# Pediatric Cardiac Surgery

## Past, Present, and Future

John D. Cleveland, MD
Associate Professor of Surgery
University of Southern California Keck School of Medicine
Children's Hospital Los Angeles

# Pediatric Cardiac Surgery

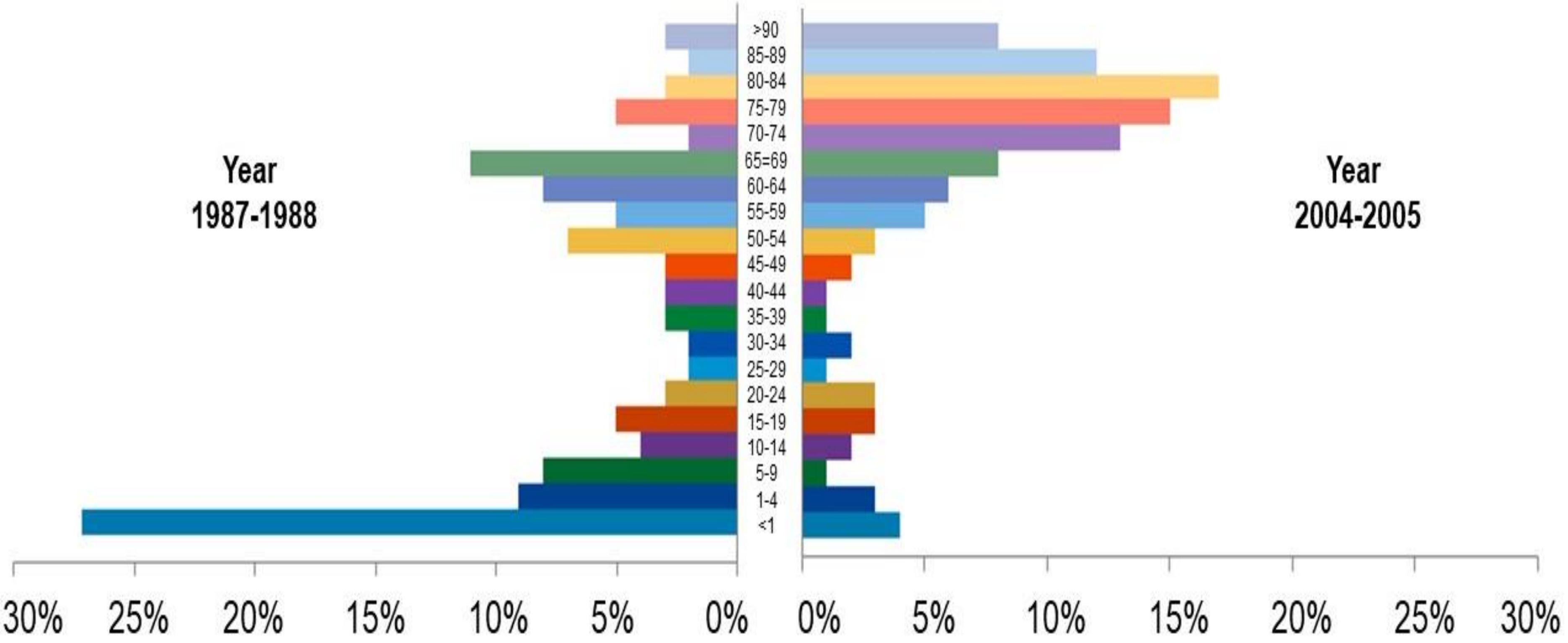
## Past, Present, and Future

## WHERE HAVE WE BEEN, WHERE ARE WE, AND WHERE ARE WE GOING?

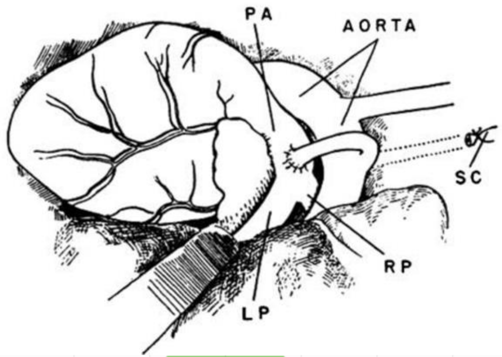
# Original Cardiac Surgery OR

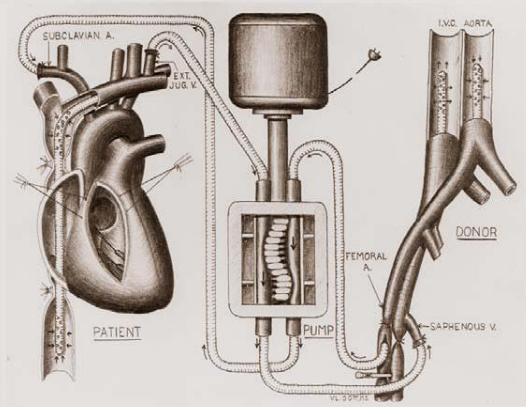
# Modern Cardiac Surgery OR

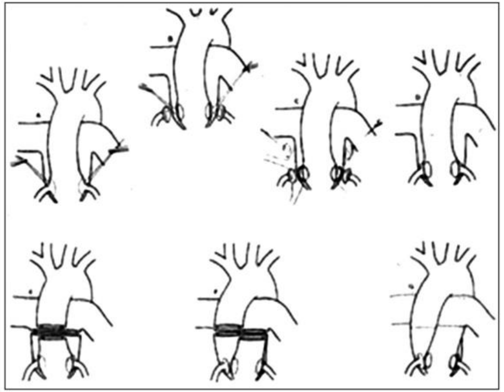
# Paradigm Shift



Children's Hospital LOS ANGELES | USC University of Southern California

