Clinical Use of a Cannula for Left Heart Bypass Without Thoracotomy: *

Experimental Protection Against Fibrillation by Left Heart Bypass

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MANY WORKERS have adopted pump-oxygenators for open-heart procedures since the first American report of utilization of such apparatus for clinical patients, presented by one of us to the American Surgical Association in 1951.[5] On the other hand, application of extracorporeal circulation for support of the failing heart is still confined to few centers.[3, 6, 8, 15, 16] The desperate need for circulatory support is apparent from the 1955 studies of Rosenberg and Malach, from the University Service of Kings County Hospital, who showed that there were no survivors of patients with acute myocardial infarction and blood pressure depression below 70 mm. Hg.[9] In 1957, Stuckey and associates[16] at Kings County Hospital reported encouraging results with use of heart-lung bypass in three patients with myocardial infarction and shock below 70 mm. Hg, one of whom is still actively engaged in his own retail business. The efficacy of this approach was nonetheless disputed in other laboratories on the basis of failure of heart-lung bypass in animal studies to demonstrate reduction of oxygen uptake by the myocardium.[6, 12, 14]

Several methods for mechanical support of the failing heart have been proposed. These are:

1. Heart-lung bypass [6, 12, 16]
2. Veno-arterial pumping [3, 8, 11]
3. Aortic counterpulsation [2]
4. Left heart bypass [4, 7, 10, 15]

Our decision to pursue left heart bypass is based upon several factors: Oxygenators introduce hematocellular damage and metabolic changes not inherent in circuits without oxygenators and, therefore, limit the duration of possible mechanical support. They also prohibit the simplicity inherent in the left heart bypass apparatus.

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This report covers work from the Research Laboratory of the Thoracic Clinic of the Karolinska Institut performed during the academic year 1960 to 1961 by Carlens, Dennis, Hall, Moreno, and Senning; work done at Zurich by Hall, Moreno, and Senning; and work performed at State University of New York since September, 1961, by Cappelletti, Dennis, and Wesolowski.

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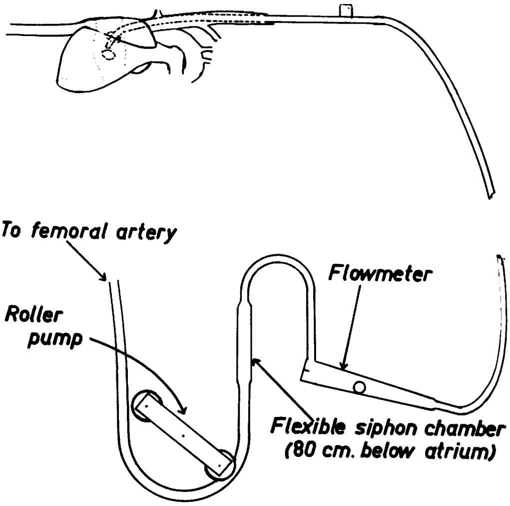

FIG. 1. Diagram of extracorporeal circuit. Left atrial blood is siphoned through the trans-jugular, trans-atrial-septal cannula into the extracorporeal circuit. It passes through a flexible walled siphonage chamber, a flowmeter, and a roller pump and back into the body by way of a cannula in a femoral artery.

Veno-arterial pumping is experimentally feasible, but Patt *et al.*[11] found it lethal in the presence of any degree of cardiac failure. Aortic counterpulsation was developed by Clauss *et al.*[2] simultaneously with our perfection of left heart bypass; there are not yet sufficient data to compare the two methods of support.

Senning had observed benefit from partial left heart bypass during the 15 to 45 minutes after open-heart repair of certain cardiac defects corrected during coronary flow interruption. Since Carlens had shown the feasibility of atrial septal puncture via the jugular vein for diagnostic purposes,[1] Senning proposed that we use the welcome year of sabbatical leave of one of us (C.D.) to work out jointly the problems of large bore left atrial cannulation without thoracotomy and to settle the question of diminution of metabolic work of the heart by such bypass.§

§ These studies were made possible through the cordiality of Prof. Clarence Crafoord, Chief of the Thoracic Clinic of the Karolinska Institut, Stockholm, Sweden, to whom all of the authors wish to express their appreciation and gratitude.

From this work, the results indicate that, in the dog, left atrial cannulation without thoractomy is consistently feasible and that the left atrial blood can be quantitatively diverted so that the left ventricle neither fills nor empties.[10, 16] We learned also that discontinuance or lessening of left ventricular filling and emptying is secondary to lowering the left atrial pressure, and that, in patients, diuresis may be sustained during prolonged periods of full bypass.[15] The group also reported sustained near-total left heart bypass over 24-hour runs with long-term survival in a series of dogs.[7] A still further report indicates that, under rigidly controlled conditions, metabolic activity of the myocardium, as measured by oxygen uptake, is always reduced by either partial or total left heart bypass.[4]

Our thesis is that acute left heart failure and shock secondary to coronary arterial occlusion may be ameliorated by left heart bypass without thoracotomy by virtue of the following factors:

1. Maintenance of normal systemic blood pressure and therefore proper perfusion of all tissues of the body except that portion of the myocardium rendered ischemic by the coronary occlusion.
2. Relief of pulmonary edema and attendant arterial unsaturation by reduction of left atrial pressure to normal or below-normal levels.
3. Reduction of the oxygen need of the myocardium, including the marginal myocardium rendered only partially ischemic by the coronary block.
4. Elevation of the oxygen tension in the myocardium, indicated by a rise in coronary sinus oxygen content on institution of left heart bypass.

It is our anticipation that left heart bypass may lessen the extent of marginal infarction.

In the dog it was found possible to utilize a properly devised, 7.0 mm., stainless-steel cannula to *palpate* the posterior and medial aspects of the right atrium after insertion via the right internal jugular vein, and to identify the fossa ovalis and the limbus of the fossa ovalis. Such localization is aided by fluoroscopy. In the dog, the substance of the fossa is fragile, allowing puncture into the left atrium easily by a blunt 3.0 mm. obturator. The canine cannula and technic are not consistently successful in the human, who possesses a thicker and tougher fossal septum. Considerable replanning of the cannula and technic resulted in the development of the human cannula as herein described.

