Oklahoma Heart Institute

LIFE AFTER CRT

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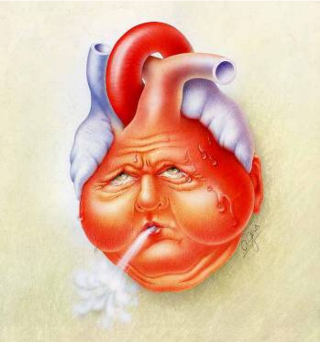
OklahomaHeart.com

Disclosures

- None

Heart Failure



The *inability* of heart *to meet* the *metabolic demands* of the body

21 MILLION

ADULTS IN THE US AND EU ARE ESTIMATED TO BE LIVING WITH HEART FAILURE, AND THIS NUMBER IS EXPECTED TO RISE[1,2]

- AGING POPULATION[3]
- INCREASING PREVALENCE OF RISK FACTORS[3]
- IMPROVED POST-MI SURVIVAL[3]

MI = myocardial infarction

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IN PATIENTS WITH HEART FAILURE

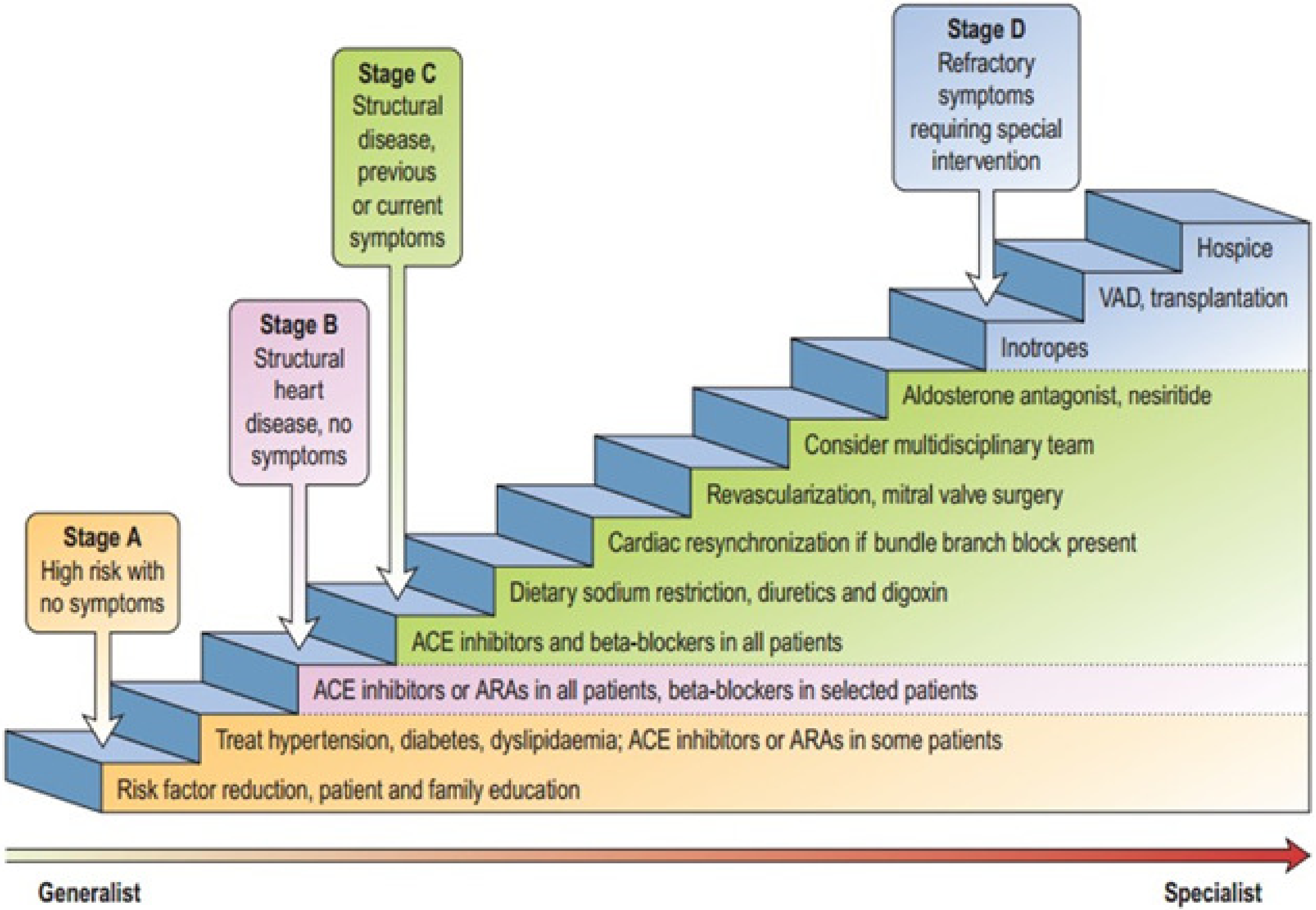
≥24% DIE WITHIN 1 YEAR OF DIAGNOSIS[3]

~50% DIE WITHIN 5 YEARS OF DIAGNOSIS[4]

Symptoms

Shortness of breath
Swelling of feet & legs
Chronic lack of energy
Difficulty sleeping at night due to breathing problems
Swollen or tender abdomen with loss of appetite
Cough with frothy Sputum
Increased urination at night
Confusion and/or impaired memory

Staging & Options



Optimized Oral HF Drug Rx

High Risk CV Surgery

Investigational Drugs

BiV Pacer

Hospice

Inotropes

VADs

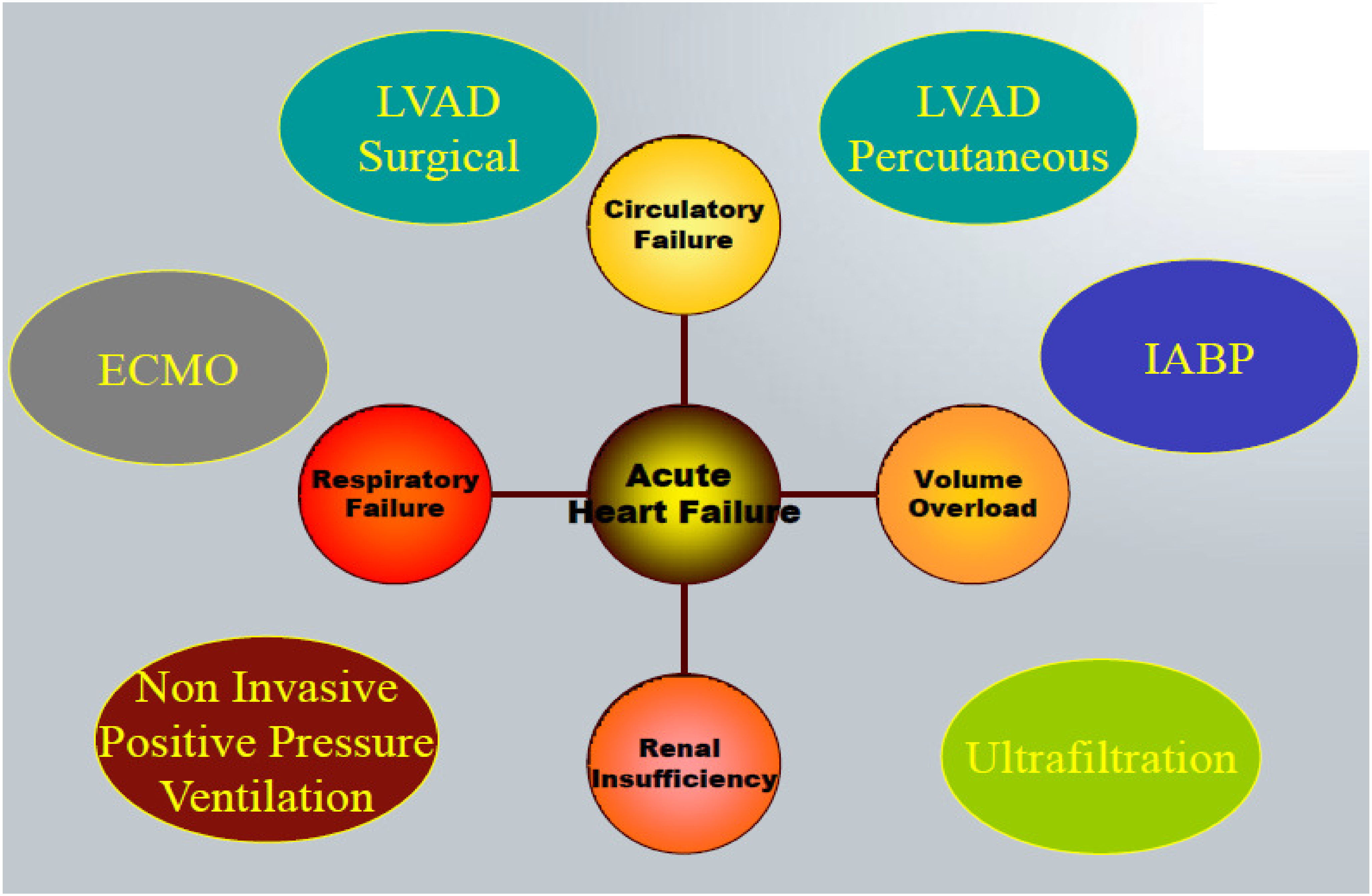
Tx

Prognostication

NYHA Class	1 Year Mortality
I	5-10%
II-III	15-30%
IV	50-60%

STAGE D (Refractory HF)

- Refractory heart failure with recurrent decompensation
- Failing medical management
- Intolerance to previously tolerated medications
- Escalating doses of diuretics
- Decreased end organ perfusion
  - Renal function
  - Liver function
  - Pulmonary function
- Chronic low output state
- Hyponatremia
- Persistent decline in functional status
- Resting symptoms


LVAD Surgical
LVAD Percutaneous
Circulatory Failure
ECMO
IABP
Respiratory Failure
Acute Heart Failure
Volume Overload
Non Invasive Positive Pressure Ventilation
Renal Insufficiency
Ultrafiltration

Goals of Management

- Improve symptoms (relieve congestion and address low output symptoms)
- Maintain oxygenation (tissue perfusion)
- Optimize volume status
- Etiology of heart failure
- Identify and address the precipitating factors

Treatment Options
End-Stage Heart Failure

- Medical management - limited by poor outcomes
- Cardiac transplantation - limited by donor shortage
- Mechanical circulatory support devices
  - Left ventricular assist device (LVAD)

Inotropic Support

I IIa IIb III — C

Until definitive therapy (e.g., coronary revascularization, MCS, heart transplantation) or resolution of the acute precipitating problem, patients with cardiogenic shock should receive temporary intravenous inotropic support to maintain systemic perfusion and preserve end-organ performance.

I IIa IIb III — B

Continuous intravenous inotropic support is reasonable as “bridge therapy” in patients with stage D refractory to GDMT and device therapy who are eligible for and awaiting MCS or cardiac transplantation.

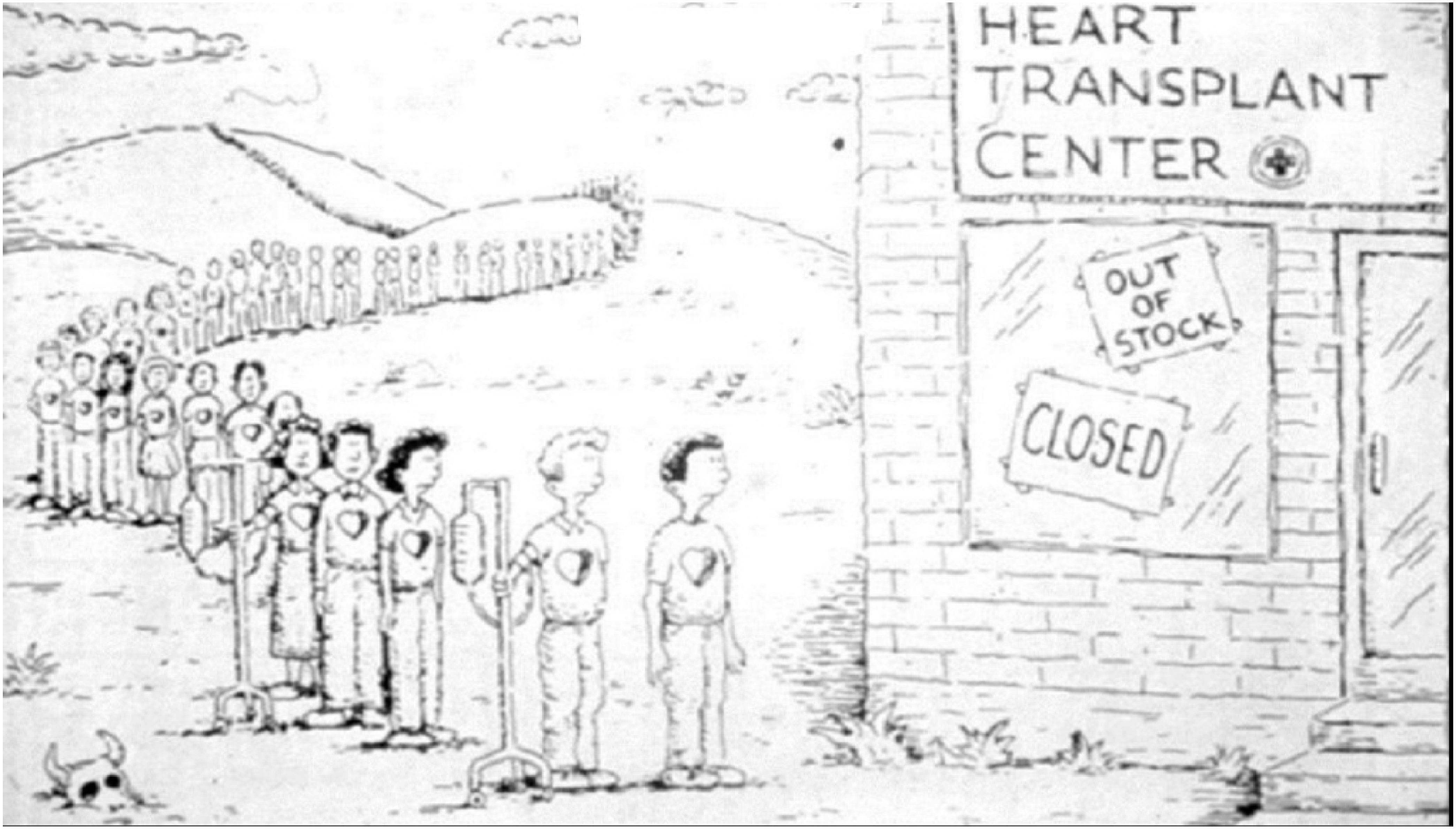
Inotropic Support

I IIa IIb III
B
Harm

Long-term use of either continuous or intermittent, intravenous parenteral positive inotropic agents, in the absence of specific indications or for reasons other than palliative care, is potentially harmful in the patient with HF.

I IIa IIb III
B
Harm

Use of parenteral inotropic agents in hospitalized patients without documented severe systolic dysfunction, low blood pressure, or impaired perfusion, and evidence of significantly depressed cardiac output, with or without congestion, is potentially harmful.


HEART
TRANSPLANT
CENTER
OUT OF STOCK
CLOSED

Evolution of Mechanical Circulatory Support

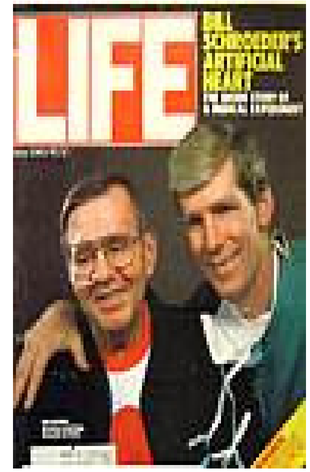
1936

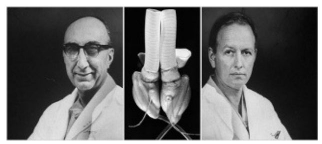
1965

1969

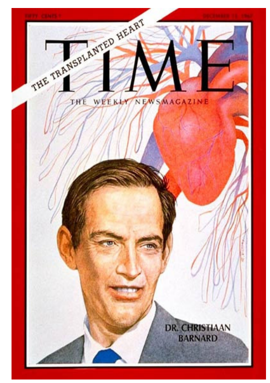
1981

1982





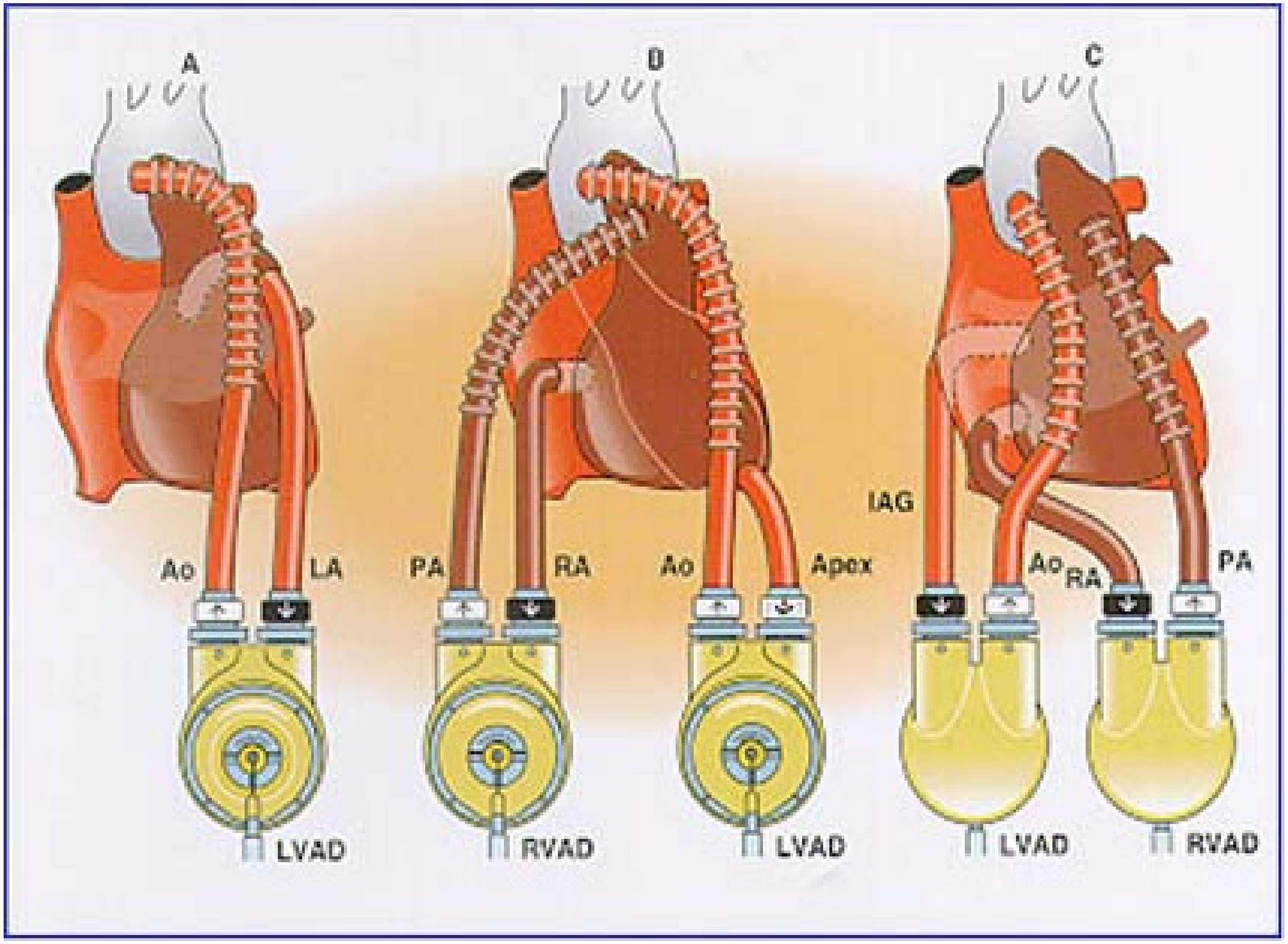
1968



As socio-political history…

Ventricular Assist Device (VAD)

