An Experimental Study of Prolonged Left Heart Bypass Without Thoracotomy *

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THE possibility of supporting circulation and reducing the work load of the left heart following acute coronary occlusion or left heart failure from other causes such as aortic or mitral vavular disease, offers intriguing investigative problems. Experimental and clinical approaches to this problem have been presented before. These mainly have concerned methods of total or partial cardiopulmonary bypass with the use of an oxygenator,[6, 7, 13, 16] veno-arterial shunting,[4, 8, 9, 11, 12] or as has been investigated by Clauss and co-workers,[3] an arterial counterpulsator. Total cardiopulmonary bypass has the disadvantage of requiring an oxygenator with resultant trauma to blood which is a limiting factor in the time that it might be used. Veno-arterial shunting has the definite disadvantage of low flow rates. The arterial counterpulsation method has the limitation of not relieving the left ventricle entirely of the work load of cardiac output, or in the case of mitral stenosis of not reducing left atrial pressure or in aortic stenosis of not removing resistance of the tight valve. It seems feasible that if the left ventricle could be bypassed almost entirely with oxygenated left atrial blood, the above mentioned disadvantages could be overcome.

In a previous publication from this laboratory,[5] it was shown that the work load of the normal heart in a dog can be effectively reduced by left heart bypass. The reduction in oxygen consumption of that part of the heart drained by the coronary sinus while on bypass was taken as significant evidence of this conclusion. It was not necessary to bypass the entire cardiac output to realize a reduction in oxygen consumption.

Salisbury[14] suggested the benefit of left heart bypass in all types of heart failure except cor pulmonale. This method has been used in this clinic as a temporary support after operation in extracorporeal circulation.

By angiography it was shown that complete bypass could be accomplished with this method.[10]

Using the Carlens technic of left heart catheterization a metal cannula (Fig. 1) was devised which could be passed from the right external jugular vein of the dog into the right atrium and with fluoroscopic

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control through the fossa ovalis into the left atrium.[15] The final design of the cannula was 7.0 mm. in diameter and 30 cm. long which will allow for a flow of 4.5 liters per minute at 90 cm. of siphonage. With such a cannula for recovery of blood from the left atrium, dogs could be placed on left heart bypass without thoracotomy, without an oxygenator in the system, and at the same time a high flow rate could be maintained, usually the entire cardiac output. With this system of bypass the left atrial pressure was reduced to or slightly below atmospheric and the left ventricle was relieved of the major part of its work load.

To evaluate this method of left heart bypass a group of 14 dogs were placed on bypass for six hours. The results were sufficiently gratifying in ten survivors, that it was believed a trial of a series of animals with a longer perfusion time should be attempted. This paper reports ten dogs placed on left heart bypass continuously for 24 hours.

Material and Methods

Ten mongrel dogs weighing between 23 and 41 kg. were placed on left heart bypass, nine for 24 hours and one for 19 hours. All dogs were anesthetized intravenously with pentothal and veronal initially, and in the latter part of the perfusion period only with pentothal.

The technic of left heart bypass is essentially as that described in Reference 15.

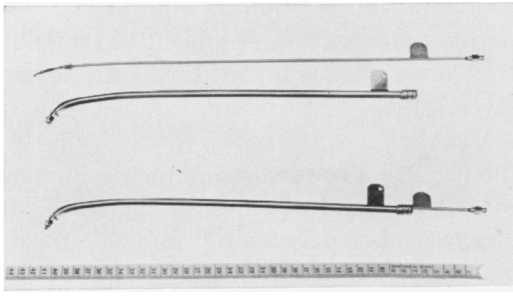

FIG. 1. Stainless steel cannula used for left atrial puncture on the dogs.