Some uncertainty has existed as to the risk of incitement of ventricular fibrillation by the institution of left heart bypass. Experimental evaluation of this factor in the possible salvage of patients with acute infarction and already irritable hearts appeared to us essential before general application of such support to clinical cases.

Material and Methods

Twenty-two mongrel dogs were anesthetized by intravenous administration of pentobarbital. In five dogs appropriate cannulations were made for cardiopulmonary bypass after thoracotomy and support of the ventilation by a Jefferson respirator. In the remainder, the left atrium was drained by a 1.0 cm. stainless steel cannula, through which left heart bypass was accomplished without blood-air contact, the return to the femoral artery being by roller pump, essentially as previously described[15] (Fig. 1). In both types of preparation, dissections of the left anterior descending coronary artery, the circumflex branch of the left coronary, the main left coronary and/or the right coronary artery were done to permit temporary occlusion of one or more. Simultaneously the blood pressure in the aortic arch and the EKG were recorded on a Sanborn Poly-Viso recorder.

The cannula for human trans-septal left atrial drainage without thoracotomy differs in some respects from that previously reported for dogs. It is of stainless-steel, 0.2 mm. in wall thickness, and of three dif-

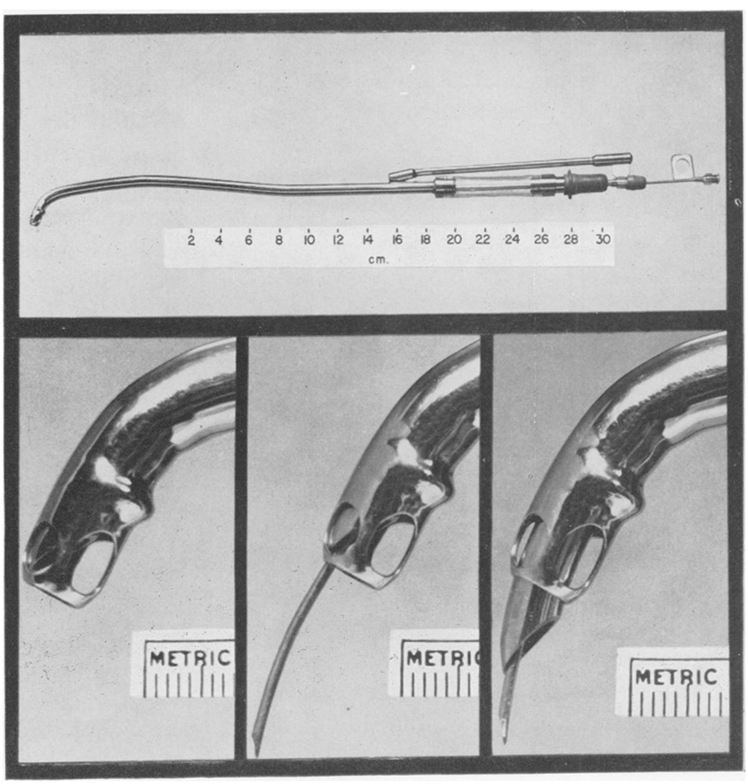

FIG. 2. The trans-septal cannula for use in the human. Top. The entire cannula. Bottom Left. Close-up of tip of cannula. Bottom Middle. Close-up of tip with aspirating needle advanced, and Bottom Right. Close-up of tip with cutting lip and needle advanced. After left atrial entry, needle and cutting tip are withdrawn fully, permitting attachment of posterior connector hub to the extracorporeal circuit.

TABLE 1. *Results of Morgue Placement of Trans-Atrial Septal Cannula*

Punctures undertaken	122
Failures	8*
Causes of failure:	
Inexperience	2
Extreme rigor mortis	2
Anomalous ridge above limbus	1
Fixation by mediastinal cancer	1
Confusion	2

* In addition, there were two instances of left atrial cannulation by puncture 5.0 mm. and 6.0 mm. away from the fossa, respectively, and six attempts in which no puncture site could be found.

ferent internal diameters, as needed in view of the size of the patients to be cannulated, being 6.0, 7.0 or 8.0 mm. (Fig. 2). The over-all length is 41 cm., that of the cannula shaft proper 29 cm. A 65° curve lies in the area between 1.0 and 3.0 cm. from the tip. The tip has a central orifice and four side orifices with a combined area 50 per cent greater than the cross-section area of the lumen of the shaft. A second curve of 15° is imposed 10 cm. back from the tip, and a semicircumferential shoulder lies just proximal to the distal orifices on the concave surface of the cannula. This curve and shoulder facilitate purchase on the limbus of the fossa ovalis and aid in maintenance of position after placement.

An obturator 3.5 mm. in diameter, fitted with a bevelled cutting tip beyond a flexible segment (to permit negotiation of the curve) may be withdrawn to permit palpation of the atrial wall with the smoothly rounded tip of the main cannula, or advanced for incision through the septum. A segment of No. 20 needle tubing with sharp tip serves as an inner obturator for preliminary puncture and aspiration of oxygenated blood from the left atrium to determine accuracy of placement of the cannula tip before advancement of the cutting edge. A side arm projects back from the proximal end of the shaft proper, on the side of the convexity of the distal curves, to provide anchorage for the large obturator in the advanced or in the retracted position, and to permit elastic suspension after placement (250 Gm.).

The proximal junctions of large obturator to main cannula and of small obturator to large are sealed against risk of air embolism with rubber cystoscopic gaskets, and for the same reason a stopcock occludes the aspirating needle. A 6.0-cm. segment of 1.0-cm. polyvinyl tubing secured to a steel sleeve for connection to the main line of the extracorporeal circuit permits cross-clamping during completion of removal of the obturators and attachment of the main tubing, a further precaution against introduction of air. Several patterns of cannula were constructed and evaluated before this pattern was adopted.*

Results

Trans-Jugular Left Atrial Cannulation. The anatomical landmarks of the human inter-atrial septum are more definitely identifiable by palpation with the new cannula than are those of the dog with the cannula devised for that species.[15]

We initially employed the canine cannula in several morgue patients and were able to pass it easily. It was passed without incident in one living patient, but failed with lethal outcome in a second (Case 2). After failure in the second case, the cannula herein described was developed and employed, after initial orientation, in 122 morgue cadavers by six different co-authors, placement being made without fluoroscopic control and before opening the chest. The results of that study are shown in Table 1.