- Left ventricular assist device (LVAD)-supports the left ventricle
- Right ventricular assist device (RVAD)-supports the right ventricle
- Bi-ventricular assist device (LVAD)-supports both ventricles

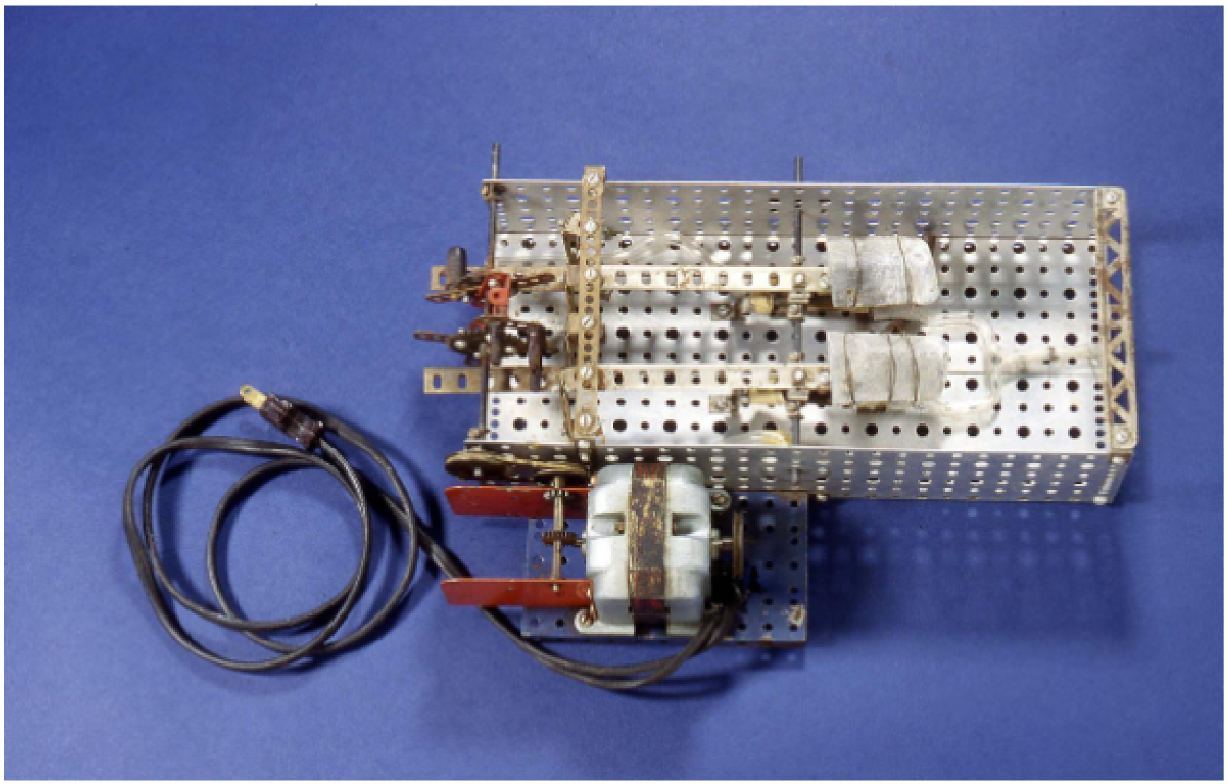

A
B
C
Ao
LA
LVAD
PA
RA
RVAD
Ao
Apex
LVAD
IAG
Ao
RA
PA
LVAD
RVAD

Firsts

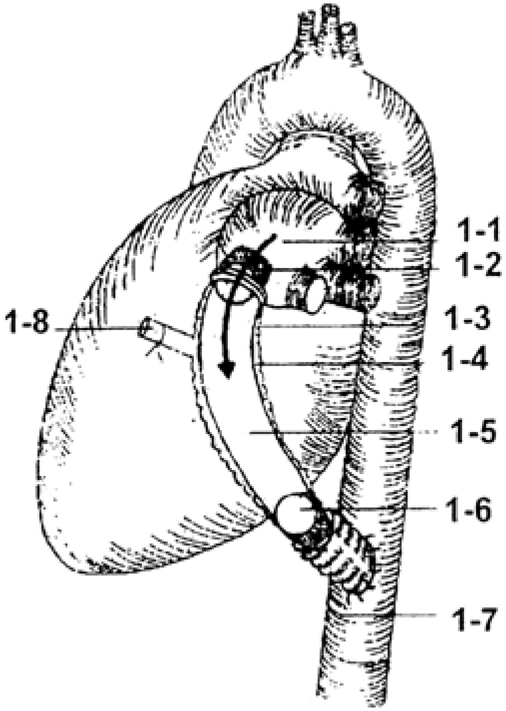
- Valdmir Petrovich Demikov - Artificial heart in 1937 in a dog
- Pioneer of Mechanical circulation and Transplant

Firsts

- Michael DeBakey in 1966 in a 37 year old woman
  - Paracorporeal circuit to provide mechanical support after surgery
  - for 10 days
- Long term implantation in 1988 by William F Bernard
  - Children's medical center MA
- FDA approved HeartMate IP LVAS in October of 1994

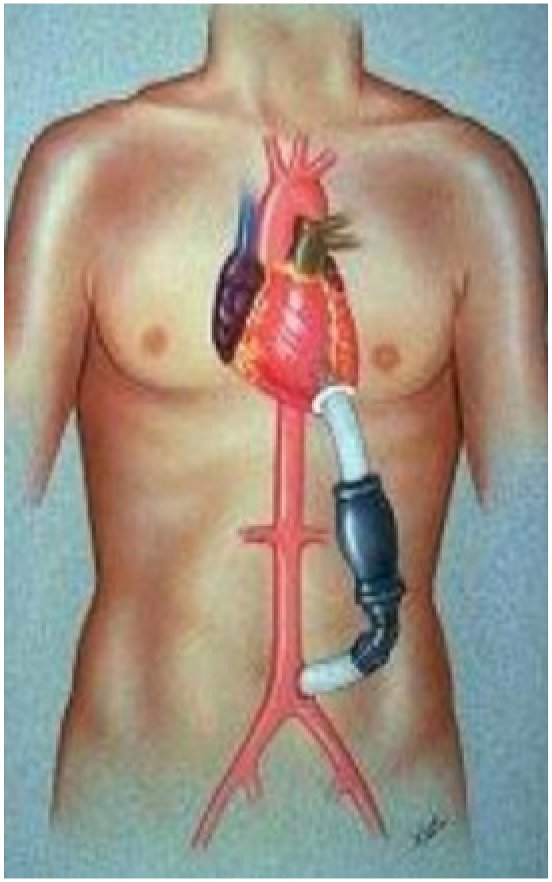


The Sewell heart pump was built by William Sewell Jr and William Glenn in New Haven – Successfully bypassed right side of a dog in 1949



Liotta-Crawford LVAS (July 19, 1963).

Drawing of the 19th July 1963 clinical prototype that was developed by Domingo Liotta at Baylor University, Houston. The pump is shown in diastole. 1= left atrium; 2= inlet valve; 3= housing of Silastic, reinforced with Dacron fabric; 4= air chamber; 5= blood chamber; 6= outlet valve; 7=descending aorta; 8= plastic tube (internal dimension, 4 mm) for air supply.



Pump Interposed between LV apex and infra-renal abdominal aorta

1984 First Successful Bridge-to-Transplant - Thoratec VAD
California Pacific Med Ctr, San Francisco

New England Journal of Medicine **314:**626-628, 1986

USE OF A PROSTHETIC VENTRICLE AS A BRIDGE TO CARDIAC TRANSPLANTATION FOR POSTINFARCTION CARDIOGENIC SHOCK

J. DONALD HILL, M.D., DAVID J. FARRAR, PH.D., JAMES J. HERSHON, M.D., PETER G. COMPTON, M.S., G. JAMES AVERY, II, M.D., BARRY S. LEVIN, M.D., AND BRUCE N. BRENT, M.D.

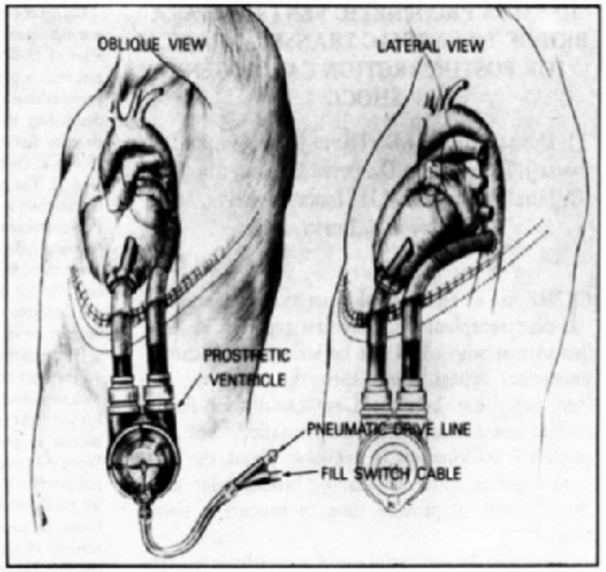


Figure 1. Prosthetic Ventricle Connected from the Left Ventricular Apex and Returning Blood Flow to the Descending Aorta.

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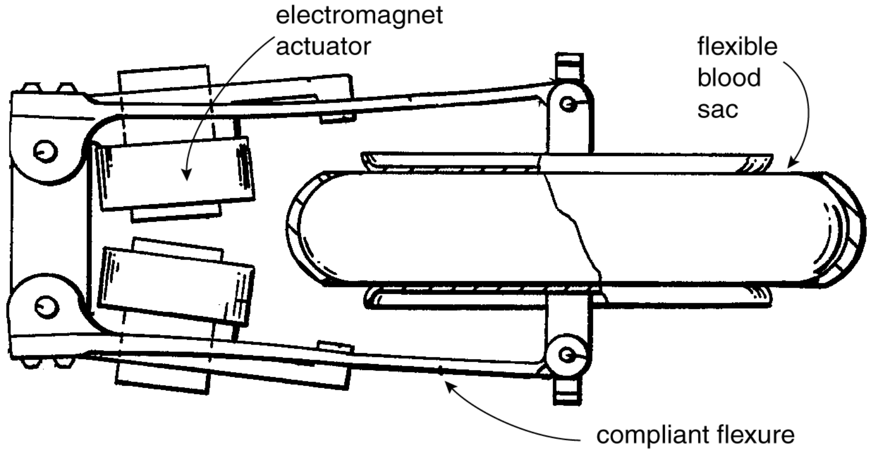
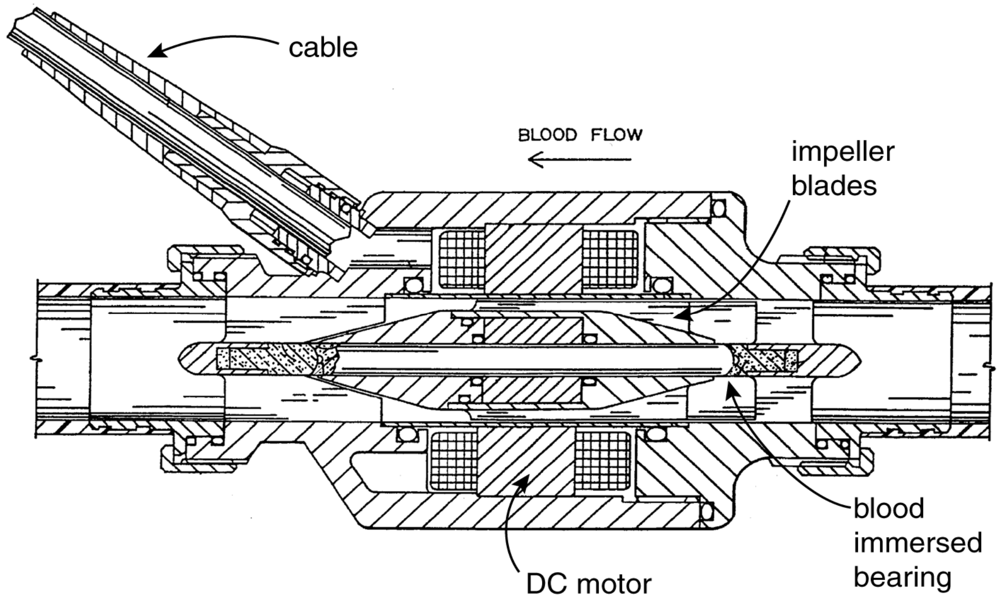
34 Day Animal Trial

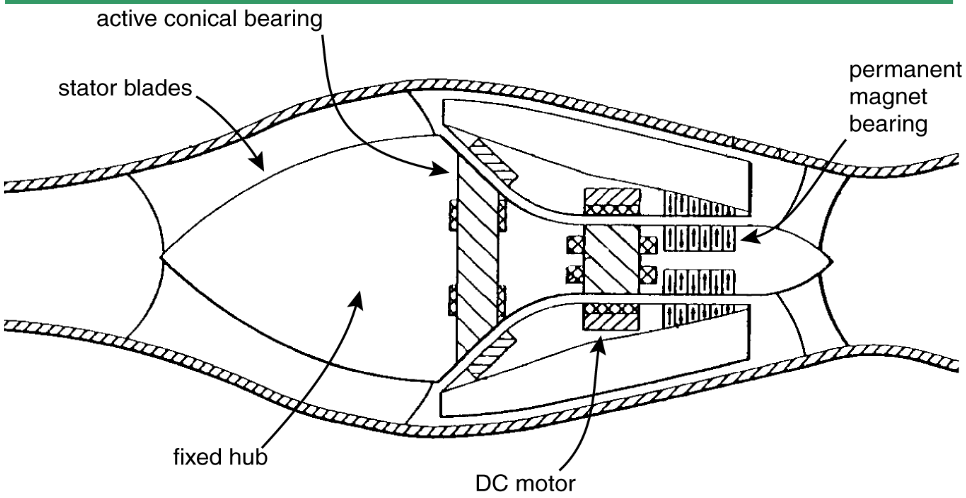
1st Generation (pulsatile)



2nd Generation (rotary)



3rd Generation (maglev)



REMATCH

- HeartMate LVAS used as a bridge to cardiac transplantation Extended periods of out of hospital support possible
  - Reasonable quality of life
- Can HeartMate LVAS be used as a long-term "Destination Therapy" for patients with end-stage heart disease (ESHD)?

REMATCH – eligibility criteria

- NYHA class IV end-stage LV failure
- LVEF ≤ 25%
- Peak VO2 ≤ 14 ml/kg/min
- Received optimal medical therapy for at least 60 of the last 90 days
- Life expectancy of < 2 years
- IV inotrope dependent with failed weaning
- Ineligible for cardiac transplantation

Survival

- 1 year survival = 51% LVAD vs. 28% OMM
- 2 year survival = 24% LVAD vs. 8% OMM
- Median survival was 408 days for LVAD patients compared to 150 days for medical therapy patients

The HeartMate II continuous-flow left ventricular assist device receives blood from the left ventricular apex and returns it to the ascending aorta.

