Overview of Advanced Mechanical Circulatory Support and Heart Transplantation

Bruce B Reid, MD  Surgical Director
Artificial Heart Program/Heart Transplantation
Embracing Progress

The Evolution of Communication

First Written Word
Movable Type
Mass Publication
Email
Twitter

140 Characters. What more is there to say?
Tweet Tweet
Early Milestones in Cardiac Surgery
“A surgeon who tries to suture heart wounds deserves to lose the esteem of his colleagues.”

Theodor Billroth (1829 – 1894)
Closed Mitral Commissurotomy
Alfred T. Blalock, MD
1899-1964
Johns Hopkins
Helen B. Taussig, MD
Helen B. Taussig, MD
1898 - 1986

Johns Hopkins University
Helen B. Taussig, MD
1898 - 1986

Children with Tetralogy of Fallot exhibit bluish skin during episodes of crying or feeding.

"Tet spell"

Tetralogy of Fallot
Four abnormalities that result in insufficiently oxygenated blood pumped to the body:

1. Narrowing of the pulmonary valve
2. Thickening of wall of right ventricle
3. Displacement of aorta over ventricular septal defect
4. Ventricular septal defect opening between the left and right ventricles
Blalock A, Taussig HB:

The surgical treatment of malformations of the heart in which there is pulmonary stenosis or pulmonary atresia.

JAMA 1945; 128:189
Vivien Thomas
First Blalock-Taussig Shunt 1944
OPERATION: Nov. 23, 1944
Dr. Alfred Glidock
Ether - Oxygen - Dr. Harrel

ANASTOMOSIS OF LEFT PULMONARY ARTERY TO LEFT SUBCLAVIAN ARTERY

This patient was an undernourished child who had cyanosis on frequent occasions. The diagnosis was pulmonary stenosis.

Under ether and oxygen, administered by the open method, an incision was made in the left chest extending from the edge of the sternum to the axillary line in the third intercostal. The second and third costal cartilages were divided. The pleural cavity was entered. The left lung looked normal. No thrill was felt in palpating the heart and pulmonary artery. The left pulmonary artery was identified and was dissected free of the neighboring tissues. The left pulmonary artery seemed to be of normal size. The superior pulmonary vein, on the other hand, seemed considerably smaller than normal to me. I had hoped that the artery to the left upper lobe might be sufficiently large to allow an anastomosis, but this did not appear to be the case. The left subclavian artery was then identified and was dissected free of the neighboring tissues. The vertebral artery and the branches of the thyrocervical axis were doubly ligated and divided. The subclavian was so short that there would not have been sufficient length for our purposes, had this not been done. The subclavian artery was then ligated distal to the thyrocervical trunk. A bulldog clip was placed on the subclavian artery at a point just distal to its origin from the aorta. The subclavian artery was then divided just proximal to the ligation. Two bulldog clips were then placed on the left pulmonary artery, the first clip being placed at the origin of the left pulmonary artery and the second clip being placed just proximal to the point where the artery entered the lung. There was ample space between these two clips for our purpose. A small transverse incision was then made in the wall of the pulmonary artery. By the use of clamps around each on fine needles, an anastomosis was then performed between the end of the subclavian artery and the side of the left pulmonary artery. A posterior row of sutures was placed first. There was practically no bleeding following the removal of the bulldog clips.

The anastomosis seemed to be a satisfactory one, and the main point of worry comes from the small size of the left subclavian artery. I was disturbed because I could not feel a thrill in the pulmonary artery after the clips were removed. I do not believe that this was due to any clot in the subclavian artery, because it seemed to pulsate vigorously. It is possible that it was due to a low pressure in the systemic circulation. I do not actually know what the systemic pressure was. Another possibility was that it might have been due to spasm of the subclavian artery. My only regret was that the subclavian artery was not bigger. It is possible that the increased red cell count in this patient may have predisposed to thrombosis.

(over)
Surgical Pioneers

Dr. Alfred Blalock

Vivien Thomas

PHOTOS BY BY THE ALAN MASON CHESNEY MEDICAL ARCHIVES OF THE JOHNS HOPKINS MEDICAL INSTITUTIONS
Blue Babies

How 2 Doctors Give New Lives To Blue Babies
Blakemore-Tennison Operation, First Tried on Dogs, Restores Flow of Blood

By Lester Grant

Baltimore, Feb. 13.—In the story of the work of two doctors—a man from Georgia and a woman from Massachusetts—who

restored the life of a baby, have

formed a bond to save the lives of

"blue babies."