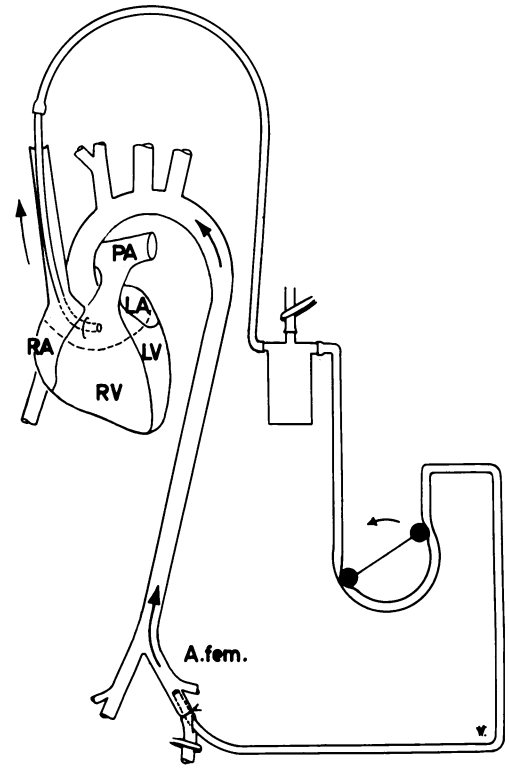

FIG. 2. Diagrammatic sketch of the bypass circuit showing the cannula placed into the left atrium from which blood flows by gravity through the flowmeter into a distensible reservoir, from which it is returned into the systemic circulation via the femoral artery by a roller pump.

In all dogs the atrial cannula was passed into the left atrium via the right external jugular vein, the superior caval vein and right atrium across the septum through the fossa ovalis.

In three of the ten dogs there was some confusion as to orientation with the cannula in the right atrium, and puncture of the septum, although in the fossa ovalis, was a little more difficult than usual and required a few more minutes of fluoroscopy time. In the remaining seven animals there was no difficulty and in none of the dogs were there any serious complications on passing the cannula into the left atrium.

The cannula was connected by polyvinyl tubing 10 mm. in diameter to a flowmeter (AGA) and then to a distensible reservoir. In the first nine dogs this consisted of a

TABLE 1. *Data on 10 Days on Prolonged Left Heart Bypass**

Dog	Wt. (kg.)	Flow Rate Ave.		Blood Trans.	Urine Output	Plasma Hemoglobin		Red Cell Count (millions)		Thrombocytes (thousands)		Sacrificed (time)
		l./min.	ml./kg. min			Onset	After 24 hrs.	Onset	After 24 hrs.	Onset	After 24 hrs	
1561	34	3.0	88	1,500	700	10.4	28.8	4.33	4.27	263.9	12.81	6 wk.
1666	27	2.0	74	2,650	650	1.2	38.0	6.10	4.93	176.9	49.30	6 wk.
1700	34	2.3	68	1,800	1,018	6.8	159.6	6.88	6.33	130.72	50.64	12 wk.
1647	27	2.9	107	2,500	673	1.0	112.0	4.46	4.37	267.6	113.62	12 wk.
1311	41	3.3	80	4,000	1,024	32.0	181.2	5.29	4.44	158.7	66.6	8 da.
1711	35	2.5	71	4,000	814	7.2	—	4.38	—	188.34	—	24 hr.
1731	27	2.0	74	2,600	1,384	10.4	74.0	4.93	3.92	133.11	47.04	Died
1735	30	2.4	80	1,970	1,078	—	92.0	6.36	—	108.12	—	8 wk.
1734	31	3.2	103	1,700	380	25.2	11.2	6.20	4.23	124.0	71.91	8 wk.
1703	23	2.3	100	1,500	—	—	—	5.90	5.30	206.5	102.22	3 wk.
Ave.	30.9	2.6	84.5	2,422	—	11.78	87.1	5.78	4.72	175.79	64.27	—

* All dogs on pump for 24 hours except Dog 1711, 19 hours.

rubber glove, but in the last dog a plastic sleeve of about 50 ml. volume was used. The change was made because in some instances at the end of the perfusion period fibrin clots were noted in the glove. It was believed that a plastic sleeve would offer less stasis of blood and thus possibly reduce the incidence of clot formation. Flow into the reservoir was by gravity and varied between 65 to 100 cm. of siphonage. The blood was then returned by means of a roller pump into the femoral artery. A diagram of the bypass circuit is shown in Figure 2. In all dogs sterile technic was used in the surgical dissection of the jugular vein and the femoral artery. The bypass circuit was cleaned by first flushing tap water through the system and following this with 10 per cent formalin which was allowed to stand in the circuit for several hours. The circuit was then thoroughly rinsed with sterile normal saline. Neither the tubing nor the reservoir was ever used more than twice. The circuit was primed with about 650 ml. of fresh heparinized blood (50 mg./l.) to which penicillin was added. The blood was drawn under sterile conditions.

