FAULTY VALVES

The four **valves** of the heart control the flow of blood. If these are damaged or do not function properly, blood may not be pumped efficiently to the rest of the body. Babies may be born with faulty valves. Valves may be damaged by diseases such as rheumatic fever and **bacterial infections**. Ageing and normal wear and tear may weaken or stiffen heart valves. To restore efficient blood **circulation**, faulty valves may require surgical repair or replacement.

Heart murmur

Heart valve defects can often be detected using a stethoscope. The normal lub … dup sounds of the heartbeat may be hidden by the sounds of blood rushing through the heart. This is called a heart murmur, and it usually indicates a valve disorder. A heart murmur may be caused by:

- backflow of blood through a valve that does not close properly. The heart works less efficiently because it has to pump some blood twice. The heart chambers may also be enlarged because they have to hold more blood.
- restricted blood flow because a valve does not open properly. Blood pressure in the heart increases because blood builds up behind the faulty valve. The heart has to work harder to pump the higher-pressure blood.

If the damage to a valve is not too severe, a surgeon may be able to repair it. Stretched tissue can be removed, and the edges may be stitched together.

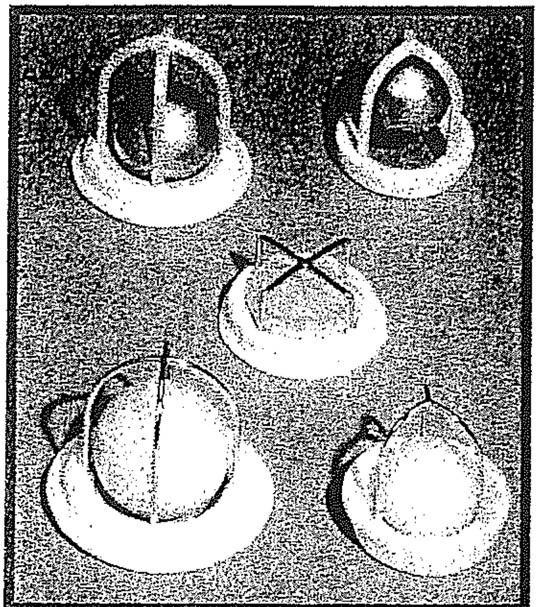
Using animal valves

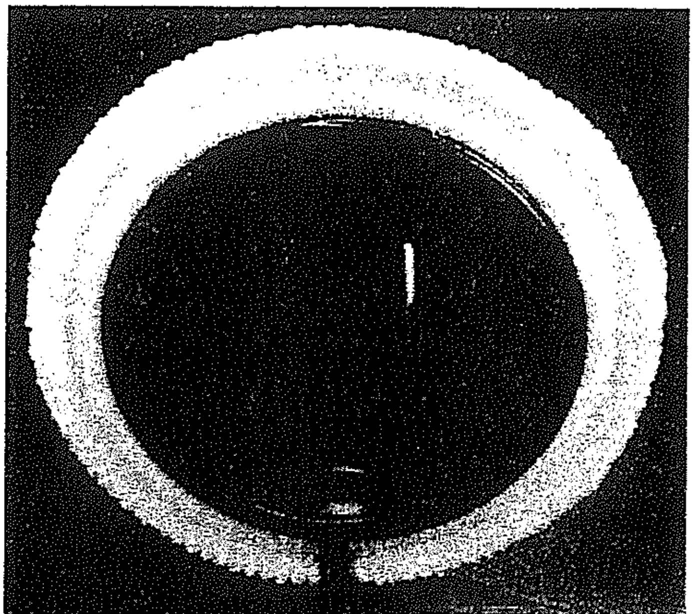
There is a lot of debate about whether it is right to use animals to cure humans. Some people argue that it is perfectly justifiable to kill a pig and remove the heart valves if this will save a person's life, and allow them to live normally and be active. Other people argue that we should respect animals and we have no right to use them in this way. What do you think? Would you want to have a pig's valve if you were ill? Or would you risk dying rather than hurt an animal? The debate will go on and on …

Replacement valves

A valve that is seriously damaged may need to be replaced with a new one. Several types of valve are available:

- from human donors: valves from a donated human heart are frozen in liquid nitrogen until the day before the operation. Very delicate surgery is needed to ensure that the donor valves fit the patient's heart exactly.
- from human tissue: a new valve can be constructed using tissue, such as part of the vena cava, from the patient's own body. The tissue is attached to a stainless steel frame to strengthen it, and is then inserted into the heart.
- from animals: valves from pigs' hearts can be successfully inserted into human hearts. Tissue from cows' hearts can also be used to make replacement valves for human hearts.
- artificial valves: a lot of research has been carried out to design and produce an artificial heart valve. The first, made in 1952, was a ball valve. The ball was pushed up, opening the valve, when blood was pumped out of the heart chamber. When blood flowed backwards, it pushed the ball back into place, closing the valve. Single disk valves were introduced in 1965, and the design was refined and improved to produce the first bi-leaflet valve in 1977. These have two disks and a hinge, and have proved to be very successful. Patients are living longer, and having fewer complications, than with the original ball valves.





