Mechanical Support of the Circulation Using a Modified Pulsatile Roller Pump

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Despite the advances that have been made in the treatment of cardiogenic shock, patients are still noted in whom the circulatory inadequacy fails to respond to treatment. Survival for these patients may depend on some form of mechanical assistance of the circulation.

Patients benefiting from mechanical assistance would include those patients with 1) cardiogenic shock from a severe myocardial infarction, 2) pre- and postcardiac surgery in the borderline patients, and 3) the severe lung trauma case with temporary cardiopulmonary insufficiency.

Any one of these conditions could be represented by our patient seen here. His color is poor, his E.K.G. and pressure curves look terrible and his perplexed cardiologist has no further medications to offer him.

Our study was undertaken to develop and test a pulsatile assist pump that could provide veno-arterial pumping properly timed to occur during the patient;s diastole.

METHODS

A standard roller pump modified to deliver pulsatile flow by means of rapid acceleration and braking of the pump head was developed in co-operation with the Sarns Corporation. Synchronization is achieved from an electrocardiograph, and pump flow is controlled by variation in both the speed and run time of the pump head.

The pump has many advantages and avoids some of the problems with present diaphragm pumps. In addition to being synchronized with the electrocardiogram it has the reliability of standard continuous flow roller pumps, can provide for a wide range of stroke volumes since there is no fixed size to the pumping changer, and it is capable of synchronization and pulsatile pumping at rapid heart rates since it is filling as it pumps.

The pump controls are conveniently mounted on a panel which also contains an oscilloscope for display of the electrocardiogram, or arterial pressure curve. Pump ejection is indicated by an interruption in the scope display. Synchronization is achieved by adjusting the delay of pump ejection so that it occurs during diastole of the subject. Pump output is determined by direct reading of a digital readout tachometer and can be expressed as liters per minute when correlated with the various tubing diameters.

The pump and controls are mounted on a portable console for use at the bedside. Clinical application would involve peripheral cannulation and the use of membrane oxygenation.

Venous blood is drained from the right atrium via the femoral vein and collected in a collapsable reservoir that avoids a blood-air interface. The venous blood is pumped through the heat exchanger and membrane lung and collected in an arterial reservoir. The synchronized pump delivers the oxygenated blood through the subclavian artery. The control unit has its own E.K.G. and a recirculation line is provided for maximum efficiency with the membrane lung.

Only a minor surgical procedure is required for appropriate cannulation and the portable nature of the unit makes quick application possible at the bedside.

EXPERIMENTAL SET-UP

The initial experimental evaluation of the pump involved the use of 20 calves in the following arrangement.

All calves were subjected to baseline hemodynamic studies and a standard ligation of the anterior descending coronary artery.

Following coronary ligation the studies were repeated and the animal was assigned to either the control or assist group.

The calves in the assisted group received a one hour period of synchronized partial veno-arterial by-pass with appropriate hemodynamic studies performed both during and following the assist period.

Calves in the control group were systemicly heparinized, and then observed for the one hour period. All animals were evaluated with myocardial staining and Cesium counting at postmortem.

To facilitate collection of hemodynamic data the following arrangement of catheters and probes was used.

Venous drainage was from the right atrium, arterial perfusion via the descending aorta.

Pressures were monitored in the cardiac chambers as well as in the femoral artery and vein.

Left coronary artery flow was measured with an electromagnetic flow meter, and cardiac outputs were determined using a thermodilution technique with injection in the right ventricle and sampling in the pulmonary artery.

At postmortem the left ventricle was sectioned and stained for L.D.H. with a Nitro-BT method. Decreased staining was noted in the infarct area as seen here, and contrasted sharply with the viable myocardium.

RESULTS

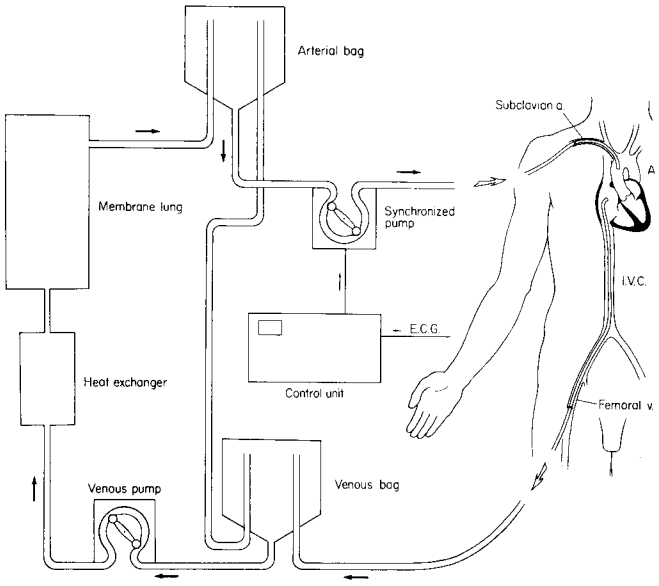
The pump was found to be capable of providing synchronized pulsatile by-pass during the assist period at pulse rates as high as 140 beats per minute.

