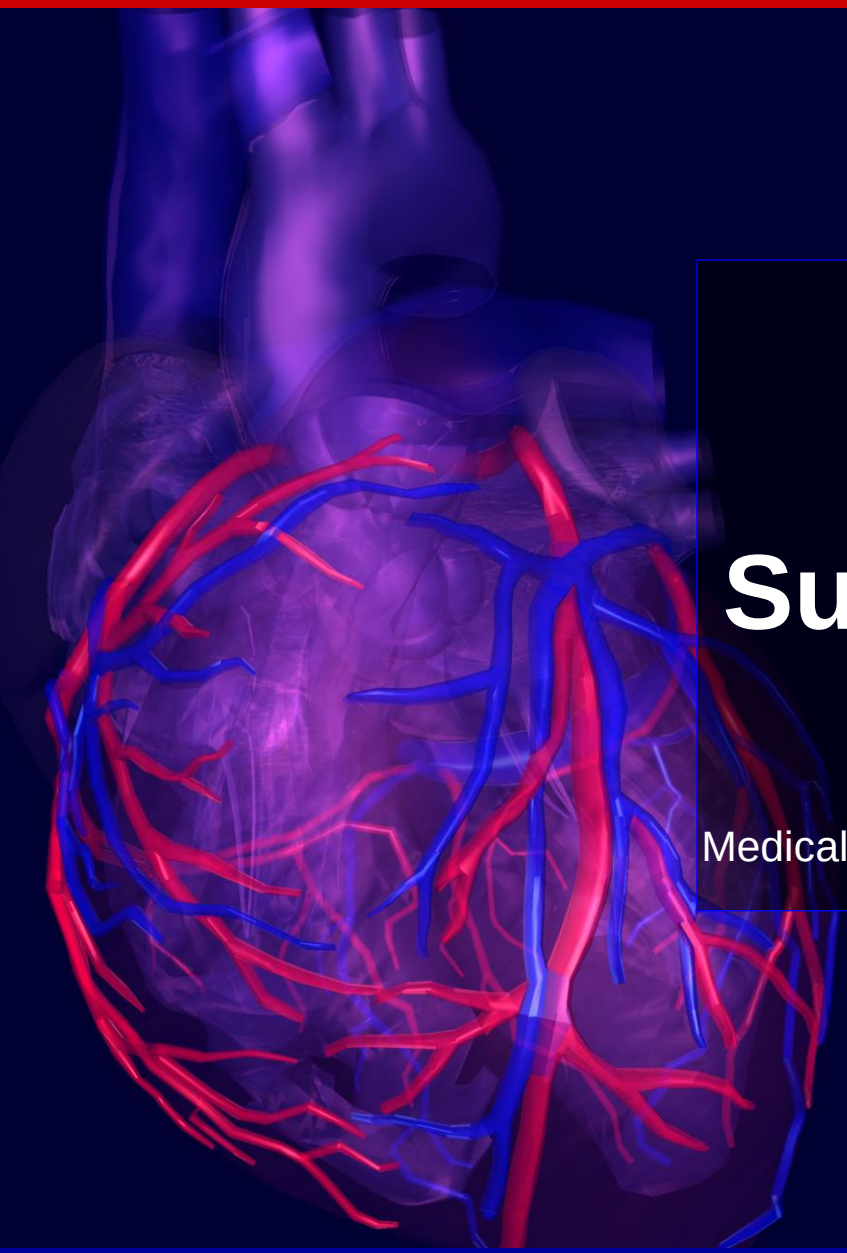


Mechanical Circulatory Support in the ICU

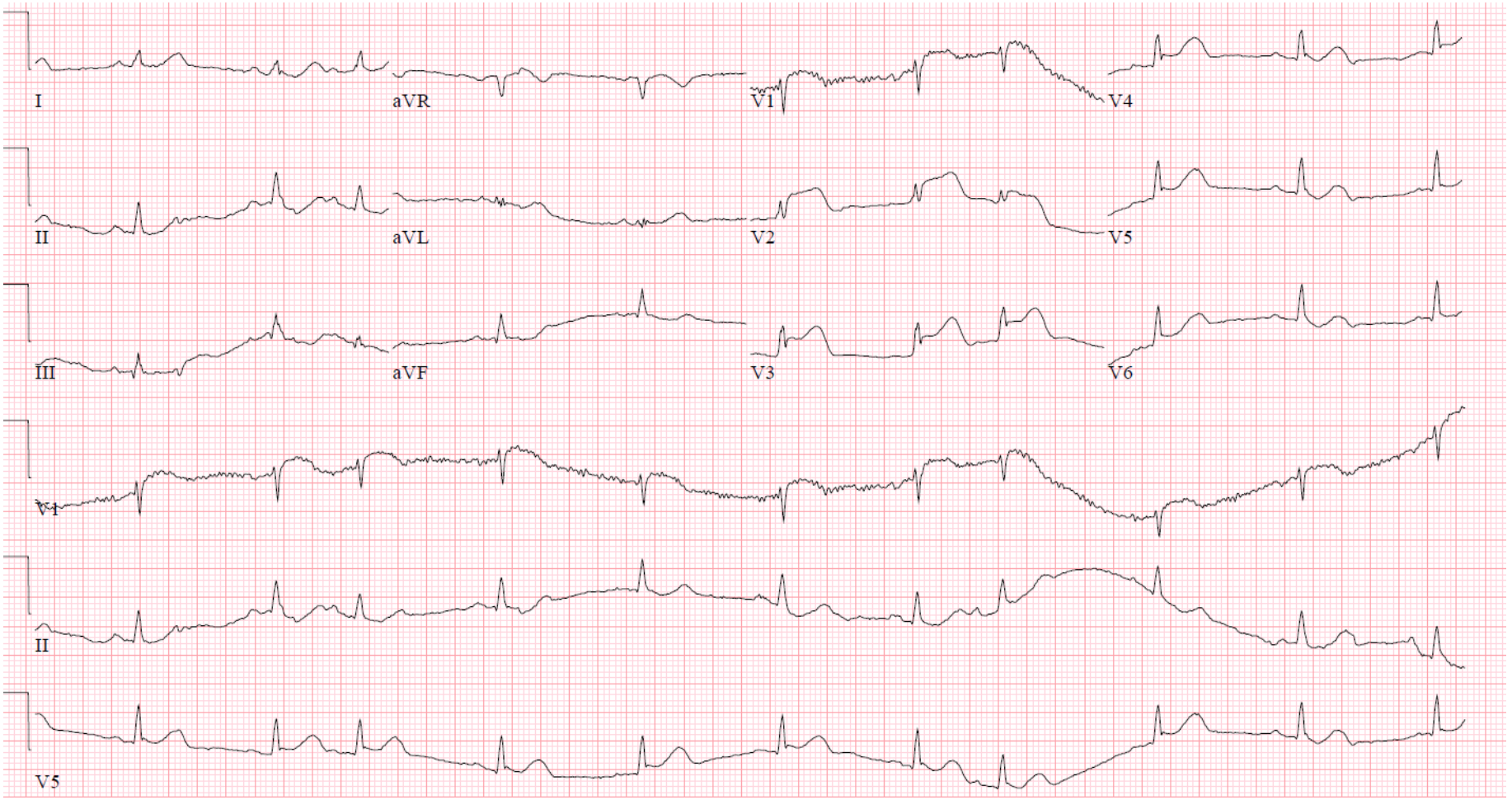
Andrew J. Sauer, MD
Assistant Professor
Medical Director, Center for Advanced Heart Failure

