Circulatory Assist Devices

Andrew Rosenberg MD
Chief, Division of Critical Care Anesthesiology
Assistant Professor Anesthesiology & Internal Medicine
Medicine
University of Michigan
Long term use of VADS

Six Years of Continuous Mechanical Circulatory Support

TO THE EDITOR: In 2001, a randomized trial comparing a pulsatile left ventricular assist device (LVAD) with medical therapy for end-stage heart failure reported a median survival advantage of 8.5 months for patients receiving the device. The patients’ quality of life was limited by serious complications related to the LVAD. In 2000, we began a long-term observational study of circulatory support with a new, miniaturized axial-flow pump. At the time, there were important questions about the reliability of a blood pump powered by a rotary electric motor and the effects of diminished pulse pressure over time.

Our first patient was 61 years of age and had no prior history of heart surgery. She received the LVAD system in 1998 and was followed for 7 years. The Jarvik 2000 LVAD (Fig. 1) was implanted directly into the apex of the heart, and the patient was weaned from extracorporeal support and discharged to her home. The patient was not discharged until extracorporeal support and warfarin was given, with the international normalized ratio (INR) maintained at 2.0 to 2.5.

Figure 1. Left Ventricular Assist Device Implanted in the Left Ventricular Apex, with the Power Cable Connected to the Skull Pedestal.
Epidemiology of Heart Failure

- 5 million Patients with CHF in US
- 1% of population over 65 years old
  - 160% increase in hospitalizations due to CHF over past decade
  - Symptomatic CHF = 45% 1-year mortality.
  - < half of 4200 patients on Tx list will receive a heart Tx.
  - 15%/year die waiting for organ
Case Study: Acute Cardiac Failure

- 52 yo male Hx; CAD, HTN, now with large Anterior Wall MI, Cardiogenic Shock, hypoxemic.
- VS; HR=105, BP=80/67, CI=1.5, PAOP=28, CVP=16
- Intubated, 100% FiO2
- Meds;
  - Dobutamine 12mcg/kg/min 12mcg/kg/min
  - Milrinone .375mcg/kg/min .375mcg/kg/min
  - Norepinephrine .13mcg/kg/min
- Oliguric, Rising creat, LFTs,, prothrombin time.
Circulatory Assist Devices

- IABP (Intra-aortic, counterpulsation Balloon pumps)
- ECLS (Extra-corporeal Life Support)
  - Cardio-pulmonary bypass
  - ECMO-cardiac \{VA ECMO\}
- (VADS)Ventricular Assist Devices
  - Minimally invasive
  - Bridge to recovery/transplant
  - Destination therapies
IABPs

Introduced 1960’s.

Most widely used mechanical circ. Support device

Reduces cardiac work by ↓afterload

Increases coronary blood flow

Indications:
1. Cardiogenic shock
   Fail to wean from CPB
   Acute MI
2. Acute mitral regurgitation
3. Unstable angina
4. Support during high-risk procedures/events
   PTCA
   Unstable Pts. Prior to CPB.
   Ventricular arrhythmias refractory to Rx.

Contraindications:
1. Aortic insufficiency
2. Aortic dissection
3. Prosthetic graft in thoracic aorta
4. Severe aortoiliac disease
Systolic time intervals used to coordinate patients electrical and mechanical events of cardiac cycle.

Polyethylene balloon, mounted on hollow catheter (arterial pressure monitor) advanced to 2 cm below left subclavian artery.

30-40 cc volume displacement

Balloon deflates at beginning of systole, increasing stroke volume by as much at 40% ↓ LV stroke work, 02 consumption.

Ballon inflates during diastole increasing coronary artery perfusion.
IABP; Complication

- Aortic dissection or arterial perforation
- Failure to advance catheter beyond iliofemoral system due to atherosclerotic disease
- Limb ischemia requiring IABP removal
  - 11-27%
- Thrombocytopenia
- Sepsis
- Balloon rupture w/ helium embolization (2%)
  - Heralded by high balloon inflation pressures, blood in connecting tubing
- Hematomas
- Pseudoaneurysm
- AV fistulas
IABP Consol Controls
to support even the most severe arrhythmias.
EXTRACORPOREAL LIFE SUPPORT

- FiO₂ 0.4
- Rate 5-10
- P 30/15
- TV
- V/P
- Bronchoscopy
- Lung Therapy
- BP
- Dry Weight
- VV Access
- Blood Flow Hct>40
- DO₂
- Patient VO₂
- VCO₂
- Circuit
- SAT
- DP
- Nutrition
- Heparin
- ACT
- VECO₂
- O₂ Carbogen
- Pump
ECMO Setup
ECLS Circuit

- Cannula
- Bladder box
- Pump
- Oxygenator
- Bridge
- Monitoring
- Hemofilter
# ECLS: World Outcomes (12/04)

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<th>ELSO Registry</th>
<th>Univ. of Michigan</th>
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<td></td>
<td>n (%survive to D/C)</td>
<td>n (%survive to D/C)</td>
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<tr>
<td><strong>Neonatal</strong></td>
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<tr>
<td>Respiratory</td>
<td>18,703 (77%)</td>
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<td>Cardiac</td>
<td>2,246 (39%)</td>
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<tr>
<td><strong>Pediatric</strong></td>
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<tr>
<td>Respiratory</td>
<td>2,640 (56%)</td>
<td>183 (75%)</td>
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<tr>
<td>Cardiac</td>
<td>3,073 (42%)</td>
<td>132 (42%)</td>
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<tr>
<td><strong>Adult</strong></td>
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<tr>
<td>Respiratory</td>
<td>933 (53%)</td>
<td>255 (52%)</td>
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<tr>
<td>Cardiac</td>
<td>568 (35%)</td>
<td>141 (38%)</td>
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<tr>
<td><strong>Total</strong></td>
<td>28,163 (67%)</td>
<td>1,520 (67%)</td>
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Cardio-pulmonary Bypass
Describing Ventricular Assist Devices

- **Extra/para-coporeal**
  - IABP
  - Tandem Heart
  - ECMO
  - Abiomed
  - Thoratec
  - Berlin Heart

- **Intracoporeal**
  - Heartmate
  - Novacor
  - Jarvik 2000
  - DeBakey Micromed

- **Ventricular Assist type**
  - Right
  - Left
  - Biventricular

- **Flow Type**
  - Pulsatile
  - Non-pulsatile

- **Drive Train**
  - Pneumatic
  - Electric
  - Magnetic
Tandem Heart
Abiomed Impella Recover

4.5 liter flow
7 day use
9Fr cannula
Hemodynamic effects from Impella

Mean increase in CO: 1.2 ± 0.4 l/min
Mean decrease in FCW: 4.2 ± 2.3 mmHg

Patients (assisted High Risk PCI):
1. Old SV3 to LAD, native RCA, LVEF 32, Unstable angina
2. 3 vessel disease, LVEF 16, Chronic stable angina
3. 3 vessel disease, LVEF 25, Unstable angina
4. Ostial LAD/ACA, LVEF 30, Chronic stable angina
5. Three vessel disease, LVEF 22, NSTEMI
6. Old SV3 to LAD/ACA, LVEF 30, NSTEMI
7. Three vessel disease, LVEF 29, Chronic stable angina

(Source: Paolo Devita, JUM 2005)
Extra/Paracorporeal Support

Thoratec Vad system
Paracorporeal
7 liter blood flow
BSA > 0.7
Full anticoagulation

FIGURE 1. The Thoratec biventricular support system.
Biventricular Support: Abiomed BVS 5000

- Extracorporeal; LVAD, RVAD, BiVad.
- Sized for BSA >1
- 5 Liter blood flow
- RVAD < LVAD flow; avoid edema
- Intermediate-term support
- Full anticoagulation
- Thermodilution, mixed venous saturations not accurate.
- Height adjustment to balance R & L flows.
- Clotting at low flow
  - (<2 liters/min)
- >6000 patients supported
  - >65% post cardiotomy
Abiomed BVS5000 Setup
Abiomed AB5000 Ventricle

Paracorporeal, Biventricular support
Same cannula as BVS5000
6 liter blood flow
21 day average support
>300 day longest to date

Plan for AB5000
Closed Chest Transition

Maintain VAD inflow cannula to left of outflow cannula

LVAD  RVAD  LVAD  RVAD
Thoratec IVAD

Only Intra-corporeal Bivad
>2800 patient implants
Pulsatile flow,
VAD support for arrhythmia

Figure 12: CSS Support During Ventricular Fibrillation
Multicenter, RCT
129 Patients end-stage Heart Fail.
Ineligible for cardiac tx
Heartmate XVE vs Best Med Rx
48% reduced risk of death
52% 1 yr survival vs 25%
23% 2 yr survival vs 8%
Serious adverse events;
Infection
Bleeding
Device malfunction
First Generation LVAD

Thoratec VAD
HeartMate LVAD
Novacor LVAD
Thoratec Heartmate I

Heartmate IP

Heartmate XVE
HeartMate I XVE

Intra-coporeal LVAD only
6-10 liter blood flow
Textured surfaces in blood chamber creates ‘neo-intima
ASA only
Three modes;
  Fixed
  Auto
  External (synchronous)
Portable power pack allows ambulation
Pushplate pump mechanism

