Chapter 17-Cardiac Assist

Cardiovascular orthotic prosthetic devices are primarily mechanical in nature, but they are always associated with various pieces of electronic instrumentation that are necessary to control the devices and to monitor their operation.

CARDIAC-ASSIST DEVICES

It has been the goal of cardiac surgeons and cardiologists to develop mechanical pumps that can be used to aid the failing heart after acute traumatic insults such as myocardial infarction or cardiac surgery. Devices ranging from pumps that can completely replace the heart to a device to reduce the load driven by the heart are being considered. In the latter case, physicians have developed an aortic-balloon system that is used clinically. It consists of a long sausage-shaped balloon that can be introduced into the aorta through a femoral artery and connected to an external drive apparatus (Jaron, 1988).

The operation of this intraaortic balloon pump is quite simple. Let us consider the balloon as being in the aorta in its inflated state, occupying a major portion of the aortic lumen but still allowing blood to flow past it. At the initiation of the next ventricular contraction, suction is applied to the balloon, causing it to collapse. The blood pumped by the left ventricle enters the aorta and replaces the volume previously occupied by the balloon. This requires only low pressure and demands less effort from the left ventricle. After the contraction, the aortic valve closes, and pressurized CO_2 is applied to the balloon, causing it to expand. CO_2 is used because it is more soluble in blood than air is. Thus if the balloon or its supply tubing should leak or rupture, there is less risk of fatal gas embolism.

As the balloon expands, it forces the blood surrounding it out of the aorta and into the rest of the body. Hence the balloon does much of the work normally done by the left ventricle and causes the blood to circulate to the periphery. The process is repeated after the next ventricular contraction.

This device must rely on a sophisticated system of electronic controls to detect ventricular contractions either from a pressure sensor at the arch of the aorta or, more commonly, from the ECG. The signal must then go through appropriate delay circuits to control the suction and pressurized CO_2 supplied to the balloon. Appropriate sensors must also be included in the system to ensure that alarms are sounded if any leaks occur.

PUMP OXYGENATORS

In cardiac surgery it is often necessary to stop the heart from pumping during certain procedures of the operation. In this case, to keep the patient alive it is necessary to replace the heart's pumping action and also the oxygenation normally provided by the lungs, because they are usually not functioning either. Machines known as *pump oxygenators* have been developed that can carry out these functions. They consist of pumps for maintaining arterial blood pressure connected in series with oxygenators that increase the blood O_2 content and remove CO_2. In surgery, the pump oxygenator is usually connected between the superior and inferior venae cavae or between the right atrium and a femoral artery, as shown in Figure 13.12. In some cases a femoral-artery-to-femoral-vein-bypass technique is used to keep all cannulae away from the heart.

Various types of pumps can be used. Roller pumps and multiple-finger pumps are often employed, because the pump itself does not come in contact with the blood. Disposable tubing can be used to contain the blood that is pinched between the propagating rollers or fingers. Pulsatile pumps—consisting of a chamber subjected to the reciprocating motion of a piston, membrane, or bladder—are also used, with appropriate check valves to direct the flow. Such pumps more closely follow the normal action of the heart and produce a pulsatile blood pressure.

Two general types of oxygenators are used with these prosthetic devices. One is the *film* type, in which a large-surface-area film of blood is drawn into contact with a nearly 100% O_2 atmosphere by rotating disks (Figure 13.12). The second type is the *membrane* oxygenator, in which blood flows through fine tubes of a membrane permeable to gas. This device has a large exchange-surface area to allow the gas transfer to take place.

Studies have shown the membrane oxygenator to have less deleterious effects on the blood than film and other direct types of oxygenators. The membrane separates the liquid blood phase from the gaseous oxygen phase, whereas in direct oxygenators such as that shown in Figure 13.12, blood and oxygen are in direct contact. This can denature some of the protein components of the blood, which can lead to formation of emboli in the patient.