The technic of placement requires exposure of the right deep jugular vein above the transverse cervical vein, with the pa-

* The authors are deeply appreciative of the collaboration and guidance offered by the research staff of AB Stille-Werner, Stockholm, Sweden, during development of both this and the canine cannula. The cannulas may be obtained from AB Stille-Werner.

tient supine and the head thrown slightly back. The cannula is filled with isotonic salt solution, lubricated with a small amount of thin mineral oil, and passed downward into the chest. With the tip advanced 8.0 to 9.0 cm. below the upper margin of the clavicle, the cannula is rotated so the tip is posteriorly directed. With light pressure posteriorly and some 10° to 15° medially, the tip is passed downward until it is felt to fall over the limbus into the fossa ovalis, usually at a point 13 cm. below the top margin of the clavicle (maximum 16.5 cm., minimum 9.0 cm., standard deviation 1.3 cm.). The lower margin of the limbus may also be identified by passage of the tip into the inferior vena cava and withdrawal along the back wall of the atrium. The diaphragmatic lip *feels* sharp and is fairly regularly located, although confusion can arise. The limbus lies from 2.0 to 11 cm. above this point of sharp palpation, but measurement after opening of the chest suggests in the last 30 cases a mean distance of 4.6 cm. (maximum 7.0 cm., minimum 2.0 cm.).

The morgue difficulties of rigor mortis and inexperience are not problems clinically. The problems of localization of the fossa and puncture without injury of the back wall of the left atrium or mitral valve are also unlikely in the living patient, for the left atrium is distended in left heart failure. There was no correlation between body height and distance from top of clavicle to lower margin of limbus. This measurement was greater if pulmonary emphysema was present.

Observations both in the dog and in man emphasize the importance of restricting puncture to the fossal area. Several specimens have been found in each species in which the atria did not lie fused in apposition above the limbic level; the human catastrophe (Case 2) arose from slightly high puncture in the presence of this anatomical variation. Our observations in the dog suggested the desirability of puncture at the top portion of the fossa to minimize risk of damage to the mitral valve. In man the mean distance from the under margin of the limbus to the posterior commissure of

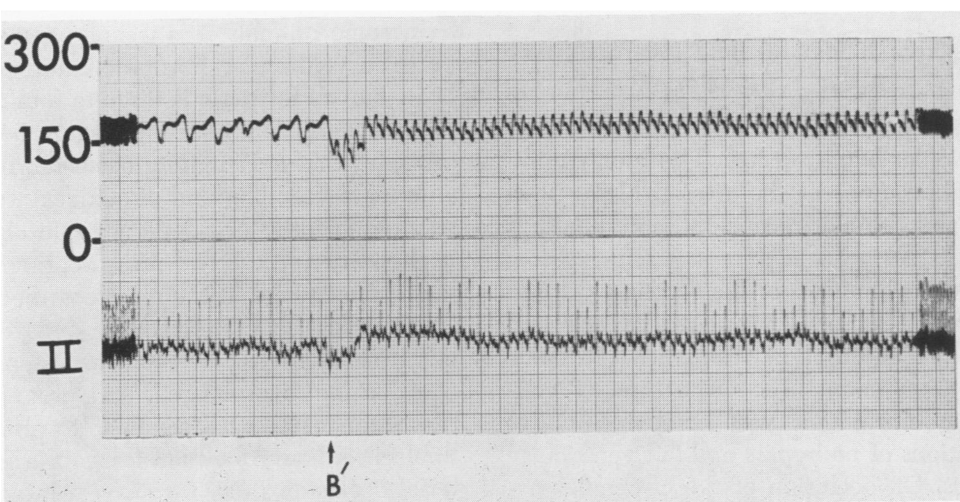

Fig. 3. Events at cessation of left ventricular bypass. Upper trace is intra-aortic blood pressure in millimeters of mercury; lower trace is EKG limb lead II. Arrow labelled B′ denotes cessation of bypass. Note that the pulse wave forms of pump activity and of left ventricular activity are independently identifiable and that cardiac take-over is smooth. In other experiments, continuous monitoring showed the intra-cavitary pressure of the left ventricle to be consistently below that of the aorta, confirming completeness of bypass.

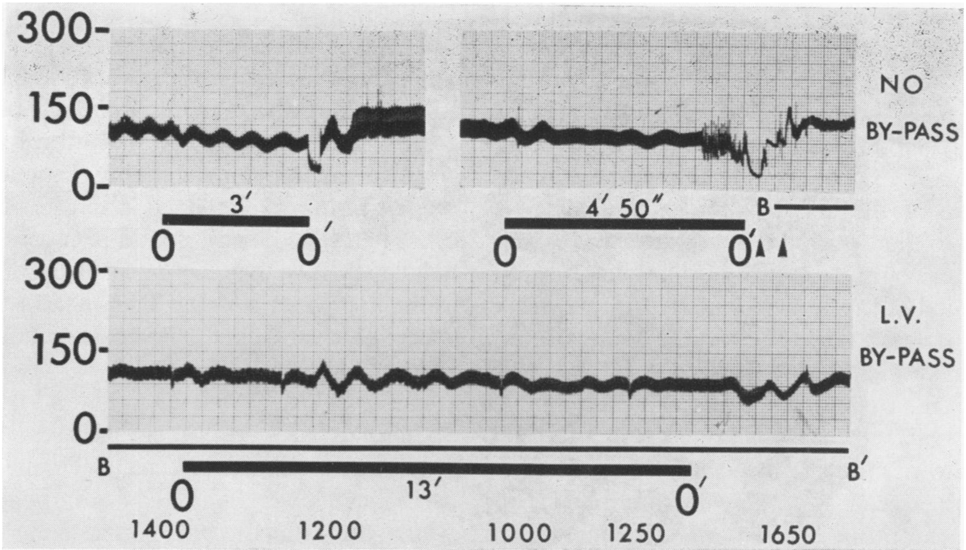

FIG. 4. Intra-aortic blood pressure tracing in occlusion of the circumflex branch of the left coronary artery. In this and all subsequent illustrations, the labelling of events is standard: 0–0′ = period of coronary arterial occlusion; B–B′ = period of left heart bypass; triangular arrow = time of electrical shock for defibrillation; numbers at bottom = minute flow of pump. (The minute flow decreases during coronary artery occlusion and increases transiently immediately after electrical shocking.) Top: Left—drop in blood pressure during 3-minute control occlusion. Right—onset of ventricular fibrillation during 4-minute 50-second control occlusion. Bottom: No ventricular fibrillation during 13-minute coronary occlusion with left ventricular bypass in the same dog.