Second generation pump
Axial Flow
Continuous Flow
No pulse
Less moving parts
Less complications compared to 1st generation pumps

Analysis of Response of Four Rotary Pumps

TABLE 3. *Preload and afterload sensitivities of the four rotary blood pumps compared with the natural left ventricle*

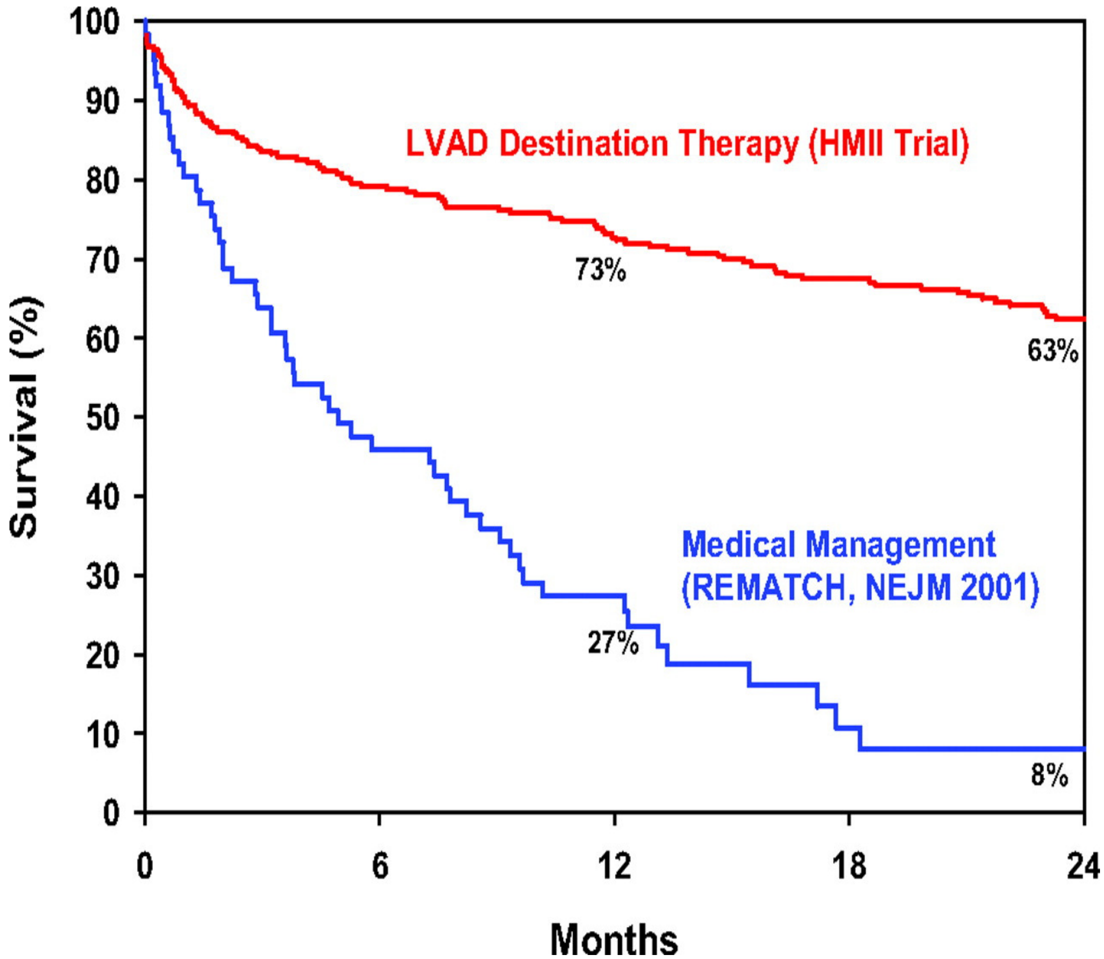
	Preload Series						Afterload Series						
	Aload	Pload loLim	Pload hilim	Flow lolim	Flow hilim	Pload Sens	Pload	Aload lolim	Aload hilim	Flow lolim	Flow hilim	Aload Sens	*P* =
Natural Ventricle	84	3	27	2.95	8.76	0.24	3	84	116	2.88	2.31	0.02	<.001
	100	3	27	2.59	7.7	0.21	15	84	116	8.27	6.63	0.05	
	116	3	27	2.31	6.85	0.19	27	84	116	8.54	6.85	0.05	
Duraheart 2000 rpm	60	0.9	18	9	10	0.06	3	51	128	0	9.6	0.12	0.7
	100	0.39	29.9	5.9	8.3	0.08	15	56.3	140	0	10	0.12	
	140	14.5	29.4	0	4.6	0.31	27	68	151	1.7	10	0.1	
Heartware 2700 rpm	60	0.58	26.1	8.3	10	0.07	3	50.8	126	0	9.1	0.12	0.7
	100	0.82	29.6	5.1	7.5	0.08	15	50.5	138	0	9.9	0.11	
	140	17.0	29.9	0	3.9	0.3	27	60.9	150	0	10	0.11	
Heartmate II 10 000 rpm	60	0.86	9.6	7	8	0.11	3	53	142	0.1	8	0.09	0.5
	100	1.8	29.4	2.6	5.8	0.08	15	65	149	0.2	8	0.09	
	140	0.37	27.8	0	1.4	0.05	27	77	148	1	8	0.1	
Incor 8000 rpm	60	2.1	28.4	5.4	6.3	0.03	3	48.0	149	0.9	5.5	0.03	0.2
	100	1.09	29.5	3.4	4.5	0.04	15	48.5	148	1.7	5.9	0.03	
	140	1.4	27.9	1.4	2.8	0.05	27	48.5	149	2.3	6.3	0.03	

Aload, afterload; Pload, preload; lolim, low limit; hilim, high limit; rpm, revolutions per minute; sens, sensitivity; P, probability of difference between preload sensitivity and afterload sensitivity. Flows are in L/min, preloads and afterloads are in mm Hg.

"… the characteristic of the HeartMate II can be considered superior to the centrifugal pumps in so far that the zone of maximum preload sensitivity occurs at the low end of the afterload scale (i.e., mean afterload of 50–90 mmHg) mostly inhabited by patients requiring mechanical assistance to the left ventricle."

Salamonsen RF, Mason DG, Ayre PJ. *Artif Organs.* 2011.

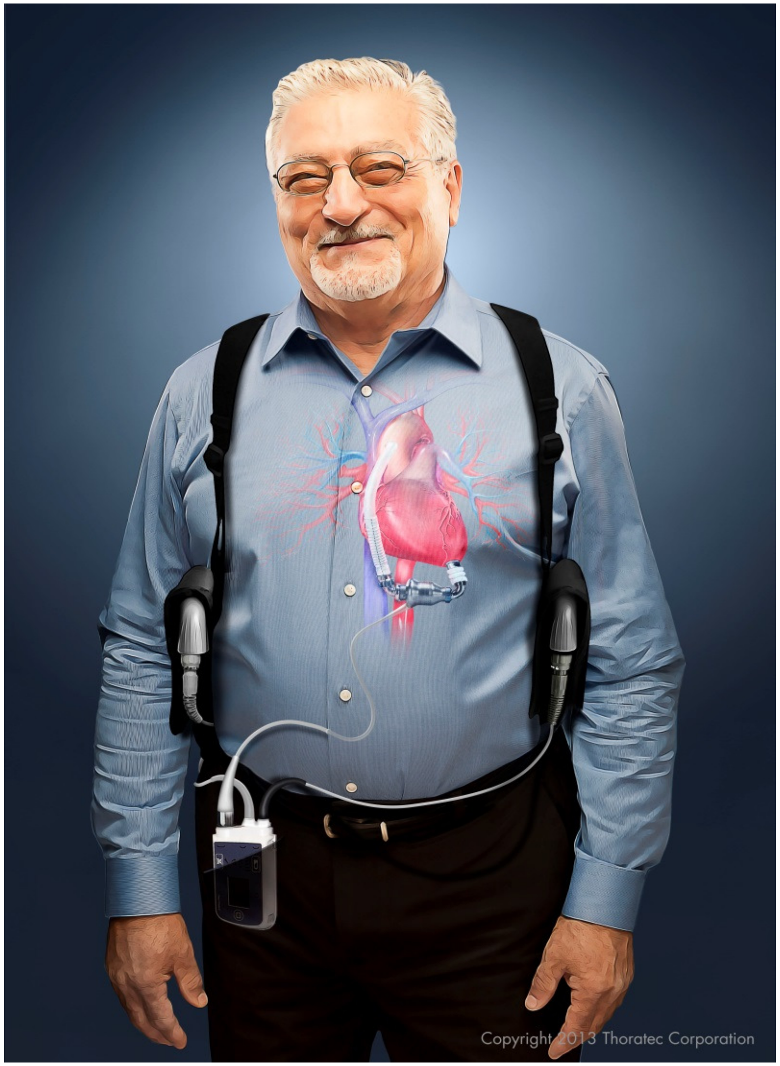
Medical Management vs. LVAD



Rose, EA; et al
NEJM 2001; 345:1435-1443

Goal of LVAD therapy

- Increase CO
- Improve end-organ function
- Improve Quality of Life
- Improve morbidity and mortality



Durable LVAD support

Bridge to transplantation

- Patient is approved or listed for transplant
- NYHA IV
- Failed maximal medical therapy

Destination therapy

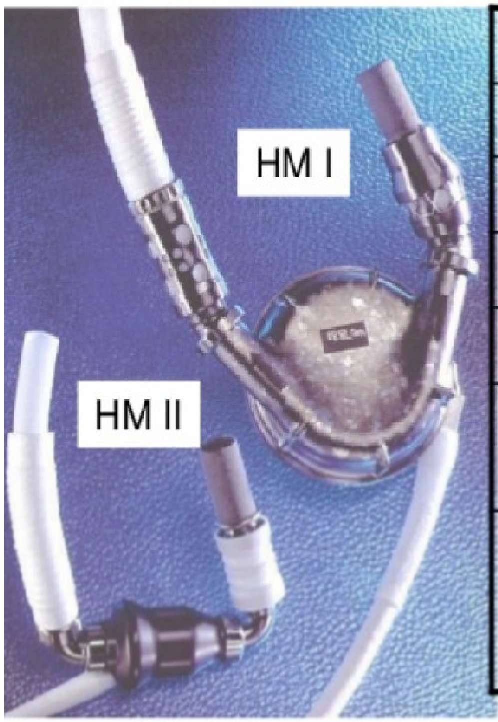
- Not a heart transplant candidate
- NYHA IV
- LVEF < 25%
- Maximal medical therapy
- Inotrope dependent (14 days)
- IABP for 7 days
- Peak Oxygen consumption of < 14 ml/kg/mt

Contraindications

- End-stage lung, liver or renal disease
- Metastatic disease
- Medical non-adherence
- Active drug addiction *
- Active tobacco Use*
- Active infectious disease
- Inability to tolerate systemic anticoagulation
- Moderate to severe RV dysfunction
- Lack of social support

Other Factors

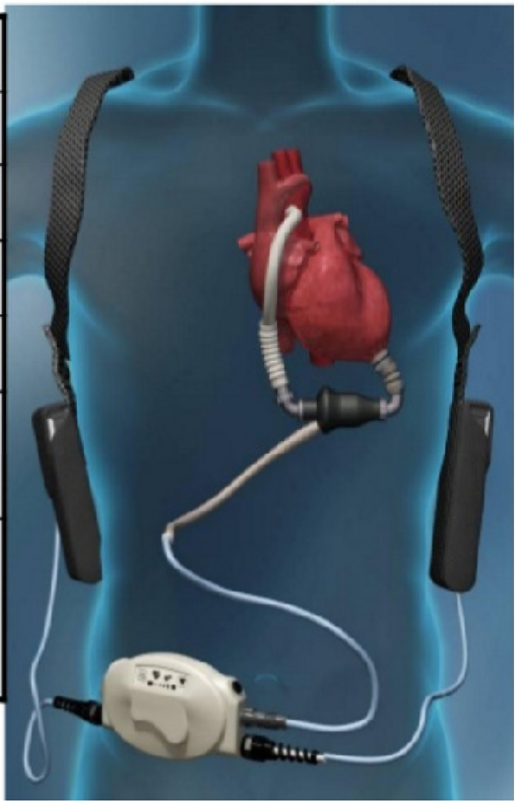
- Support person
- Transportation
- Dressing supplies
- Insurance
- Co morbidities
- NO strict age limit
- Malignancy?
- If there are psychosocial factors that make the patient ineligible for transplant, it is unlikely that the patient will be an LVAD candidate



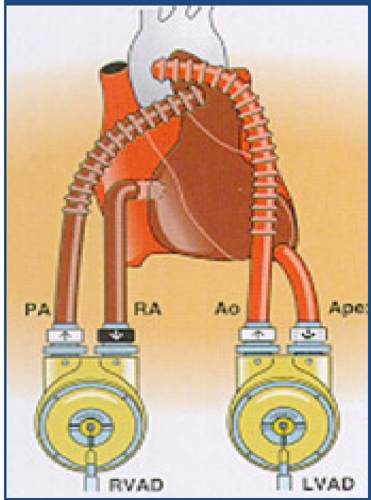
	HM I	HM II
Weight (gm)	1250	280
Volume (ml)	450	63
Noise	Audible	Silent
Moving parts	Many	One
Maximal flow (l/min)*	10	10
Clinical Durability (yr)	1.5	Est. > 5

* at mean pressure=100 mm Hg

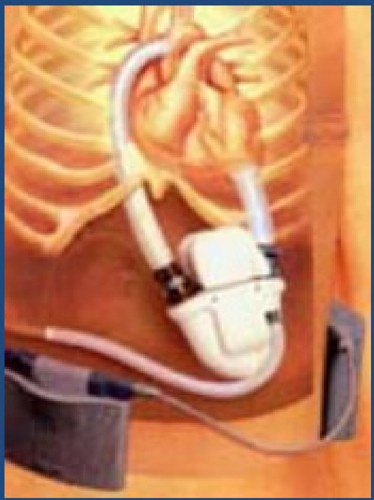
HM II with controller and batteries



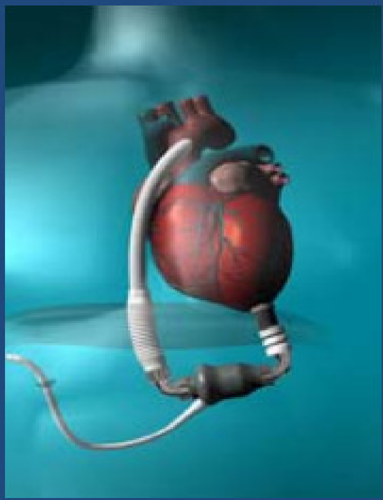
The Evolution of MCS Devices



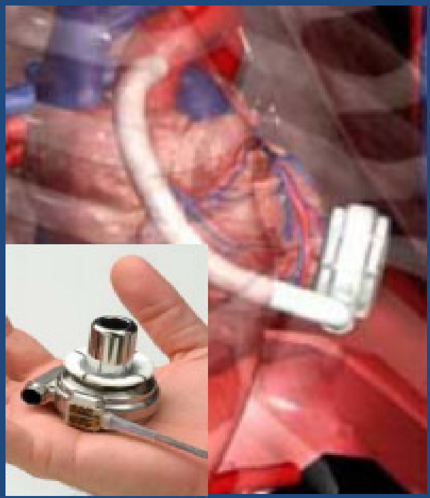
- Paracorporeal
- Pneumatic
- Pulsatile
- Uni- or Biventricular



- Implantable
- Electric
- Pulsatile
- Large
- Multiple moving parts



- Implantable
- Electric
- Continuous flow
- Axial design
- Smaller
- Single moving part



- Implantable
- Electric
- Continuous flow
- Centrifugal design
- Smaller
- Bearingless

- Implantable
- Electric
- Continuous flow
- Axial design
- Smaller
- Partial support

Evolution of implantable mechanical cardiac assist technologies

1st Generation:
Pulsatile, Volume Displacement Devices

HeartMate XVE
Thoratec IVAD
Thoratec pVAD
Novacor

Continuous-flow Rotary Devices

2nd Generation:
Continuous-flow Rotary Devices
- Contact Bearing Design
- Axial Blood Flow Path

HeartMate II
DeBakey
Jarvik Flowmaker

3rd Generation:
Continuous-flow Rotary Devices
- Non-contact Bearing Design

Centrifugal Blood Flow Path

- Magnetic Levitation
- External Motor Drive System

DuraHeart*

- Magnetic Levitation
- Bearingless Motor Drive System

Levacor
HeartMate III
HVAD (HeartWare)*

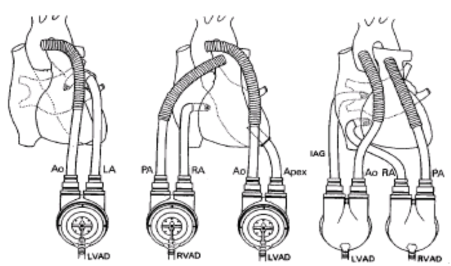
- Hydrodynamic Levitation
- Bearingless Motor Drive System

VentrAssist

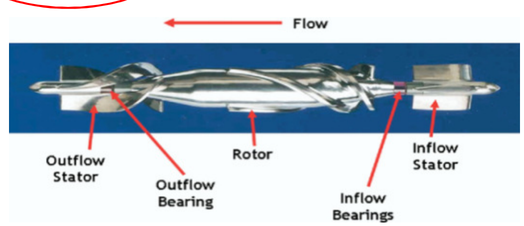
Axial Blood Flow Path
- Magnetic Levitation
- Direct-drive Motor System