(left) A selection of ball valves: as blood is pumped out of the heart chamber, it lifts the ball; backflow of blood pushes the ball back into place. (right) A modern bi-leaflet valve, with two disks and a hinge.

Replacing Heart Valves

A heart valve replacement is performed when a diseased valve that cannot be repaired is removed and replaced with a substitute mechanical or biological valve (Figure 4.2). The first artificial valves were used around 1960. Mechanical valves are constructed of durable materials such as dacron, teflon, titanium, and pyrolytic carbon; they are very sturdy and can be expected to last a lifetime. Mechanical valves require the long-term use of anticoagulation medication to prevent formation of blood clots on the valve prosthesis. They can also be noisy as they open and close.

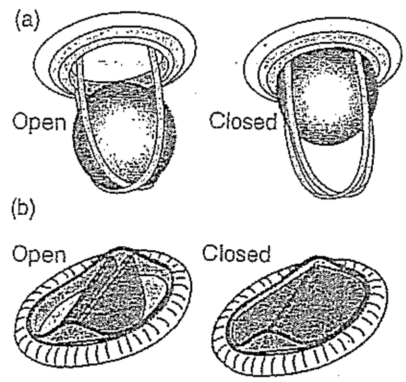


Figure 4.2 Mechanical heart valves (a) Ball-in-cage (b) Bileaflet disc valve

Early mechanical heart valves used a ball-in-cage design (Figure 4.2). The forward flow of blood pushed the ball outwards opening the valve. The reverse flow of blood forced the ball against the ring and closed the valve. The design was rather bulky and caused too much turbulence in the blood. The invention of pyrolytic carbon has allowed much better mechanical valves to be developed. Pyrolytic carbon is a dense form of carbon produced at high temperatures and pressures that is both durable and does not cause the blood to clot. Most modern mechanical valves use pyrolytic carbon in bileaflet disc valves as they have greater durability and fewer problems with clotting (Figure 4.2). The leaflets are supported by a corrosion-resistant metal ring with an attached layer of dacron cloth or expanded teflon cloth so that it can be stitched to the walls of the heart. This material is used as it can be made into a cloth that resists tearing, is biocompatible and does not promote clotting of the blood. The small leaflet-shaped discs open to allow forward flow and then close to prevent reverse flow. Leaflet valves can open more vertically than earlier valve designs and thus reduce turbulence.

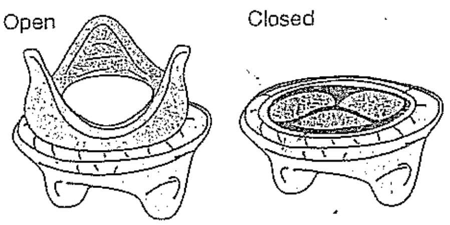


Figure 4.3 Biological heart valves The leaflets are the same as normal human valves but the edge is strengthened

Biological valves are made of tissue taken from pigs, cows or human donors (Figure 4.3). Because they are biological materials they do not require anticoagulation medication. However, their durability is not as good as mechanical valves and they have to be replaced more often. Recently it has been found that chemical treatment helps improve mechanical strength and reduces problems with immune rejection. The three valve leaflets are attached to a strengthening ring covered with cloth to allow attachment to the heart. The ring is made of teflon coated plastic or of corrosion-resistant metal coated with dacron.

Replacing heart valves

Name	Construction	Advantages	Disadvantages
Allograft from cadavers 1962)	Valves taken from cadavers with no heart disease.	No blood clotting and less postoperative infection. They are especially suitable for young women and children, and for patients with recurrent, inflammation of the heart wall.	Difficulty in finding donors. Tissue failure but it is more gradual than for biological or mechanical devices.
Autograft 1967 but not widely used until 1990s)	Pulmonary valve taken from own body to replace aorta valve; pulmonary valve replaced by an allograft.	No blood clotting or tissue rejection; less postoperative infection.	Difficulty in finding donors for allograft. Tissue failure but it is more gradual than for biological or mechanical devices.

Mechanical valves

There are three major types of *mechanical valves*, with many modifications on these designs.

Another variety, utilizes a metal cage to house a metal ball. When blood pressure in the chamber of the heart exceeds that of the pressure on the outside of the chamber the ball is pushed against the cage and allows blood to flow. When the chamber has emptied the majority of the blood and the pressure outside the chamber exceeds that inside the chamber the ball moves back against the base of the valve forming a seal. In 1952, Dr. Charles Hufnagel implanted caged-ball heart valves in ten patients (six survived the operation), marking the first long-term success in prosthetic heart valves. One Ball valve was invented by Miles "Lowell" Edwards and Albert Starr in 1960 (commonly referred to as the Starr-Edwards Silastic Ball Valve). The first human implant occurred on Sept 21, 1960. Currently, the only caged-ball design approved for use in the US is the Starr-Edwards valve. It consists of a silicon ball enclosed in a cage formed by wires originating from the valve housing. The ball moves with the flow in order to open and close the valve.