the mitral valve was much greater than in the dog, the mean being 4.5 cm. (maximum 6.5 cm., minimum 3.5 cm.).

Protective Effect of Left Heart Bypass Against Fibrillation

In the dog initiation and cessation of left ventricular bypass occurred with only minimal aberrations of the arterial blood pressure and the electrocardiographic fiindings (Fig. 3).

Various branches of the coronary arterial tree were occluded for finite periods and the time of onset of resultant ventricular fibrillation noted. The onset time of ventricular fibrillation was compared under conditions of no bypass and left ventricular bypass. On occlusion of the circumflex artery during left heart bypass, there was a significant prolongation of the time of occlusion that led to ventricular fibrillation as compared to controls (Fig. 4). Repetition of test occlusions during alternate periods of control and left heart bypass produced reproducible results in a given experimental animal.

In some animals it was not possible to produce ventricular fibrillation during left heart bypass for periods three to four times the control fibrillation time. Figure 5 demonstrates that a 17-minute occlusion of the anterior descending and circumflex arteries resulted in little or no perceptible change in the intra-aortic blood pressure, but there was some change in the electrocardiogram. Ischemia is characterized by progressive elevation of the ST segment as the period of occlusion is prolonged, and progressive restitution of the ST segment toward the isoelectric line follows release of the arterial occlusion (Fig. 6).

The most dramatic changes in this phase of the study occurred during occlusion of the left main coronary artery. Within two to three minutes in control determinations, left main artery occlusion resulted in pro-

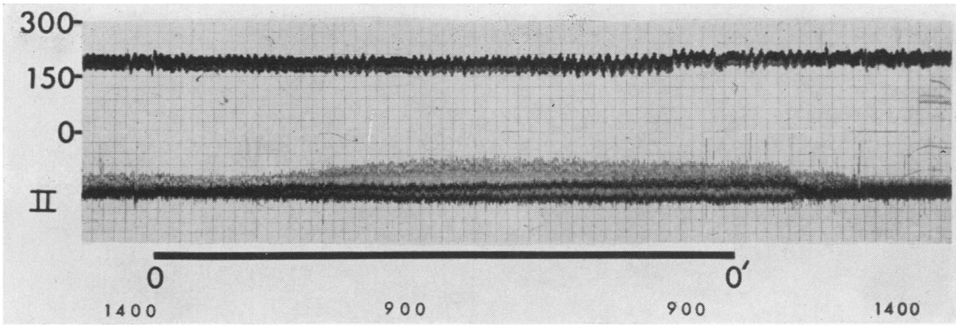

FIG. 5. Intra-aortic blood pressure and EKG limb lead II during left ventricular bypass with 17 minutes of occlusion of the anterior descending and circumflex branches of the left coronary artery. Note the following: absence of ventricular fibrillation, continued maintenance of blood pressure, heightening of the R and T waves on limb lead II and significant decrease in minute flow during coronary arterial occlusion with reversion to normal minute flow after release of occlusion. The latter figures imply that the left coronary artery flow can represent 30% of the total cardiac output under conditions of left ventricular bypass.

gressive dilatation of the left ventricle and absence of ejection into the aorta, with intra-aortic blood pressure falling rapidly toward zero. During left ventricular bypass there was some drop in intra-aortic blood pressure after a ten-minute period of occlusion. Ventricular fibrillation occurred in these experiments mainly following release of the occlusion rather than during it (Fig. 7).

On institution of left ventricular bypass approximately five minutes after left main coronary artery occlusion, there was immediate and dramatic improvement in the intra-aortic blood pressure (Fig. 8). Institution of bypass in such an ischemic heart exhibited no particular propensity to incite ventricular fibrillation.

As might be expected, ventricular fibrillation during occlusion of the *right* main

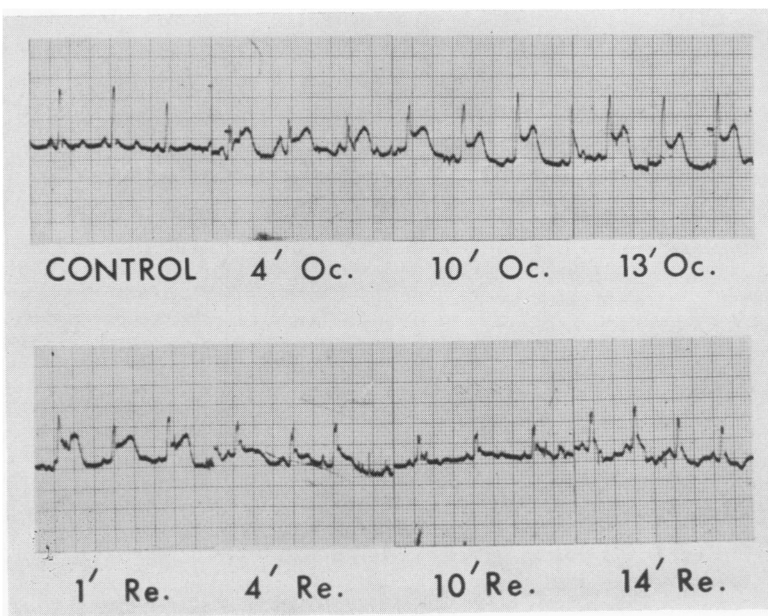

FIG. 6. Progressive electrocardiographic changes during and after temporary occlusion of the anterior descending and circumflex branches of the left coronary artery during left ventricular bypass. Oc = occlusion, Re = past release of occlusion. (See text.)