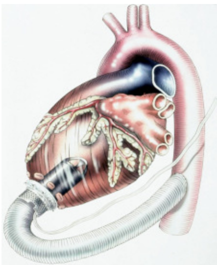
Incor

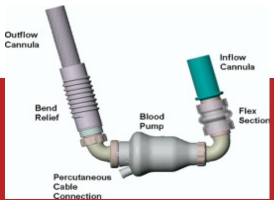
I



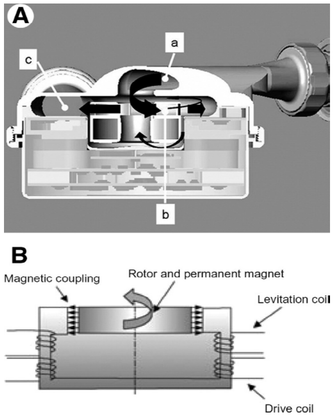
II





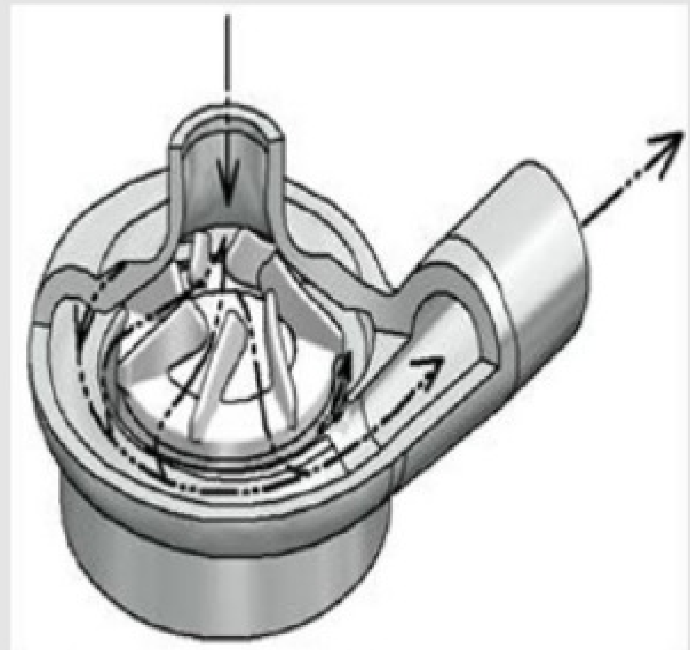


III

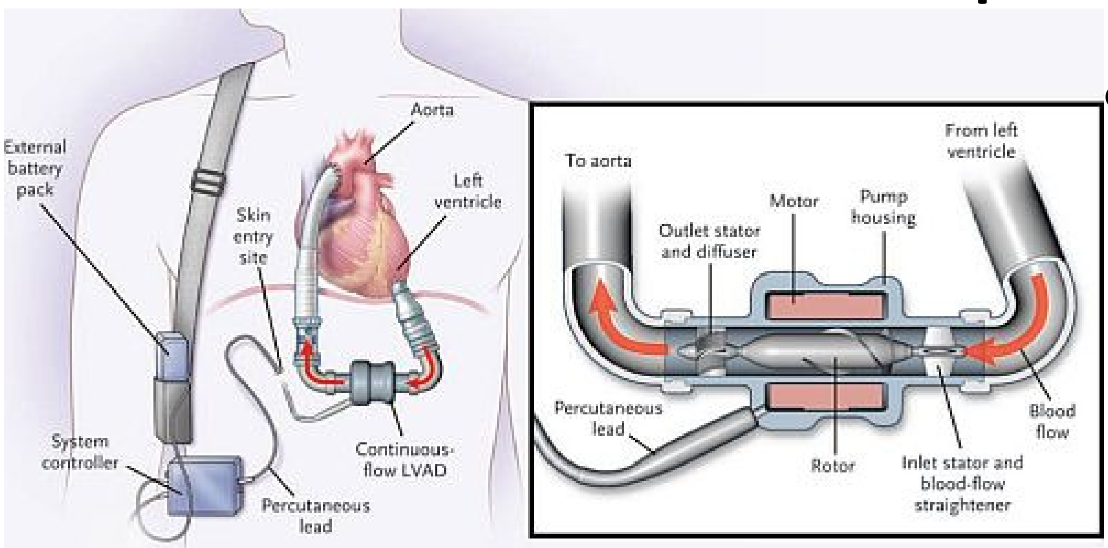


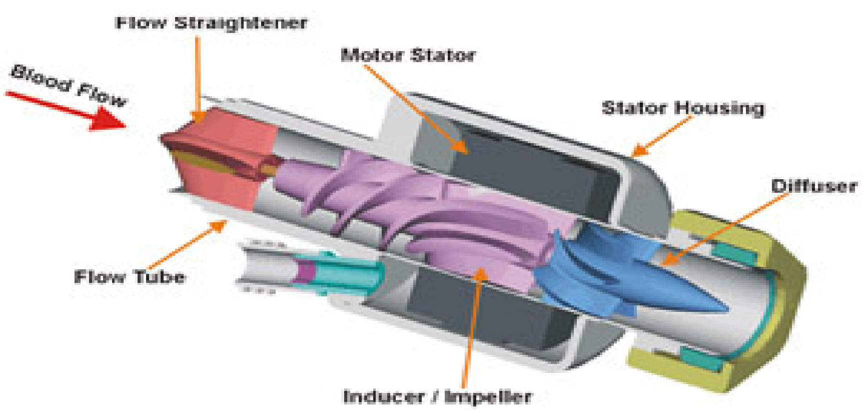
Axial Vs Centrifugal

Comparison of Axial and Centrifugal Rotary Pump Response to Physiologic Conditions

Conditions	Axial pump	Centrifugal pump
		
	Propeller in a pipe	Bladed disk spinning in a cavity

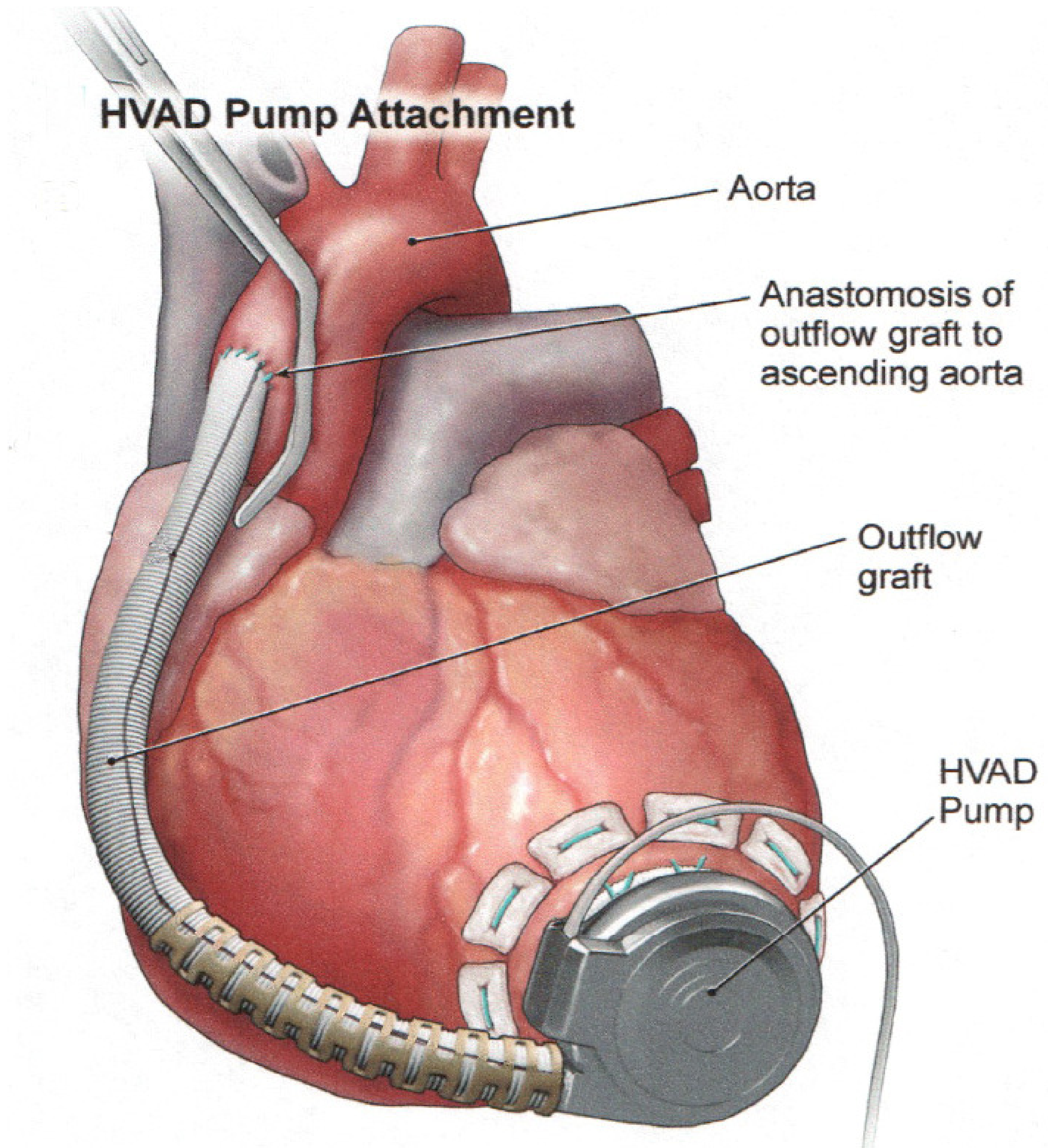
The HeartMate II pump (Thoratec)

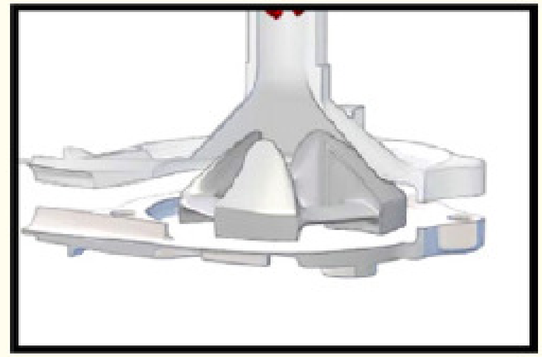




- The only continuous – flow pump currently approved as *bridge to transplantation* ***AND*** *as destination therapy*
- Stroke volume =63ml
- Pump speed = 8000 - 12000 RPM
- Estimated Flow = 10L/min

HeartWare (HVAD)

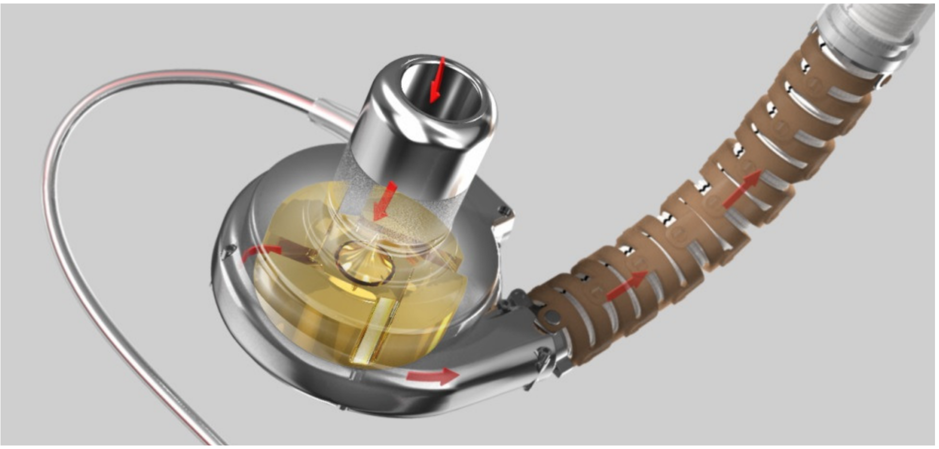


Surgical LVAD Types	Pump Design	Device Illustration
Third-generation LVADs VentrAssist LVAS† HeartWare LVAD† DuraHeart LVAS† Levacor VAD†	Continuous flow (Centrifugal flow pump)	

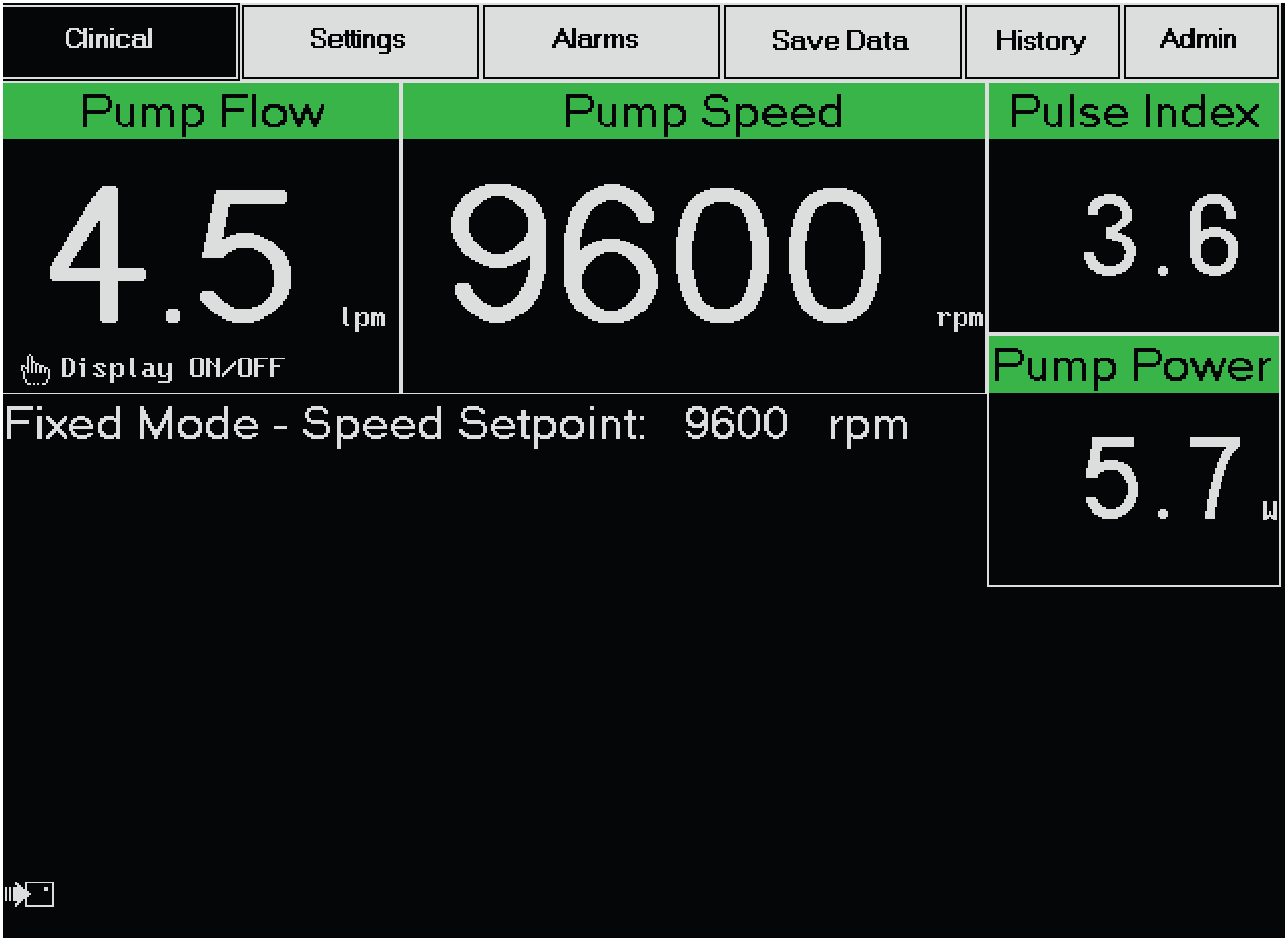
In the centrifugal pumps, the rotors are shaped to accelerate the blood circumferentially and thereby cause it to move toward the outer rim of the pump

HVAD (Heart Ware) Pump Suspension: Magnetic and Hydrodynamic

- Wide-blade impeller is magnetically (levitated) and hydro-dynamically suspended
- Speed range: 1800-4000 RPM



VAD Parameters



Continuous Flow LVADs

- Typically pulseless
- Preload dependent
- Afterload Sensitive
- Anticoagulation required
- Patients can still have heart failure
- Chest compressions are to be administered by LVAD team or under their directions

LVAD parameters

- Flow:
  - Measured in liters per minute
  - Correlates with pump speed (↑speed=↑flow, ↓speed=↓flow)
  - Dependent on Preload and Afterload
- Speed:
  - How fast the impeller of the internal pump spins
  - Measured in revolutions per minute (rpm)
  - Can be manipulated

LVAD parameters

- Power:
  - The amount of power the VAD consumes to continually run at a set speed
  - Sudden or gradual sustained increases in the power can indicate thrombus inside the VAD

Pulsatility Index (PI)

A measure of the pressure differential inside the pump during native cardiac cycle (systole and diastole). PI is the magnitude of this flow pulse

- The pulsatility index (PI) will normally <u>decrease</u> as pump speed is increased
- PI changes with conditions that affect stroke volume
  - physiologic demand
  - volume status
  - Right ventricle function
  - Native heart contractility

Symptoms & Signs

- Decompensation
  - JVP, Lower extremity edema
  - SOB
- Arrhythmia
  - Palpitations, ICD shocks, fatigue and weakness
- Volume status
  - Volume depleted or overloaded
- Infection
  - Fevers, chills, discharge at driveline site
- Bleeding
  - Epistaxis, melena, hematochezia, hematemesis

Symptoms & Signs

- Hemolysis
  - Dark urine, flank pain, fatigue and weakness
- Stroke
  - Hemorrhagic or ischemic
  - Dizziness, visual symptoms
  - Focal weakness
- VAD and vital sign log
- Daily weights
- Any trauma

Trouble-shooting power abnormalities for HEARTMATE II

- Pump speed (rpm) will remain constant unless there is a suction event:

- ↓ Flow with ↓ PI and constant pump speed
  - inflow obstruction
  - outflow obstruction
  - RV failure
  - dysrhythmia
  - hypertension

Trouble-shooting power abnormalities for HEARTMATE II

- Pump speed (rpm) will remain constant unless there is a suction event:

- ↓ Flow with N or ↑ PI
  - suckdown

- ↑ Power with ↓ PI (+/-)
  - pump thrombosis

Trouble-shooting power abnormalities for HEARTMATE II

- ↑ Flow with ↑ PI
  - normal physiological response to increased demand
  - myocardial recovery
  - fluid retention

Low Pump Output (not speed or rate related)

Evaluate:
CVP, PAP, PAOP, MAP and Echo

CVP	↓	↑	↑	↑	↑
PAP	↓	↓	↑ or No Change	↑	↑
PAOP	↓	↓	↓	↑	↑
MAP	↓	↓	↓	↓	↓
Echo	Under filled	Signs of RV Compression	RA/RV Dilated	LA/LV Dilated AV opening Inflow Malposition	LA/LV Dilated AV opening
Diagnosis	Hypovolemia or Obstruction	Tamponade	Right Heart Failure	Inflow Obstruction (rare)	Outflow Obstruction (very rare)

Treatment Recommendations

Hypovolemia or Obstruction:
Hgb <10: Transfuse PRBC (leukopoor)
Hgb >10: infuse colloid (eg 5% albumin)
Evaluate and Treat Continued Bleeding

Tamponade:
Emergency Situation Surgical Intervention Required
*
Decreased flow unresponsive to fluid challenge is tamponade until proven otherwise*

Right Heart Failure:
Treatment Goals:
Cb2.2 CVP 4-14

↑PVR &↑ MAP:
nitroprusside *or* Nitric Oxide or *then* Milrinone, *or* Dobutamine, or epoprostenol, *then* Implant temp RVAD
↑PVR &↓MAP:
Add Milrinone or Dobutamine, then Nitric Oxide or nitroglycerin, *then* Implant temporary RVAD

Inflow / Outflow Obstruction:
Surgical Intervention Required
(if clinically significant drop in pump flow)

LVADs are Prone to

- Mechanical failure
- Pump thrombosis

Complications

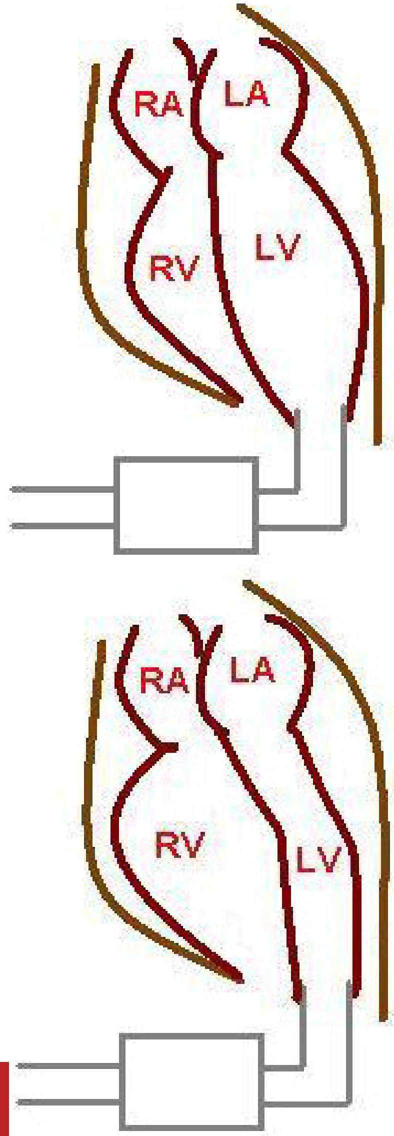
- Infection (Driveline Exit site infection)
- Hemolysis
- Pump thrombosis
- GI bleeding (acquired arteriovenous malformations)
- Right heart failure
- Stroke
- Aortic Insufficiency
- Device failure or malfunction

Right Ventricular Failure

- 10 to 20% of patients after LVAD
  - Significantly increased mortality and morbidity
  - Higher rates of hemorrhage
  - Higher rates of renal failure
- Pre-operative RV dysfunction and tricuspid regurgitation
- Need for inotropes > 14 days
- Need for RVAD

Suck down and RV Failure

- Left ventricular collapse or "suckdown" → right-heart failure
- When LV is sucked dry, the septum gets displaced
- With septal dysfunction, the RV dilates and may go into failure



Speed Optimization

Optimum Speed Setting

- Normal cardiac index
- Normal LV size
- No septal shift
- Intermittent aortic valve opening

LVAD Flow

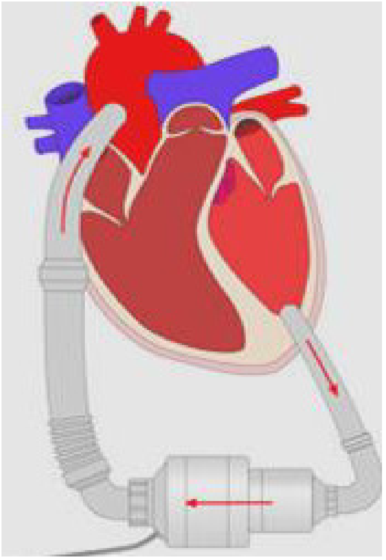
Flow in Series

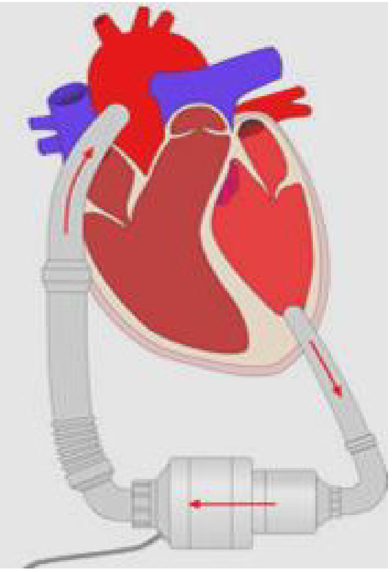
(AoV Closed)

LV → LVAD → Aorta (systemic circulation)

LV → LVAD → Aorta (systemic circulation)

LV → Ao Valve → Aorta (systemic circulation)

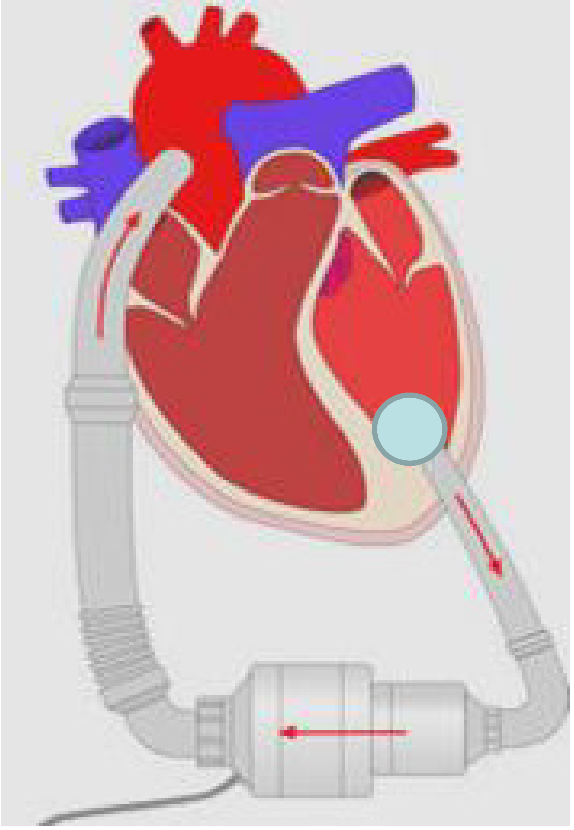




Clinical Significance of LVAD-related AI

Recirculation with AI

LV → LVAD → Aorta (systemic circulation) → LV →
Regurgitant Flow > Systemic Flow



Therapy of LVAD – related AI

- Surgical intervention
- Park- stich closure of the AoV
- Bioprosthetic Ao V
- Controversial data about which is better
- Latest: Bio > to closure → the stich has less survival benefit

Bleeding/Hemorrhage

- Post-operative
  - 20 to 40% undergo reoperation
  - Hypoperfusion and MODY
  - Massive transfusion can lead to RV failure and respiratory failure
- Chronic therapy
  - Mucosal bleeding
    - GI bleeding
    - Epistaxis

Risk factors for bleeding

- Need for anticoagulation
- Continuous flow (lack of pulse)
- Prolonged cardiopulmonary bypass
- Extensive surgical dissection
- Hepatic dysfunction

Gastrointestinal Bleed (GI bleed)

- LVAD related → Ao valve closed (mimics the AS)
- Anticoagulation related → pre LVAD GI pathology → bleeding due to supra-therapeutic INR
- The management of anti-coagulation in these patients must balance the concern for continued or recurrent bleeding with the risk of pump thrombosis or thromboembolic stroke

Diagnosis and therapy of GI bleed

- U EGD/ L EGD/ Small bowel capsule endoscopy/ Enteroscopy
- Endoscopic and interventional techniques: cauterization/ injection/ clipping of a visible vessel/ mesenteric angiography with coil embolization
- Adjunct medical therapy (? Not really proven):

octeotride/ primarin/ danazole

- OHT

Post-Op Heparin May Not Be Required

Slaughter, et al. conducted a retrospective study to evaluate the effects of heparin use on thromboembolic and bleeding complications after implantation of the HeartMate II

- The results indicate that patients who do not receive early post-operative anticoagulation therapy with IV heparin as a transition to warfarin and aspirin are at decreased risk of bleeding events
- These patients do not appear to be at any early elevated risk of thrombotic events
- Eliminating the routine use of post-operative heparin in patients with low risk of thrombosis appears to be appropriate for most cases

ELSEVIER

The Journal of Heart and Lung Transplantation

http://www.jhltonline.org

Post-operative heparin may not be required for transitioning patients with a HeartMate II left ventricular assist system to long-term warfarin therapy

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KEYWORDS:
HeartMate II;
LVAD;
heparin;
anticoagulation management;
thrombosis

BACKGROUND: Anti-coagulation with heparin is often used after left ventricular assist device implantation as a transition to long-term warfarin therapy. We retrospectively evaluated the effects of heparin use on thromboembolic and bleeding complications after implantation of the HeartMate II left ventricular assist device (LVAD).

METHODS: LVAD patients ($n = 418$) implanted as a bridge to transplant were divided into three groups: Group A patients (therapeutic, $n = 118$) received heparin and had a partial thromboplastin time (PTT) of >50 seconds on two or more occasions; Group B patients (sub-therapeutic, $n = 178$) had at least one PTT value in the range of 40 to 55 seconds; and Group C patients (no heparin, $n = 122$) had no PTT values >40 seconds. All patients were transitioned to warfarin and aspirin therapy. The following adverse events were evaluated: ischemic stroke; hemorrhagic stroke; pump thrombosis; bleeding requiring surgery; and bleeding requiring ≥2 units of packed red blood cells in 24 hours.

RESULTS: There was no difference in the percentages of patients with ischemic (5%, 4%, 3%) or hemorrhagic (3%, 3%, 5%) strokes or pump thrombosis (3%, 2%, 2%) after post-operative day (POD) 3 among Groups A, B and C, respectively. From PODs 3 to 30, the percentage of patients requiring transfusion for bleeding was significantly lower for Group C (18%) than for Groups A (32%) and B (26%) ($p = 0.04$); differences after 30 days were not significant. Multivariate analysis revealed that post-operative heparin use, low post-operative platelet count and low baseline hematocrit value were independent risk factors for bleeding events between PODs 3 and 30.

CONCLUSIONS: In patients receiving the HeartMate II LVAD who were directly transitioned to warfarin and aspirin therapy without intravenous heparin there was no short-term increase in risk of thrombotic or thromboembolic events, and bleeding requiring transfusion was significantly reduced. Additional long-term follow-up is needed to evaluate possible late effects.

J Heart Lung Transplant 2010;29:616–24

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1053-2498/$ -see front matter © 2010 International Society for Heart and Lung Transplantation. All rights reserved.
doi:10.1016/j.healun.2010.02.003

Slaughter MS, Yoshifumi N, John R, et al. Post-operative heparin may not be required for transitioning patients with a HeartMate II left ventricular assist system to long-term warfarin therapy. *J Heart Lung Transplant*. 2010;29:616-24.

What happened?

The NEW ENGLAND JOURNAL *of* MEDICINE

ORIGINAL ARTICLE

Unexpected Abrupt Increase in Left Ventricular Assist Device Thrombosis

Randall C. Starling, M.D., M.P.H., Nader Moazami, M.D., Scott C. Silvestry, M.D., Gregory Ewald, M.D., Joseph G. Rogers, M.D., Carmelo A. Milano, M.D., J. Eduardo Rame, M.D., Michael A. Acker, M.D., Eugene H. Blackstone, M.D., John Ehrlinger, Ph.D., Lucy Thuita, M.S., Maria M. Mountis, D.O., Edward G. Soltesz, M.D., M.P.H., Bruce W. Lytle, M.D., and Nicholas G. Smedira, M.D.

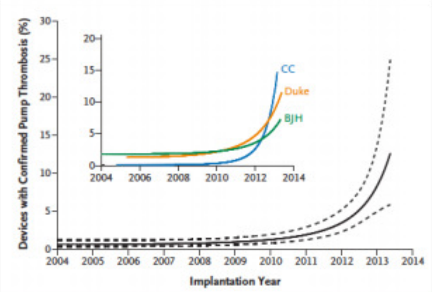
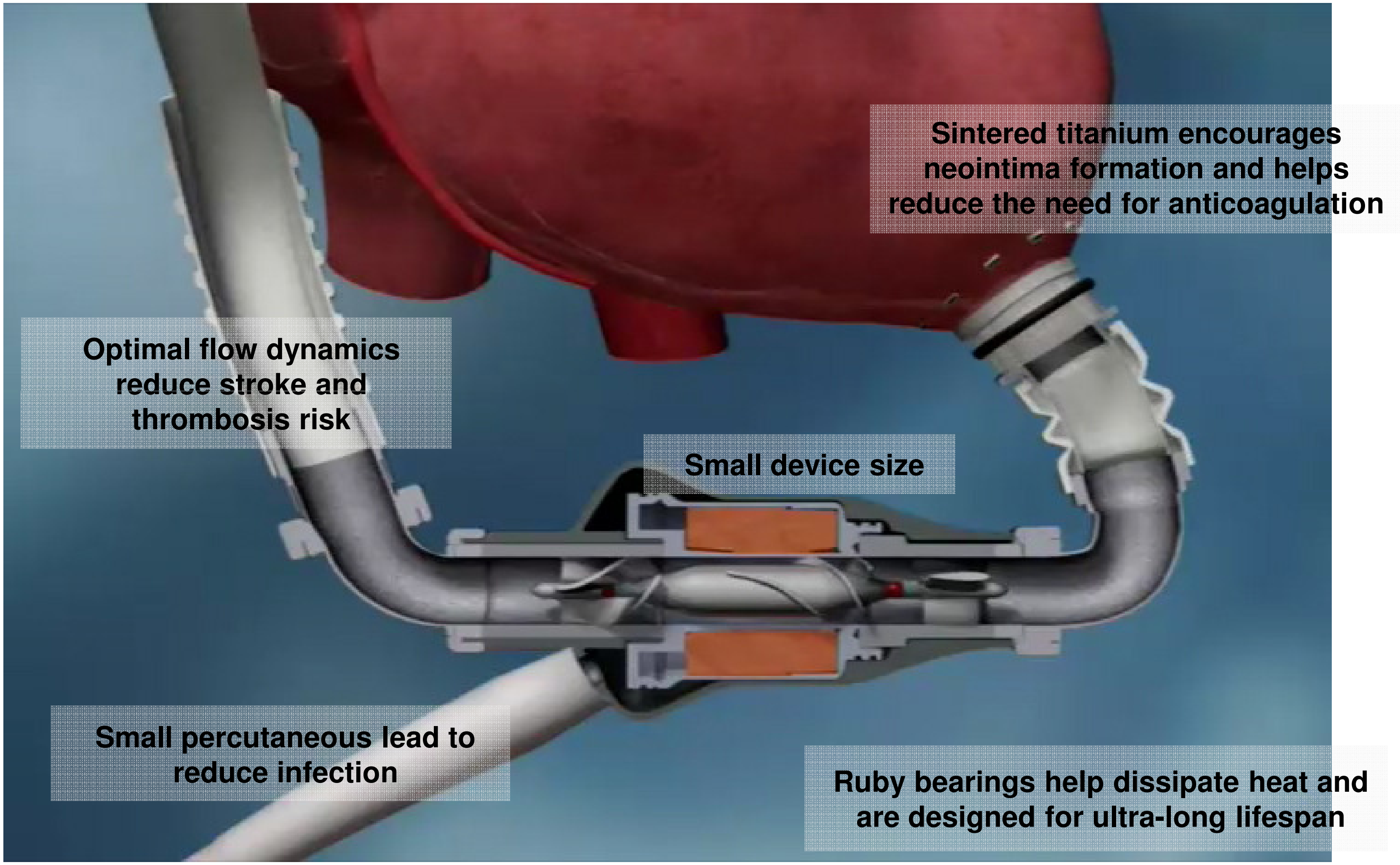


Figure 1. Overall Occurrence of Confirmed Pump Thrombosis at 3 Months after HeartMate II Implantation.

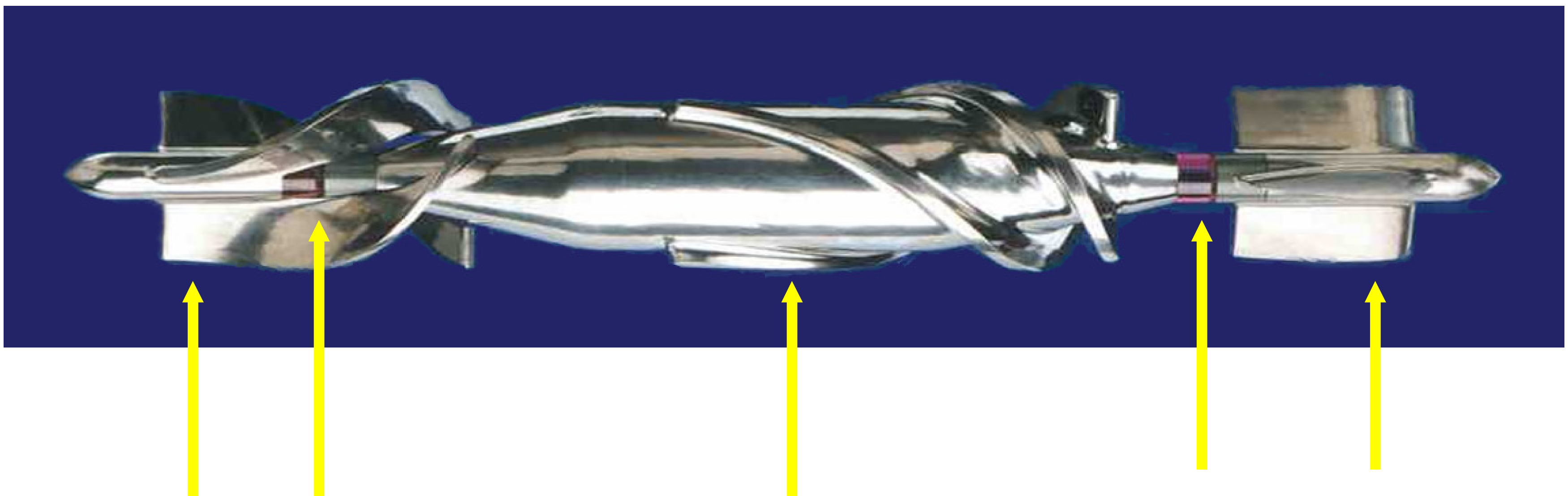
Dashed lines represent the 95% confidence interval. There was a steep increase in the occurrence of thrombosis starting in early 2011. The inset shows the changing occurrence of confirmed pump thrombosis according to study site (Cleveland Clinic [CC], Barnes–Jewish Hospital [BJH], and Duke University Medical Center [Duke]).

HeartMate II® — Designed To Minimize Adverse Events

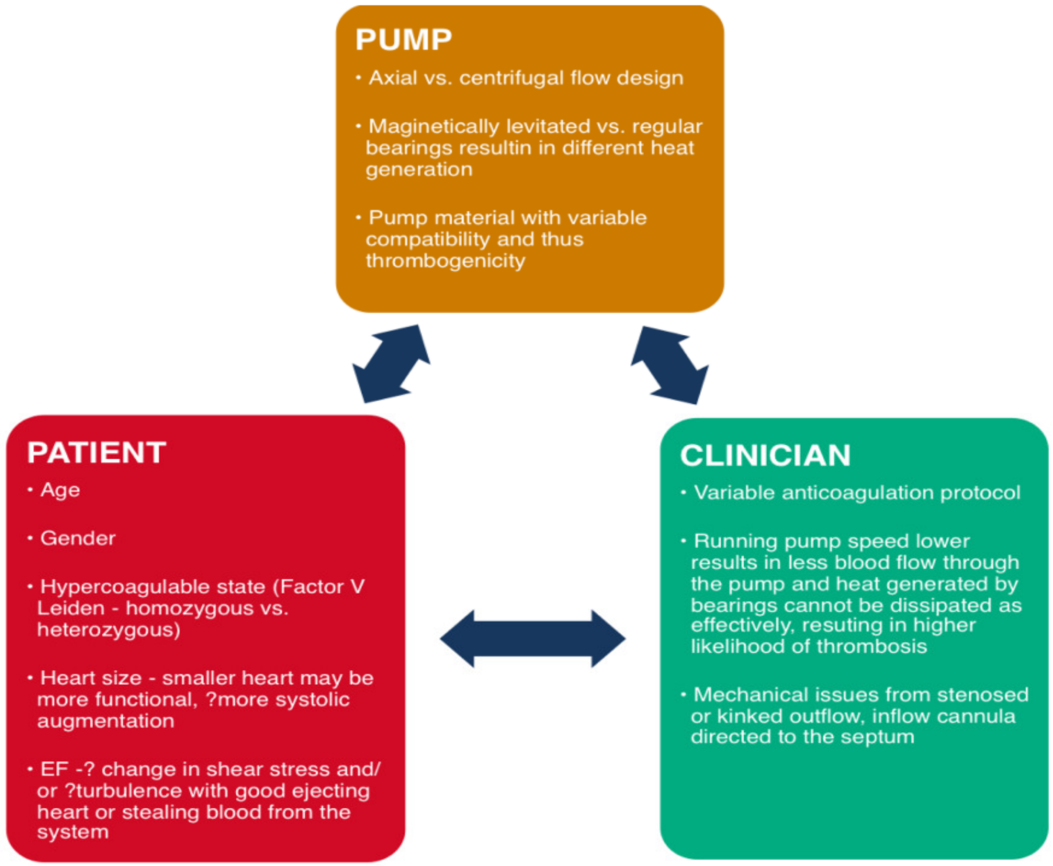


PUMP ROTOR and STATORS

BLOOD FLOW

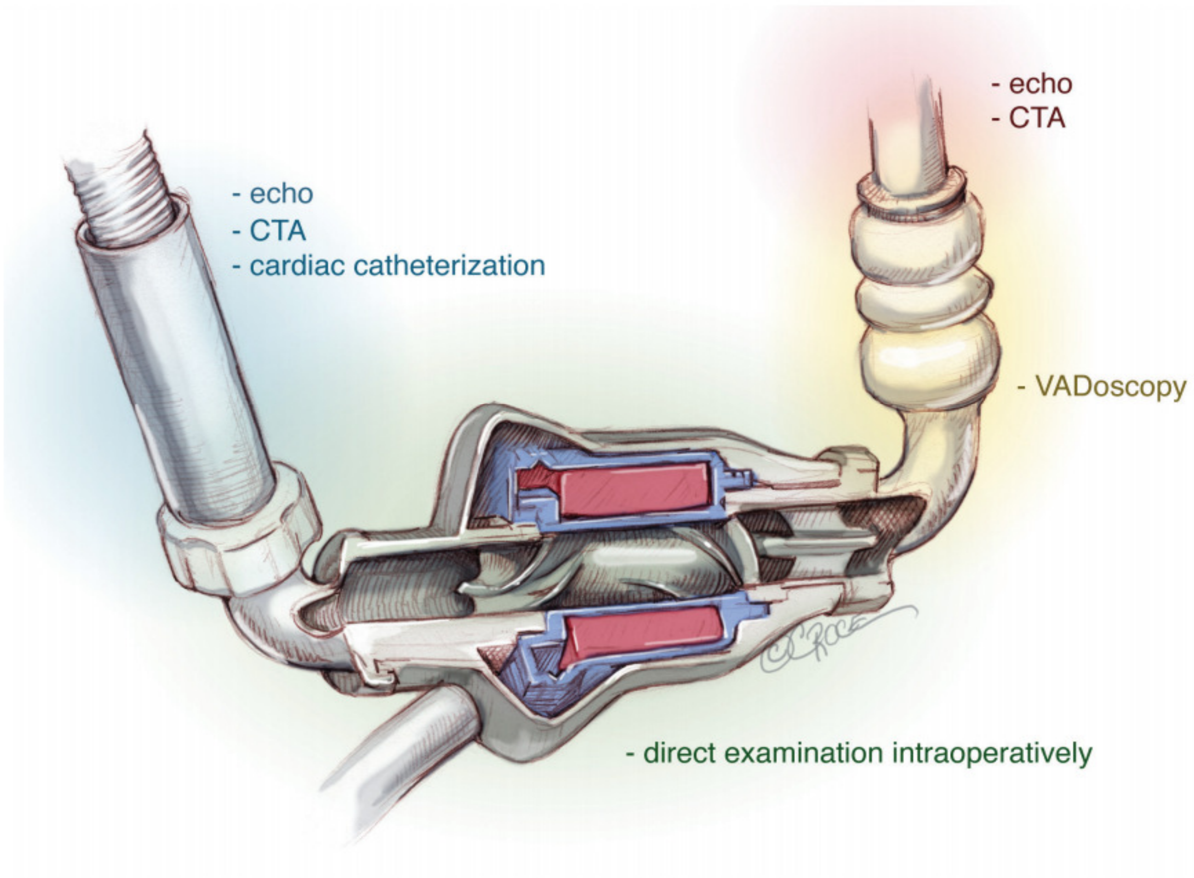


PUMP THROMBOSIS



Factors causing thrombosis of continuous flow left ventricular assist devices (CF LVADs).

Where is the thrombus



Diagnostic studies for localizing the affected area of the pump.

Pump Thrombosis: Predisposing Factors

- Patient
  - Conditions that render patient to have thrombotic complications
    - CHF is a prothrombotic state
    - Atrial fibrillation
    - Pre-existent LV thrombus/trabeculation
    - Mechanical prosthesis
    - Infection
    - Malignancy

Predisposing Factors: VAD related

- Device
  - Inherent to the technology
    - Heat generated by pump rotors
    - Outflow graft kink or compression
      - Disconnected graft protector with impingement (HM II)
      - Positional

Predisposing Factors: Management

- Management (Medical & Surgical)
  - Implantation technique
    - Malposition of inflow cannula
  - Anticoagulation
  - Pump speed

Management of pump thrombosis

Pump Exchange

Avoids resternotomy morbidity
Direct access to pump
Groin cannulation or off pump
Reserved for pump thrombus limited to pump housing.
Shorter CPB, less bleeding
Shorter LOS

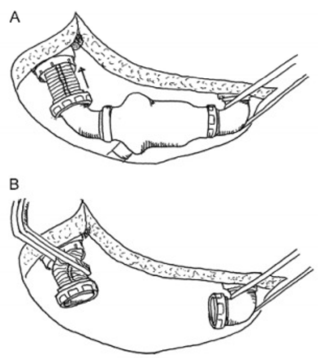


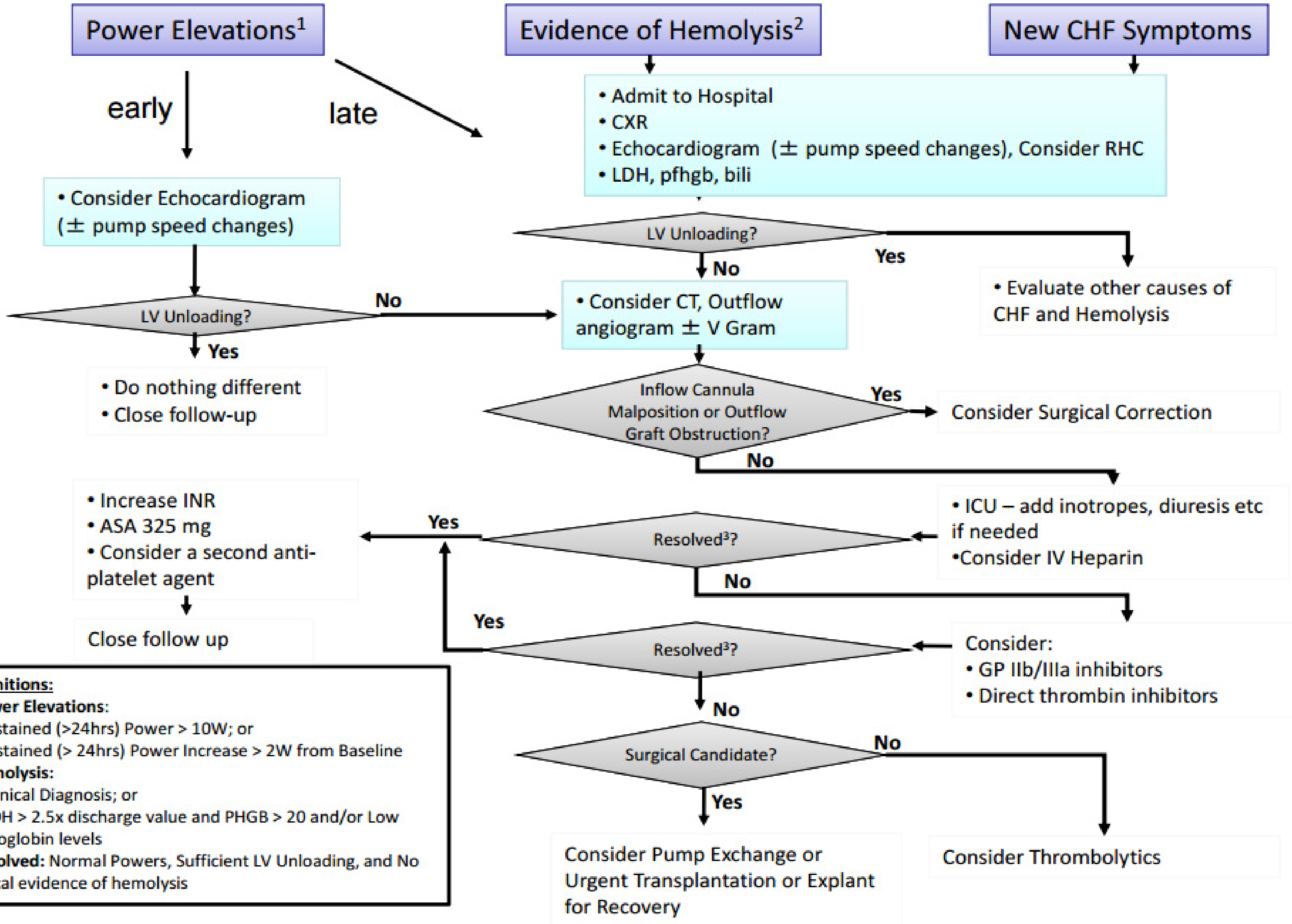
Figure from Ota et al JHLT 2014

Table 3 Operative approaches for VAD thrombosis

Operative approach	Procedures that can be performed
Subxiphoid	Pump exchange Vadoscopy Removal of thrombus from distal inflow and proximal outflow grafts
Subxiphoid with right anterior thoracotomy	Pump exchange Outflow graft repair/replacement
Subxiphoid with small left anterior thoracotomy	Pump exchange Inflow graft repair/replacement
Redo sternotomy	Pump exchange Re-coring cardiac apex and total VAD exchange

VAD, Ventricular assist device.

Workgroup Proposed Management of Suspected Pump Thrombosis



Definitions:

[1]**Power Elevations**:
a)Sustained (>24hrs) Power > 10W; or
b)Sustained (> 24hrs) Power Increase > 2W from Baseline

[2]**Hemolysis:**
a)Clinical Diagnosis; or
b)LDH > 2.5x discharge value and PHGB > 20 and/or Low haptoglobin levels

[3]**Resolved:** Normal Powers, Sufficient LV Unloading, and No clinical evidence of hemolysis

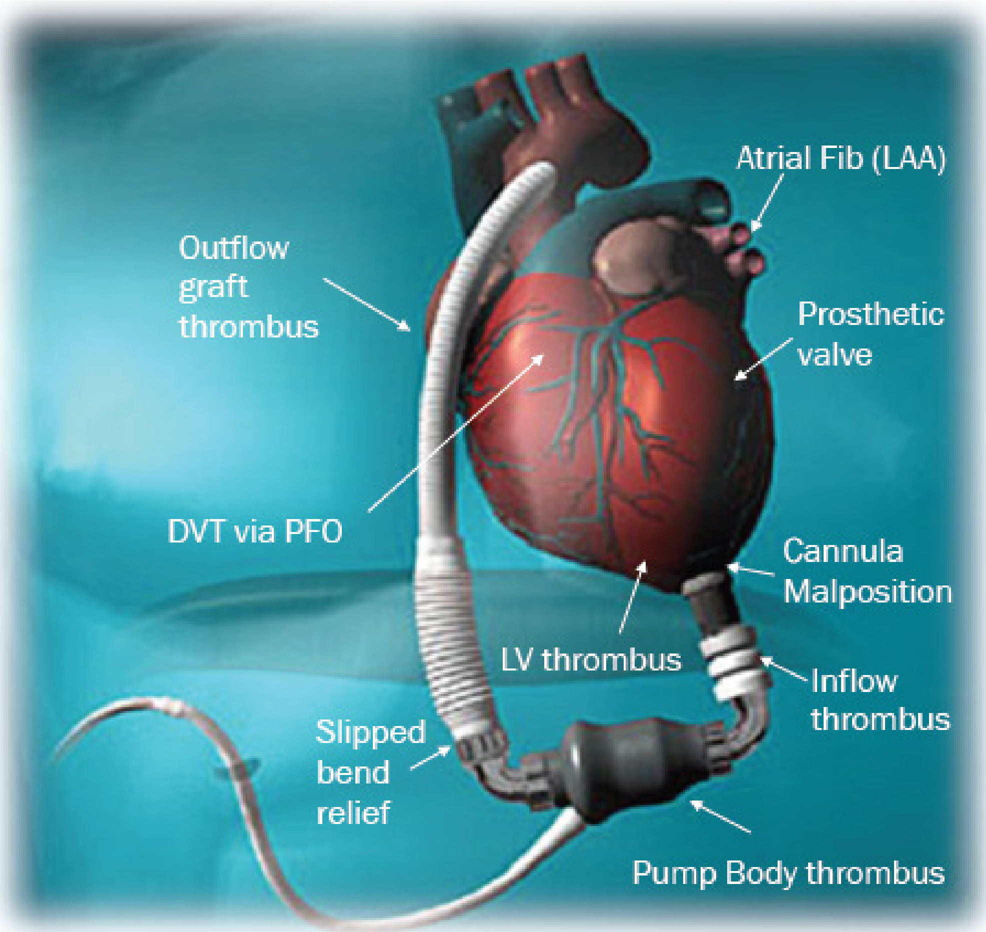


Figure 6 Sites of formation of pump thrombosis (PT). The thrombus may originate proximal to the inflow cannula and embolize to the pump, it can originate *de novo* on the pump itself, or it can originate in the outflow portion of the pump and extend proximally. The figure depicts the potential origins of PT.

Thromboembolism

- Sub-optimal anticoagulation
- Presence of infection
- Pump design
- Revascularization of carotid and peripheral arterial disease
- Cerebrovascular is more common

VT or VF

- STABLE
  - Patient may “feel funny” “light headed” or “different”
  - Pump speeds and flows are normal, low normal, or very low
  - Consider cardioversion after consultation with Mechanical Assist Device Coordinator

- UNSTABLE
  - Patient unresponsive
  - Treat as unstable VT/VF

LVAD PATIENT TRANSPORT

- Transport to LVAD center
- Spare batteries, PBU and the display module should be brought to the hospital with the patient
- All modes of emergency transportation are acceptable
- Aviation electronics will NOT interfere with LVAD and visa versa

Echo evaluation

- Pericardial effusion +/- Tamponade
- Left ventricular failure secondary to incomplete emptying (? Non obstructive thrombus Vs Aortic insufficiency)
  - Increased mitral inflow peak E wave diastolic velocity
  - Increased E/A and E/e' ratio
  - Decreased deceleration time of mitral E velocity
  - Increased LA volume
  - Worsening MR
  - Elevated PA pressure

Echo evaluation

- Right Ventricular Failure
  - Increased RA size or pressure
  - Decreased RV systolic function
  - Increased tricuspid regurgitation
  - Inter-atrial septum deviated to left atrium
  - Reduced RVOT VTI
  - Reduced spectral Doppler of LVAD inflow and outflow velocities
- Excessive LV unloading or inadequate LV filling
  - Decreased LV dimensions
  - Septal deviation to left ventricle

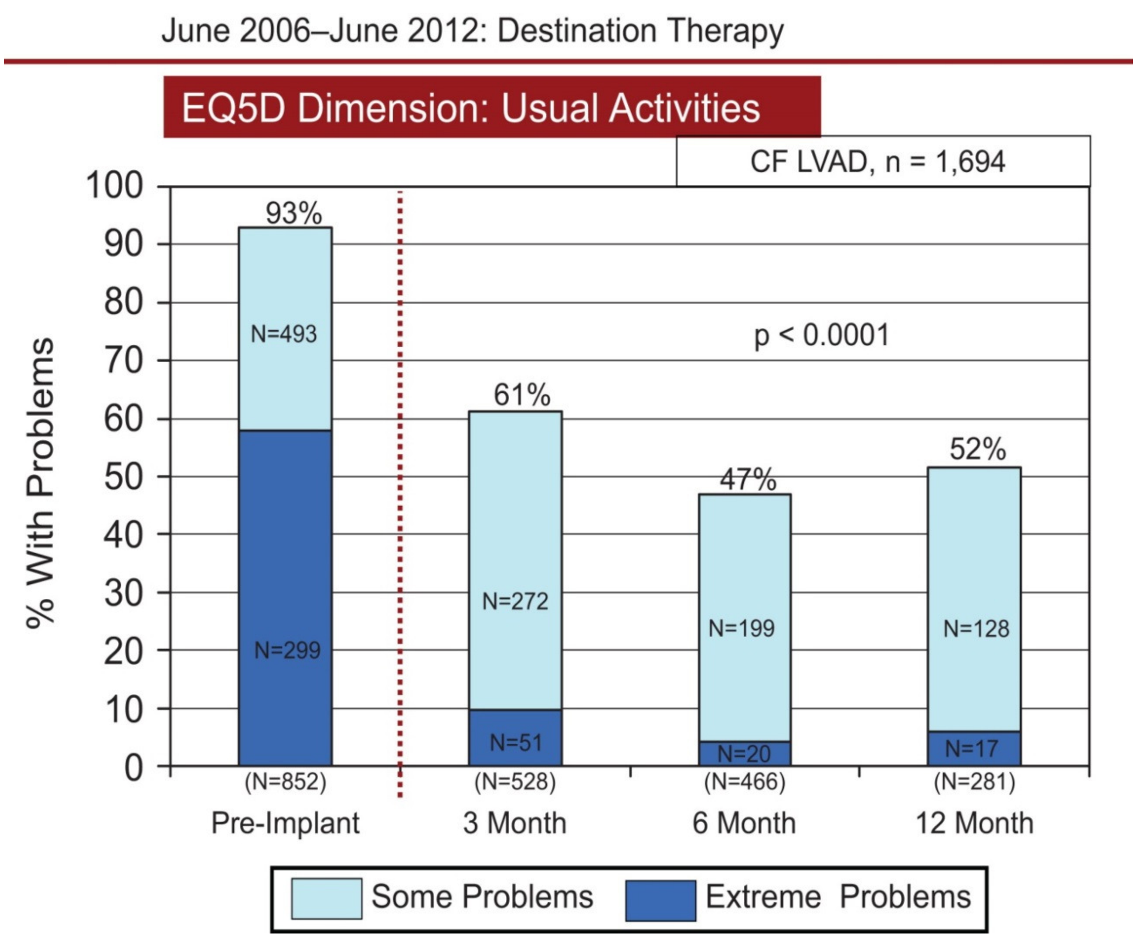
Echo evaluation

- LVAD suction or induced ventricular ectopy
  - Under filled LV
  - Mechanical impact with endocardium
- Aortic insufficiency
  - Systolic, diastolic or continuous
  - Regurgitant jet to LVOT outflow tract height ratio > 47%
  - Relative decreased RVOT Stroke volume
  - Increased LVEDD
- Intra-cardiac thrombus
  - RA or LA thrombus
  - LV apical or aortic root thrombus