All animals were heparinized intravenously prior to placement of the atrial cannula with either 3.0 or 6.0 mg./kg. of body weight. Heparinization was maintained by repeating one half the initial dose every one or two hours. Periodic samples of blood were taken for the determination of plasma heparin level,[2] clotting times, and fibrinogen determinations. The results of these studies will not be reported here since the problem of heparinization for long-term perfusion is still under investigation.

Ventilation was assisted periodically by the Engström respirator and the position of the dogs was frequently changed in an effort to prevent atelectasis and pneumonitis.

Arterial pressure was measured by a polyethylene catheter (PE190) in the aor-

tic arch inserted via the femoral artery and recorded with an Elema strain gauge and Mingograf recorder.

Rectal temperature was recorded on all animals. An effort was made to keep the temperature normal by heating pads under the animal as well as circulating water of controlled temperature in plastic tubing alongside the tubing in the bypass circuit. No heat exchanger as such was employed in the circuit.

At the conclusion of the bypass period and after the cannulae had been removed all dogs were given protamine or Polybrene intravenously until the clotting time (Lee-White) returned to seven to 10 minutes.

Results

The main data from the individual experiments are listed in Table 1.

Survivors. Nine dogs were on left heart bypass for 24 consecutive hours, with eight surviving. One was sacrificed at eight days because of burns to one thigh from a heating pad and a wound infection in the neck. The remaining seven dogs were sacrificed electively at three weeks (1); six weeks (2); eight weeks (2); and 12 weeks (2). All of these dogs at the time of sacrifice appeared to be in good health.

In the one dog that failed to survive there was blood loss and no blood available to replace it at that time. Therefore, in the latter part of the perfusion period the blood pressure dropped to about 30 mm. Hg and for about three hours remained between 60 to 70 mm. Hg. At this time also the hematocrit dropped from about 31 to 18 per cent following dextran which had been given several hours before. During the period of low blood pressure, the blood in the pump circuit became cyanotic on several occasions for short periods which was thought to be due to the atrial cannula slipping back into the right side. Following this period of hypotension the respirator was required and the lid reflexes were sluggish or absent. Likewise no anesthesia was required during the pumping period. Coming off the pump it was not possible to maintain an adequate blood pressure. At autopsy it was seen that there was a rather large hematoma of the posterior wall of the left ventricle and atrium as well as the atrial septal area. It is believed that this animal expired as a result of cerebral damage secondary to a low blood volume and pressure. Trauma to the heart probably was the result of the beating of an empty heart against the metal cannula. Also, this particular cannula was of a different design with less curvature at the tip and this might have played a part in the extensive cardiac trauma.

The one remaining dog was removed from bypass at the end of 19 hours because of excessive blood loss into a retroperitoneal hematoma, the result of an earlier faulty cannulation of the femoral artery. After removing the arterial cannula and giving protamine the bleeding stopped and with blood transfusion the arterial pressure rose to an acceptable level. The dog was sacrificed after 24 hours, because she was pregnant and it was thought she was in labor. At autopsy it appeared that the puppies had not died until the dog was sacrificed.

Flow Rates: An attempt was made to maintain maximum bypass flow during the entire period. This was done by lowering the reservoir to the siphonage level that would permit the greatest flow without collapsing the atrial wall about the cannula tip and thus obstructing it. This was difficult to judge at times, but with excessive siphonage the flow would drop, some left ventricular beat could usually be seen on the aortic pressure tracing, and a *biting* sensation could be felt in the metal cannula. Flow rates on the dogs averaged between a low 2.0 l./min. to a high of 3.3 l./min. and from 68 ml. to 107 ml./kg./min. A flow rate as high as 4.0 l./min. was obtained at times in some of the larger animals.