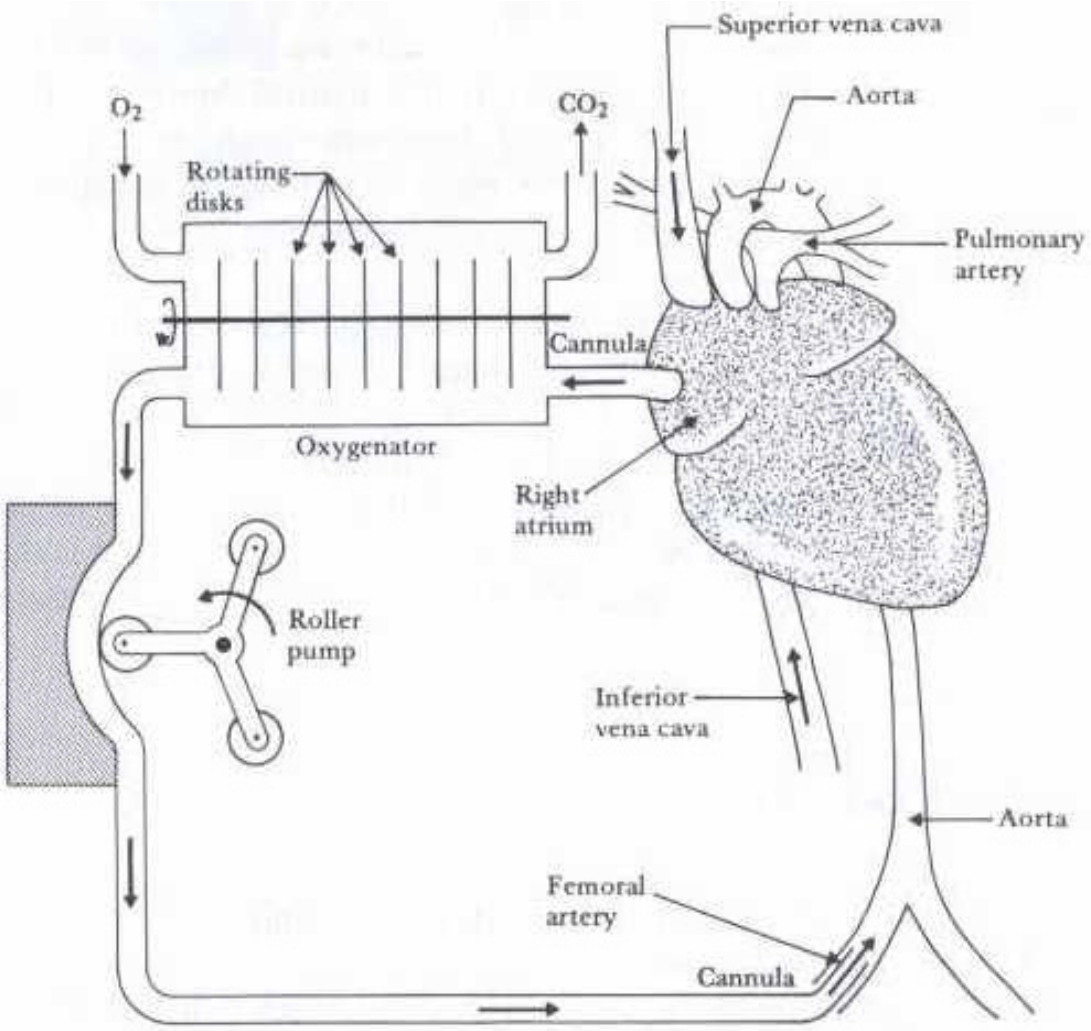

Figure 13.12 Connection of a pump oxygenator to bypass the heart A disk-type oxygenator is used with a roller pump. Venous blood is taken from a cannula in the right atrium, and oxygenated blood is returned through a cannula in the femoral artery.

Pump oxygenator systems are also applied in newborn intensive care. Infants who have severe lung disease that cannot be treated any other way have been put on pump oxygenators for several days to allow the diseased lung to "rest." The lungs recover in a significant number of these infants, who can then be removed from the pump oxygenator. This therapy, which is based on the extra corporeal membrane oxygenator (ECMO), has been demonstrated to be effective for seriously ill term infants, but the same approach has not shown any therapeutic efficacy in adults.

TOTAL ARTIFICIAL HEART

Blood pumps have been miniaturized and constructed of such materials that they can replace the natural hearts of patients. They are implanted in the thoracic cavity and operate via pneumatic and electric connections to an external drive apparatus (DeVries and Joyce, 1983; Yared and DeVries, 1988). Such devices were the subject of many popular press reports during the period in which they were studied in human subjects. The most notable of the devices was the Jarvic 7, which has been used as both a temporary and a permanent heart replacement (Jarvic, 1981). In the former case, the device was used to keep a patient alive until a suitable natural donor heart could be found for transplantation. Total heart replacements enabling patients to live for up to 620 days after surgery have been reported. Technical problems, however, continue to plague the device, and its use has been halted pending further technical improvement.

Electronic instrumentation is essential when pumps or pump oxygenators are used. It is necessary to monitor the hemodynamics of the patient during the procedure. In addition, the ECG, aortic, and central-venous pressure waveforms must be carefully watched. The pump oxygenator itself must also be monitored. The degree of oxygenation of the blood, as well as its pressure, must be recorded. And it is necessary to protect the patient from leaks in the system that could cause O_2 to enter the blood vessels or result in the serious loss of blood.