Echo evaluation

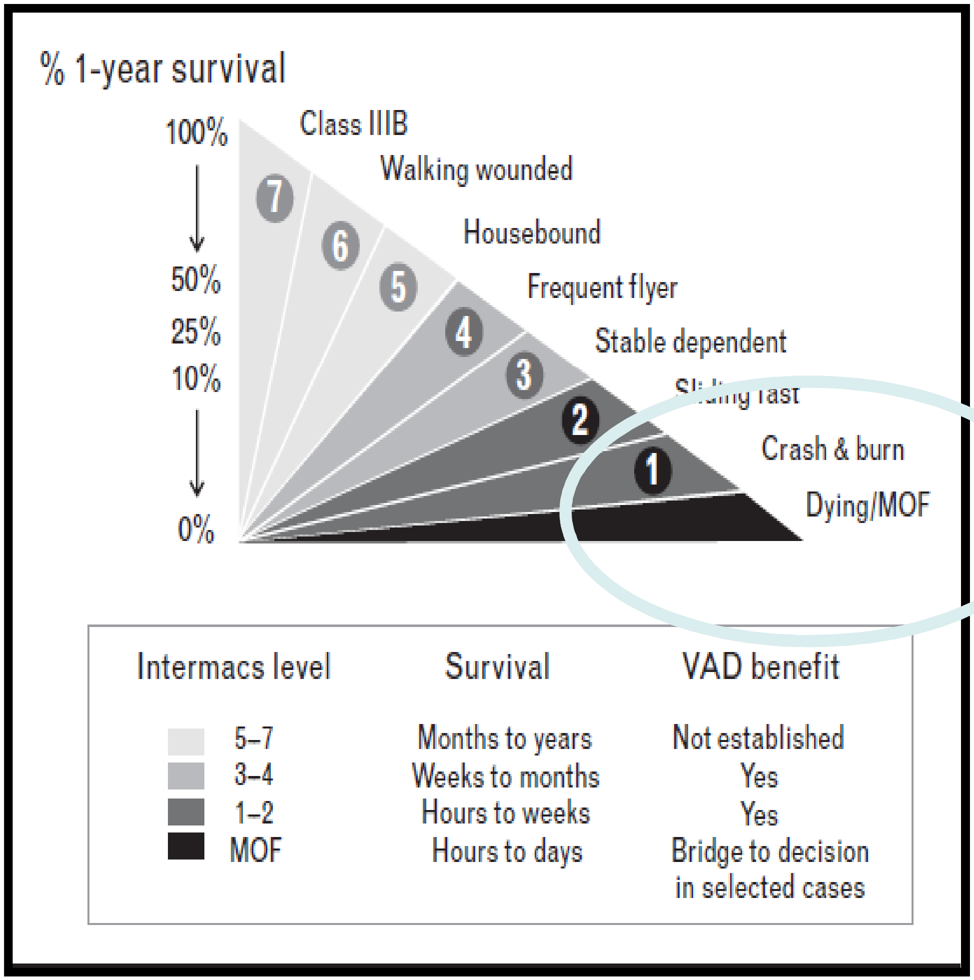
- Inflow Cannula obstruction, malposition
- Outflow Cannula Kinking or thrombosis

ADLs of DT Patients



Kirkland, JK, et. al
JHLT 2013; 32:141-156

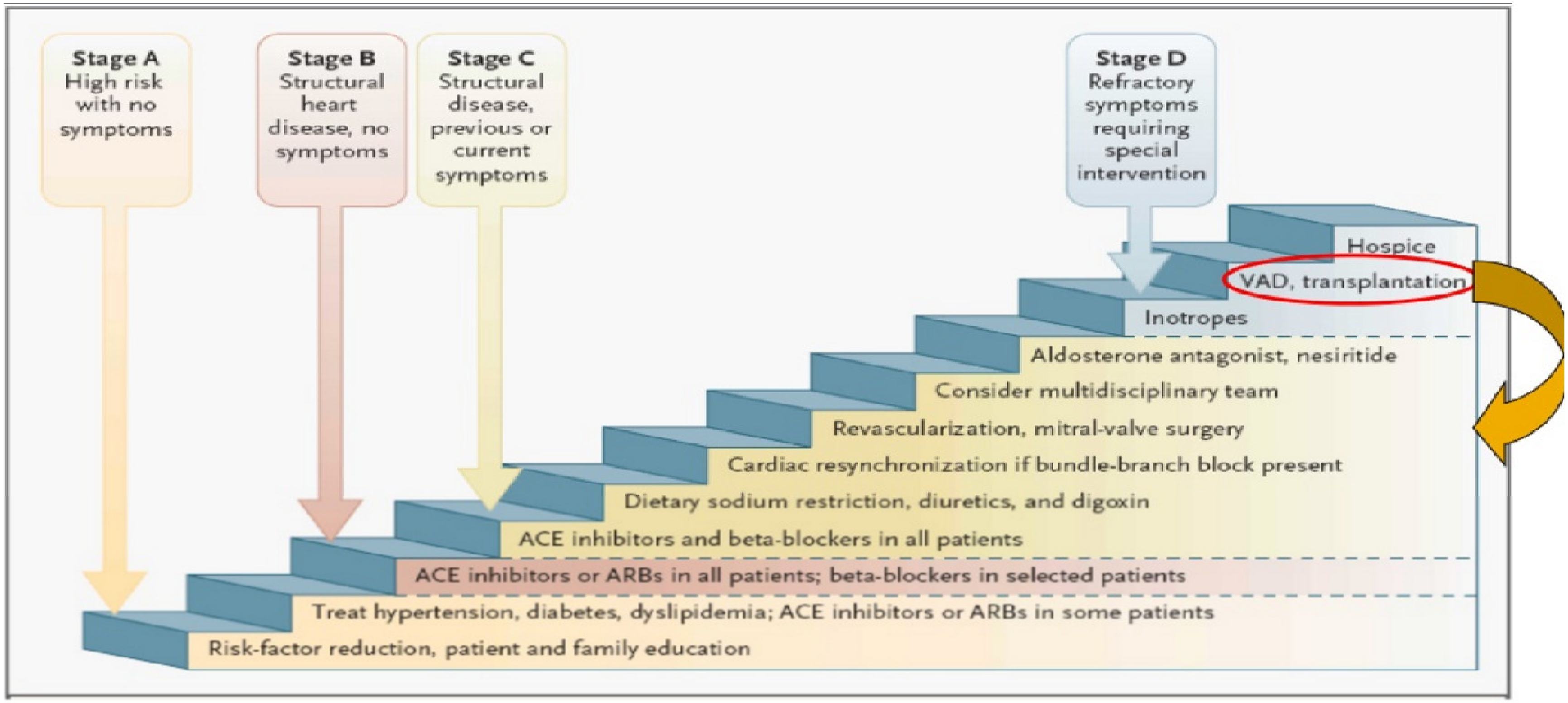
Who does worse



- Shock Team Evaluation for mechanical circulatory support (MCS)
- Try to avoid the bridge to decision or the bridge to nowhere

Critical Factors for Success

- Timing of referral
- Patient selection
- Implantation techniques
- Post-op management
- Experienced patient care teams
- Knowledge of continuous flow physiology
- Outpatient management



Jessup M, Brozena S. *N Engl J Med* 2003;348:2007-18.

Emergencies

- LVAD patients are EXTREMELY stable
- Until
  - Device Failure
    - Not common, but can be catastrophic.
  - Disruption of Inflow or Outflow graft
    - Patient fall
    - Chest compressions

Warnings & Restrictions

- No excessive jumping or contact sports
- No exposure to MRI
- Avoid static discharge
- No immersion in water
- No external chest compressions
- No pregnancy

Staff Education

- Comprehensive training of staff regarding:
  - Indications
  - Anatomy
  - Pump function
  - Troubleshooting
  - Infection control
  - Alarm resolution
  - Emergencies
  - "Train the Trainer" sessions

LVAD Patient Assessment

- Airway, Breathing, Circulation
- Assess pump function
- Vital signs
- Pump rate, Flow, PI and power
- Mental status, level of consciousness
- Driveline connection to System Controller and exit site wound

Keys to Success

- Appropriate patient selection
- "Right-time" implant
- Improve quality
  - Fewer total days, ICU days, drug, and complications
  - Minimize re-hospitalizations for HF, GI bleeding, thrombosis
  - Minimize pump exchanges

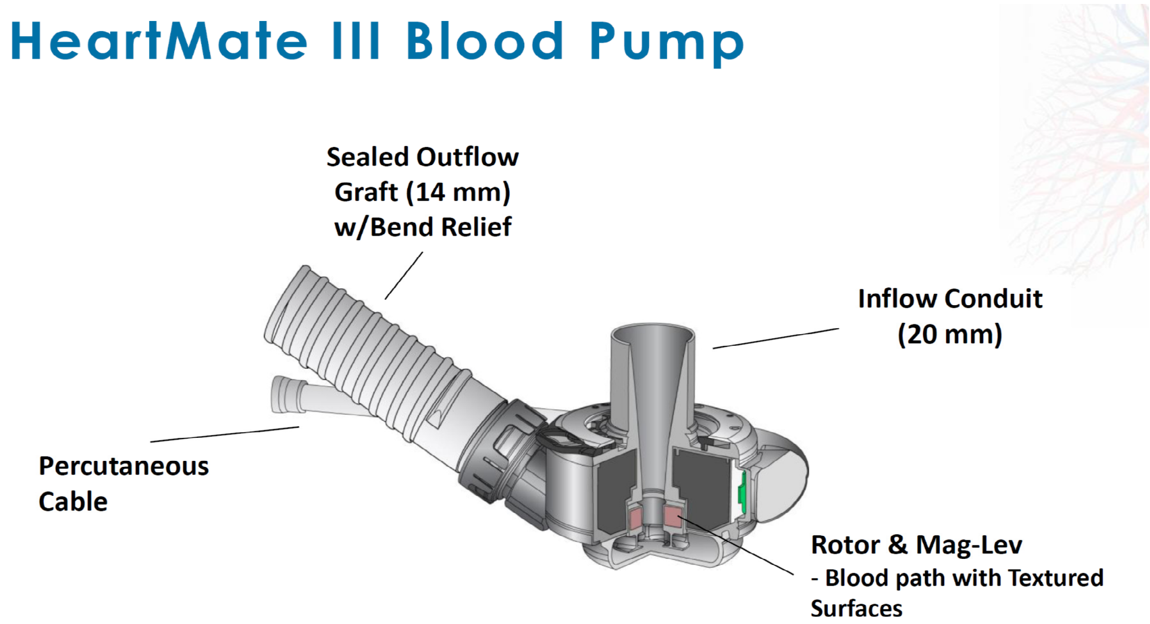
Fully Magnetically Levitated Left Ventricular Assist System

HeartMate III

Three important feature design:

1) True magnetic levitation
2) Artificial pulse
3) Internal sintering with textured titanium microsphere to allow for a biocompatible surface

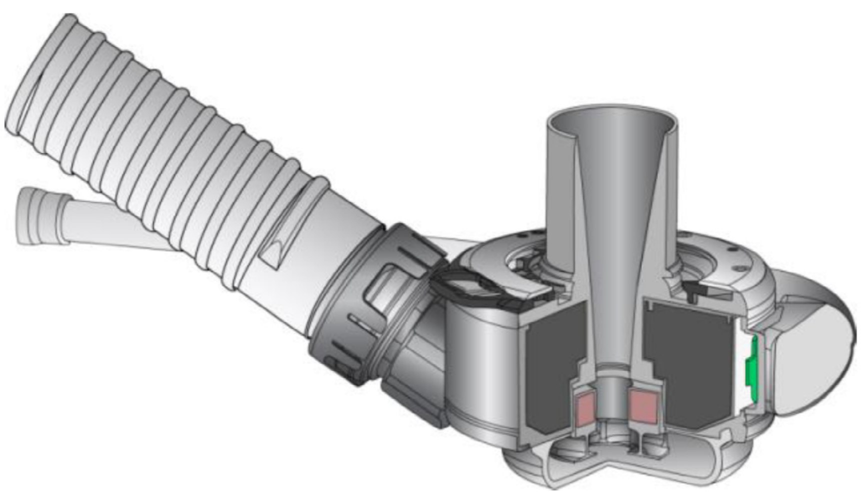
Fully Magnetically Levitated Left Ventricular Assist System

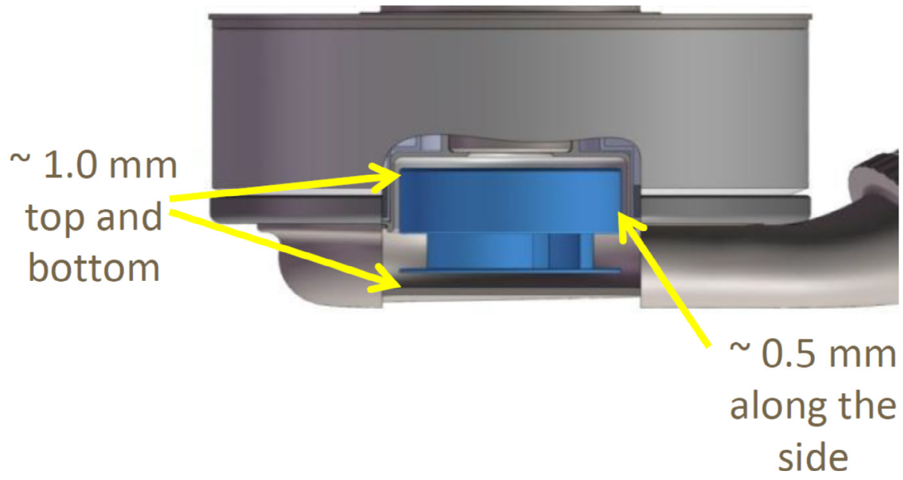


Fully Magnetically Levitated Left Ventricular Assist System

– HeartMate III secondary flow paths are ~0.5 mm along the side, and ~1.0 mm pump above and below the rotor.
– HeartMate III pump surfaces are flat and flow is undisturbed.