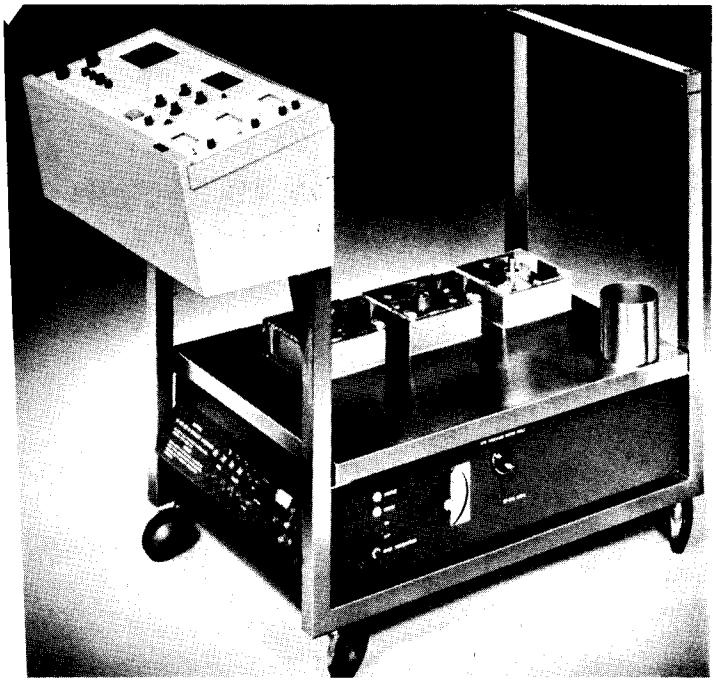
Using the pressure curves of the pump and the animal, the pump ejection phase could be quickly timed to occur during diastole. Here the pump is initially out of phase, but proper use of the delay control allows for correct placement of the pump ejection phase in diastole. Initial synchronization was obtained at low pump flow, but the assist system was capable of providing up to 84% of the calf's total perfusion with a mean level of 52%.

Properly synchronized pump flow leveled the aortic root pressure, but maintained pulsatile flow in the left coronary artery that was synchronous with pump ejection during diastole.

HEMATOLOGY

Some destruction of the formed elements of the blood was experienced with our present system using a bubble oxygenator, and there was a slight rise in the plasma hemoglobin level during the perfusion period as well as a moderate drop in the platelet count.





Whole blood was used for priming and the hematocrit remained steady at approximately 38% throughout the experimental period.

Satisfactory arterial pH, pO2 and pCO2 values were maintained throughout the entire experimental period.

HEMODYNAMICS

Cardiac output showed a slight drop following coronary artery ligation, but was maintained at normal levels throughout the pump period. Approximately half of the animals perfusion of 4.2 L/minute during the pump period was being maintained by the assist system.

Stroke work showed a moderate drop after ligation that correlated with a drop in cardiac output. A marked drop in stroke work to 1.52 K-Cm was noted during pumping while normal perfusion was maintained. The calves were able to maintain normal stroke work following perfusion.

CORONARY ARTERY FLOW—INFARCT SIZE

Mean coronary artery flow was maintained at close to preligation levels during the period of assisted circulation, and we noted a slight increase in coronary flow in the assisted animals following perfusion, when they were compared with the non-assisted controls.

Post-mortem measurements revealed infarction involving 23% of the left ventricle in the control animals and 16% in the experimental animals. Infarct size varied widely in the control animals, and the percentage difference is not statistically significant.

The Cesium-131 studies, however, did show a significant difference in the blood flow to ischemic myocardium when the assisted animals were compared with the controls. Control animals had a Cesium uptake of only 6.4 and 5.6% of normal left ventricle, whereas the assisted animals had uptake values approximately three times as high.

CONCLUSION

We believe that we have been able to develop a reliable synchronized pulsatile perfusion system that allows for a decrease in heart work during the assist period while providing normal systemic perfusion and coronary artery flow.

The Cesium-131 uptake studies lend support to the concept that properly applied pulsatile assisted circulation may well increase coronary collaterals and sustain improved blood flow to ischemic myocardium.

We are presently planning for clinical application of this assist system, and of course expect the immediate beneficial effects seen in the next slide. We anticipate that the improvement will not be transient, but will lead to the eventual rehabilitation of the patient and his discharge from the hospital.

The system is relatively compact and with even the most rudimentary forms of transportation, it should be possible to provide assisted circulation for almost any community.

ADDENDUM

Dear Ed:

I have enclosed two prints related to the paper submitted by John Dufek on the Sychronis Pulsatile Pumping Unit.

The photo of the heart assist unit itself is copied from a color photograph. The other photograph is the circuit diagram which was prepared at the University of Michigan specifically for their project.

While writing this letter to you, John called and I told him that I was going to send these two photographs to you. It dawned on me that I had better explain that the photograph of the heart-assist unit itself is of the new equipment we are shipping to Wisconsin this week. The work John has been involved in is on the older style of equipment which was in a modular form. The photograph of this equipment is the new generation unit with additional capabilities.

In this configuration of equipment, we have three pumps with the pump closest to the control panel synchronis. The other two pumps are full range, 250 RPM pumps. The unit has a Normothermia System built into it which, of course, eliminates the need for hospital supplied water. It also contains batteries for battery operation on all three pumps. The Normothermia System is, of course, excluded from battery operation because of the great amount of power it consumes. With the exception of the Normothermia System, however, the entire unit is self-contained and portable due to the battery operation.

Sincerely yours,

Lawrence P. Baldwin
Sales Department Supervisor
Sarns, Inc.