Five Pearls of Cardiac Devices

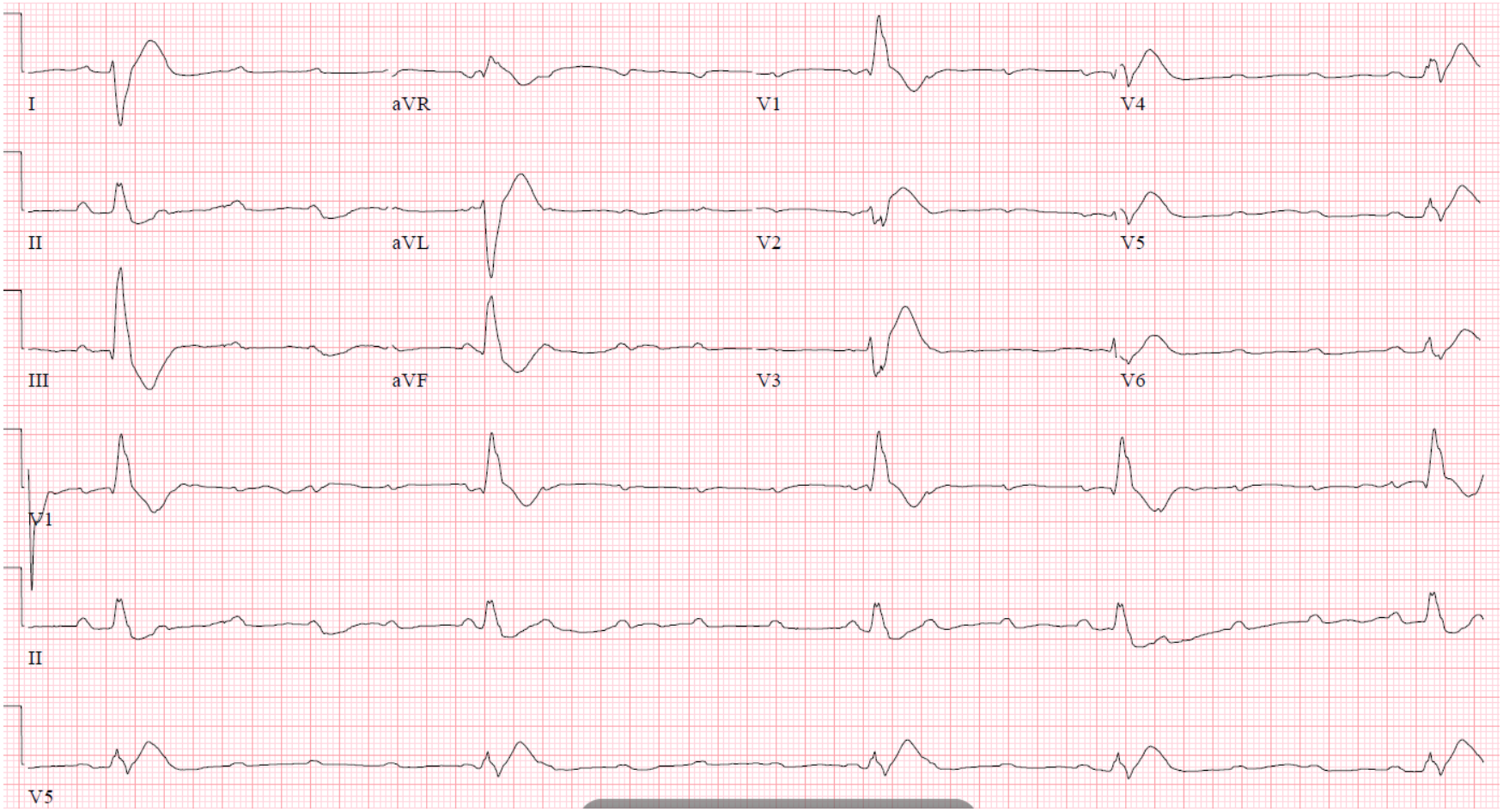
1. Consider Chronotropy (CO = SV x **HR**)
2. Define Trajectory (and keep defining it)
3. Respect the Vitals (and don't walk away)
4. Define Risk (including risk of doing nil)
5. Device (Know how they work and pitfalls)