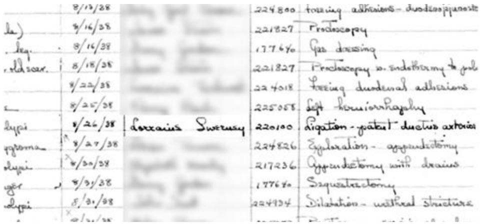


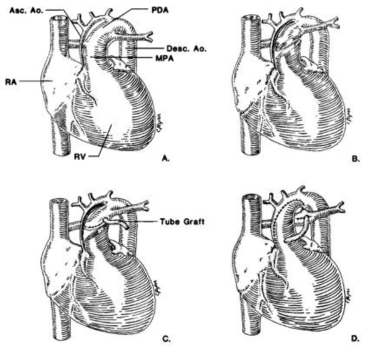



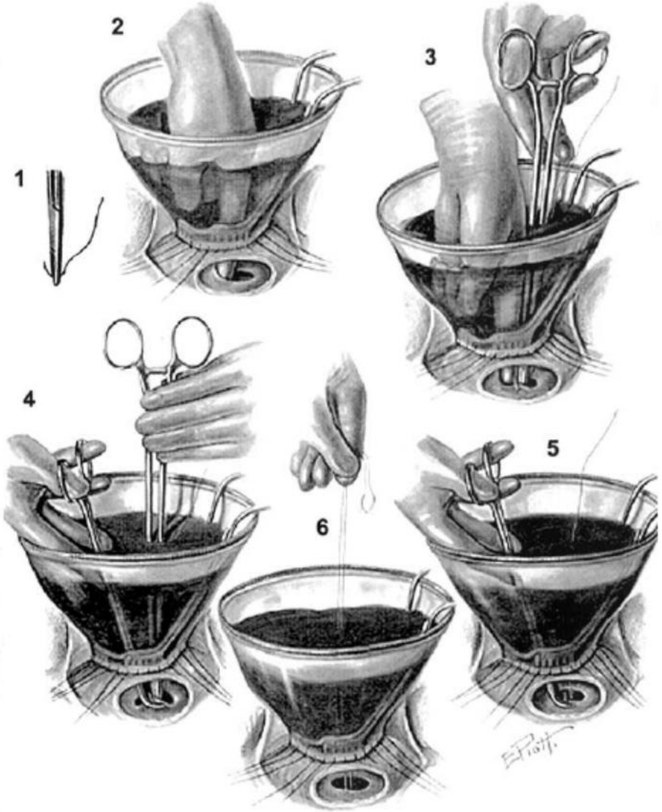
- 1938 – Gross- PDA Ligation
- 1944 – BTT Shunt for TOF
- 1944 – First Coarctation Repair
- 1953 – John Gibbon- Cardiopulmonary Bypass
- 1955 – Lillehei, Kirklin, Debakey, Cooley
- 1958 – Atrial Switch Procedure
- 1967 – First Heart Transplant
- 1967–1972 – Advent of Infant Cardiac Surgery
- 1975 – Arterial Switch
- 1976 – 1st clinical use PGE
- 1983 – First Successful Norwood
- 1984 – Neontal ASO

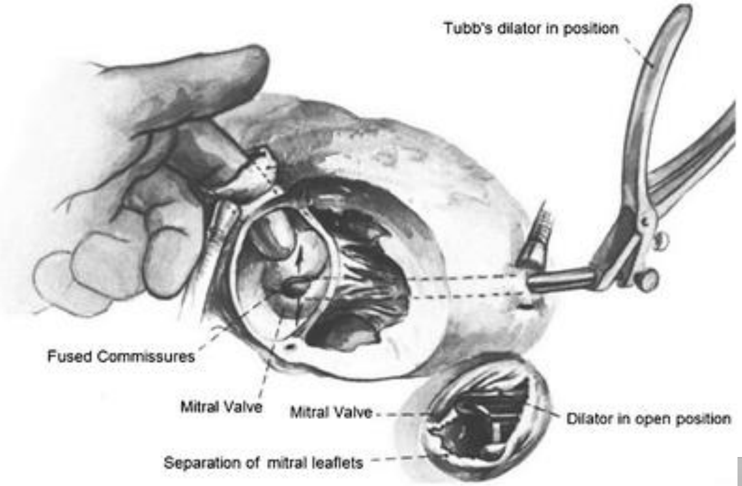
1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986

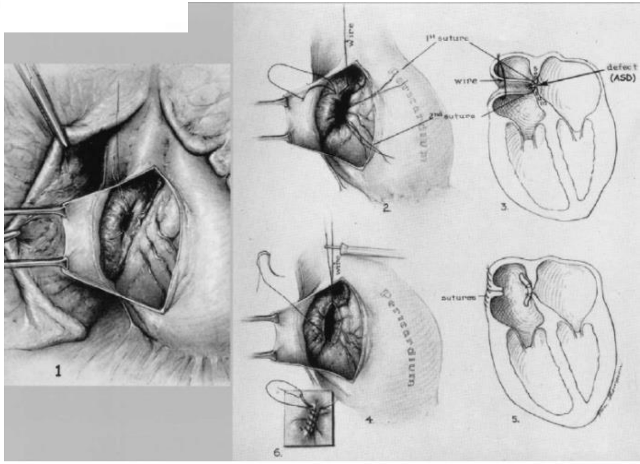


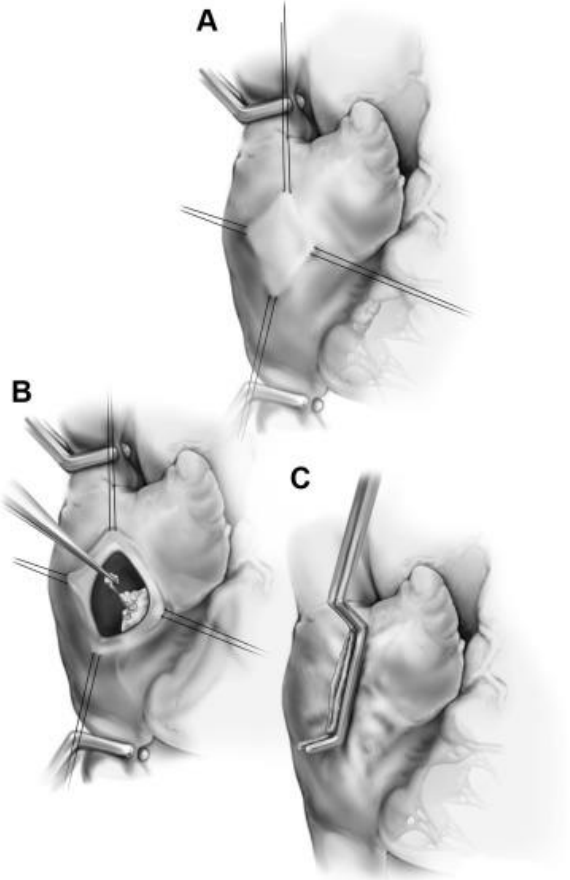
# Early Intracardiac Operations



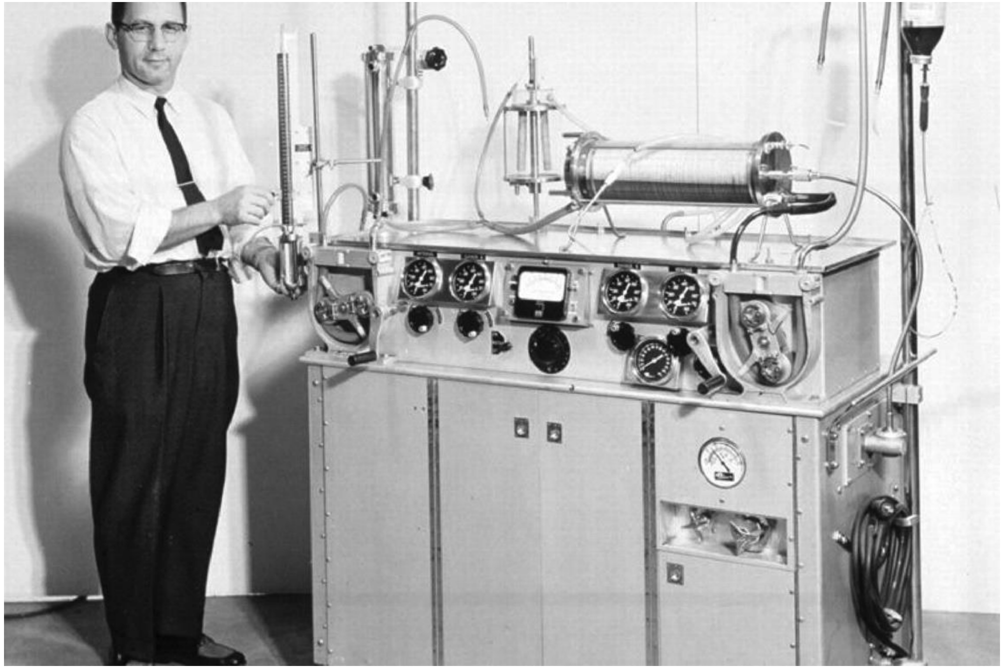
# Inflow Occlusion and Hypothermia



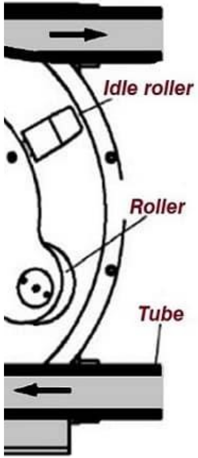
# Cardiopulmonary Bypass

## The Problems:

- Anticoagulation
- Reversal agent
- A Pump
- Oxygenator



# Pumps



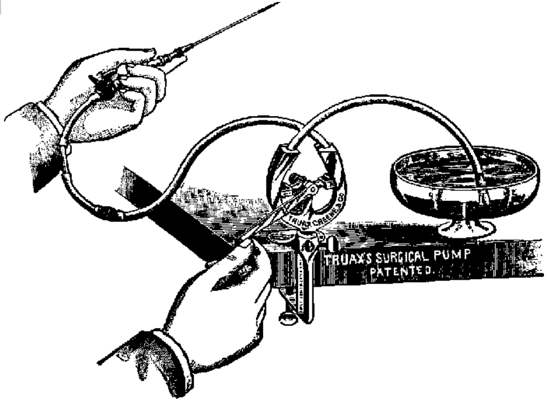



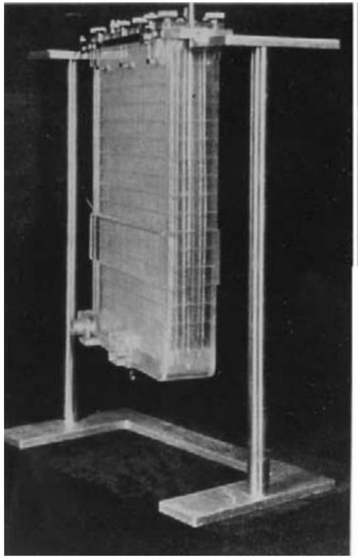

**Figure 5.** *"Author's Surgical Pump (The improved Allen)"* (22). The first

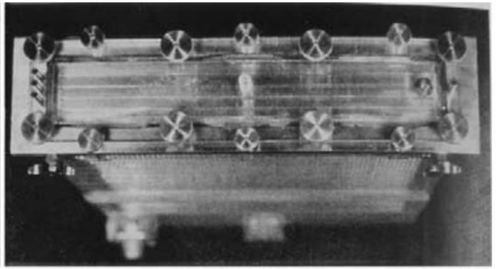
Children's Hospital LOS ANGELES | USC University of Southern California

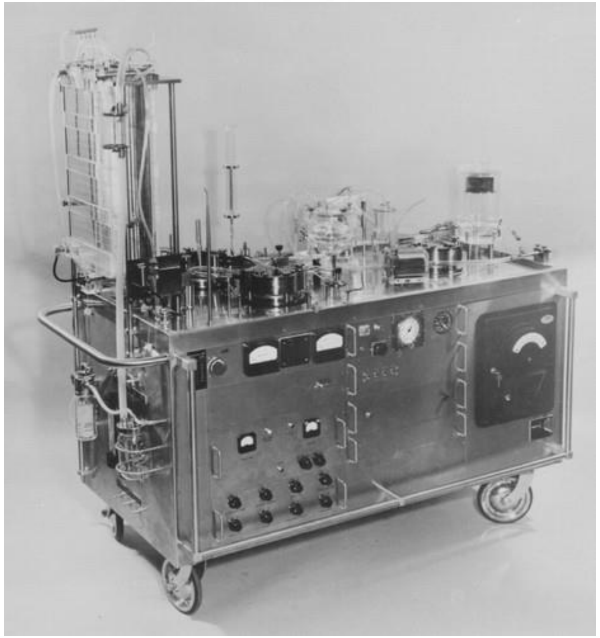
# Screen Oxygenator

## The Problems:

- Large Blood Prime
- Large Surface Area
- Clotting Issues
- Massive Air Interface
- Air Embolism



