Artificial Hearts
Shannon Mooney
Trinette Wright
The Human Heart

- Aorta
- Pulmonary trunk
- Left atrium
- Pulmonary veins
- Left ventricle
- Superior vena cava
- Right atrium
- Right ventricle
- Inferior vena cava

[1]
Blood Flow

- Atrioventricular
  - Mitral/Bicuspid (L)
  - Tricuspid (R)
- Semilunar
  - Aortic (L)
  - Pulmonary (R)
Heart Failure

- Failure to adequately pump blood to the rest of the body
- Congestive if filling pressures are normal
- Only severe cases may be eligible for heart transplant

<table>
<thead>
<tr>
<th>Class</th>
<th>Patient Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I (Mild)</td>
<td>No limitation of physical activity. Ordinary physical activity does not cause undue fatigue, palpitation, or dyspnea (shortness of breath).</td>
</tr>
<tr>
<td>Class II (Mild)</td>
<td>Slight limitation of physical activity. Comfortable at rest, but ordinary physical activity results in fatigue, palpitation, or dyspnea.</td>
</tr>
<tr>
<td>Class III (Moderate)</td>
<td>Marked limitation of physical activity. Comfortable at rest, but less than ordinary activity causes fatigue, palpitation, or dyspnea.</td>
</tr>
<tr>
<td>Class IV (Severe)</td>
<td>Unable to carry out any physical activity without discomfort. Symptoms of cardiac insufficiency at rest. If any physical activity is undertaken, discomfort is increased.</td>
</tr>
</tbody>
</table>
History

- Cardiopulmonary bypass (CPB) machine was first used by surgeons starting in 1953
- 1957 first artificial heart designed by Akutsu and Kolff and implanted in a dog
- Early 1960s left ventricular assist devices were invented for longer-term ventricular assistance
  - First one implanted in 1963 in a patient that went into cardiogenic shock after an aortic valve replacement

[7]
History

- 1967 first successful cardiac transplant performed by Christiaan Barnard
- 1969 first total artificial heart replacement surgery performed
  - Heart developed by Baylor Laboratories
- During the 1970s many pump devices invented to act as a bridge between heart failure and surgery (max of 30 days)
  - Norcor LVAS (developed in Ottawa)
  - HeartMate LVAS (developed in California)
History

- Second total artificial heart replacement surgery performed in 1981
  - Due to limited immunosuppressant drugs, contamination during transplant of the artificial heart made patients susceptible to bacterial infection
- Jarvik-7 was the first successful total artificial heart replacement surgery
  - Patient lived 112 days (death unrelated to TAH)
  - Patients used hearts for 2 to 620 days
- 1985 first successful bridge surgery using total artificial heart replacement performed

[7]
History

- Early 1990s improvements made to Jarvik-7 (renamed CardioWest in 1991), AbioMed invents another total artificial heart AbioCor
- 1998 the 100th artificial heart is implanted
- 2004 FDA approves the SynCardia total artificial heart (formerly CardioWest) for bridge transplantation
- Currently 2 artificial hearts available
  - AbioCor and SynCardia
# Types of Artificial Hearts

- **2 types of artificial hearts**

<table>
<thead>
<tr>
<th>Ventricular Assistant Devices</th>
<th>Total Artificial Heart</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Implanted to assist the natural heart</td>
<td>- Heart is removed and an artificial heart is implanted</td>
</tr>
<tr>
<td>- Patients not eligible for heart transplant</td>
<td>- Patients may be eligible for heart transplant</td>
</tr>
<tr>
<td>- Implant is designed to lessen the load on the heart and possibly help the healing process</td>
<td>- Heart has completely failed and only option remaining is an artificial heart</td>
</tr>
</tbody>
</table>
Total Artificial Hearts

- Implanted to pump blood from the heart in place of the ventricles
- Takes over functions of heart valves
- Currently 2 categories of artificial hearts

