shock occurred.

DISCUSSION

Venesection in the treatment of acute left ventricular failure has had a sound physiological basis since Blumgart and Weiss demonstrated that the amount of blood present in the lungs is increased in left ventricular failure. These investigators (7) found that the average velocity of the blood in the lungs in these cases was slower than in normal subjects. In the absence of a striking diminution in cardiac output, this decrease in velocity could only result from an increase in the size of the cross section area of the pulmonary bed. The volume of blood filling this dilated bed must, therefore, be greater than in normal subjects. This increase in volume of blood in the pulmonary bed in acute left ventricular failure is the result of temporary imbalance in the function of the right and left ventricles, so that the right ventricle brings more blood to the lung than the left ventricle can remove (8). The removal of blood from the body by phlebotomy decreases the amount of blood contained in the engorged lungs and hence relieves the symptoms.

Few investigators have studied the effect of tourniquets on the circulation, although clinicians have long recommended them as a substitute for phlebotomy. Tabora (1) in 1910, showed that venous tourniquets applied to the extremities caused relief of symptoms and a decrease in venous pressure in patients with congestive failure. Fuchs (9) produced symptoms of shock in 5 of 7 subjects studied by this method. The venous pressure decreased moderately in the 2 subjects who did not develop collapse; it was not measured in the others. Brams and Golden (10) found that there was no significant change in blood pressure, pulse rate or venous pressure after the application of venous tourniquets to the extremities of patients with congestive failure and therefore concluded that the procedure had little value. Hamilton and Morgan (11) studied the effect on the vital capacity of the application of venous tourniquets to four extremities in normal subjects. They made observations on the subjects in the dorsal recumbent and standing positions. With tourniquets the vital capacity was definitely increased in the dorsal recumbent position; it was little changed in the standing position. They interpret these data as suggesting that the amount of blood in the lungs can be decreased in normal subjects by pooling blood in the extremities. Jarisch and Gaisböck (12) found that, when the circulation to both legs and one arm was occluded rapidly, the cardiac output decreased because the normal venous return from the extremities was occluded. If the arterial occlusion was prolonged for 15 or 20 minutes the cardiac output rose.

The results of this study show that in normal subjects the volume of blood circulating in the head, trunk and arm at rest is decreased by 580 to 890 cc. by placing venous tourniquets on three extremities. This is more effective than the removal of a corresponding amount of blood by phlebotomy because in the first case the blood is removed from the head, trunk and arm volume, and in the latter instance it is removed from the total blood volume. It is significant that a measurable amount of fluid is lost from the blood stream during the period of venous engorgement. This is in part the result of the increased capillary pressure (13). More fluid would have been lost if the period of congestion had been prolonged. This loss of fluid from the blood stream explains in part the clinical observation that in the treatment of acute left ventricular failure the beneficial effects of tourniquets persist for some time after their release.

In the treatment of congestive failure more dramatic results are obtained in those subjects in whom failure of the left ventricle predominates. When marked failure of the right ventricle is present, the veins are already distended. In addition, when the tissues are tight with edema fluid it is more difficult to pool blood in the extremities because the venous bed is less distensible.

The appearance of the symptoms of vascular collapse after venous tourniquets in half the group of normal subjects is further proof that a large amount of blood is removed from the head, trunk and arm. More blood can probably be pooled in hypertensive than in normal subjects because the venous tourniquets can be inflated to higher levels without interfering with the arterial inflow to the extremities. In the 2 hypertensive subjects studied, profound collapse occurred, the systolic pressure falling from 210 and 150 mm. to 90 and 100 mm., respectively. While venous pressures were not taken in these experiments, the venous pulsations in the neck decreased and the veins of the free extremity appeared empty and collapsed. In addition to the fall in peripheral venous pressure, the pulmonary venous pressure was probably lowered in the case of F. C. This subject had early left ventricular failure and a marked mid-diastolic gallop. The gallop occurred at the time of rapid ventricular filling and was greatly accentuated by exercise. It was a manifestation of the greater than normal pressure differential between the auricle and ventricle in early diastole which caused a rapid flow of blood into the ventricle and produced a sound. When the venous tourniquets were applied, the gallop disappeared as blood was pooled in the extremities because the volume of blood and the venous pressure in the lungs were decreased. On release of the tourniquets the blood pressure returned to normal and the gallop slowly reappeared. The gallop was not present during the period of hyperpnea which occurred 10 to 15 seconds after the release of the tourniquets. This indicates that the increase in respirations is not caused by pulmonary congestion from the sudden release of the tourniquets. If the pulmonary venous pressure had been suddenly increased by this mechanism, the gallop would have been present. The hyperpnea probably results from chemical stimulation of the respiratory center as the blood with a lowered pH returns from the extremities.

SUMMARY AND CONCLUSIONS

1. In 5 subjects (4 normal and 1 with chronic arthritis) the basal blood volume averaged 5580 cc. The blood volume of the head, the trunk, and one arm averaged 4680 cc. Therefore, the average amount of blood in one upper and two lower extremities was 900 cc., or approximately 16 per cent of the total blood volume.

2. In the same 5 subjects an average of 720 cc. of blood was removed from head, trunk and arm by placing venous tourniquets at diastolic pressure on three extremities. This represented 15 per cent of the volume of blood normally circulating in the head, trunk and arm.

3. In 4 of 7 normal subjects tested, sufficient blood was pooled in the extremities to produce symptoms of collapse, *i.e.,* nausea, sweating and pallor. In 2 hypertensive subjects the venous tourniquets produced a marked fall in arterial pressure and profound collapse.

4. In 1 hypertensive subject pooling of blood in the extremities caused the disappearance of a marked diastolic gallop. This indicated that the tourniquets were effective in lowering the pulmonary venous pressure.

5. When tourniquets were applied to the extremities, the plasma volume was lowered by transudation of fluid into the tissues. Thus the beneficial effect of the tourniquets persists in part for some time after release.

6. This investigation demonstrated that as much blood was removed from the general circulation by venous tourniquets as by the usual phlebotomy. It presents a rational basis for this method of treatment of left ventricular failure.

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