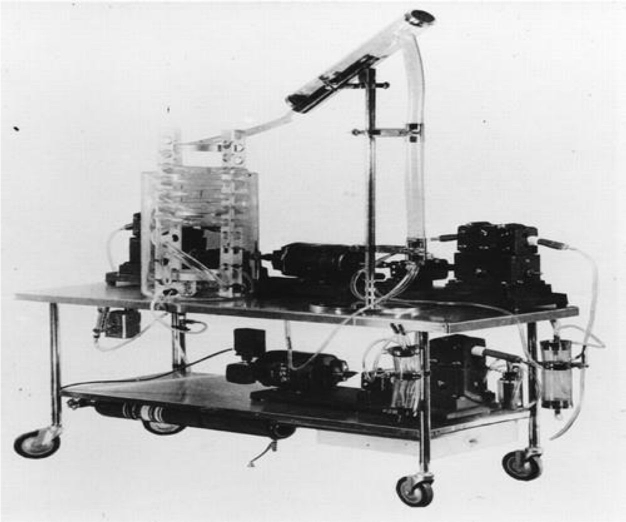


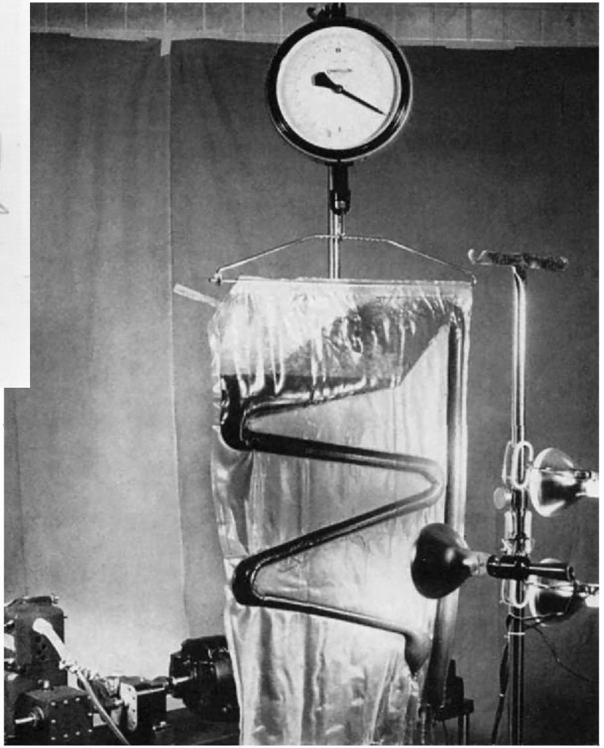


# Bubble Oxygenator

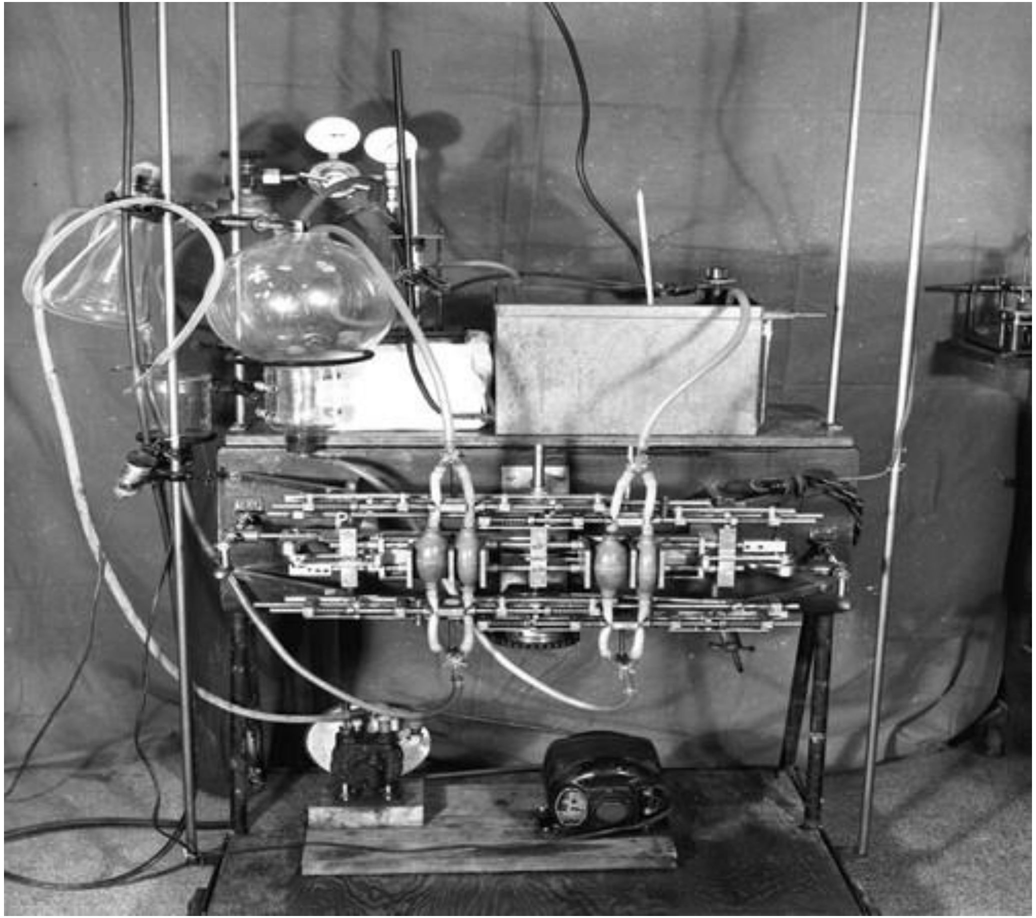
## The Problems:

- Large Blood Prime
- Large Surface Area
- Clotting Issues
- Massive Air Interface
- Air Embolism