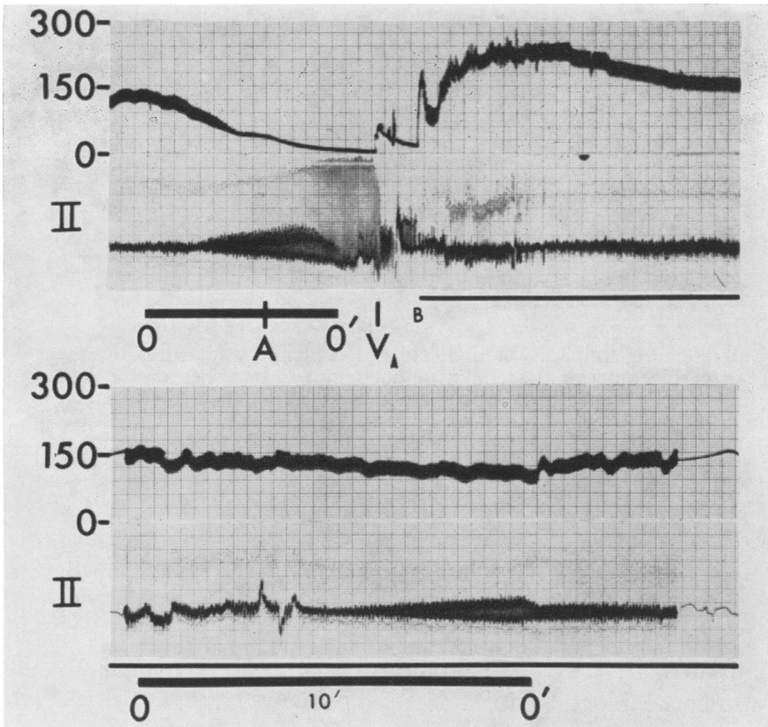

FIG. 7. Intra-aortic BP and EKG limb lead II during left main coronary artery occlusion. Top traces refer to control occlusion and bottom to occlusion during left ventricular bypass. A = time of effective cardiac arrest due to absence of left ventricular ejection. V = time of onset of ventricular fibrillation. (See text.)

coronary artery was not delayed by left heart bypass (Fig 9). However, when the right coronary artery was occluded in conjunction with the anterior descending coronary artery, there was a definite prolongation of the time of onset of ventricular fibrillation with left ventricular bypass (Fig. 10). Figure 10 also exemplifies our repeated observation that institution of left ventricular bypass facilitates electrical defibrillation and resuscitation of the heart. It will be noted in the upper set of tracings that four attempts at ventricular defibrillation were unsuccessful following the release of the occlusion to the coronary arteries, but that upon institution of left ventricular bypass a single identical shock resulted rapidly in the restitution of a normal sinus rhythm.

Summary of the crucial experiments in-

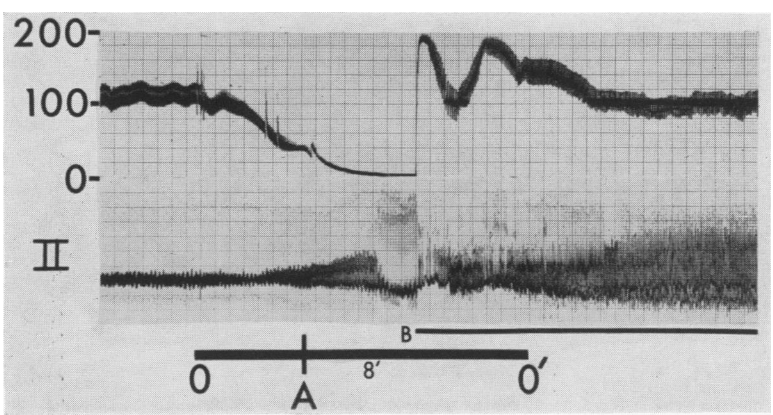

FIG. 8. Beneficial effect of institution of left ventricular bypass (instituted at B) upon the intra-aortic blood pressure during continued occlusion of left main coronary artery. No ventricular fibrillation.

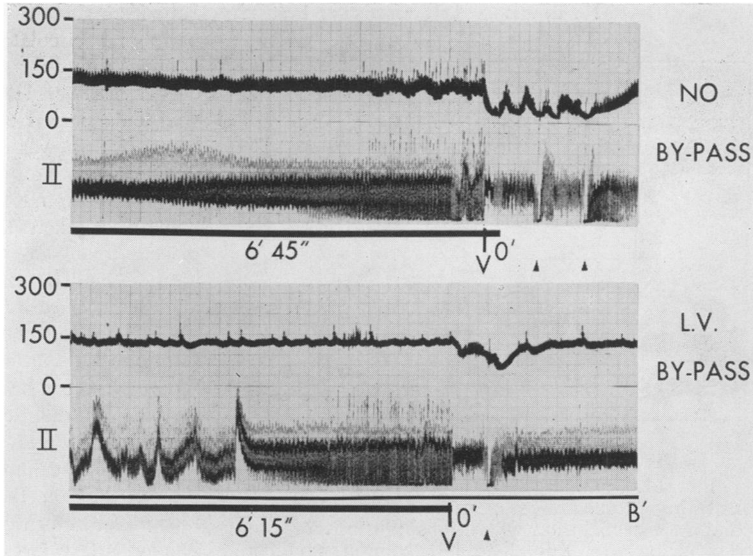

FIG. 9. Intra-aortic blood pressure and EKG limb lead II tracings demonstrating lack of protection from ventricular fibrillation of *left* ventricular bypass during *right* coronary artery occlusion.

volving left ventricular bypass is presented in Figure 11. As a general rule, protection from ventricular fibrillation by left heart bypass occurred when any of the branches of the left coronary artery were occluded.