The doctors are Alfred Blakemore, forty-six, surgeon in chief at Johns Hopkins Hospital, and Helen B. Tennison, thirty-four, who have

been brought to the attention of the medical world by the

treatment of a baby with the disease known as "blue babies."

The baby, born in the Blakemore-Tennison operation, was the first operation of its kind in the

world, and it was performed under the guidance of Dr. Blakemore at Johns Hopkins Hospital.

The operation involved the insertion of a tube into the heart of the baby, through which oxygen

was pumped into the bloodstream. The baby was then observed for several weeks, and the

results were considered to be successful.

The doctors have now begun to perform the same operation on other babies with similar

conditions, and they hope to be able to save the lives of many more children in the future.

The operation is still in the experimental stage, and more research will be required before it

can be considered a standard treatment.

Dr. Blakemore and Dr. Tennison are the leaders in this new field of medicine, and they

are expected to make many more contributions in the future.

The success of the operation has been hailed by medical experts, who have praised the

bravery and dedication of the doctors involved. The public has also been quick to express its

appreciation of the work being done by these two individuals.

The doctors have been tireless in their efforts to save the lives of these innocent children,

and their work is a testament to the power of love and compassion. They have shown that

even in the face of seemingly insurmountable odds, it is possible to save lives and make the

world a better place.

Intermountain Heart Institute
Intermountain Medical Center
Blalock and Taussig in London
Legacy to Children
The left subclavian artery is divided and connected to the left pulmonary artery. This allows blood to flow to the lungs to pick up oxygen.

© 2004 - Duplication not permitted
Donor
Cross Circulation
Lillehei CW, Cohen M, Warden HE, et al

The results of direct vision closure of ventricular septal defects in eight patients by means of controlled cross circulation.

Surg Gynecol Obstet 1955; 101:446
Pioneer in the development of extracorporeal circulation
Massive Pulmonary Embolus
Early Heart Lung Machine
Nothing so conclusively proves a man's ability to lead others as what he does from day to day to lead himself.

Thomas J. Watson Sr., Founder, IBM
“Our work is one of service.”

--Thomas J. Watson, Sr
May 16, 1953

Thomas Jefferson University

First successful open heart surgery using cardiopulmonary bypass
Science Unveils Machine That Acts As Both Heart and Lungs of Humans

Philadelphia (AP) — A machine that functioned as both heart and lungs of a human being for the first time in medical history was unveiled yesterday by surgeons at Jefferson Medical College Hospital.

Invented by Dr. John H. Gibbon Jr., director of surgical research at the college, the machine was shown to newsmen yesterday with the announcement that it had performed the combined functions of both organs while surgeons closed an abnormal opening in the wall of a patient's heart.

The operation was performed Wednesday on Miss Cecelia Bavolek, of Swoyersville, Pa., 18-year-old student at Wilkes College in Wilkes-Barre, Pa.

For years the girl had suffered large opening between the auricles causing the trouble. Dr. Gibbon said the opening "about the size of a half dollar" meant that a large portion of her blood was continuously being recirculated through her lungs. Only a small part of it was pumped through the remainder of her body, causing a condition known as circular septal defect which deprives the muscles and bones of the body of their normal nourishment.

Dr. Gibbon described the operation in this way:

The patient's heart was opened and the abnormal opening closed. The surgeons placed tubes in the two big veins leading to the heart and another in the artery in the chest. The tubes in the veins were connected to pumps which drew the blood out and circulated it...
Heart Lung Machine
Modern Cardiopulmonary Bypass
Heart Transplantation

• “Thus saith the Lord God, ‘A new heart also will I give you, and a new spirit will I put within you; and I will take away the stony heart out of your flesh, and I will give you an heart of flesh.’”

• Ezekial, chapter 36, verse 26
Moments in History

In December, 1967, a young woman, Denise Darvell, was walking across a street in Woodstock to buy a cake when a car struck her. She died in Groote Schuur Hospital and in doing so achieved immortality by becoming the world’s first heart donor when Christian Neethling Barnard transferred her heart into the chest of Louis Washkansky.