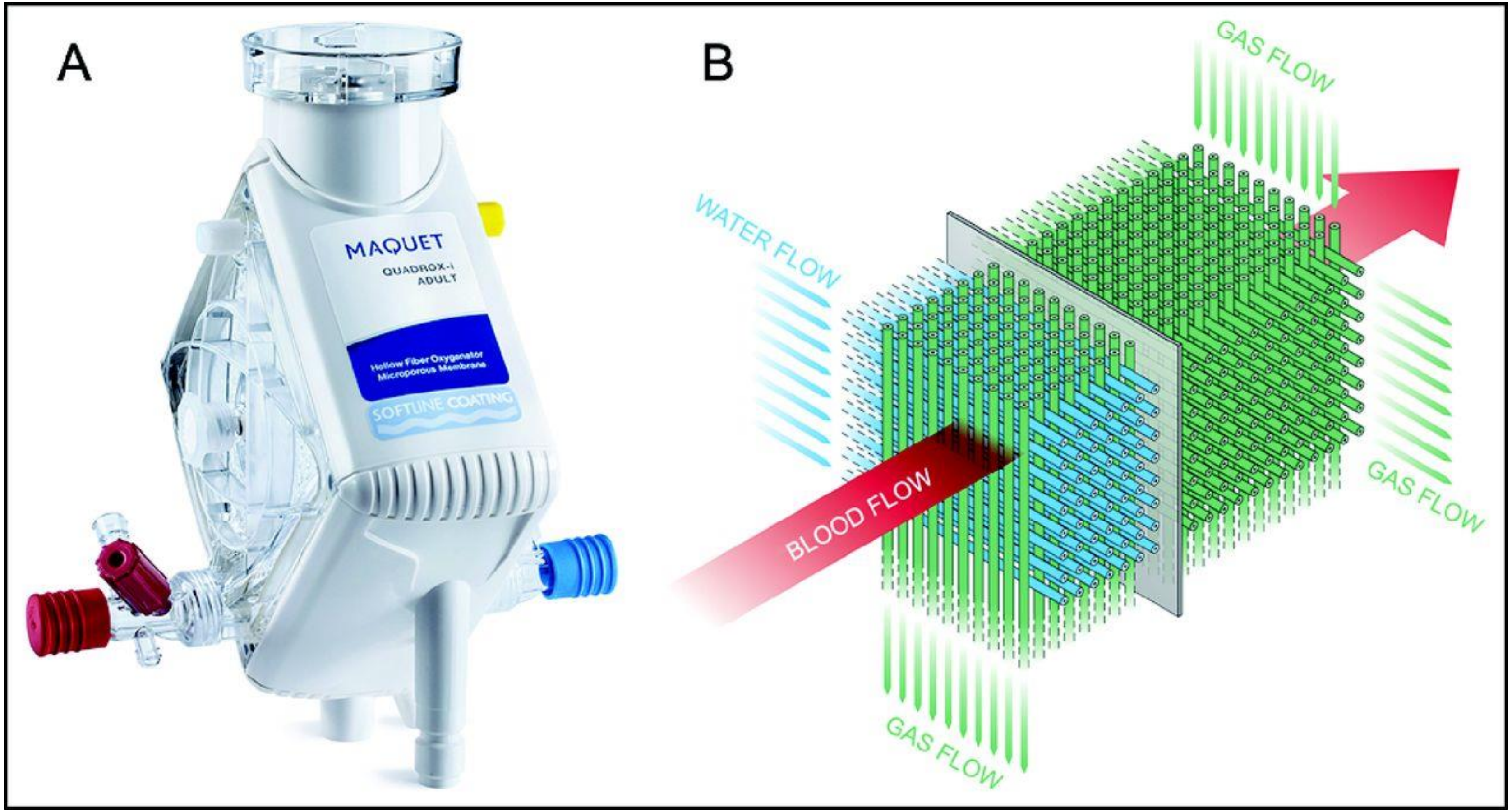




# Monkey Lung Oxygenator



# Membrane Oxygenator

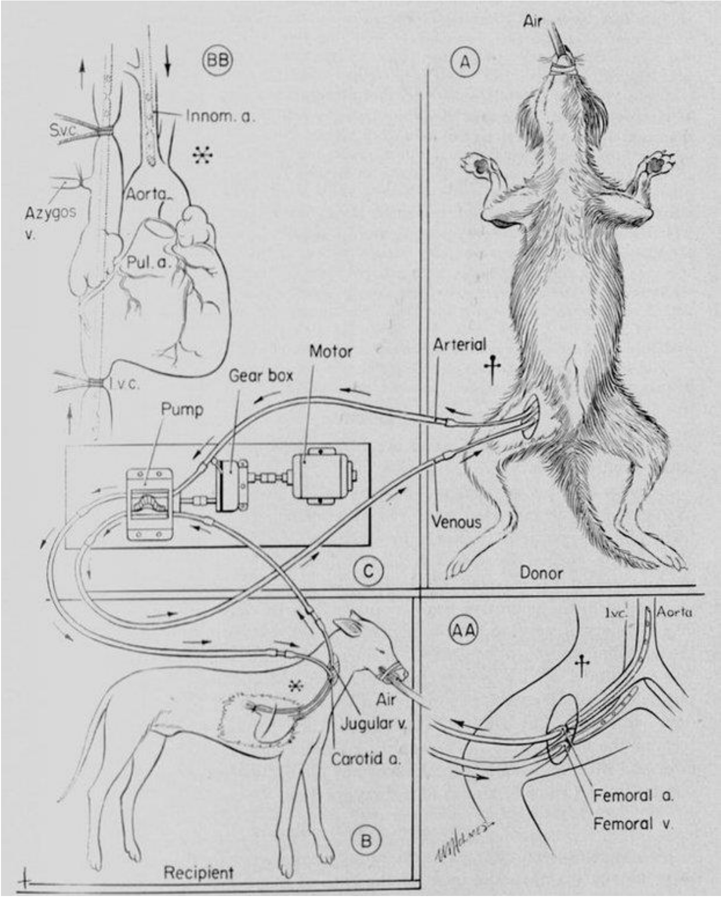


# Outcomes of Pediatric Cardiac Surgery

*Table 1. Early Attempts at Open-Heart Surgery With a Heart-Lung Machine*

| Name | Year | No. | Outcome |
|---|---|---|---|
| Dennis | 1952 | 2/2 | Died |
| Gibbon | 1953 | 5/6 | Died |
| Helmsworth | 1953 | 1/1 | Died |
| Dodrill | 1953 | 2/2 | Died |
| Clowes | 1954 | 2/2 | Died |
| Mustard | 1954 | 5/5 | Died |
| | Total | 17/18 (94.5%) | Died |

# Cross Circulation



# Cross Circulation

TABLE II. DIRECT VISION INTRACARDIAC SURGERY
CROSS CIRCULATION - 45 PATIENTS
March 26, 1954 - July 19, 1955*

| Pathology | Corrective Operation | No. Cases | Deaths |
|---|---|---|---|
| Ventricular Septal Defect | Suture Closure of Defect | 27+ | 8 |
| Patent Ductus | Exploratory Ventriculotomy Division of Ductus | 1 | 0 |
| Tetralogy of Fallot | Suture Closure of VSD and Resection of Infundibular Stenosis | 10 | 4 |
| Atrioventricularis Communis | Closure of Atrial and Ventricular Defects, Correction Valvar Deformities | 5 | 4# |
| Isolated Infundibular Pulmonic Stenosis | Resection of Infundibulum | 1 | 0 |
| Pulmonary Stenosis Plus IASD and Anomalous Pulmonary Drainage | Ventricular and Atrial Cardiotomies, Transposition of Pulmonary Veins | 1 | 1 |

*Cross circulation was used exclusively from 3/26/54 through Feb. 1955. Beginning 3/1/55 other bypass methods (bubble oxygenators, dog lung oxygenator, arterial reservoir) were utilized for lower risk patients. Cross circulation was reserved for high risks. By mid-summer 1955, the bubble oxygenator became the sole method.

+Of the 19 patients who survived ventricular septal defect closure, 10 were under 2 yrs of age, 7 under one year, and 4 were less than 6 mos of age at operation. Sixteen of the 19 survivors were recatheterized and in 12 there was no shunt. Four patients had a residual shunt and in 3 the postoperative pulmonary pressures were normal indicating that the residual shunts were small[20].

#Two late deaths due to mitral insufficiency.