Soon after came **tilting-disc** valves, which have a single circular occluder controlled by a metal strut. They are made of a metal ring covered by a tissue, into which the suture threads are stitched, in order to keep the valve in place once implanted. The metal ring holds, by means of two metal supports, a disc which opens and closes as the heart pumps blood through the valve. The disc is usually made of an extremely hard carbon material (pyrolitic carbon), in order to allow the valve to function during years without wearing out. The Medtronic-Hall model is the most common tilting-disc design in the US. In some models of mechanical valves, the disc is divided into two parts, which open and close as a door.

St. Jude Medical is the leader in **bileaflet valves**, which consist of two semicircular leaflets that rotate about struts attached to the valve housing. This design was introduced in 1979 and while they take care of some of the issues that were seen in the other models, bileaflets are vulnerable to backflow and so it cannot be considered as ideal. Bileaflet valves do, however, provide much more natural blood flow than caged-ball or tilting-disc implants.

Mechanical heart valves are today very reliable and allow the patients to live a normal life. One of the main advantages of these valves is that they are well tolerated by the body. Only a small amount of blood thinner is needed to be taken by the patient each day, in order to prevent clotting of the blood when flowing through the valve. Any medication however can lead to other complications.

Durability

Mechanical heart valves are considered to be extremely durable in comparison to their bioprosthetic counterparts. The struts and occluders are made out of either pyrolytic carbon or titanium coated with pyrolytic carbon, and the sewing ring cuff is Teflon, polyester or dacron. The major load arises from transvalvular pressure generated at and after valve closure, and in cases where structural failure does happen, it is usually as a result of occluder impact on the components.

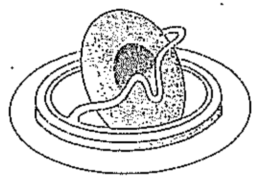
Impact wear and friction wear dictate the loss of material in MHV's. Impact wear usually occurs in the hinge regions of bileaflets, between the occluder and ring in tilting-discs, and between the ball and cage in caged-ball valves. Friction wear occurs between the occluder and strut in tilting-discs, and between the leaflet pivots and hinge cavities in bileaflets.

MHV's made out of metal are also susceptible to fatigue failure owing to the polycrystalline characteristic of metals, but this is not an issue with pyrolytic carbon MHV's because this material is not crystalline in nature.

Blood damage

One of the major drawbacks of mechanical heart valves is that patients with these implants require consistent anti-coagulation therapy. Clots formed by red blood cell (RBC) and platelet damage can block up blood vessels and lead to very serious consequences.

Because all models experience high stresses, patients with mechanical heart valve implants require anti-coagulation therapy. Bioprosthetics are less prone to develop blood clotting, but the trade-off concerning durability generally favors their use in patients older than age 65.


the Liks-2 monoleaflet tilting disc valve

Biological valves (BIOPROSTHETICS)

Biological valves are valves of animals, like pigs, which undergo several chemical procedures in order to make them suitable for implantation in the human heart. The porcine (or pig) heart is most similar to the human heart, and therefore represents the best anatomical fit for replacement. Implantation of a porcine valve is a type of Xenotransplantation, or Xenograft, which means a transplant from one species (in this case a pig) to another. There are some risks associated with a Xenograft such as the human bodies tendency to reject foreign material. Medication can be used to retard this effect, but is not always successful.

Another type of biological valve utilizes biological tissue to make leaflets that are sewn into a metal frame. This tissue is typically harvested from the *Pericardial Sac* of either Bovine (cows) or Equine (horses). The pericardial sac is particularly well suited for a valve leaflet due to its extremely durable physical properties. This type of biological valve is extremely effective means of valve replacement. The tissue is sterilized so that the biological markers are removed eliminating a response from the host's immune system. The leaflets are flexible and durable and do not require the patient to take blood thinners for the rest of their life.

The most used heart valves in the US and EU are those utilizing tissue leaflets. Mechanical valves are more commonly used in Asia and Latin America. The following companies manufacture artificial heart valves: Medtronic, Edwards Lifesciences, and St. Jude.

Functional requirements of heart valve prostheses

The functioning of natural heart valves is characterised by many advantages:

- Minimal regurgitation - This means that the amount of blood lost upstream as the valve closes is minin
- Minimal transvalvular pressure gradient - Whenever a fluid flows through a restriction, such as a valve, a pressure gradient arises over the restriction. This pressure gradient is a result of the increased resistance to flow through the restriction. Natural heart valves have a low transvalvular pressure gradient as they present little obstruction to the flow through themselves (Fixme: Give indicative value). A desirable characteristic of heart valve prostheses is that their transvalvular pressure gradient is as small as possible.
- Non-thrombogenic - As natural heart valves are lined with an endothelium continuous with the endothelium lining the heart chambers they are not normally thrombogenic.
- Self-repairing - Although of limited extent compared to well vascularised tissue (e.g. muscle), the valve leaflets do retain some capacity for repair due to the presence of regenerative cells (e.g. fibrobla: