The Changing Face of Cardiovascular Surgery: An Introduction

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Disclosures

• None
If you would understand anything, observe its beginning and its development.

-Aristotle
The Human Heart

- Size of a fist
- 100,000 heart beats per day
  \(\frac{100K}{24h \times 60 \text{ min}} = 69 \text{ bpm}\)
- 2000 gallons of blood per day
- In a 70 year lifespan, that’s more than 2.5 BILLION heartbeats
The Heart Is Like an Engine

- Fuel Lines
- Valves
- Electrical System
- Lubricant/ Coolant
- Inflow
- Outflow
- Turbo
- Pistons
Some Things Pills Cannot Fix
History

- 1896: Ludwig Rehn: Suture Cardiac Stab Wound
- 1920: Cutlet & Beck: Mitral Valvulotome
- 1925: Henry Souttar: Finger fracture Mitral Valve
  – (never referred another case: "nonsense")
- 1934 DeBakey – Roller pump
- 1937: Robert Gross: Ligation of PDA
- 1948: Harken: Mitral Valvulotome (closed)
- 1953 Gibbon - Cardiopulmonary bypass
Cardiopulmonary Bypass

“What mankind can dream, research and technology can achieve”

– C. Walton Lillehei, MD, University of Minnesota, 1952

University of Minnesota, (Heart Surgery Classics, 128-139, 1994)
Heart-Lung Machine

- 1953
- JH Gibbon
- 3 out 4 patients died intraoperatively
- “The AHA and the NIH had stopped funding any projects for the study of heart-lung machines, because it was felt that the problem was physiologically insurmountable.”
  – JW Kirklin, 1955
Heart Lung Machine
Heart-Lung Machine Circuitry

Membrane oxygenator (Medtronic Affinity)

Centrifugal Pump (BioMedicus)

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<tr>
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### OR Schedule Today

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<tr>
<td>Perc. AVR</td>
<td>LVAD</td>
<td>Min Inv OPCAB</td>
<td>TEVAR</td>
<td>Redo AVR/CABG</td>
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<tr>
<td>VAD supported High risk PCI</td>
<td>Clinic</td>
<td>Min Inv MVR</td>
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“This is not your father’s Oldsmobile”

Oldsmobile 442, REGULAR GAS, 310hp, 0-60 7.5 sec
High complexity
Hybrid technology

Fisker Karma, 100mpg, 400hp, 0-60 6.0 sec.
Cardiac Surgery in 2010

- Diagnostic Radiology
- Interventional Radiology
- Genetics
- Vascular Surgery
- Cardiology
- Research

Cardiac Surgery
Ischemic Heart Disease
Ischemic Heart Disease

- Affects more than 1.5 million people EACH YEAR
- Leading cause of death for both men and women
- Progressive, lifelong disease
- Medical therapy, behavior modification are paramount
- Revascularization (catheter based or surgical) for symptoms or prevention of further myocardial damage or heart failure
Atherosclerotic Coronary Artery Disease

**FIGURE.** Self-reported prevalence* of history of myocardial infarction or angina/coronary heart disease among adults aged ≥18 years — Behavioral Risk Factor Surveillance System, United States, 2005

* Age adjusted to the 2000 U.S. standard population of adults.
Surgical Indications (Classic)

• Left main disease
• 3-vessel disease
• 2-vessel disease with proximal LAD lesion
• Impaired ejection fraction
• Severe ischemia with multi-vessel disease
• Diabetes with multi-vessel disease
Coronary Revascularization in the United States

Coronary Artery Bypass Grafting and Percutaneous Coronary Interventions

Data from the National Hospital Discharge Survey
CABG vs. DES

- Washington Hospital Center
  - 1680 pts over 18 months with 1 year follow-up, 700 with CABG, almost 1000 with DES
  - Excluded for cardiogenic shock, significant LM disease, associated valve pathology
  - End points
    - Death
    - MI
    - CVA
    - TVF (target vessel failure)
Clinical 12-month outcomes for 3-vessel CAD
CABG vs. DES part deux

- NYS Registry retrospective review
  - October 2003 – December 2004
  - Excluded for LM CAD, recent MI, previous revascularization, out of state resident
  - 9963 pts had DES, 7437 pts had CABG
- End Points
  - MI leading to readmission, death, or revascularization
Drug-Eluting Stents vs. Coronary-Artery Bypass Grafting in Multivessel Coronary Disease

Figure 1. Rates of Revascularization within 18 Months after Initial Procedure.
CABG denotes coronary-artery bypass grafting, and PCI percutaneous coronary intervention.

Third Time’s a Charm

• Multicenter, multinational trial
• Prospective, randomized, nonblinded
• 1800 patients
• Cardiac Surgeon and Interventional Cardiologist each reviewed cardiac cath for “equivalence.”
• End points: death, stroke, MI, repeat revascularization at 12 months
Percutaneous Coronary Intervention versus Coronary-Artery Bypass Grafting for Severe Coronary Artery Disease

A) Death from Any Cause

B) Death from Any Cause, Stroke, or MI

C) Repeat Revascularization

D) Major Adverse Cardiac or Cerebrovascular Event

Percutaneous Coronary Intervention versus Coronary-Artery Bypass Grafting for Severe Coronary Artery Disease

A Low SYNTAX Score

B Intermediate SYNTAX Score

C High SYNTAX Score

Study Conclusions

• A significant mortality and MACCE advantage for CABG over PCI was seen in the overall population with 2- and 3-vessel CAD; however, after adjustment for baseline variables, this advantage remained significant only in the diabetic populations.

• In conclusion, based on this study, for diabetic patients with multivessel disease, revascularization by CABG may be preferable to PCI with DES. Although DES use has greatly reduced restenosis and TVF, outcomes associated with these stents in high-risk patient subsets (especially diabetics) are still inferior to CABG.

Circulation 2007;116:I-200-I-206
Study Conclusions

- For patients with multivessel disease, CABG continues to be associated with lower mortality rates than does treatment with drug-eluting stents and is also associated with lower rates of death or myocardial infarction and repeat revascularization.

Study Conclusions

• CABG remains the standard of care for patients with three-vessel or left main coronary artery disease, since the use of CABG, as compared with PCI, resulted in lower rates of the combined end point of major adverse cardiac or cerebrovascular events at 1 year.

Surgical Perspective

• VICTORY! ABSOLUTION! AT LAST!
• CABG remains superior to other therapies in patients with DM and multivessel CAD even with modern medical therapy and DES
• NOT ALL PATIENTS ARE GREAT SURGICAL CANDIDATES
• Pedicled LIMA to LAD
• Use of adjunctive technology
Valvular Heart Disease
Valvular Heart Disease

- 1960: Harken: AVR (ball in cage)
- 1960: Starr: MVR (ball in cage)
- 1962: Ross: Homograft valves
- 1966: Tilting disc / Bileaflet valves
- 1967: Carpentier: Gluteraldehyde xenograft valves
- 1983: Carpentier: Valve repair techniques
Modern Mechanical Valves

• Advantages
  – Durable
  – Technical ease
  – Effective orifice area

• Disadvantages
  – Anticoagulation
  – Flow characteristics

St. Jude bileaflet valve
Modern Tissue Valves

- Advantages
  - No anticoagulation

- Disadvantages
  - Durability

CE pericardial valve

St. Jude stentless porcine valve

Aortic homograft

Medtronic Mosaic
Aortic Valve Disease

Stenosis
- Acquired (calcific)
- Congenital
- Rheumatic

Insufficiency
- Calcific (coexisting with aortic stenosis)
- Degenerative (idiopathic)
- Connective tissue disorders (Marfan’s Syndrome)
- Endocarditis
- Aortitis (syphilis, viral syndromes, giant cell, Takayasu’s)
- Aortic dissection
Anatomy
Mitral Annulus

- “Saddle Shaped” – hyperbolic paraboloid with two-directional curvature
- Shape present in all mammalian mitral valves
- Reduces stress on apparatus – specifically on leaflets

Circulation 2002; 106: 711-717
Percutaneous Aortic Valve
Percutaneous Aortic Valve

• Emerging technology
• Limited in US to clinical trials
• Other products available internationally
• Transfemoral or Transapical approach
• Highly selected, high risk patients
Trans-femoral or Trans-apical Aortic Valve Insertion

On going FDA trial: PARTNER Trial
Initial (European experience) encouraging, 30 day mortality nears 30%
Access vessels an issue in 30-40% patients (7 mm)
Percutaneous Aortic Valve
PARTNER Trial

UWMC is one of 15 centers nationwide involved in this trial

Critical AS, Sx (AVA 0.7, MG 40, 4 m/sec), LVOT< 25mm
No CAD, PVD, CVA, expected survival > 1 year
Extensive screening by 2 CTS surgeons and ICs
Echo, cath, CTA

Stratum A
High risk surgical (STS > 10%)

Stratum B
Inoperable

AVR
Perc AVR
Perc AVR
Medical Rx (BAV)
Transfemoral AVR
Transapical Surgical Aortic Valve Replacement: Procedural Steps

1) Small incision between the 5th & 6th ribs of the left chest wall

2) Introducer sheath placed through apex of the heart & balloon valvuloplasty performed

3) Valve deployed over a guidewire using balloon catheter into native aortic annulus

4) Valve fully deployed
Transapical approach
UWMC Experience

• 12 transfemoral, 5 transapical implant

• More than 100 patients in active screening
Minimally Invasive and Robotic Cardiac Surgery
“Open Heart” Surgery

Benefits
• Safe
• Reproducible
• Reliable
• All components via single incision
• Avoidance of pleural spaces
• Easily Teachable
• Sternotomy well-tolerated

Limitations
• Recovery
• Sternal Precautions
• Increases complexity of Redo operation
• ? Length of stay
• ? Blood transfusions
Sternal Fixation: Hybrid Orthopedics

Fracture fixation wires/cables (1960s technology) replaced by titanium plates/screw systems (5 fold increase strength)

High risk patients (obese, COPD, DM, osteoporosis)
Minimally Invasive Cardiac Surgery

Benefits

- Recovery
- Cosmesis
- Public/Provider Demand
- Facilitates Redo operation
- Decreased length of stay
- Decreased blood loss

Limitations

- Longer OR time/CPB time
- Expensive instrumentation/equipment
- Cannot perform all operations through one incision
- Pleural complications
- Groin complications
- Thoracotomy pain
AVR
Minithoracotomy

AVR Hemisternotomy

MVR
Minithoracotomy

CABG Minithoracotomy

MVR Hemisternotomy
Minimally Invasive AVR
Minithoracotomy AVR
Isolated Aortic Valve Replacement
UWMC

Percent Minimally Invasive

Year

2005 2006 2007 2008
Case Presentation

• 21 y/o male with medically refractory Crohn’s disease and albumin of 1.2. Admitted with fevers/chills and diagnosed with a PICC infection.
Case Presentation

• Due to ongoing GI bleeding, underwent a total abdominal colectomy/ end ileostomy and allowed to recover for 1 week.
2 months
Robotic Cardiac Surgery

• Advantages
  – No tremor
  – Motion scaling
  – Magnification
  – Minimally invasive
  – Market appeal

• Disadvantages
  – Time consuming
  – Learning curve
  – Expensive
  – Public distrust
da Vinci Surgical System
Robotic LIMA Harvest
Small Thoracotomy OPCAB
Case Study

• 54 y/o male with HepC induced end stage liver disease. Underwent liver transplant complicated by acute rejection and re-transplant 2 weeks later. 2 month ICU stay. Suffered NSTEMI in perioperative period, found to have CHF and EF 20%.
Case Study
Case Study
Clinical Course

• Discharged home of POD # 6, POD #1 s/p RCA stent. Periop afib.
• Six month f/u shows improvement in EF to 35% and no heart failure symptoms.
Thoracic Aorta
Aortic Surgery

- Aneurysm – enlargement of vessel greater than 50% of normal
- Pseudoaneurysm – localized dilation of vessel whose wall does not contain all layers of the vessel, due to trauma, infection or previous operation
- Dissection – intimal tear resulting in creation of a pressurized false lumen between the intima and media and adventitia
Aortic Anatomy

- Aortic Root
- Sinotubular Junction
- Ascending aorta
- Aortic Arch
- Descending Thoracic Aorta
Laplace’s Law

\[ T = \frac{P \times R}{M} \]

- \( T \) = wall tension
- \( P \) = pressure difference across the wall
- \( R \) = radius
- \( M \) = wall thickness

Therefore, increased radius and decreased wall thickness lead to increased wall tension...
Risk of Rupture

- Connective tissue disorders
  - Marfan’s, Ehler’s-Danlos, Loeys-Dietz, etc
- Size at diagnosis
- Rate of growth
- Inflection point at 6.0cm, smaller for connective tissue disorders
Descending Thoracic Aneurysms