76 yo AA F Presents with Chest Pain

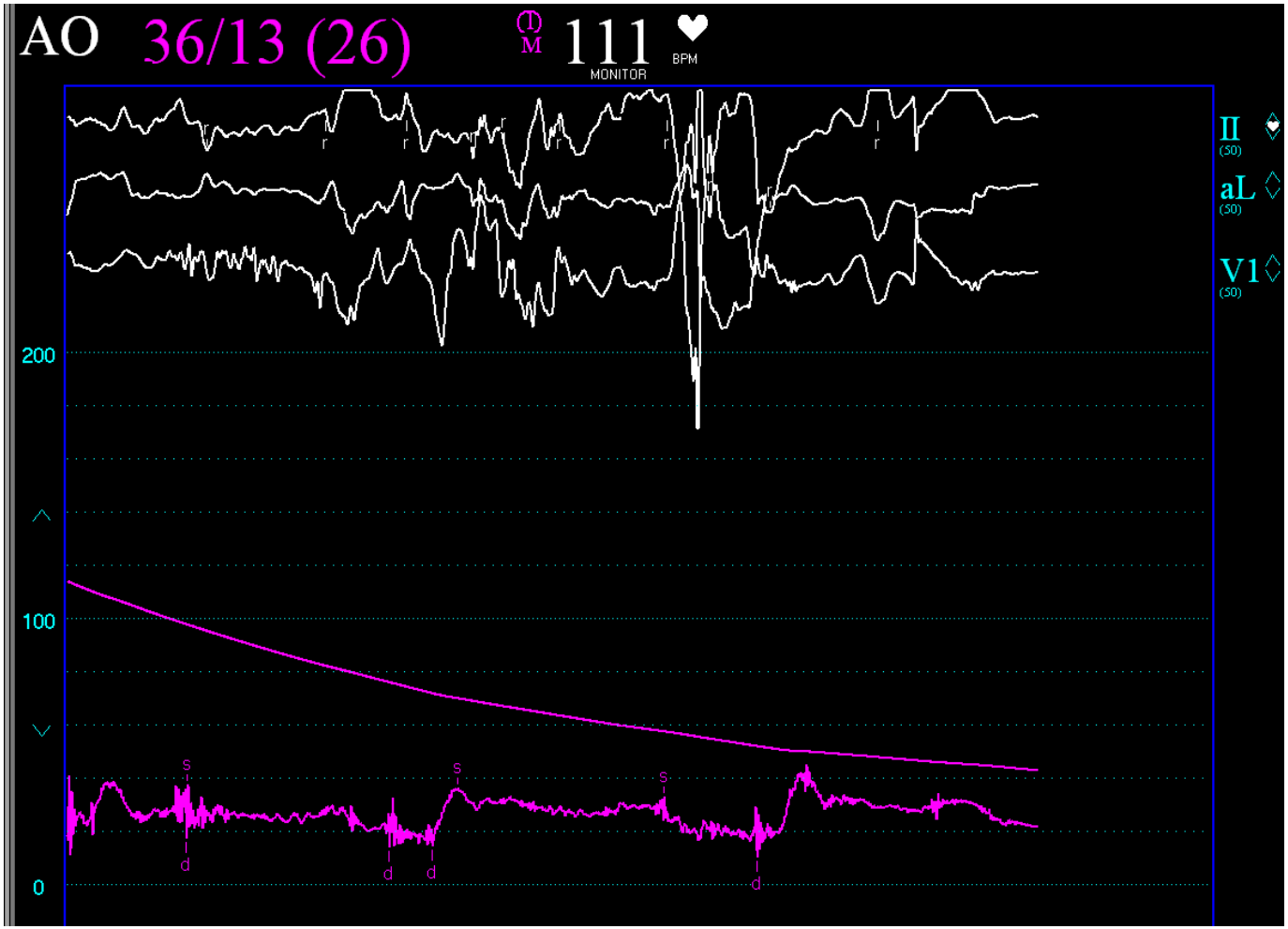
Presenting ECG (11:49 PM)



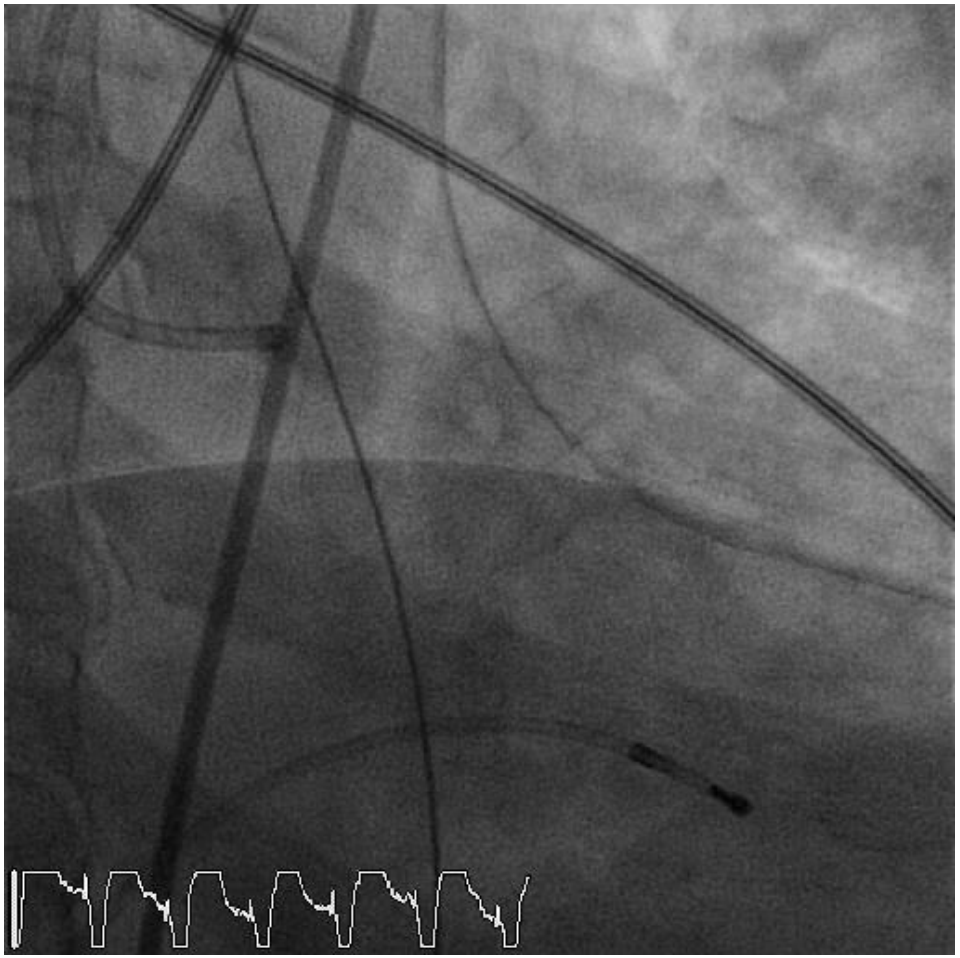
Post-VF arrest ECG (12:01 AM)