Another group of experiments was performed to test the effect of *partial cardio-pulmonary* bypass upon protection from ventricular fibrillation by coronary artery occlusion. These results are summarized in Figure 12, which show results similar to those of left ventricular bypass.

Clinical Application for Left Heart Bypass

Case 1. A 60-year-old merchant was admitted to Sabbatsberg Hospital, Stockholm, on March 16, 1961, with a five-day history of precordial pain of sudden onset. Three days before admission the patient was digitalized with little improvement. On the day of admission, he developed dyspnea, cyanosis, and coldness of the hands and feet. At Sabbatsberg Hospital the blood pressure was 130/100, the pulse was fast and regular, but very weak. A harsh systolic mumur was audible over the whole precordium and there were rales in

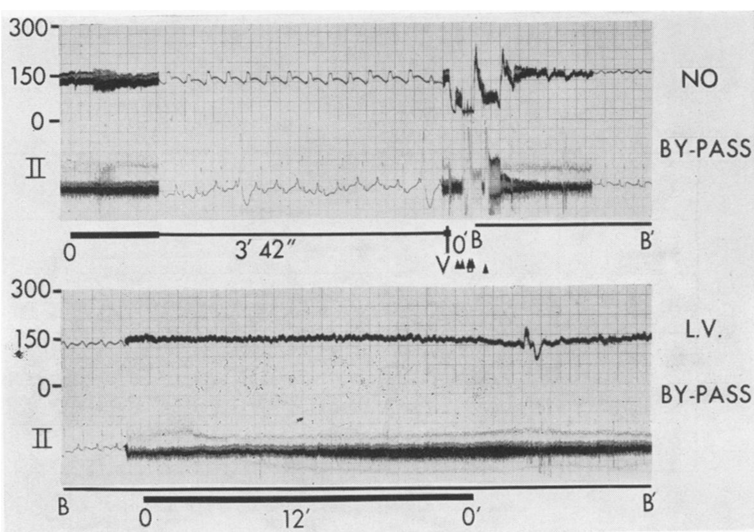

FIG. 10. Intra-aortic BP and EKG limb lead II in combined occlusion of right coronary artery and anterior descending branch of left coronary artery. Note that left ventricular bypass delayed ventricular fibrillation. Note under upper traces grouping of triangular arrows, indicating electrical shocks, and ease of defibrillation after institution of bypass.

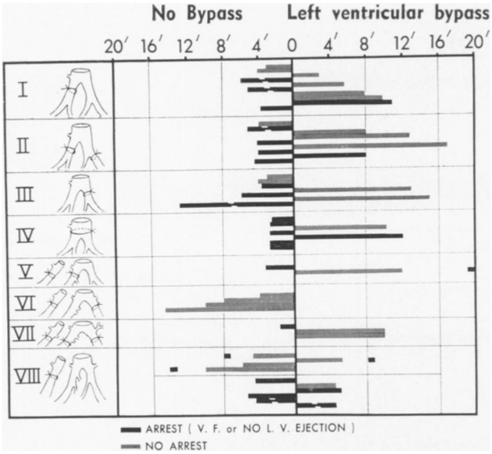

FIG. 11. Summary of critical experiments demonstrating protective effect of left ventricular bypass during occlusion of various portions of the coronary arterial tree. The left column contains diagrams indicating the specific coronary arterial branches occluded in each experiment. The coronary arterial occlusion was released at the time corresponding to the end of each bar. Multiple determinations with and without bypass were made in each experiment. The interrupted solid bars indicate the onset of ventricular fibrillation upon release of the coronary arterial occlusion while a time-spaced black block following a cross-hatched bar represents the delayed onset of ventricular fibrillation at the indicated interval following the release of coronary arterial occlusion. (See text for interpretation.)

both lung bases. Electrocardiogram suggested a large low posterior myocardial infarction. After a few hours the blood pressure began to fall and the patient was transferred to the Karolinska Hospital for consideration of left heart bypass. On arrival he appeared better than he had at Sabbatsberg, but within a few hours developed peripheral circulatory collapse. He now had a Grade V murmur over the precordium, maximal over the lower left sternal border, suggesting a ventricular septal defect with a large shunt. Left heart bypass was decided upon as a desperate effort at salvage. A tracheostomy was done, an Engstrom respirator was connected, and the patient was taken to the x-ray department and placed upon an angiocardiographic table. The internal jugular was exposed under nitrous oxide anesthesia, the cannula was passed, and the fossa ovalis localized without difficulty. After passage through the septum, bright-red blood could be aspirated. Angiocardiographic study was attempted through the 3.0 mm. obturator of the cannula, but was unsuccessful because of back leakage. The cannula was used to determine that the pressure in the left atrium was 35 cm. of blood. The return cannula was placed in the right femoral artery just distal to the profunda femoris. The patient was taken to the recovery area, where connections were made to the extracorporeal circuit, primed with heparinized blood. Immediately after starting the apparatus, the flow rate was 4.3 liters per minute and the mean blood pressure 170 mm. Hg as measured with a catheter in the left radial artery. Within 15 minutes the blood pressure dropped to about 110 mm. Hg where it remained throughout most of the period of bypass. During the 14 hours of left heart bypass, the flow varied from 3.7 liters to 5.0 liters per minute. The peripheral cyanosis and pulselessness disappeared within two hours, and the patient developed good peripheral circulation. The patient continued to be carried on the Engstrom respirator by means of a tracheostomy and was given supplementary heparin, demerol and tubocararine as

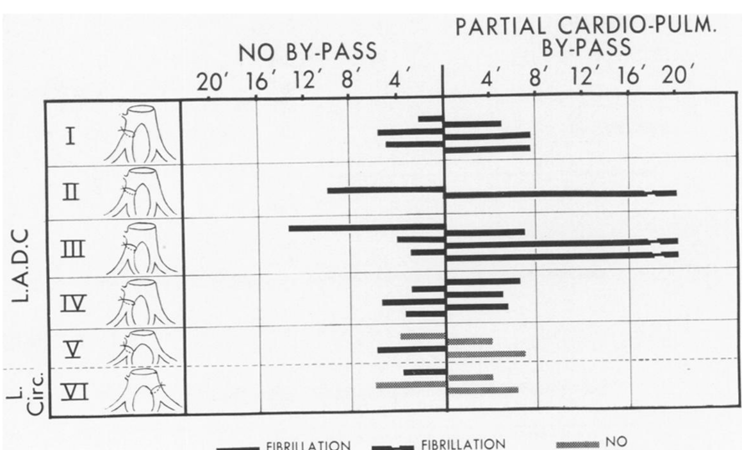

FIG. 12. Summary of critical experiments demonstrating protection from coronary-arterial-occlusion-induced ventricular fibrillation by partial cardiopulmonary bypass. Note that bypass has a definite beneficial effect.

needed. The patient developed a very good urinary output almost at once, with over 300 cc. in the first half hour.