- 10 per 100,000 person-years
- 5 year survival overall 19%
  - Of these pts, greater than 50% die of rupture

Current Recs:
- >6cm size or growth of >1cm per year
Descending Thoracic Aneurysms

- Big Operation
  - Physically
  - Physiologically
  - Recovery
  - Complications

- Complex Operation
  - Technically challenging
  - Arch pathology
  - Adjunctive perfusion
Open Approach
Complications of Open Thoracic Aneurysm Repair

- Dependent upon co-morbidities
- Respiratory Failure 25-45%
- Renal Failure 10-20%
- Paraplegia 10-20%
- Mortality 10-20% at 30 days
Thoracic EndoVascular Aneurysm Repair (TEVAR)
TEVAR

- 1st FDA approved device in 2005
  - Gore TAG
- Approved 2008
  - Cook Zenith TX2
  - Medtronic Talent
- Upcoming
  - Relay Thoracic Stent Graft
Similar intermediate (5 yr) outcomes, less morbidity compared to open techniques in appropriately selected patients. Access vessels, landing zones still issues, long term F/U essential.
TEVAR Challenges

- Size of “normal” aorta (40mm)
- Proximal and distal fixation sites (2cm)
- Arch disease
- Visceral vessel involvement
- Iliofemoral occlusive disease
- Arterial Tortuosity
Complications

- Vascular Access
  - 8mm access vessels
- Paraplegia
  - Spinal drainage
  - Subclavian and long segment coverage
- Renal Failure
  - IV Contrast
- Endoleak
What’s Next?

• Long term data not available
  – Endograft 5+ year durability
  – Increasing delayed endoleak rate (as seen in AAA)
  – Emerging biotechnology, newer grafts

• Hybrid approaches to complex lesions
Aortic Dissection

Adventitia

Media

Intima

Blood flow

Intimal tear

Dissection

Debakey System

Stanford Classification

Type A

Type B
Aortic Dissection

- Avoid term “dissecting aneurysm”
- Many classification schemes
- Important considerations
  - Location (ascending/arch vs. descending)
  - End organ ischemia (heart, brain, viscera, extremities)
  - Aortic insufficiency
  - Cardiac tamponade
  - Acute vs. chronic
UWMC Experience

- More than 80 TEVARs in 2008 at UWMC and HMC (exponential growth)
- All three FDA approved devices available
- Participant in Relay trial
- Multidisciplinary team of Cardiac and Vascular surgeons
Case Presentation

- 42F with hx of prior spontaneous LAD dissection Rx for presumed Wegner’s presents with acute chest pain and dysphagia.
- CTA demonstrated a new massively enlarged ascending, arch, DTA aneurysm
- Rheumatologic w/u: active aortitis (MAGIC Syndrome: mouth/genital ulcers, inflammatory chondritis, hydradenitis, aortitis: 5/7 surgical cases literature died, can involve root and AV)
- Normal EF, no acute CAD (apical HK)
- Treated with Solumedrol for 5 days with normalization of CRP and ESR
Pre-operative Imaging

Normal aortic root
Ascending 65 mm
Arch/PDTA 60
Normal cerebral vessels
Normal distal aorta
Traditional Surgical Plan
De-Branching: Extend TEVAR Landing Seal Zones

3-5 cm LZ for perfect seal

Modified from Hughes et al. JTCVS July 2008
UW performed > 12 procedures in 2008
Intra-Operative Imaging

Fully deployed EV stents, no endo leak
Long term Follow-up

Discharged home on POD#6, no complications
Two years: Stable CTA, several recurrences of aortitis
Heart Failure
“Leaders are visionaries with a poorly developed sense of fear and no concept of the odds against them.”

- Robert Jarvik
Perspective

- 5 million patients in the U. S. with heart failure
- ~ 250,000 - 500,000 patients have refractory advanced heart failure; 1 year survival < 50%
- Heart transplantation - only means of improving survival and quality of life, remains the standard against which other therapies are compared
- Shortage of organs ~ 2,300 U.S. per year
Heart Transplant History

- 1905 Carrel and Guthrie - heterotopic canine heart transplant
- 1960 Lower and Shumway – canine orthotopic heart transplant
- 1964 Hardy – chimpanzee to human xenograft
First Heart Transplant