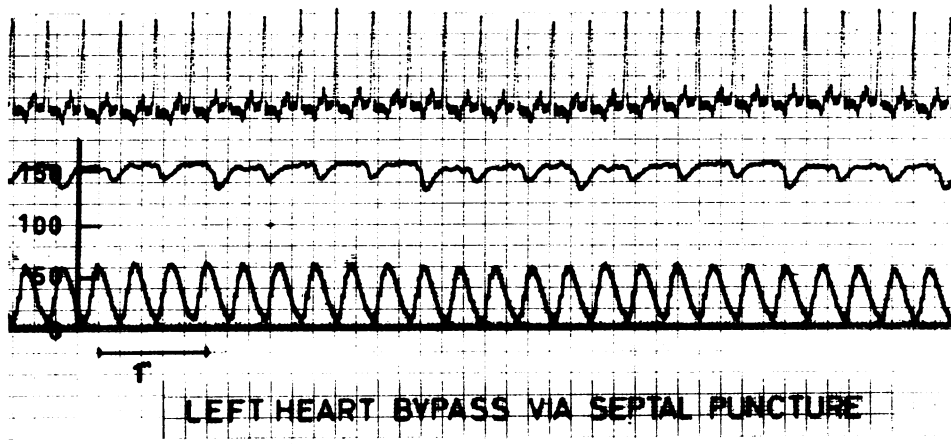

FIG. 3. Tracing of aortic arch pressure, EKG and left ventricular pressure while the animal is on full left heart bypass. Left ventricular pressure remains well below that of the aorta. Pulsations seen in the aortic tracing are the result of the pump.

Blood Pressure: In general there was a tendency for a gradual drop in mean arterial pressure from about 140 mm. Hg before bypass to 120 to 100 mm. Hg during the bypass. Usually a drop in pressure was preceded by a drop in flow rate and both could be returned to an acceptable level by adequate blood replacement. In all dogs, except the one that died, after coming off bypass it remained above 110 mm. Hg. after giving adequate transfusion. In none of the dogs was it necessary to use vasopressor drugs to maintain pressure. Most of the time the arterial pressure curve showed only the pulsation of the roller pump (Fig. 3). However, when the full cardiac output was not carried by the bypass, occasional left ventricular pulsations could be seen in the tracing (Fig. 4).

Blood Loss and Replacement: A definite attempt at good surgical hemostasis by both ligatures and cautery was made in the neck and groin dissections. However, in most animals there was a tendency toward oozing of blood after several hours on bypass. This did not seem to be related to the amount of heparin given initially or to the heparin level maintained in the blood.

The amount of blood for replacement ranged between 1,500 and 4,000 ml., with an average of 2,250 ml. for a 24-hour period. Frequently the dogs were transfused in addition to this at the end of the procedure with the blood in the pump circuit in the amount of 300 to 500 ml. Adequate blood replacement was difficult to determine at times since loss was not measured but only roughly estimated. A drop in flow rate was found to be the most reliable indication of an inadequate blood volume.

Other intravenous fluids consisted of dextrose 5.0 per cent in water and Ringers solution given in total amounts of 40 to 60 ml./kg./24 hours.

Urinary Output: The total urinary output was measured in nine dogs by a urethral catheter inserted into the bladder. The 24-hour output varied between 380 and 1,384 ml. (12.3–51 ml./kg./24 hours). In some instances the urine contained blood, gross or microscopic. It was uncertain whether this was the result of trauma from the catheter or renal bleeding from prolonged heparinization.

Thrombocytes: Thrombocyte counts were obtained at intervals during the procedure. Initially all counts were within normal limits. In all of the dogs there was a drop, the lowest being to 12,810. The average count ten minutes after going on the

pump was 165,790 with a drop after 24 hours to an average 64,270 at the end of the pumping procedure.

Red Cell Count: There was a slight drop in the red cell count in all the dogs. The average count was 5.78 million initially with a drop to an average of 4.72 million.