After six hours the pumps were slowed to 3.0 liters per minute for a minute or two to see whether the patient could manage by himself. This was followed by a drop in blood pressure to first 85, then 75, then 60 mm. Hg, with recovery after return of full bypass taking place slowly over another two hours. The decision, therefore, was made that repair of the defect would be essential. Twelve hours after institution of support, the patient was taken to the operating room with the left heart bypass still functioning. A midline sternotomy was performed and a heat exchanger put in the system. A right heart bypass was also instituted with a separate circuit. The temperature was carried down to an esophageal level of 12.6° C. The aorta and pulmonary artery were cross-clamped, the cavae were occluded and the left heart pump permitted to run for about 30 seconds, after which the left heart pump also was turned off.

The right ventricle was opened and there was revealed a large infarct over the lower posterior part of the ventricular septum extending from a cm. from the apex to about 1.5 cm. from the atrio-ventricular ring. The defect was closed with 2-0 silk sutures using Ivalon sponge mattresses for security. The anterior right ventricular wall was closed, and the patient rewarmed. When the esophageal temperature had reached 27° C. the heart was defibrillated, resulting in a regular rhythm with vigorous contractions. After some minutes, the right pump was disconnected and the cannulas were removed. When the temperature was 36.2° C. the left bypass was stopped. The left heart took over immediately with regular rhythm, satisfactory electrocardiogram and blood pressure between 130 and 140 mm. Hg. Alomst at once it was apparent that some blood was escaping from the neighborhood of the sutures and Ivalon mattresses on the back wall of the heart. Left bypass was re-instituted and further repairs were attempted. After some minutes the systolic thrill gradually re-appeared, and it became apparent that the septal defect again was opening. After further attempts at repair, all cannulas were removed and the patient was given polybrene in the hope that this might diminish the bleeding somewhat. The pressure at this time was maintained by the patient at 150 to 160 mm. Hg, but the bleeding became more marked. The patient then went into ventricular fibrillation and our attempts were abandoned. During the period of left heart bypass the patient secreted 650 ml. of urine during each eight-hour period. Blood pH at no point fell below 7.32 and the partial pressure of carbon dioxide remained between 34 and 43.5 mm. Hg.

Case 2. Our second patient was a woman in her mid-50's who came to the Karolinska Hospital with massive myocardial infarction for support by left heart bypass. In order to avoid the need to move the patient after cannula placement, attempts were made to cannulate in the recovery room area. Fluorscopic visualization with portable equipment was extremely difficult. Identification of the fossa was not successful, and puncture occurred just above the limbus into an anomalous deep cleft between the right and left atria, and cardiac tamponade resulted. The defect was closed at emergency thoracotomy, at which time efforts to pass the blunt-tipped cannula used in the first case proved extremely difficult because of failure to appreciate landmarks with the tip and because of the toughness of the membrane of the fossa ovalis. Bypass was thus established too late and too traumatically to salvage the patient.

In view of this experience and in view of further morgue studies, the cannula was modified to provide: 1) readier palpation of the fossal area to permit orientation without fluoroscopy; 2) a slender center needle for sampling oxygenated blood from the left atrium as a safety measure before puncture with the larger cannula; and 3) a retractable cutting edge to permit easier passage of the cannula after establishment of proper position by palpation and needle aspiration for oxygenated blood.

These ends were achieved by the creation of the cannula described under *Methods*. Greater ease of palpation was provided by increasing the curvature of the tip of the cannula and by lengthening somewhat the segment beyond that curve. Provision of the other factors has already been described.

***Case 3.** A 43-year-old white woman was placed on left heart bypass on April 11, 1962, at the Eugene Talmadge Memorial Hospital. She had

* The authors wish to express their thanks and appreciation to Dr. Robert G. Ellison, Professor and Chief of Thoracic and Cardiovascular Surgery, Medical College of Georgia, for permission to include this case.

derived no benefit from an Ivalon sponge spindle placed in the mitral orifice two months earlier for severe mitral insufficiency, and could not be brought out of failure by conservative measures. Placement of a Starr mitral valve seemed the only course likely to help, and left heart bypass was adopted as the only available means to prepare the patient for placement of same.

The cannula herein described was placed without difficulty under local anesthesia, and bypass was carried at from 3.1 to 4 liters per minute for a period of 16 hours. During this time she secreted 1,150 ml. of urine, probably largely in response to infusion of 500 ml. of mannitol solution, and her blood urea nitrogen level dropped from a starting value of 56 to a final value of 29 mg.%. During bypass she remained conscious, her pulmonary edema cleared completely, and the murmur of mitral insufficiency in large measure temporarily disappeared. At no time did full diversion of cardiac flow occur through the extracorporeal circuit. It was found after 16 hours that she could maintain her circulation and respiration nicely without support, and bypass was therefore discontinued for a few hours in preparation for thoracotomy. Later the same day she had a Starr valve placed without incident, with the aid of extracorporeal circulation. After this the left atrial pressure was found to have fallen to 10/8 mm. Hg, a drop from 40/32 mm. Hg observed before placement of the valve, but the pulmonary arterial pressure remained high (65 to 70 mm. Hg).