- December 2, 1967 – Christiaan Barnard
- Patient: Louis Washlansky – 55 y/o diabetic with ischemic cardiomyopathy
- Donor: Denise Darvall – MVC
- Operation: 9 hours, 30 team members
- 18 day survival – succumbed to pneumonia
- First US heart transplant – Jan 6, 1968
Other important milestones

• 1961 Calne and Murray – Azathioprine prolongs survival of kidney transplants
• 1973 Caves – Transvenous endomyocardial biopsy
• 1977 Watson - Distant donors
• 1981 – Cyclosporin A
What is a Ventricular Assist Device (VAD)

- Mechanical device which supports ventricular function by removing blood from one cardiac chamber and propelling it forward
- May be used on the right or left side
- May be temporary or “permanent”
- May be used in a variety of situations
History of Mechanical Support

- 1957 Kolff – Total artificial heart in a dog
- 1963 DeBakey - LVAD
- 1966 Liotta – 1st successful LVAD removal
- 1968 Kantrowiz – Clinical use of Intraaortic ballon pump
- 1969 Cooley – 1st attempted Bridge to Transplant
- 1982 DeVries – Jarvik 7 implant
- 1984 Hill (UCSF) and Oyer (Stanford) - 1st successful Bridge to Transplant 2 days apart
Goals of VAD Therapy

- Bridge to Re-evaluation
- Bridge to Recovery
- Bridge to Transplant
- Destination Therapy
Use of a Continuous-Flow Device in Patients Awaiting Heart Transplantation

Leslie W. Miller, M.D., Francis D. Pagani, M.D., Ph.D., Stuart D. Russell, M.D., Ranjit John, M.D., Andrew J. Boyle, M.D., Keith D. Aaronson, M.D., John V. Conte, M.D., Yoshifumi Naka, M.D., Donna Mancini, M.D., Reynolds M. Delgado, M.D., Thomas E. MacGillivray, M.D., David J. Farrar, Ph.D., and O.H. Frazier, M.D., for the HeartMate II Clinical Investigators*
<table>
<thead>
<tr>
<th>Outcome</th>
<th>Value</th>
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<tr>
<td>Principal outcomes at 180 days — no. of patients (%)</td>
<td>100 (75)</td>
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<tr>
<td>Heart transplantation†</td>
<td>56 (42)</td>
</tr>
<tr>
<td>Cardiac recovery with device explanted‡</td>
<td>1 (1)</td>
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<tr>
<td>Ongoing device support &gt;180 days</td>
<td>43 (32)</td>
</tr>
<tr>
<td>On waiting list for transplantation§</td>
<td>32 (24)</td>
</tr>
<tr>
<td>Eligible for transplantation¶</td>
<td>11 (8)</td>
</tr>
<tr>
<td>Other outcomes — no. of patients (%)</td>
<td>33 (25)</td>
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<tr>
<td>Death at &lt;180 days</td>
<td>25 (19)</td>
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<tr>
<td>Ongoing device support at &gt;180 days but ineligible for transplantation owing to medical issues∥</td>
<td>5 (4)</td>
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<tr>
<td>Device replaced with another LVAD; patient withdrawn from study</td>
<td>3 (2)</td>
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<tr>
<td>Transplantation, recovery of cardiac function, or ongoing support at 180 days — no. of patients (%)***</td>
<td>105 (79)</td>
</tr>
<tr>
<td>With no pump replacement — no. (%)†††</td>
<td>100 (75)</td>
</tr>
<tr>
<td>Alive with LVAD support — %‡‡‡</td>
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<tr>
<td>At 1 mo</td>
<td>89±3</td>
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<tr>
<td>At 6 mo</td>
<td>75±4</td>
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<tr>
<td>At 1 yr</td>
<td>68±6</td>
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<tr>
<td>Alive after transplantation — no. (%) §§</td>
<td></td>
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<tr>
<td>At 30 days</td>
<td>64/68 (94)</td>
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<tr>
<td>At 1 yr</td>
<td>12/15 (80)</td>
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Use of a Continuous-Flow Device in Patients Awaiting Heart Transplantation

- 4 pts removed themselves from the transplant list
- 5 (4%) pts required temporary RVAD support; 17 pts (13%) required right heart inotropes support for > 14 days
- 65 pts were in Class I/II NYHA heart failure (p<0.001)
- Minnesota Living with Heart Failure Questionnaire score improved from 73 to 45 (p<0.001)
Destination Therapy