Cape Town has been witness to many historic moments since the day Van Riebeeck anchored in Table Bay. Few, if any, brought more limelight to the city than the heart transplant. For the surgeon, Dr. Barnard, soon to be a household name throughout the world, “the heart is merely a pump”. But for those who equated the heart with love and death, the transplant seemed close to a miracle.

“Mr. Louis Washkansky, the 55-year-old Cape Town man whose life is being sustained today by the heart of a dead 23-year-old woman after the world’s first successful heart transplant yesterday, is conscious in Groote Schuur Hospital and in a satisfactory condition.” Monday, 4th December 1967
Christiaan N. Barnard, MD
First Transplant in US 1968
“OK, the old one’s in my right hand, the donor’s in my left. Right?”
Heart Transplantation

• First performed in 1967—clinically useful in the early 80s
• Inherent limitations—lack of donors
• ~2000 transplants per year; 3200 listed (many patients die on the waiting list)
• 15-20 transplants at IMC per year
• The majority of transplant recipients in the modern era are “bridged” to the procedure with an LVAD
Heart Transplants Reported per Year

NOTE: This figure includes only the heart transplants that are reported to the ISHLT Transplant Registry. As such, the presented data may not mirror the changes in the number of heart transplants performed worldwide.
Kaplan-Meier Survival by Era
(Transplants: January 1982 - June 2010)

1982-1992 vs. 1993-2002: p < 0.0001
1982-1992 vs. 2003-6/2010: p < 0.0001
1993-2002 vs. 2003-6/2010: p < 0.0001


ISHLT 2012
Cumulative Prevalence in **Survivors** at 1, 5 and 10 Years Post-Transplant (Follow-ups: April 1994 - June 2009)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Within 1 Year</th>
<th>Total N with known response</th>
<th>Within 5 Years</th>
<th>Total N with known response</th>
<th>Within 10 Years</th>
<th>Total N with known response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension</td>
<td>73.2%</td>
<td>(N = 24,229)</td>
<td>93.1%</td>
<td>(N = 10,485)</td>
<td>97.4%</td>
<td>(N = 2,238)</td>
</tr>
<tr>
<td>Renal Dysfunction</td>
<td>26.8%</td>
<td>(N = 25,254)</td>
<td>31.1%</td>
<td>(N = 12,146)</td>
<td>36.8%</td>
<td>(N = 3,681)</td>
</tr>
<tr>
<td>Abnormal Creatinine &lt; 2.5 mg/dl</td>
<td>18.1%</td>
<td>7.0%</td>
<td>21.0%</td>
<td>7.3%</td>
<td>24.3%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Creatinine &gt; 2.5 mg/dl</td>
<td>7.0%</td>
<td>0.3%</td>
<td>7.3%</td>
<td>0.5%</td>
<td>6.2%</td>
<td></td>
</tr>
<tr>
<td>Chronic Dialysis</td>
<td>1.5%</td>
<td></td>
<td>2.3%</td>
<td></td>
<td>4.8%</td>
<td></td>
</tr>
<tr>
<td>Renal Transplant</td>
<td>0.3%</td>
<td></td>
<td>0.5%</td>
<td></td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>58.1%</td>
<td>(N = 25,572)</td>
<td>87.8%</td>
<td>(N = 11,800)</td>
<td>93.3%</td>
<td>(N = 2,659)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>27.4%</td>
<td>(N = 25,292)</td>
<td>36.6%</td>
<td>(N = 11,154)</td>
<td>38.5%</td>
<td>(N = 2,401)</td>
</tr>
<tr>
<td>Cardiac Allograft Vasculopathy</td>
<td>7.8%</td>
<td>(N = 22,853)</td>
<td>31.0%</td>
<td>(N = 8,197)</td>
<td>51.8%</td>
<td>(N = 1,830)</td>
</tr>
</tbody>
</table>
“Your insurance won’t pay to transplant a human heart or even a baboon heart, so we’ll be using an artichoke heart.”
Lisa waits for a heart

50,000 Americans need new hearts. Most will never get one. Who lives? Who dies?