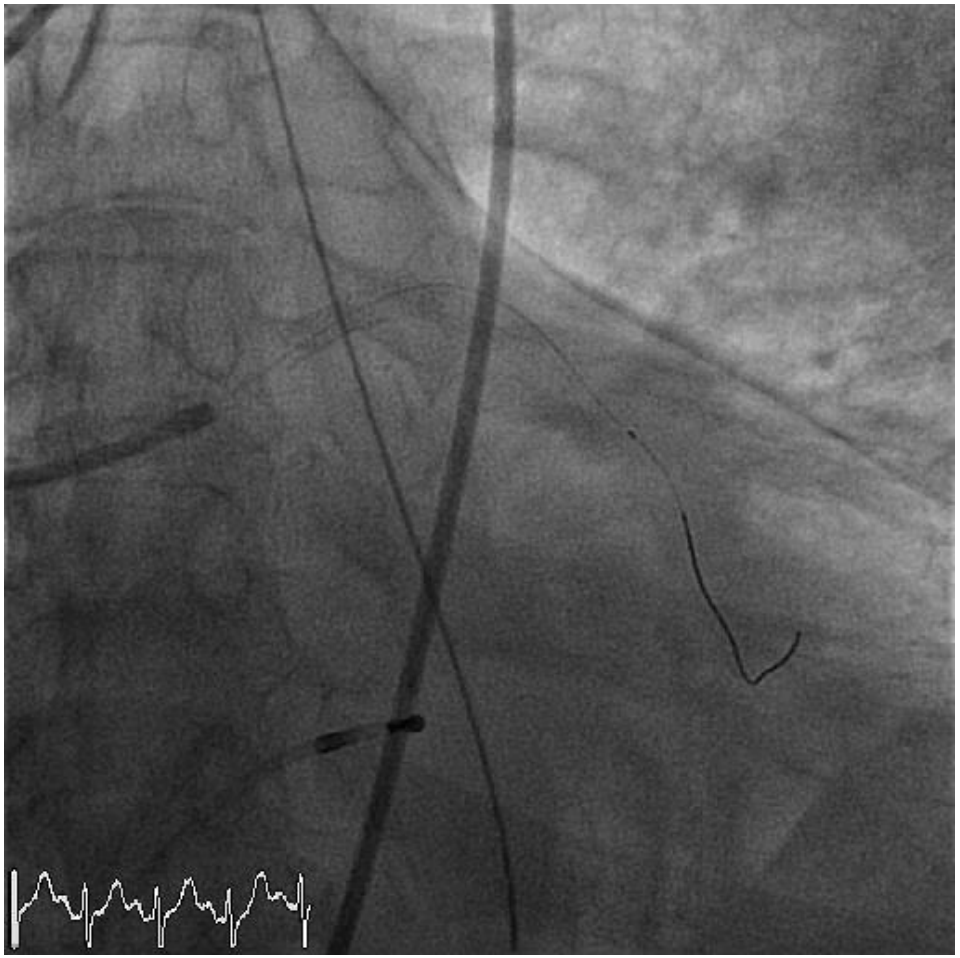
Initial Aortic Pressure



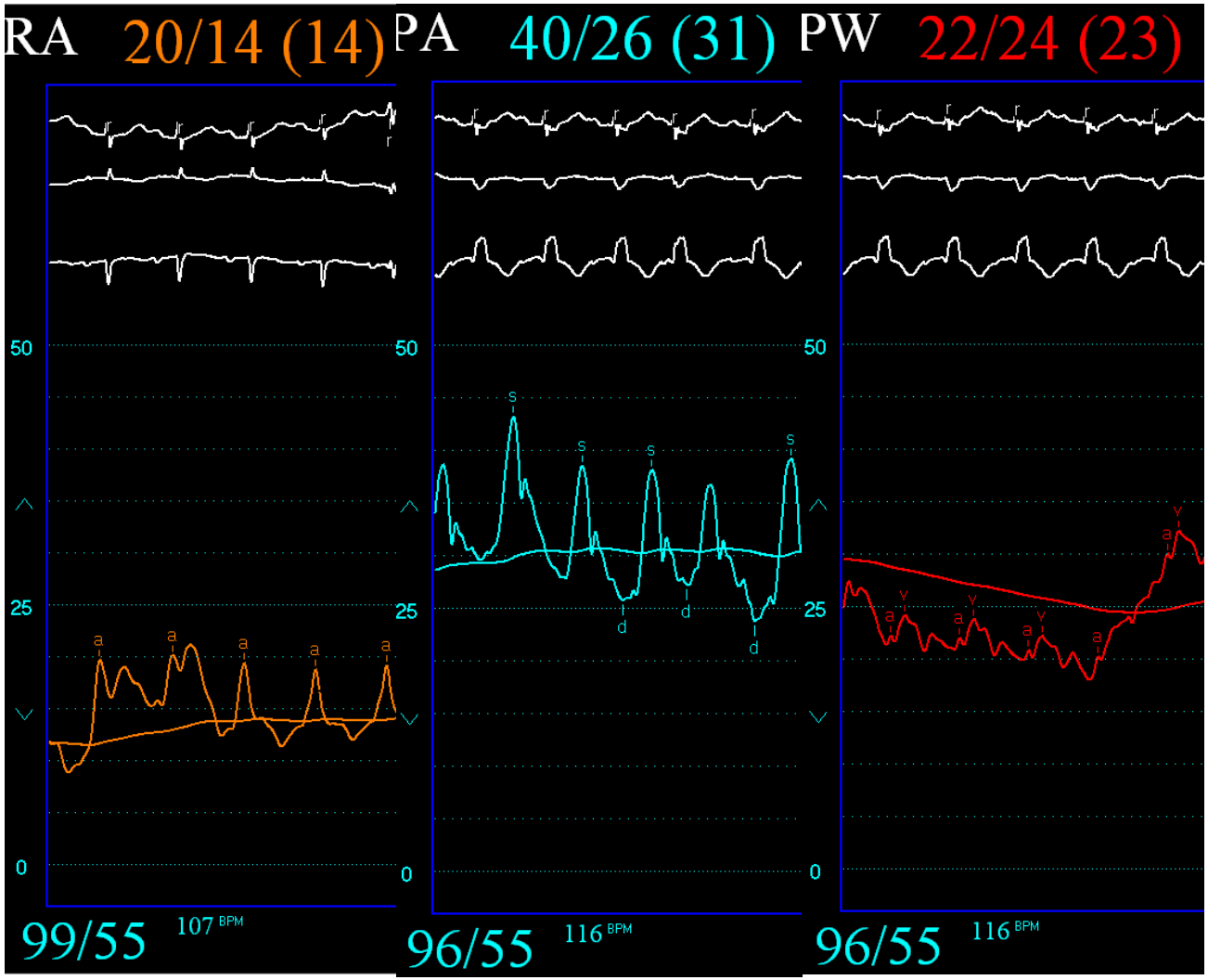
Proximal LAD Thrombus



Post-PCI Angiography