Figure 1.4  Solenoid Closed (Start Of Eject Phase)

Figure 1.5  Pump Nominally Empty (End Of Eject Phase)
Novacor LVAS

- Intra-corporeal
- 6-8 liter flow
- Long duration
- ? Best destination therapy device
- Full anticoagulation
Advances in LVADs

- Smaller sizes
  - Jarvik 2000

- Increased durability/duration
  - Thoratec IVAD
  - WorldHeart Novacor II
  - DeBakey
Second Generation LVAD – Axial Flow Pumps

*Jarvik 2000*

*HeartMate II*

*DeBakey VAD*
Thoratec Heartmate II

- Intracorporeal
- High-speed, axial flow (non-pulsatile), rotary pump
- BSI < 1 possible
- 6,000 to 15,000 rpm (usual 9200 rpm)
- 4-8 liter blood flow
- Fixed and auto speed modes
Thoratec Heartmate II; Axial flow

- Small size
- No hemolysis
- Flow = 5-10 liters/min
Third Generation LVAD

- Centrifugal flow design
- Magnetically-levitated
- Long pump durability

WorldHeart Novacor
Rotary VAD

HeartMate III

HeartQuest

DuraHeart
Total Artificial Hearts: Abiomed AbioCor

AbioCor

First Completely self-contained total artificial heart

2 lbs.

Still in FDA review

Not eligible for natural heart transplant
Artificial Hearts; Syncardia Heart

- Intra-corporeal
- Biventricular support
- Bridge to Transplant
- 7-10 liter flow
- Full anticoagulation

Jarvik Heart
VAD Controllers

AB5000 Console

Thoratec Bi-VAD
VAD Management Issues
Hemodynamics (0-12 hrs.)

- **Adequate LVAD filling**
  - MAP ≈ 70 mmHg.
  - Flow rate ≈ 3-4 l/min,
  - Fixed rates of 75, changing to auto rate control over time.
  - RPMs 8000-9000, Pulsatility index > 4
  - HR 96-110, small volumes ejected, more frequently from RV
    - Collapsed LV, interventricular septum bowing
    - Increased venous return
    - RV dilation, reduced effective RV geometry, tricuspid regurgitation
    - RV ischemia

- **CVP 8-15 mmHG (prompt response to increases!)**
  - Low LVAD flow + low/nl CVP = hypovolemia
  - Low LVAD flow + high CVP = RV overload/failure, PHTN

- **CVP >20 associated w/ ↓ GFR, diuretic unresponsiveness, ARF.**
  - CVVH to remove extra volume if diuretic resistant
Complications: Hypotension

- **LVAD**
  - Low intravascular volume, obstructed LV filling, Aortic emptying
  - Because of non-occlusive system; require high enough pump speeds to avoid pressure differentials below expected Ao pressures (avoid regurgitant flow)
  - Rotary pumps can generate large negative pressure at inlet
  - Obstruction of inlet/outlet cannulae, inadequate filling conditions
- **RV failure**
  - Fluid overload, excessive LVAD flow, ↑PVR, excessive systemic vasopressors, vasopressors, acid-base
- **Systemic Vasodilation**
  - SIRS
  - Milrinone, dobutamine
- **Hemorrhage** {remember abdominal}, tamponade
- **Obstructive shock; tamponade, auto-peep**
- **Sepsis, anaphylaxis, adrenal insufficiency**
Managing Hypotension-cont’d

- Normal RV + low or nl SVR
  - Fluids to maintain CVP 10mmHg
  - ↓ milrinone to .125 mcg/kg or turn off if LVAD flow flow are > 4l/min
  - Increase Nor-epi, vasopressin
  - Increase LVAD flow

- Poor RV fxn + nl SVR
  - Maintain Nitric Oxide 5 to 20 ppm
  - Milrinone 0.5 mcg/kg/min
  - Dobutamine 8-10 mcg/kg/min ± Epi, Dopamine, Isuprel Isuprel
Avoiding Right Heart Failure

- **Pre-op**
  - Inotropic support
    - PA-Catheter, Echo
    - Milrinone, Vasopressin, Dobutamine, Nor-epi
  - Improve R heart volume overload
    - Diuretics
    - CVVH
  - Correct Coagulopathy (vitamin-k,

- **Intra-op**
  - Same inotropic support
  - Aprotinin
  - Nitric Oxide

- **Post-operative**
  - Warm
  - Correction of acidosis, Mild respiratory alkalosis
  - Fast RV heart Rate, A-V pacing
  - Aggressive correction of volume overload, increasing CVP
Effects of nonpulsatilie blood flow