• REMATCH
  Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure

• Cooperative agreement among Thoratec, NIH and Columbia University

• 21 Centers

• 129 pts

• 68 pts randomized to HeartMate VE LVAD

• 61 pts randomized to Optimal Medical Management (OMM)

N Engl J Med 2001; 345:1435-1443
REMATCH Survival

- 1 yr survival = 51% LVAD vs. 28% OMM
- 2 yr survival = 27% LVAD vs. 10% OMM
- Median survival was 408 days for LVAD patients compared to 150 days for medical therapy patients
Advanced Heart Failure Treated with Continuous-Flow Left Ventricular Assist

Mark S. Slaughter, M.D., Joseph G. Rogers, M.D., Carmelo A. Milano, M.D.,
Stuart D. Russell, M.D, John V. Conte, M.D., David Feldman, M.D., Ph.D.,
Benjamin Sun, M.D., Antone J. Tatooles, M.D., Reynolds M. Delgado, III, M.D.,
James W. Long, M.D., Ph.D., Thomas C. Wozniak, M.D.,
Waqas Ghumman, M.D., David J. Farrar, Ph.D., and O. Howard Frazier, M.D.,
for the HeartMate II Investigators*

Destination Therapy Results

Destination Therapy

- Heartmate II DT Trial now complete and FDA approved
- Heartmate II has supported patients longer than 4 years and in animals, is still functioning at more than 6 years
Case Presentation

- 73 y/o with nonischemic dilated cardiomyopathy. Currently with Class IIIB to IV symptoms. Creatinine elevated from baseline of 2.1 to 3.4. Admitted from clinic for tailored therapy.
Case Presentation
HeartMate II Implant

Nahush A. Mokadam, MD
Assistant Professor of Surgery
Division of Cardiothoracic Surgery
University of Washington
Hospital Course

- Intubated for 24h postop
- 15 day postop length of stay
- Creatinine stabilized at 1.8
- Currently home with Class I symptoms
- Currently mows 3 acres of lawn regularly
UWMC Experience*

- 73 HeartMate II
- 73 HeartMate IP/VE/XVE
- 34 Thoratec PVAD/IVAD
- 26 TandemHeart
- 19 Abiomed AB5000
- 9 Abiomed Impella 2.5L
- 1 Ventracor VentrAssist

* As of May 15, 2010
UWMC Implantable VADs
UWMC LVAD Experience

1997-2008
n=104

Hazard Ratio at 180 days = 0.11, P<0.001

J Heart Lung Transplant, in press.
UWMC LVAD BTT Results

Survival

30 Day 1 Yr 5 Yr 10 Yr
90±4% 86±4% 71±6% 60±7%

Years
Heartware HVAD

• Miniature Implantable LVAD
• Blood lubricated
• In US Pivotal Trials
• 10 liters per minute
Levacor

- True Magnetic Levitation
- Centrifugal pump with unique inflow
- UWMC in Pilot (First-In-Man) Trial
- 10 liters per minute
Percutaneous VADs

- Abiomed Impella 2.5, 5.0
- TandemHeart
Taking the Next Steps
The Specialty of Cardiac Surgery

1948-1969: Innovation
   Research and Development

1970-1999: Industrial Age of CABG
   Standardized technique employing full sternotomy, cardiopulmonary bypass, and cardioplegic arrest

2000-2009: The Lost Years

2010-: Innovation
   Research and Development
Mending Broken Hearts in the 21st Century

- Transition from Applied technology to Biotechnology
- “Era of Vascular Biology”
  - Modifying Intimal Proliferation
  - Therapeutic Angiogenesis
  - Cardiomyocyte Transplantation
  - Modifying Ischemia / Reperfusion
  - Tissue Engineering
Medtronic CorValve
Bioengineering

• Bioengineered valves
  – Grow patient’s cells on biocompatible scaffold
  – Successfully done in animals
Biologic VADs

- Tissue matrix of collagen and cultured heart cells
- “Slipped” over hearts
- Contractile properties and ventricular restraint
HeartWare MVAD

4 liters per minute

Microaxial Pumps

3 liters per minute
Conclusions

• Modern Cardiac Surgery is a “Multidisciplinary Specialty”
• Technological advances impact almost every aspect of the field, and ultimately have served to benefit our patients.
• Close collaboration with our colleagues in related specialties has resulted in an explosion of hybrid techniques
Thank You!

Questions?