# The Era of Cardiopulmonary Bypass

*Table 4. Hospital Mortality According to Age and Years*

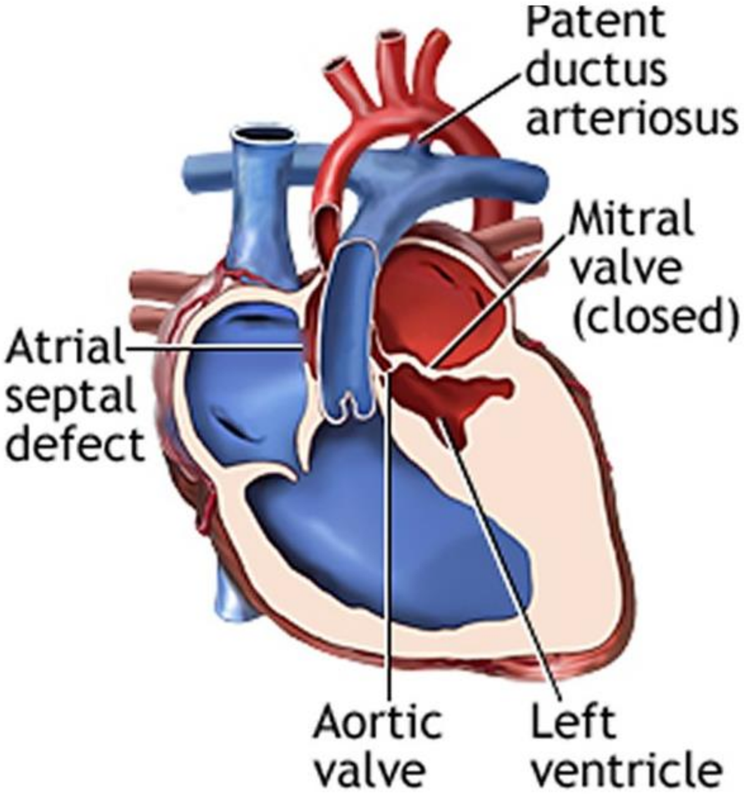
| | Hospital Mortality | |
|---|---|---|
| Age (yrs) | 1954–1960 | 1995–2000 |
| <1 | 4% | |
| 1 < 5 | 21% | |
| 5 < 12 | 20% | |
| >12 | 24% | |

# Modern Mortality Rates

| Year | STAT Category 1 (%) | STAT Category 2 (%) | STAT Category 3 (%) | STAT Category 4 (%) | STAT Category 5 (%) |
|---|---|---|---|---|---|
| 1998 | 0.9 | 3.5 | 7.4 | 13.9 | 44.4 |
| 1999 | 1.2 | 2.2 | 5.3 | 14.1 | 20.6 |
| 2000 | 0.4 | 2.3 | 1.4 | 6.6 | 29.6 |
| 2001 | 1.1 | 1.5 | 2.4 | 9.1 | 25.1 |
| 2002 | 0.8 | 2.0 | 3.0 | 10.9 | 29.5 |
| 2003 | 0.5 | 1.6 | 3.2 | 7.8 | 22.3 |
| 2004 | 0.7 | 1.6 | 3.2 | 7.5 | 15.6 |
| 2005 | 0.6 | 1.6 | 2.9 | 8.2 | 17.8 |
| 2006 | 0.7 | 1.7 | 2.6 | 7.7 | 18.9 |
| 2007 | 0.5 | 2.0 | 3.4 | 8.1 | 18.1 |
| 2008 | 0.7 | 1.7 | 2.4 | 7.9 | 17.4 |
| 2009 | 0.5 | 1.5 | 2.4 | 7.1 | 16.7 |
| 2010 | 0.8 | 1.7 | 2.6 | 7.0 | 16.9 |
| 2011 | 0.7 | 1.4 | 2.4 | 7.0 | 18.0 |
| 2012 | 0.6 | 1.4 | 2.6 | 6.6 | 15.3 |
| 2013 | 0.4 | 1.2 | 2.3 | 6.6 | 15.2 |
| 2014 | 0.3 | 1.6 | 1.6 | 5.8 | 11.9 |
| 2015–2019* | 0.4 | 1.4 | 2.2 | 6.2 | 13.3 |
| 2016–2020* | 0.4 | 1.5 | 2.3 | 6.3** | 13.6** |

# Case Study: Hypoplastic Left Heart Syndrome

- Uniformly fatal before 1983
- Invention of Norwood Procedure
- "The First Twenty"



# Plateauing Results

| Era | Years | Mortality |
|---|---|---|
| 1 | 1984-1988 | 40.4% |
| 2 | 1989-1993 | 33.6% |
| 3 | 1994-1998 | 28.7% |
| 4 | 1999-2003 | 14.9%* |
| 5 | 2004-2008 | 11.2%* |
| 6 | 2009-2013 | 15.7%* |

*$P < .03$ compared with eras 1 to 3.

# Transitioning from Present→Future

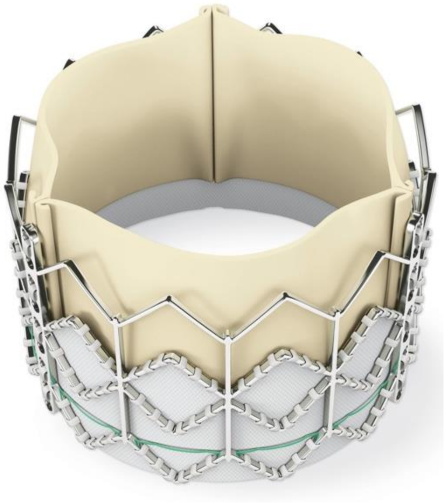
- The large barriers to entry have been addressed
- Reduction in mortality where it can be avoided
  - Refinement in technique
  - Refinement of technology
  - Streamlining processes
  - Protocolization
  - Etc….
- The Focus of the PAST and PRESENT was Mortality
- The Future <u>MUST</u> Focus on Quality of Life
- The Future <u>REQUIRES</u> Paradigm Shifts

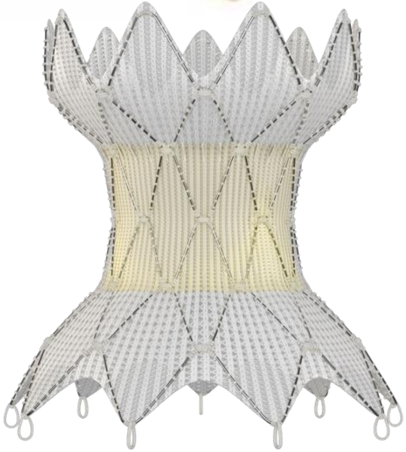
# Quality of Life

- Reduction in Interventions
- Reduction in deleterious effects from CHD and its treatments
- Minimize residual lesions
- Maximize cardiac output
- Improve Neurodevelopmental Outcomes