A special report
The Magnitude of CHF

- 6 million suffer from heart failure: 550,000 new cases per year
- Only form of heart disease increasing in prevalence
- 262,000 deaths per year
- Incidence doubles each decade after 40
- 1 in 5 over age 40 have heart failure
- One year mortality is 28% in men over 75
- Most common cause of hospitalization in patients over 65
Economic Impact of CHF

- Annual cost of $30 billion in U.S.
- Most costly diagnosis in the Medicare population
- More costly than all forms of cancer combined
- 11 million office visits; 3.5 million hospitalizations
- Average total annual cost in Utah of $46 million dollars (79% paid for by the government)*
- $19,843 per hospitalization in Utah*

*Utah Department of Health
Coronary deaths are down by half

But heart failure has almost tripled

Enhanced survival in other CV diseases leads to expansion of HF Population

Source: National Hospital Discharge Survey data. Centers for Disease Control and Prevention/National Center for Health Statistics and National Heart, Lung, and Blood Institute.
NYHA CLASS

- Class I
- Class II
- Class III
- Class IV

Adapted from Bristow, MR Management of Heart Failure, Heart Disease: A Textbook of Cardiovascular Medicine, 6th edition, ed. Braunwald et al.
1969 - first artificial heart to be implanted into a human (Dr. Denton Cooley).

The patient was sustained by the device for 3 days, but only lived for 36 hours post transplantation.

The patient’s widow accused Cooley of making her husband the “unfortunate victim of human experimentation.”
1982 – Barney Clarke with Mrs. Clarke after his initial recovery.
Jarvik, DeVries and Kolff examine Clarke’s artificial heart after autopsy.
Total Artificial Heart
REMATCH Summary

- NEJM November 2001
- LVAD vs. optimal medical management
- LDS Hospital - largest enrollment in the country
- Landmark trial leading to FDA approval
- 129 patients with NYHA Class IV CHF ineligible for transplant
- 48% risk reduction of death with LVAD
- 52% vs. 25% survival at 1 year
- 24% vs. 8% survival at 2 years
- Improved quality of life (LVAD patients felt better, less depressed, more mobile and active)
TRIAL SUMMARY:

- Total of 200 patients
- Median age of 62 years (range 26 to 81)
- Mean LVEF of 17%
- 77% of patients receiving IV inotropes
- 2:1 Randomization HM II vs. HM XVE (stopped at mid-study point due to favorable results)
- All 200 patients were followed for at least 2 years or until death, transplantation or device explantation
- QOL improvement to NYHA Class I - II
<table>
<thead>
<tr>
<th></th>
<th>HM II</th>
<th>HM XVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival @ 2 years</td>
<td>58%</td>
<td>24%</td>
</tr>
<tr>
<td>Median duration of support</td>
<td>1.7 years</td>
<td>0.6 years</td>
</tr>
<tr>
<td>Relative Risk (95% CI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device repair or replacement</td>
<td>0.06</td>
<td>0.51</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.13</td>
<td>0.22</td>
</tr>
<tr>
<td>LVAD-related infection</td>
<td>0.48</td>
<td>0.90</td>
</tr>
<tr>
<td>Bleeding requiring surgery</td>
<td>0.23</td>
<td>0.29</td>
</tr>
<tr>
<td>Rehospitalization</td>
<td>2.64</td>
<td>4.25</td>
</tr>
</tbody>
</table>
Former Vice President Dick Cheney

- HeartMate II implant August 10, 2010 as BTT
- 1.5 years of support
- Successful bridge to transplant
- Age 70

“It’s brought me back from end-stage heart failure,” says Cheney, who has suffered five heart attacks, the first at age 37. “I was in bad shape 14 months ago. Now I’m back to leading a relatively normal life. I fish, hunt a little bit, write books, (am) able to travel.”
An increasing percentage of patients listed for cardiac transplantation require VAD support as a bridge.

**OUTCOMES AT OUR CENTER:**
HM II Survival to Transplant: 100%
Bridge to Transplantation (BTT)

- **2011**: 60% Bridge requiring VAD/Artificial Heart, 40% Traditional Transplantation
- **2012**: 57% Bridge requiring VAD/Artificial Heart, 43% Traditional Transplantation
- **2013**: 21% Bridge requiring VAD/Artificial Heart, 79% Traditional Transplantation
- **2014**: 18% Bridge requiring VAD/Artificial Heart, 82% Traditional Transplantation

Recent transition to HeartWare HVAD with excellent outcomes as bridge.
Mechanical Circulatory Support

**Short Term / Emergency**
- Time frame: hours to days
- Rapid MCS for cardiogenic shock, post cardiotomy failure, or during high-risk Cath Lab procedures