The patient suffered cardiac arrest the night following operation, which was only temporarily resuscitated. It was believed the patient's unfortunate outcome was secondary to the advanced pulmonary vascular changes rather than to the method of management.*

* Note—Four additional patients with diagnoses of myocardial infarction and shock have been placed on bypass since presentation of this paper. The major problem has been that of speedy institution of extracorporeal support, as 2 patients suffered arrest and a third lost all reflexes in advance of cannulation. In all 4 the situation had advanced beyond relief by left heart bypass before it was established; yet the 2 with arrest regained a strong heart beat temporarily, one regaining consciousness only to die of recurrent arrest after removal of the cannulas. A most gratifying observation has been that orientation and septal puncture may be accomplished with far more ease and assurance in the living patient than in the cadaver. We are currently streamlining our procedure to permit bypass within 30 minutes of the decision.

Comment

Ten years ago Wesolowski and associates studied the response of the canine heart to complete coronary arterial occlusion for 30 to 60 minutes, while supporting the circulation with a pump-oxygenator. Upon restitution of coronary arterial flow, resuscitation of the heart was not possible without extracorporeal circulatory support, but with such support for an hour after release of the coronary arterial occlusion, regular restitution of a normal sinus rhythm occurred.[17]

The short series of patients placed upon partial heart-lung bypass five years ago at Kings County Hospital[16] provided reason to suspect that support for a small number of hours might also enhance the ability of the myocardium to survive after massive myocardial infarction with shock.

Inasmuch as the majority of significant coronary arterial occlusions would appear clinically to involve the left coronary arterial tree, and because of the simplicity of the apparatus necessary and the avoidance of the problems of mechanical oxygenators, we have elected to pursue the effect of left heart bypass both experimentally and in the critically ill patient with myocardial infarction and shock. We were encouraged in this decision by the observation of Senning that left heart bypass for brief periods greatly facilitates the myocardial recovery after surgical occlusion of the coronary blood flow during certain open-heart operations.

Material already published by members of this group would appear to establish that left heart bypass can satisfy the aims of restoration of the systemic circulation, reduction of the work that must be done by the damaged heart, relief of pulmonary edema by decrease in left atrial pressure, and decrease of the oxygen demand of the left ventricular myocardium while increasing the partial pressure of oxygen in that tissue.

The ease of development of ventricular

fibrillation in myocardial infarction has led to some uneasiness about the hazards of this complication secondary to establishment of left heart bypass. The studies here reported would suggest that functioning diversion of blood from the left ventricle provides definite protection against fibrillation in association with acute coronary arterial occlusion, but leaves unsettled the question of the possibility that the manipulations of placement may augment this hazard. Some reassurance on this matter is provided by absence of fibrillation in three patients, two with massive infarcts, one of whom underwent extremes of manipulation in an effort to pass into the left atrium. The extensive autopsy studies have been performed and the cannula here described has been developed in order to gain assurance of our ability to pass through the fossa ovalis consistently with a minimum of manipulation.

There appears no basis for concern about the hemodynamic significance of the septal defect left after such puncture, which usually measures in dogs less than the diameter of the cannula. In two animals observed three months after 24-hour periods of bypass, the defects had closed.[15]

In the light of the studies here presented, we believe the method of left heart bypass without thoracotomy for therapy of massive myocardial infarction with shock is ready for intensive clinical evaluation.

Conclusions

1. A cannula has been devised for total diversion of blood returning to the left heart without thoracotomy.

2. Placement of the cannula into the left atrium by way of the internal jugular vein with puncture of the fossa ovalis can be consistently performed in the autopsy room and in living patients without fluoroscopy.

3. Left heart bypass offers definite protection against the ventricular fibrillation which succeeds acute occlusion of all or part of the left coronary arterial tree.

4. The method has been used to accomplish total left heart bypass in clinical cases for relief of acute left heart failure.

5. Since left heart bypass reduces the oxygen need of the heart, maintains normal aortic pressure for adequate systemic circulation, reduces left atrial pressure and therefore pulmonary edema, raises the partial pressure of oxygen in coronary venous blood, and finally can be readily and relatively safely accomplished without thoracotomy, the method appears ready for intensive clinical trial in patients with acute, otherwise unmanageable, left heart failure.

6. It is believed such support should reduce the area of marginal infarction and possibly facilitate direct thrombectomy before frank infarction develops.

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Discussion

Dr. Oscar Creech, Jr. (New Orleans): Since I have no experience with this or any other method of supporting the failing heart, I must confine my comments to what Dr. Dennis has presented.

Dr. Dennis has emphasized that by this method of left heart bypass one can effectively support the circulation; that this work reduces the myocardial work of the left ventricle as measured by oxygen consumption; and, finally, that it does increase the partial pressure of oxygen in the myocardium.

An ischemic heart, unlike the ischemic limb, must nourish itself. It appears that the general failure of the circulation, including that of the myocardium, is the principal factor leading to death of the heart after infarction rather than the amount of work the heart has to perform. Therefore, it appears that adequate and prolonged support of the circulation would be an essential element in recovery.

If this is done and the myocardium is not irreparably damaged, recovery should follow, and this has been demonstrated by the cardiologists from time to time when they have used vasopressor agents. However, it it often necessary to continue this support for a period of days. Dr. Dennis' method provides for support of the circulation for relatively long periods and, in fact, he has used it for as long as 24 hours. Thus, it is promising.

The difficulty of cannula placement, however, should be overcome before the method is widely adopted. The patient who has suffered a massive myocardial infarct is in no condition to withstand the consequences of an improperly placed cannula.

Dr. Robert Schramel, one of my associates, has worked with prepulmonary oxygenation as a method of supporting the failing lung. Since an oxygenator is used in this circuit, destruction of platelets and erythrocytes occurs to a tremendous extent over a period of eight hours of perfusion. In his paper Dr. Dennis alluded to the lack of hematologic change following left heart bypass. I wonder if he would comment more specifically to what extent the platelets and erythrocytes are damaged.

Then, I would like to ask him these questions: Does right ventricular work remain unchanged during total left heart bypass?

Second, he refers to the frequency of ventricular fibrillation with this method. In the presence of adequate systemic and myocardial circulation, would not fibrillation further reduce the work of the heart over that associated with a sinus mechanism?

Third, would pulsatile flow offer any advantage over the presumably nonpulsatile flow that he has used?