Hemolysis: The average plasma hemoglobin 10 minutes after going on the pump was 21 mg.% and increased to an average of 87 mg.% at the end of the period. In seven of eight dogs there was a decrease in the final plasma hemoglobin below its maximum increase. The highest recorded plasma hemoglobin was 259 mg.% at 18 hours which fell to 181 mg.% at 24 hours. In none of the dogs was there any evidence of renal complication as a result of hemolysis.

Pathologic Findings: All dogs were examined at the time of death or sacrifice. The pathological changes in the heart as the result of cannulation have been described previously.[15] Examination of lungs, liver, spleen, gastro-intestinal tract, pancreas and kidneys revealed nothing unusual other than evidence of infarcts or emboli in some instances. These were found in the kidneys in seven dogs, in the liver in one, and in the spleen in one dog. These observations were made on gross examination.

Discussion

There is a definite need for a means of external support for a failing left heart. This means should be relatively simple, safe and include no major surgical procedure. The method described allows complete bypass as controlled by pressure recordings and angiography.

Survival of nine of ten dogs after a 24-hour perfusion seems to show the relative safety of the procedure. At postmortem, seven dogs had small infarcts in the kidneys and one each in the liver and the spleen, despite heavy heparinization. This indicates that there is a need for further investigation of the problem of anticoagulation.

There was a surprisingly low hemolysis reaching a maximum after 12 to 18 hours, usually decreasing towards the end of the perfusion. The reason for this decrease is not known and there was no hemoglobinuria at the end of the bypass.

The decrease in platelets was significant, but there was no bleeding tendency after heparin neutralization.

Stability in blood pressure, during or after

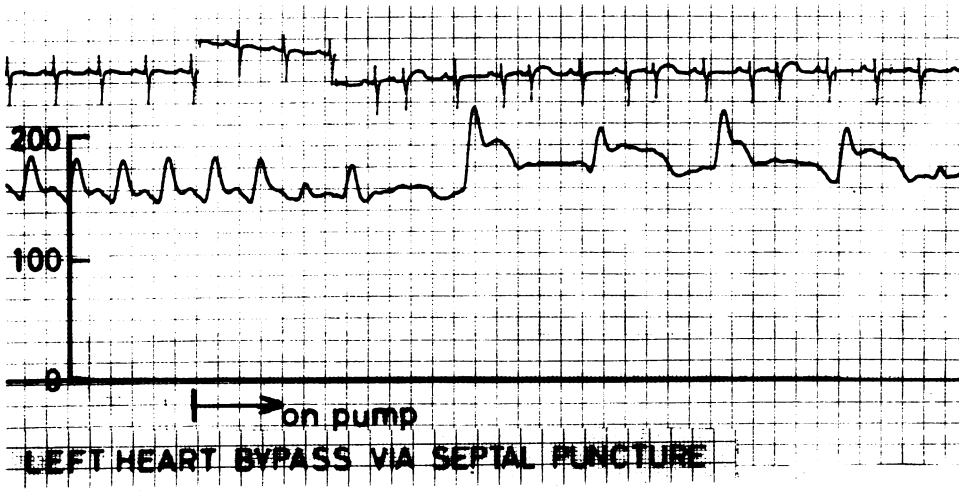

FIG. 4. Tracing which demonstrates an occasional left ventricular beat coming through into the aortic pressure which is the result of a partial bypass.

a 24-hour bypass, when adequate blood volume was present, indicates maintenance of myocardial and peripheral vascular function.

This method seems to us to fulfill criteria desired of a means to support a failing left heart—may it be from an aortic or mitral valvular lesion, or an acute coronary occlusion. It diminishes the work load of the left ventricle by bypassing the cardiac output. It increases the cardiac output with oxygenated left atrial blood. As it requires no major surgical procedure, it seems justified to use it clinically in cases refractory to medical therapy.

Summary

1. A technic of left heart bypass without thoracotomy and without an oxygenator is presented.

2. Ten dogs were bypassed at flow rates equal to cardiac output for 24 hours consecutively with nine survivors sacrificed from 24 hours to 12 weeks.

3. Results regarding flow rates, blood pressures, blood loss and replacement, urinary output, thrombocytes, red cell counts, hemolysis and pathology are briefly presented.

4. The possible clinical applications of such a method of bypass are discussed.

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