- Provides 2-10 lpm

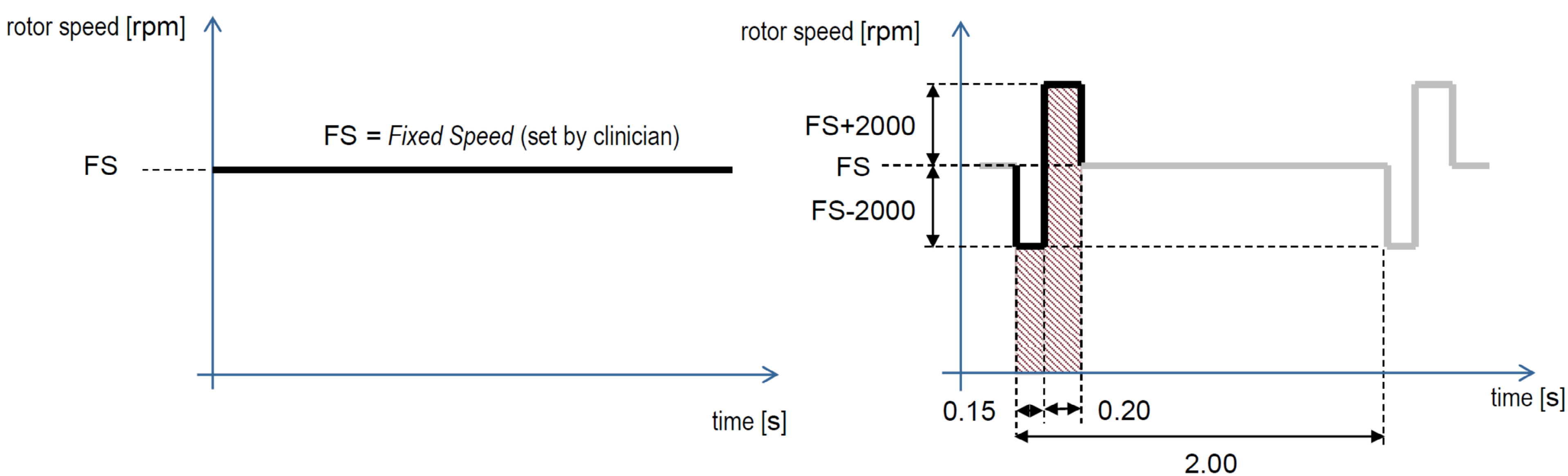




Fully Magnetically Levitated Left Ventricular Assist System

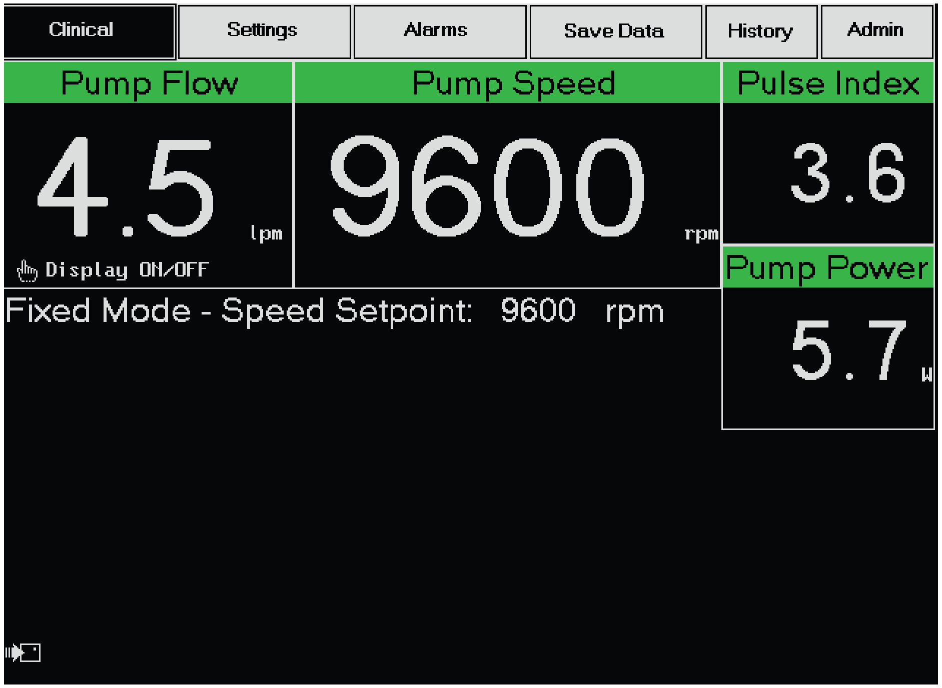
Artificial Pulse Overview

Augmenting the pulsatility – might benefit in AI/ bleeding/ thrombogenesis

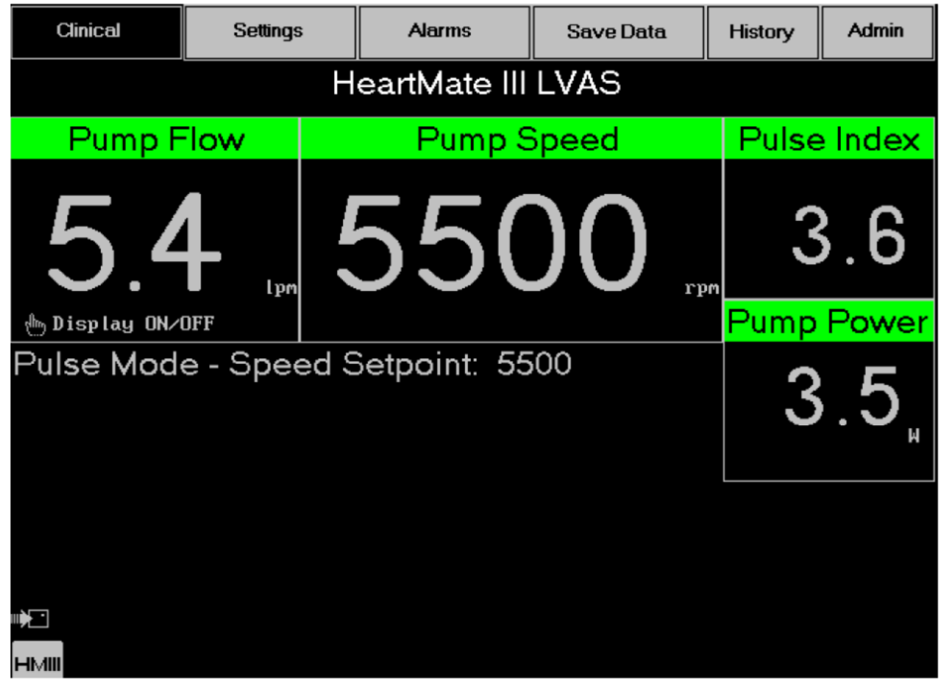


System Monitor – Clinical Screen

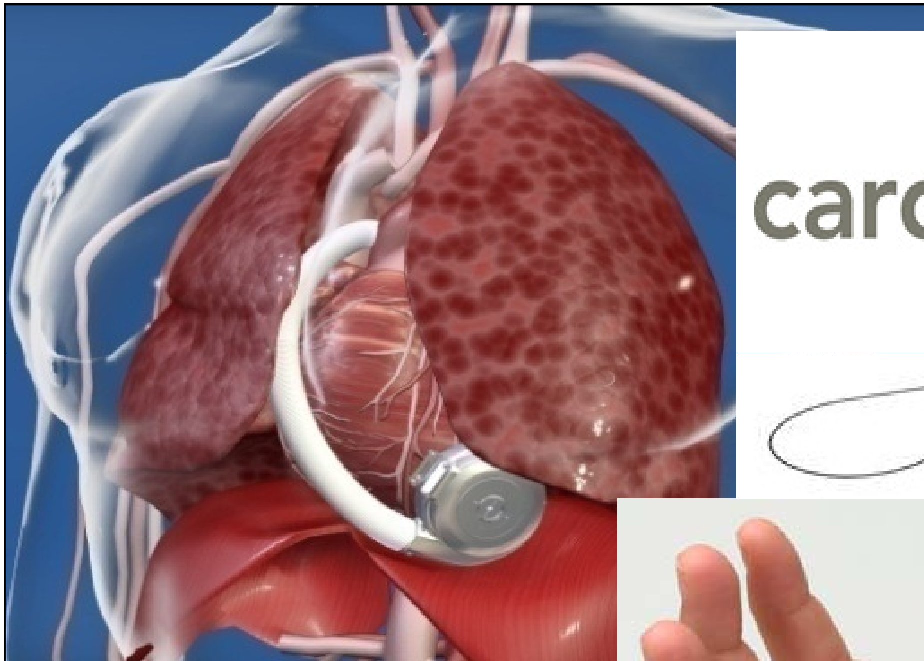
Heart Mate II

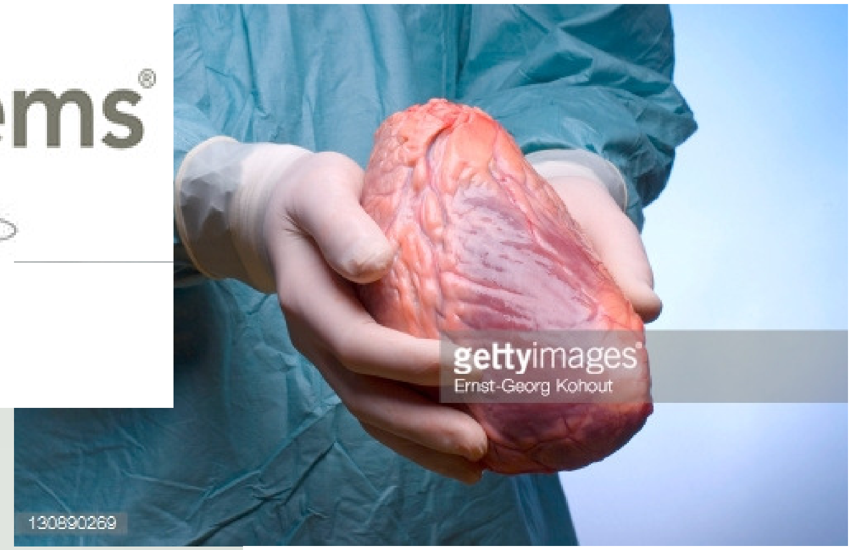


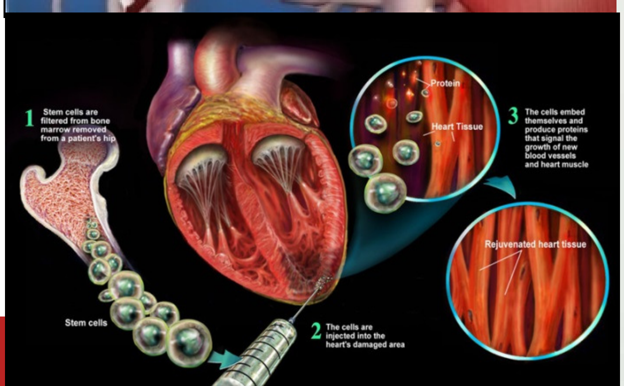
Heart Mate III

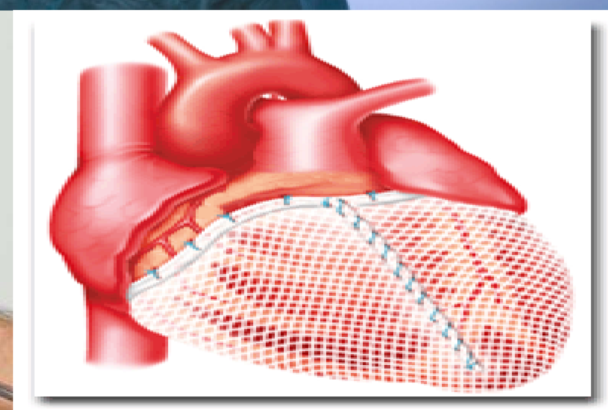


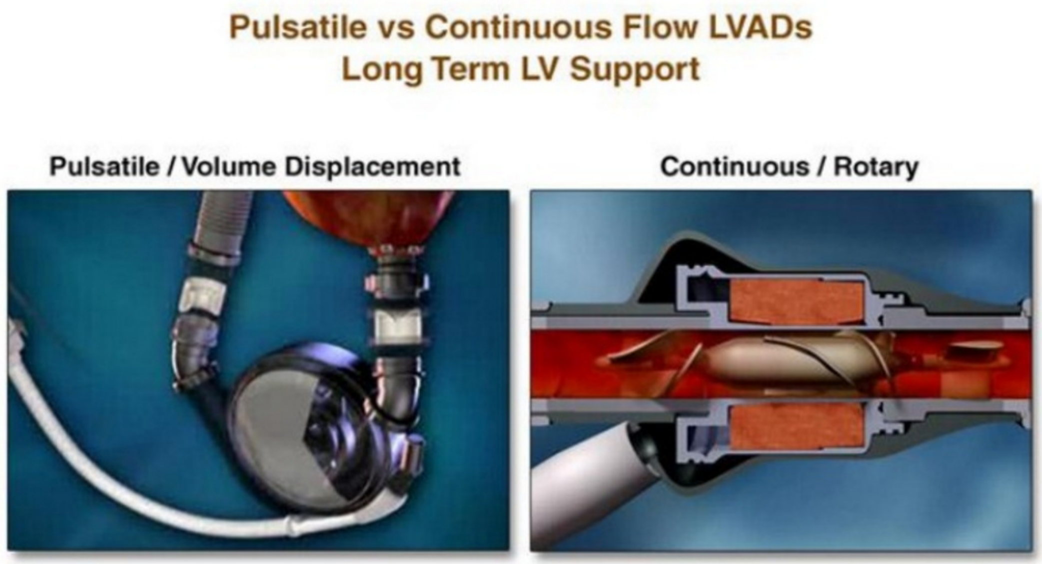
We do have more gadgets

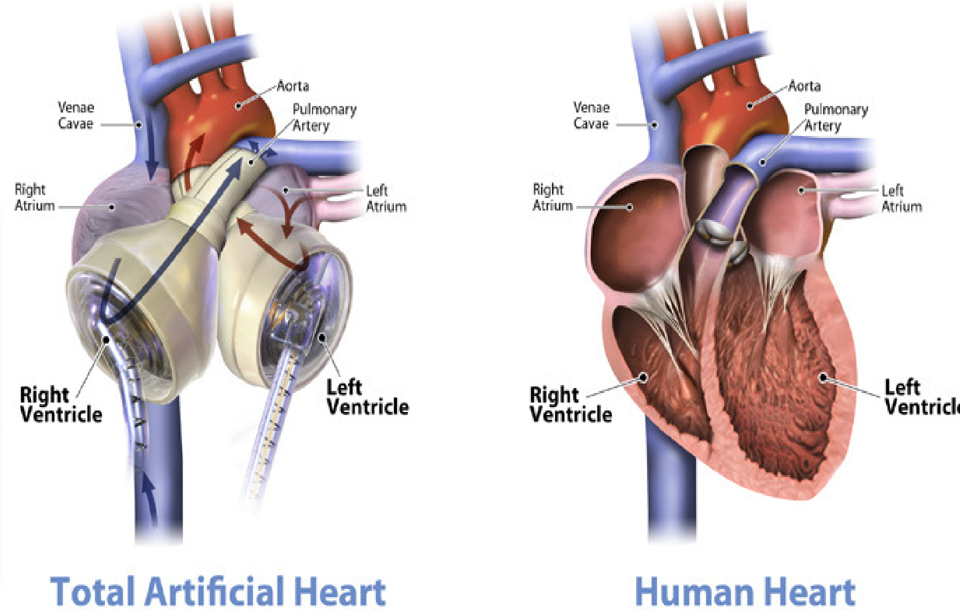


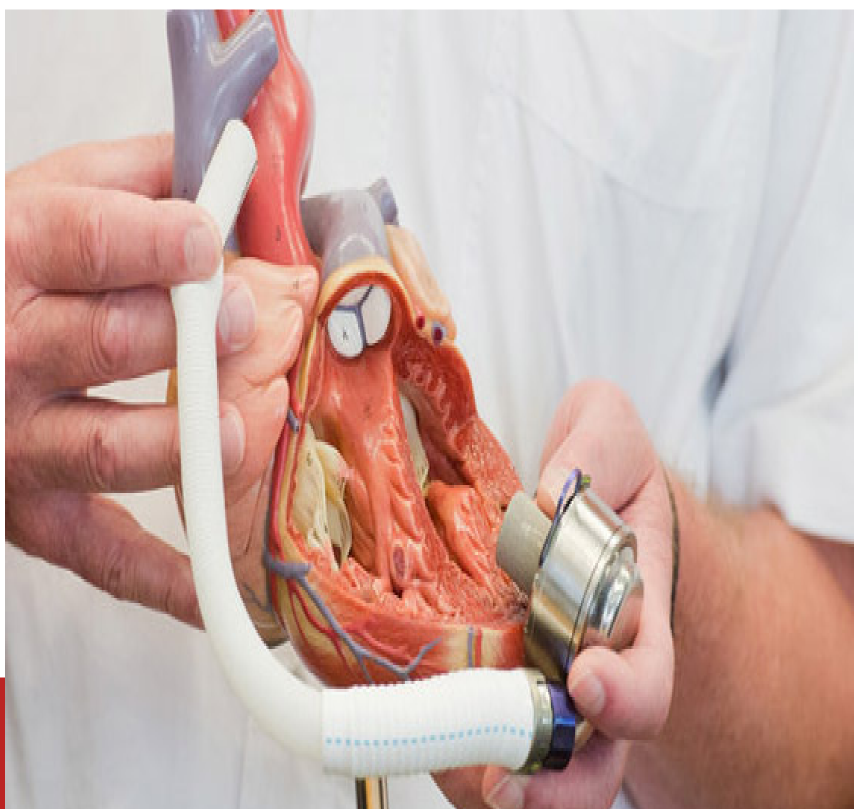


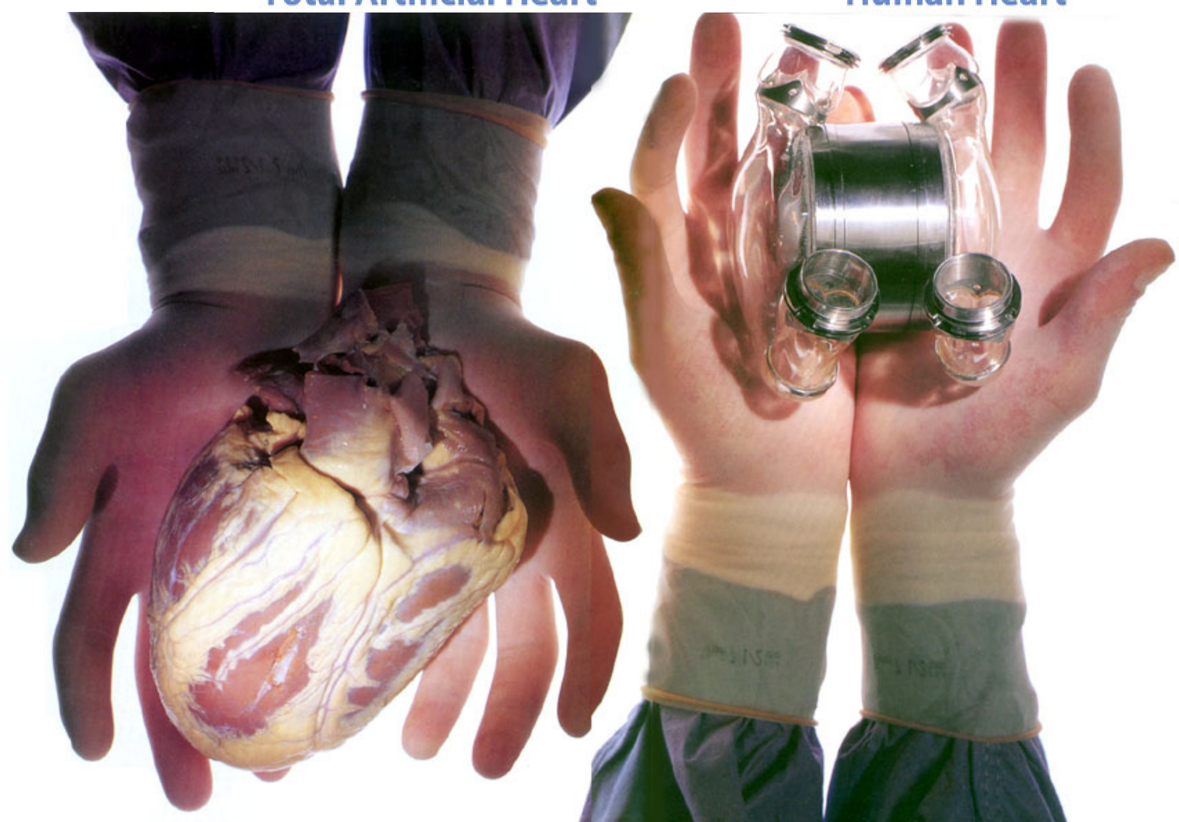





Pulsatile vs Continuous Flow LVADs
Long Term LV Support
Pulsatile / Volume Displacement
Continuous / Rotary


Venae Cavae
Aorta
Pulmonary Artery
Right Atrium
Left Atrium
Right Ventricle
Left Ventricle
Total Artificial Heart
Human Heart





Oklahoma Heart Institute

Thank you!