CARDIOPULMONARY BYPASS AND THE HEART LUNG MACHINE

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STATISTICS

- every 7 minutes in Canada, someone dies from heart disease or stroke
- in 2006 it was 2/3 leading causes of death in Canada
- an estimated 70,000 heart attacks each year
- up to 45,000 cardiac arrests each year
- over 16,000 Canadians die each year due to a heart attack
- 1% of people are born with a congenital heart defect
OVERVIEW

- Introduction
- Circulatory System
- What goes Wrong?
- Blood
- Cardiopulmonary Bypass
- Heart Lung Machine
- Complications
- Future
THE CIRCULATORY SYSTEM
THE CIRCULATORY SYSTEM

- Used to pass nutrients, gases, hormones, blood cells, etc. to and from cells in the body
- It helps stabilize body temperature and pH to maintain homeostasis
- Move blood to sites where it can be oxygenated
- Oxygenated blood is carried to the tissues of the body
THE CIRCULATORY SYSTEM

- Works on a Closed Circulatory System

- Blood and lymph are the fluids that move through the system

- Human body functions on Cardiovascular System
THE CIRCULATORY SYSTEM

- **Pulmonary Circulation**: oxygen depleted blood taken from the heart to the lungs
- **Systemic Circulation**: oxygenated blood from heart to rest of the body and depleted blood back to the heart
- **Coronary Circulation**: blood supply to the heart
THE HEART

- Heart pumps oxygenated blood to the body and deoxygenated blood to the lungs for purification.

- Heart connects the systemic circulation and the pulmonary circulation.

- Deoxygenated blood flows through the right part of the heart and oxygenated blood flows through the left.
THE HEART
WHAT CAN GO WRONG?
WHAT CAN GO WRONG?

**Coronary Artery Disease**
- failure of coronary circulation to supply adequate circulation to the heart
- most common form of heart disease
- many causes, including smoking, diabetes, hypertension etc.
- a myocardial infarction is a complication of coronary disease
WHAT CAN GO WRONG?

Stenosis or Leakage of Valves

- four valves: tricuspid, pulmonary, mitral and aortic
- narrowing due to valve flaps thickening, stiffening or fusing together (stenosis)
- backflow due to valve not closing properly
- can cause heart failure, stroke, clots or sudden cardiac arrest
WHAT CAN GO WRONG?

Aortic Aneurysm
- weakening and dilation of the wall of the aorta
- can be a birth defect or can be due to a disease of injury

Thrombus (Blood Clots)
- the final step of blood coagulation
- in a blood vessel it can decrease or fully stop blood flow
- can happen anywhere in the body (coronary vessels, pulmonary vessels etc)
WHAT CAN GO WRONG?

Congenital Heart Defects

- a defect of heart and its vessels present at birth
- most common type of congenital defect
- four classes: hypoplasia, obstruction defects, septal defects, cyanotic defects
BLOOD
BLOOD FUNCTIONS

- Supply oxygen and nutrients to tissues
- Removal of waste
- Immune System: circulates white blood cells and detects foreign bodies
- Coagulation
- Messenger: transport hormones
- Regulate pH and body temperature
BLOOD COMPONENTS

- 54.3% Plasma
- 45% Red blood cells (erythrocytes)
- 0.7% White blood cells (leukocytes) and platelets (thrombocytes)
NEWTONIAN OR NOT?

- Newtonian Fluid: stress-strain curve is linear and passes through origin
- Viscosity is independent of shear rate
- Blood Density = 1060 kg/m³
- Water = 1000 kg/m³
NEWTONIAN OR NOT?

- Blood acts Newtonian in regions of high shear rate
  - Large Arteries
    - Shear Rate > 100s⁻¹
- Blood acts non-Newtonian in regions of low shear rate
  - Smaller Arteries and Capillaries
  - Due to red blood cells (hematocrit level)
Below a critical blood vessel radius, blood viscosity becomes dependent on vessel radius
- Critical radius = 1 mm
FAHRAEUS-LINDQVIST EFFECT

- Beneficial: less resistance, especially in regions with highest flow resistance (arterioles)
  - Lower perfusion pressure
  - Lower blood pressure
  - Smaller pump (heart!)
BLOOD: A VISCOELASTIC FLUID