- **Benefits of pulsatile flow:**
  - Reduces critical capillary closing pressure
  - Improves lymphatic flow
  - Improves tissue perfusion; enhances diffusion of oxygen and other substrates

- **Adverse effects of nonpulsatile flow**
  - Neuroendocrine responses from lack of baroreceptor, renal and endothelial stimulation;
    - Vasoconstriction
    - Increased oxygen consumption
    - Acidosis
    - Edema formation
  - Renal Effects;
    - Increased renin, angiotensin II, Aldosterone
    - Reduced cortical and medullary blood flow

- Decreased gastric mucosal pH

Wienstein et al. ATS, ’79
Hamulu, Perfusion, ‘98
Effects on Systemic Perfusion with Pulsatile and Non-Pulsatile Blood Flow

Shock
Acidosis
Oliguria
↑Epinephrine

Yes
+/−
No

Non-Pulsatile

Pulsatile

Flow cc/Kg

4000cc/80kg = 50cc/kg/min

Bartlett, ELSO,2000
Tominaga, JTCS,94
Golding, ASAIO,82
Bernstein, TransASAIO,74
Recent Post-operative Anticoagulation/Antiplatelet Therapy

- **Antiplatelet Agents;**
  - platelets ≥ 50,000,
  - CT drainage < 30 to 50 ml/hr x 4 hours
    - ASA 81-325 mg/d; POD 1-3,
    - Dipyridamole (Persantine) 75 mg tid; POD 1-2
    - Pentoxifylline (Trental) 400 mg tid; POD 1-2

- **Anticoagulants**
  - Heparin 2-5 U/kg/hr; POD 1-3, no bolus
  - Warfarin 2 mg hs; POD 5 to 7; nl hepatic/renal fxn
Other Post-operative issues

- Turn on AICD if present
- Out of bed, incentive spirometry
- Nutrition; early enteral feed (may require feeding tube)
- Plasma free hemoglobin (3-10 mg/dl)
Weaning from VADs

As flow is decreased, native ejections should become more prominent on arterial waveform.

Figure 14: Native Ejections During Weaning
# VAD Comparison Chart

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The End
Cannulation
ECMO circuit pump and controller
Cardiac Output and Mixed venous monitor
Cardio-pulmonary Bypass
Abiomed AB5000

AB5000 Ventricle

Plan for AB5000 Closed Chest Transition

- Maintain VAD inflow cannula to left of outflow cannula

AB5000 Support Demographics

- RVAD 22%
- BiVAD 46%
- LVAD 33%

AB5000 Indications

- Implant Indications All Patients
  - Others 5%
  - Acute Cardiomyopathy 10%
  - ANI Shock 25%
  - Failed Tx 6%
  - PCCS 40%
  - Myocarditis 4%
Abiomed BVS clinical pearls

Helpful Clinical Hints

Thermodilution Cardiac Output and Continuous Cardiac Output will be inaccurate on Bi-VAD or RVAD support.

Height of blood pumps may need to be adjusted independently for patients on biventricular support to maintain balanced flows and avoid pulmonary edema. It is not unusual for right flow to exceed left flow in the early support period. If right flow exceeds left, watch for signs of pulmonary edema or right heart failure, but there is no need to intervene if patient is asymptomatic.

Maintain blood pumps 0-10 inches (0-25 cm) below the level of patient's atrium when using the 42 Fr. (14 mm) cannula and 4-14 inches (10-35 cm) when using the 32 Fr. (10.7 mm) or 38 Fr. (12 mm) cannula.

Maintain filling pressures on the high side of normal (CVP 12-15mmHg; PCWP/LAP 10-14mmHg).*

Maintain SVR between 900-1200 dynes per second and PVR between 100-250 dynes per second.*

For patients on univentricular support, watch for signs of failure of the unassisted ventricle.

Do not apply direct heat or cold to blood pumps. Use tubing covers as needed.

**No Chest Compressions or Pre-cordial thumps.** Consider placing sign at head of bed.

To assist PA catheter insertion in a patient on RVAD or BiVAD (support), decrease flow through the right blood pump by turning on the weaning mode. Decrease flow to approximately 2 liters to fill the patient's ventricle and allow the catheter to pass into the pulmonary artery. Once catheter is in place, return to full support by turning off the weaning mode.

When assisting with TEE, reduce flow to approximately 2 liters to fill the ventricle in order to assess ventricular wall motion. Reduce flow by utilizing the weaning mode as outlined above. Upon completion of TEE, return to full support by turning off the weaning mode.

All hemodynamic parameters are recommended guidelines only, please refer to normal values set by your institution.