**Bridge to Transplant (BTT)**
- Time frame: months to years
- Temporary implanted MCS for patients waiting for a donor heart to become available

**Destination Therapy (DT)**
- Time frame: Permanent (years)
- Long-term implanted MCS for patients who are not eligible for a heart transplant
HeartWare HVAD™

- Centrifugal pump
- One moving part
- Short integrated inflow cannula
- 10mm outflow graft
- Dual motor stators
- Thin, flexible driveline
- Sewing ring
HeartWare HVAD

- Inflow cannula integrated with device
- Small pump housing: 2 inch outside diameter, displaced volume of 50 cc
- Magnetically suspended impeller, only moving part (increased durability potential)
- Intrapericardial – no pump pocket
- Requires warfarin (INR: 2.0 - 2.5)
- Approved for use in Europe
- Destination Therapy clinical trial in U.S. (ENDURANCE)
- UAHP: 43 implants to date
Unique Features

- No abdominal surgery or pump pocket
- Fits in the pericardial space
- Anatomically fits smaller patients
- Less surgery; potentially minimizes blood transfusions
- Novel impeller design enables excellent hemodynamics
- Accurate flow estimation
- Log files enable flow and power waveform analysis
Interior of pump shown after 427 days of support in human patient

**IMPELLER**

- Impeller only moving part
- Completely suspended by a combination of passive magnets and hydrodynamic thrust bearings
- Never touches pump housing

**PUMP HOUSING**
MCS Case Review

• 68 year male with 12 year history of IDC
• Sudden death in August 2009
• Discharged with BiV ICD
• Progressive deterioration to class III/IV
• Multiple hospitalizations over the following year
• Outpatient dobutamine
• Multidisciplinary review to assess candidacy for DT LVAD
• Enrolled in ENDURANCE trial—randomized to receive the HeartWare HVAD
• 3rd HVAD implant in the United States for DT
Postoperative Day #1
3 months later...
Adoption of Technology

CONSUMPTION SPREADS FASTER TODAY

Intermountain Heart Institute
Intermountain Medical Center
Technology Adoption

Innovators

Early Adopters

Early Majority

Late Majority

Laggards

"The Chasm"

Technology Adoption Lifecycle

Area under the curve represents number of customers
Automobile
Automobile
Automobile

• Ford Model T
• 1908 – 1927
• First affordable automobile
• Mass production
• Moving assembly line: every three minutes
• 20 horsepower 1.7 L 4 cylinder engine
• Top speed ~40 mph
Automobile

- Most influential car of the 20th Century
- Widespread adoption worldwide
- 50% of all cars in 1920
- 1909: 10,666 produced and sold for $825 ($21,650 in 2015)
- 1925: 1.9 million sold for $260 ($3,500 today)
Aviation
Life Expectancy – Pancreatic Cancer

• Best case scenario
  – Node negative
  – Clear margins at surgical resection (Whipple)

• 20% survival at 5 years for Stage I

• 10% survival at 1 year for all stages
Who and When?

Class III
- 25% of HF Patients
- Frequent hospitalizations
- Worsening symptoms despite drug therapy
- Significant opportunity for new therapies

NYHA CLASS

Adapted from Bristow, MR Management of Heart Failure, Heart Disease: A Textbook of Cardiovascular Medicine, 6th edition, ed. Braunwald et al.
Evaluation Criteria

Consider an evaluation when **three** of the following indications are present:

- Class III – IV heart failure symptoms
- Inability to walk < 1 block without dyspnea
- Sodium < 136 mEq/L
- BUN > 40 mg or Cr > 1.8 mg/dL
- ACE/ ARB/ BB intolerance
- Diuretic dose > 1.5 mg/kg/d
- 1 HF admit in the past 6 months
- No clinical improvement with CRT
Steps to Clear the Adoption Chasm

- Viable tool for management of CHF
- Improve patient selection and perioperative management
- Fewer complications and shorter length of stay
- Smaller, less expensive, more durable devices
- 100% success as a bridge to transplantation
- 5 - 10 year DT survival equal to transplantation
- Enhance patient length and quality of life
Bruce B Reid, MD
Office: 801-507-3600
Cell: 801-719-8253
24 Hour Hotline: 801-507-LVAD
Bruce.Reid@imail.org
Increasing the LENGTH and QUALITY of life for patients with heart failure…