

Management of the Artificial Heart Driver: A New Role for the Perfusionist?

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Abstract

The recent success of the first permanent total artificial heart implant has brought to light a possible new role for the perfusionist. The specialized skills necessary to monitor hemodynamic parameters of the drive system for the artificial heart are currently held by a few people with extensive research experience. The skills of an experienced perfusionist are similar to those needed to monitor and operate the drive system. This paper examines the requirements for operating the drive system and the suitability of a perfusionist's training for performing this function.

Introduction

The advent of the clinical use of the total artificial heart has created the need for personnel trained in completely new technical skills. This is very similar to the situation which developed as a result of instituting the use of the intra-aortic balloon pump. While separate training programs could be established for this new position, it would seem logical for the cardiovascular perfusionist to add these skills to his armamentarium. The basic human anatomical and physiological concepts are well understood by the perfusionist, and with minimal additional training the operation of the total artificial heart drive system can become an avenue for the perfusionist to broaden the scope of his profession.

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Description of the Total Artificial Heart

The Utah total artificial heart has been modified by many scientists over the last twenty years. The current pump includes design modifications made by Dr. Robert Jarvik^{1,2,3} and carries his name. The ventricles are constructed of a smooth blood surface fabricated of Biomer™,^a segmented polyurethane. The diaphragms consist of highly flexible four layer sheets of this Biomer™ which make the diaphragms infinitely pliable.

The heart is pneumatically driven consisting of two separate ventricles with air chambers. Air is pulsed at adjustable rates of 40-200 beats per minute in and out of the air chamber activating the diaphragm (Fig. 1). The ventricles are fashioned so that the blood surface is attached to the housing in a continuous layer. The two ventricles displace a total of 680 ml. Each ventricle has a stroke volume of 100 ml. The overall shape is spherical with anatomic transitions to the great vessels and atria. Four clinical grade pyrolytic carbon disk valves are used to achieve unidirectional flow. The connections to the natural atria are achieved by atrial cuffs fabricated of dacron felt connected to the total artificial heart by quick connect systems consisting of coated rigid polycarbonate segments. The connections to the great vessels consist of dacron vascular prosthetic grafts. The drivelines consist of ¼ inch reinforced polyurethane tubing exiting the body in the left periumbilical area. These tubes are connected to the drive system by two eight-foot length ⅜ inch I.D. PVC tubes.

The Utah pneumatic heart driver is connected to a source of compressed air, vacuum, and electric-

^aEthicon, Inc., Somerville, NJ 08876.

ity. The compressed air may be adapted from specialized hospital outlets or from portable cylinders of nitrogen or compressed air. Portable cylinders the size of two scuba tanks will support the patient for approximately four to six hours. The vacuum line is optional and it appears in our patient to have made very little difference in the overall performance of the heart. The electrical system is backed up by rechargeable batteries in order to compensate immediately in the case of power failure.

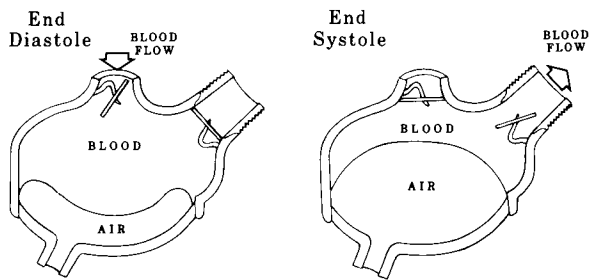


FIGURE 1. Diagram of blood flow pattern in and out of pumping chamber effected by air-driven movement of flexible diaphragm.

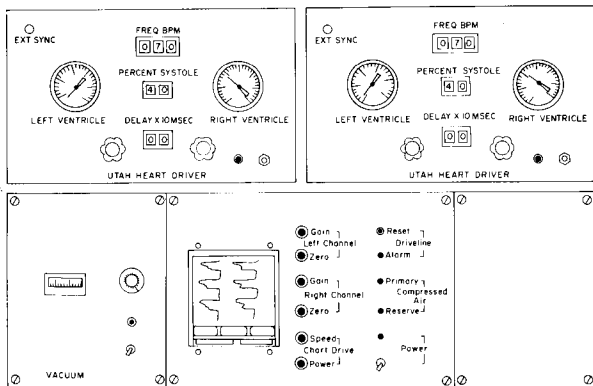


FIGURE 2. Control panel for drive system demonstrating separate right and left heart controls.

The drive system may be regulated as to the number of beats per minute and the individual driving pressures on the right and left ventricles (Fig. 2). There also is an opportunity to adjust the percent systole for the two ventricles. The present drive system (Fig. 3) is about the size of an adult wheel chair and weighs approximately 375 pounds. This is being streamlined to a more portable and compact unit that will be available shortly.

The heart obeys Starling's Law relationships with cardiac outputs as high as 13 liters per minute at inflow pressures of 18 millimeters of mercury. Characteristic individual ventricular exhaust flow

waveforms are provided by a cardiac output monitor and diagnostic unit, called the "COMDU". This unit has proven to be extremely valuable in monitoring the patient's early post-operative course and has been of critical significance in its ability to diagnose problems with the artificial heart and driver (Fig. 4). The "COMDU", is designed to display every third heartbeat on a screen. The information includes: the stroke volumes, filling rates, and calculated cardiac output in liters per minute for both the right and left ventricles.