Children's Hospital LOS ANGELES | USC University of Southern California

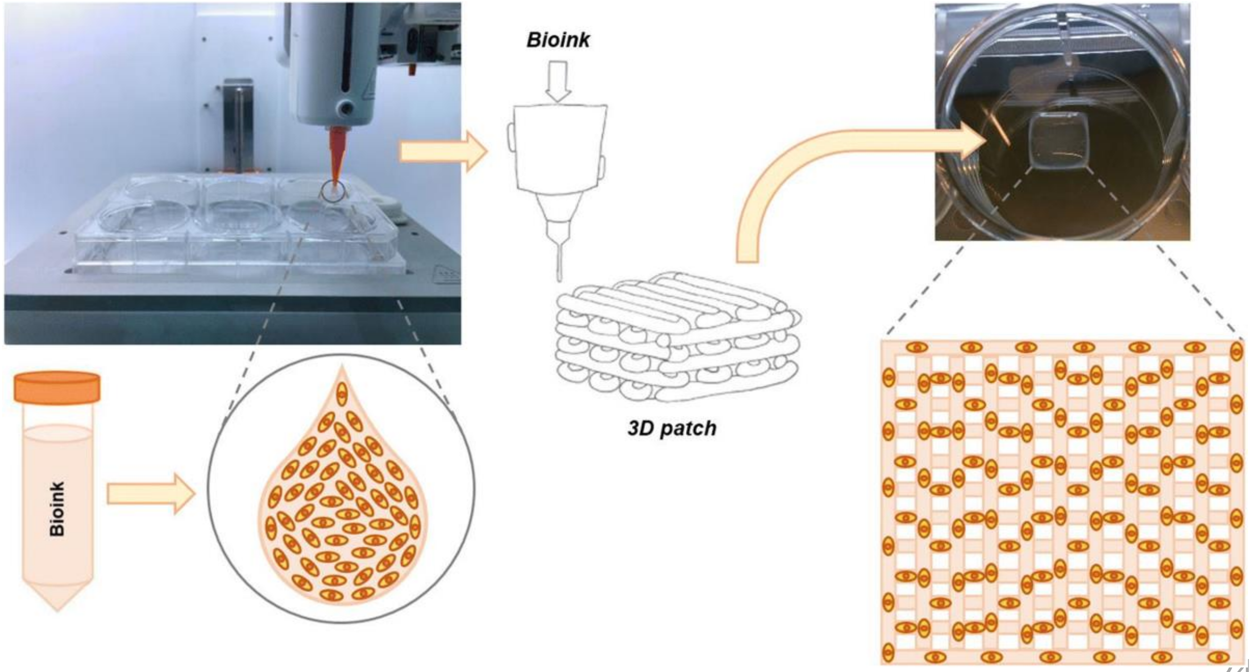
# Novel Valves





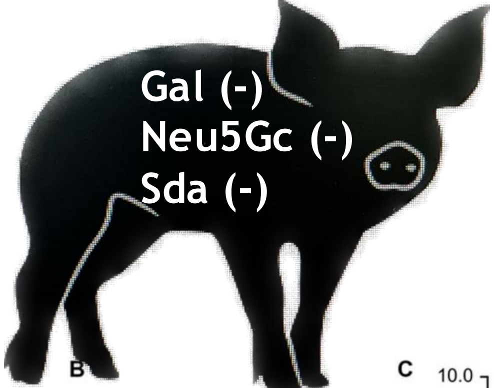
# Novel Tissue

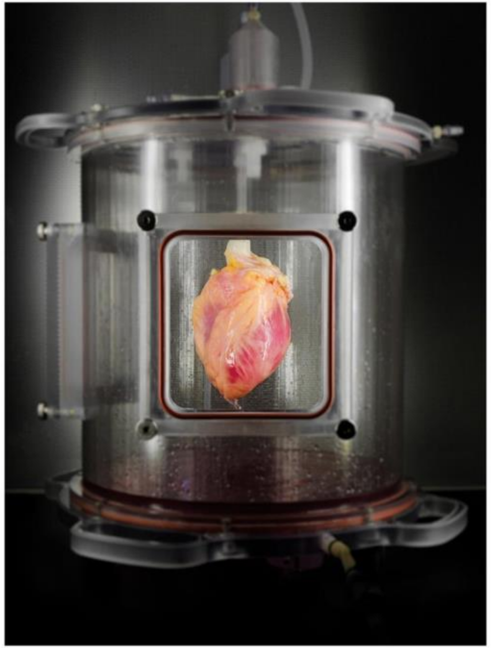
- In Vitro Culture and Growth
- Populating Human Scaffolding
- 3-D Printing?