- Region 1: red blood cells at rest stack together
- Region 2: force that splits them causes elastic deformation and adds elastic E to cell
- Region 3: sliding of internal cell needs energy input, released via viscous friction
CARDIOPULMONARY BYPASS
A HISTORY
HISTORY

- Concept of using the oxygenator has been around since the 17th Century by Robert Hooke

- First mechanical takeover of both heart and lung functions was on April 5th, 1951

- First successful open heart surgery was carried out on May 6th, 1953
HISTORY

- Before 1950’s → Conceptual and development Period
  - John Heysham Gibbon made the first heart lung machine in 1937

- 1950-1970 → Applied Technological Period

- 1970-Present → Refinement Period
CARDIOPULMONARY BYPASS USES
USES

- Cardiopulmonary Bypass Process is carried out using the Cardiopulmonary Bypass Machine (CBM)

- Biomedical Device that is used to carry out open-heart bypass surgeries on patients

- Hundreds of thousands of patients lives are saved every year due to this procedure
USES

- The machine is used for two reasons:
  - Heart can be stopped for surgery
  - Help a person with heart failure
USES

- Coronary artery bypass surgery
- Cardiac valve repair or replacement
- Repair large septal defects
- Repair of congenital heart defects
- Transplantation
- Repair of large aneurysms
- Pulmonary thromboendarterectomy (PTE)
- Pulmonary thrombectomy
THE PROCEDURE
PROCEDURE

- A cannula (tube) is placed in the right atrium, vena cava or femoral vein to withdraw blood from body

- The blood is sent to cardiopulmonary bypass machine (CBM)

- Cardiovascular perfusionist assembles the circuit as per the patients requirements and makes sure that the heart lung machine runs specific to a given patient
PROCEDURE

- Oxygenator performs the same function as the lungs

- It is filtered, cooled, oxygenated and pumped back via a second cannula in the aorta or femoral artery

- A third tube near or in the heart flushes it with potassium solution to stop the heart
  - cardioplegia
CARDIOPULMONARY BYPASS

1. Oxygen-poor blood leaves the heart to enter the heart-lung machine.
2. Heart-lung machine pumps and adds oxygen to the blood before it returns to the body.
3. Oxygen-rich blood returns to the body, skipping the heart and lungs.
THE HEART-LUNG MACHINE
THE HEART LUNG MACHINE

- CBM, “The Pump”
- Six main parts
  - Cannulae
  - Reservoir
  - Oxygenator
  - Temperature Control
  - Filter
  - Roller/Centripetal Pump
- Connected by a series of silicone or PVC tubes
OXYGENATOR

- Takes place of the lungs
- Exchanges $O_2$ for $CO_2$ in the blood pumped from the reservoir
- Three types:
  - Bubble
  - Membrane
  - Heparin-coated
MEMBRANE OXYGENATORS

- Thin gas permeable membrane separates blood and gas flow
- Blood flow = 3-5 L/min
- Gas flow is 60% of blood flow
- Blood contacts membrane → direct oxygenation
HEPARIN-COATED OXYGENATOR

- Heparin is an anticoagulant
- Added to oxygenator polymer
- Avoid complications resulting from abnormal pressure gradient across oxygenator
- Reduces need for systemic herparinization
PUMP

- Takes place of the heart
- Roller Pump
  - Made up of several motor-driven pumps
  - Peristaltically massage the tubing, propels the blood through
- Centripetal
  - RPM of the pump head is altered to cause blood flow due to centripetal force
  - Thought to be superior to roller pump as it produces less blood damage
THE HEART-LUNG MACHINE
VIDEO
COMPLICATIONS
COMPLICATIONS

- Postperfusion/Pump-head syndrome
- Hemolysis
- Capillary leak syndrome
- Clotting of blood in the circuit
- Air embolism
- Inflammation
THE FUTURE
IMPROVEMENTS FOR THE FUTURE

Lifebridge B2T
- First portable heart-lung machine
- Been around since 2007
- Weighs 17.5 kilograms
- Can be used by emergency room physicians and paramedics on the site, for critical patients
IMPROVEMENTS FOR THE FUTURE

MiniHLM
- Miniaturized heart-lung machine for infants
- Functions of the machine are integrated, to make the machine small and compact
THANK YOU
QUESTIONS?
REFERENCES

- <http://www.heartandstroke.com/site/c.ikIQLcMWJtE/b.3483991/k.34A8/Statistics.htm>
- <http://www-linux-host.org/energy/spump.htm>