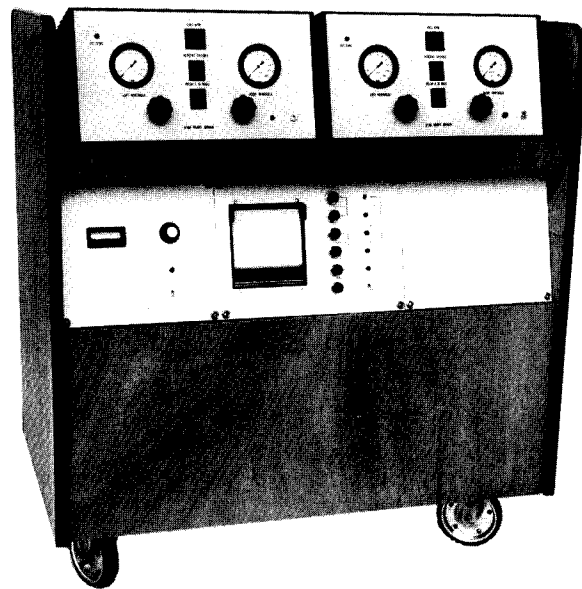


FIGURE 3. Drive system in current use.

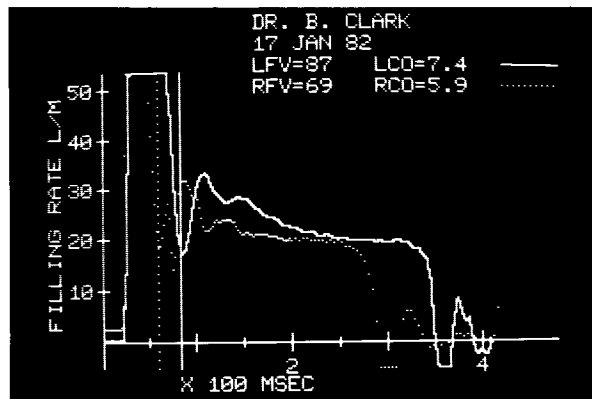


FIGURE 4. "COMDU" computerized diagnostic readout for total artificial heart patient, Dr. Barney Clark.

Suitability of the Perfusionist's Training for Operating the Artificial Heart Drive System

A well-trained and experienced clinical perfusionist has an intimate understanding of the

hemodynamics of patients undergoing cardiopulmonary bypass. Perfusionists study the anatomy, physiology, and pathology of the heart and the vascular bed. This curriculum provides the perfusionist with the knowledge necessary to manipulate blood flows and pressures to achieve adequate perfusion for all the patient's vital organ systems.

One of the most powerful tools available to the perfusionist is the waveform produced by monitoring systems. An understanding of these blood pressure waveforms and the ability to respond both medically and mechanically to given physiologic changes as indicated by these waveforms are basic skills of the qualified perfusionist and are also essential to the proper management of the total artificial heart.

Most perfusionists have a working knowledge of the intra-aortic balloon pump. This knowledge of the principles of its operation and its effect on the patient's hemodynamics enables the perfusionist to modify the normal physiology, increasing blood flow to the coronary vessels and reducing the workload of the heart.

The use of mechanical devices to effect changes in physiological processes, is within the scope of a perfusionist's knowledge and abilities. The perfusionist who treats patients with these devices is able to deal with emergencies that may present during the course of these procedures, because of his training in, and knowledge of, the manipulation of physiological functions.

Discussion

Current drive system operators are individuals who have extensive laboratory experience with the device. The use of the system on the animal model has contributed much practical knowledge of the functions of the drive system. Personnel who are qualified to operate the system have academic training in the anatomy and physiology of the circulatory system. Laboratory experience has documented methods by which the drive system may be used to produce desired effects and to compensate for undesirable physiologic conditions.^{4,5,6} The extensive animal experience has led to the identification of precise relationships of the drive pressures to actual circulatory conditions.^{7,8} This knowledge is unique at present, but is based

on the fundamentals of circulatory anatomy and physiology.

The concept of one heart has been supplanted by externalization of the control mechanisms, and the realization that the ventricles need not function in synchrony to perform their primary function. The operator of such a drive system must adjust his knowledge of the normal cardiopulmonary system to accommodate this ability to control the ventricles independently. This feature allows for compensatory changes that the native heart may not be able to duplicate. Using the Utah Heart Drive System it is possible to regulate ventricular function by varying a series of parameters including, left and right ventricular drive pressure, heart rate, percent systolic duration, and exhaust vacuum. (Fig. 2) The noninvasive monitoring of pumping efficiency is made possible through the analysis of the air drive pressure waveform and exhaust flow characteristics. These techniques simplify monitoring the cardiac output, ejection and filling characteristics of each ventricle noninvasively.

The operator of the drive system must understand the limitations of the heart's capabilities. The ventricles themselves are non-sucking pumps. That is, they only pump out what enters during the filling cycle (Starling's Law). That characteristic of the device allows the body's vascular tone to vary the total output of the heart with no change in rate or driving force. The function of the ventricles with their driver is a complex interdependence, which requires considerable knowledge of cardiopulmonary physiology and the ability to correlate the functions of the artificial heart and the patient's physiologic needs.

The present heart driver has only one heart rate control, and one control for systolic duration, for left and right ventricles (Fig. 2). If the individual ventricles need to be driven with different heart rates, or systolic durations, two drivers must be used, one for each ventricle. The operator of the system needs to understand the alarm features of the driver, and the emergency back-up power supplies. The systems used for emergency power are not unlike those utilized in the drive console of an intra-aortic balloon pump. The operator needs to be able to recognize when the systems are operable, and when they need to be renewed or replaced.

The perfusionist's training in the use of the intra-aortic balloon pump should facilitate the

training that would be required in the use of the Utah Heart Drive System. The pneumatics needed to drive the intra-aortic balloon pump are similar conceptually to the pneumatics of the Utah Drive System. An understanding of the independent pumping characteristics of the right and left ventricles could be easily grasped by the perfusionist interested in pursuing this area of total circulatory assist.

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