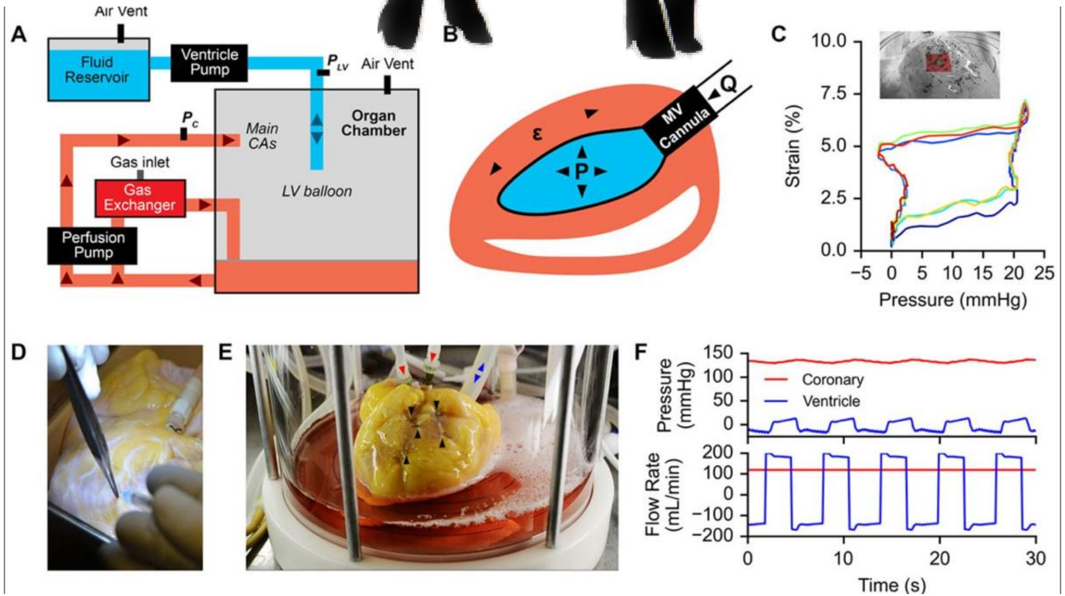


# Cardiac Transplant

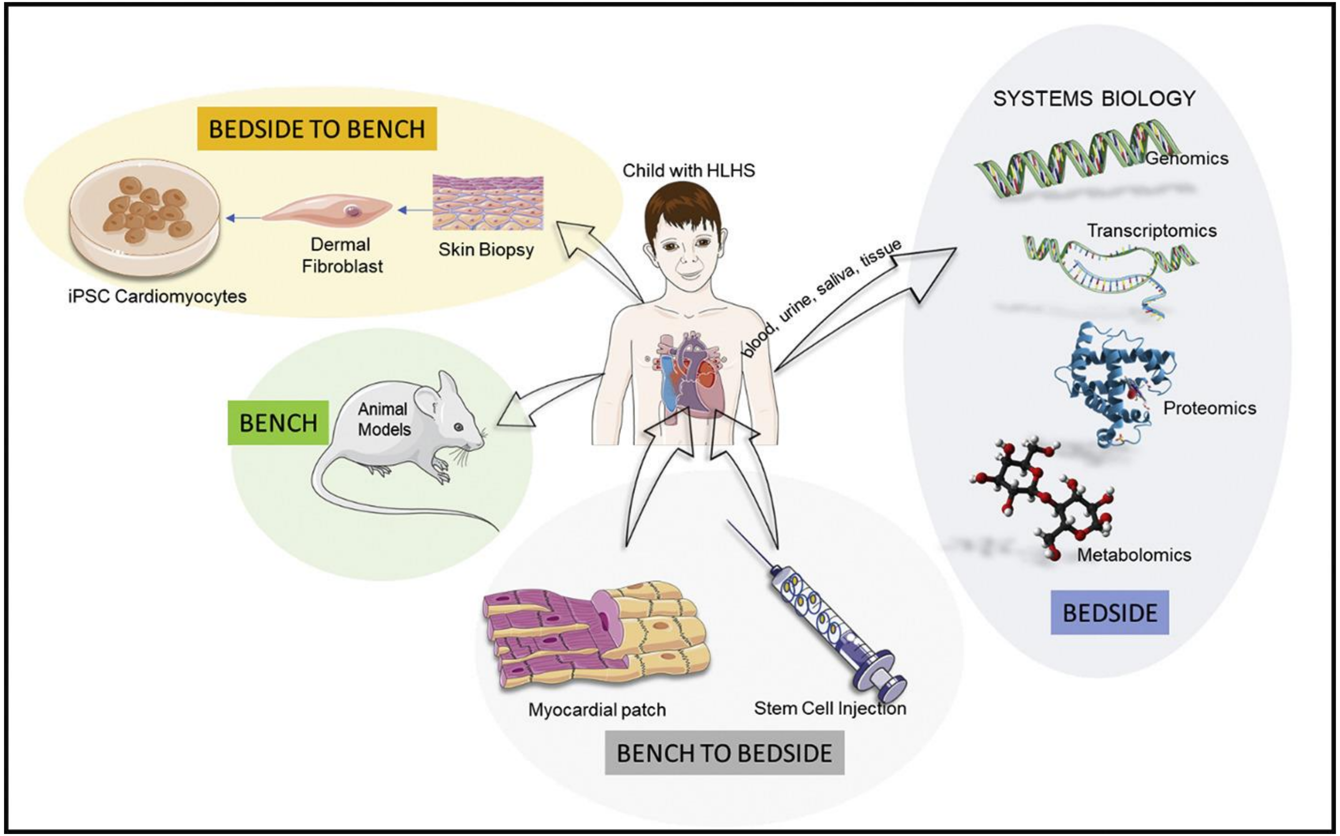
- Xenotransplantation
- Bioengineered Human Hearts





# Regenerative Technologies



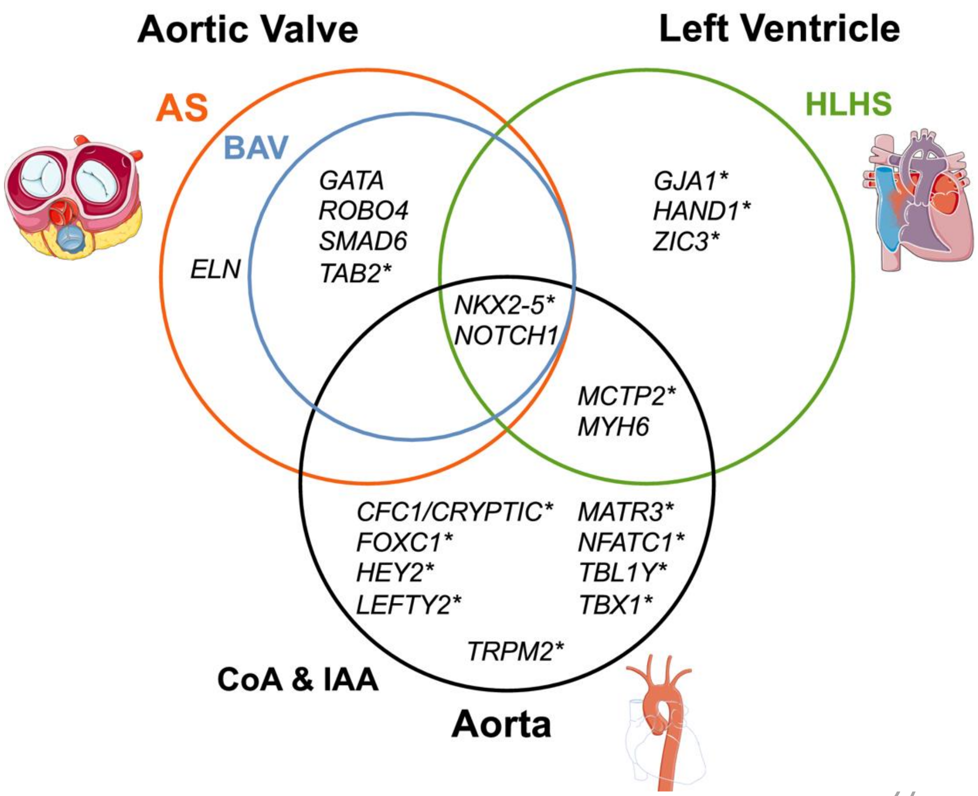
# Stop the Problem Before It Starts

1. Understanding the genetic basis for disease

2. Identifying targets for intervention

3. Identifying timing for intervention

4. Possessing the technology to safely intervene



# QUESTIONS & DISCUSSION