<table>
<thead>
<tr>
<th>SynCardia</th>
<th>AbioCor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient eligible for heart transplant</td>
<td>Patient ineligible for heart transplant</td>
</tr>
<tr>
<td>External power supply; wires/tubes penetrating the body wall</td>
<td>Implanted power supply; no body wall penetration</td>
</tr>
</tbody>
</table>
SynCardia Artificial Heart

- Used as a bridge to transplant
- Restore kidney and liver function
- Prevent tissue damage
Power Supply

- Connected by tubes through chest wall to external pneumatic driver
- Implant driver vs. Discharge driver
AbioCor Artificial Heart

- Patients are not eligible for heart transplant
- Fully implantable
- Hydraulic pump
- Ventricles contract at different times
AbioCor Heart

http://www.youtube.com/watch?v=oHvlwkYRFV4&feature=related
Power Supply

- Internal and External batteries
- Uses Transcutaneous Energy Transfer (TET)
Implantation Surgery

- Outflow and atrial grafts are stretched to make connection to the body easier
- Outflow grafts are sealed using preclotting or synthetic spray
- Patient is transferred to a cardiopulmonary bypass machine
- Ventricles and valves are removed leaving the valvular rings
- Modification to the atrium is made to prevent thrombus formation
• Outflow grafts are sutured to the aorta and pulmonary arteries and the atrial grafts are sutured to the atrium
• Grafts are checked for leakage and sealed
• SynCardia heart, left and right ventricles are attached to the grafts
• AbioCor heart, the apex cannulas are inserted into the left and right atrium
• The system is started and the patient is weaned off of the cardiopulmonary bypass machine
• Average implant surgery is 7 hours
Artificial Heart Fluid Mechanics

Graphs showing fluid mechanics at different time intervals:

- a: $t/T = 0$
- b: $t/T = 0.25$
- c: $t/T = 0.5$
- d: $t/T = 0.75$
- e: $t/T = 0.5$
- f: $t/T = 0.75$

Velocity (m/s) scale at the bottom of the pages.

[14]
Artificial Heart Fluid Mechanics

[Diagram]

[14]
Turbulent Flow

- Turbulent flow in the artificial heart puts excessive force onto the veins and arteries that are attached to the artificial heart.
- Not a problem for a bridge patient experiencing an average waiting time between heart failure and cardiac transplant.
- Problem for bridge patients that wait years before transplant and patients that are using artificial hearts to extend life.
- Causes wear on device.
Areas of Wall Shear

Color scales of wall shear magnitude:
- LOW: 0 s\(^{-1}\)
- MODERATE: 500 s\(^{-1}\)
- HIGH: > 1000 s\(^{-1}\)
AbioCor Heart

- AbioCor heart designed to minimize turbulent blood flow
- Ventricles are tube shaped
- Still turbulent blood flow around the motor as it pushes the blood out of the ventricle

[8]
Communication with the Central Nervous System

- Central nervous system needs to communicate with the artificial heart to vary the rate at which it beats.
- Artificial hearts use vascular conductance to measure the rate at which it should be beating.

[Diagram of the cardiovascular system with annotations: Living body, Cardiovascular center, Receptor, Signal, Control loop, Control function, Pump output, TAH, TAH drive parameter, Total artificial heart system.]
Future

- Increase life expectancy of patient
  - AbioCor patient life expectancy is 18 months
  - SynCardia patient life expectancy is to heart transplant

- Increase the durability of the artificial heart
  - Projected lifetime is to be increased to 10 years

- Decrease the size of the device
Future

• Change technology from an axial pump to a continuous flow pump
  ◦ Continuous flow pumps are better able to adapt to the human body’s changing need for blood
  ◦ Continuous flow pumps use the pressure of the blood flowing into the heart to determine the rate at which it pumps blood

• Still under animal testing

[18]
Hopefully advances in artificial hearts will improve the survival rate of patients living with stage 4 cardiac failure
References


References


References