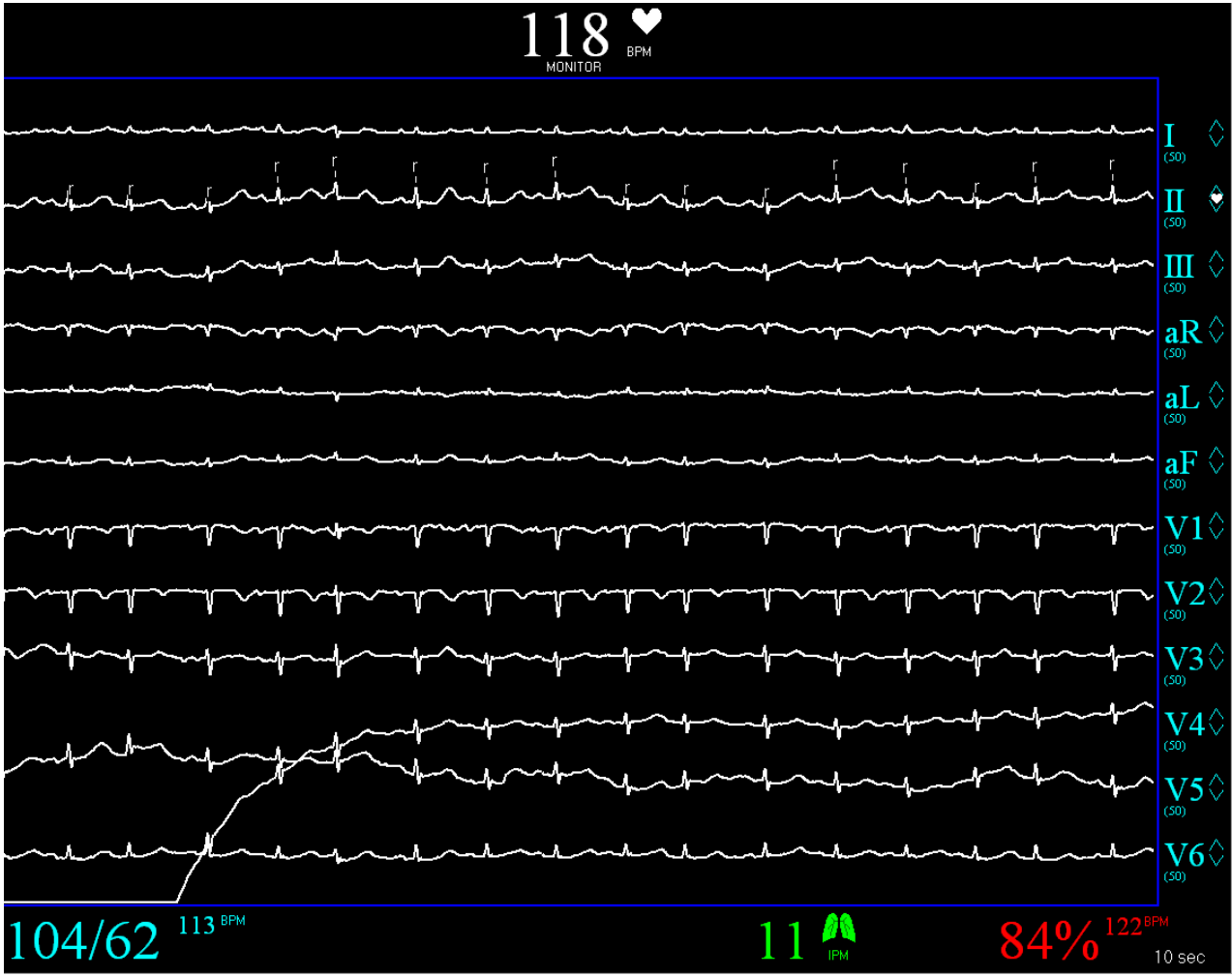


Right Heart Catheterization



Cardiac Index = 2.81 L/min/m2

- Aortic
  - PaO2 81%
- Pulmonary
  - PaO2 54%



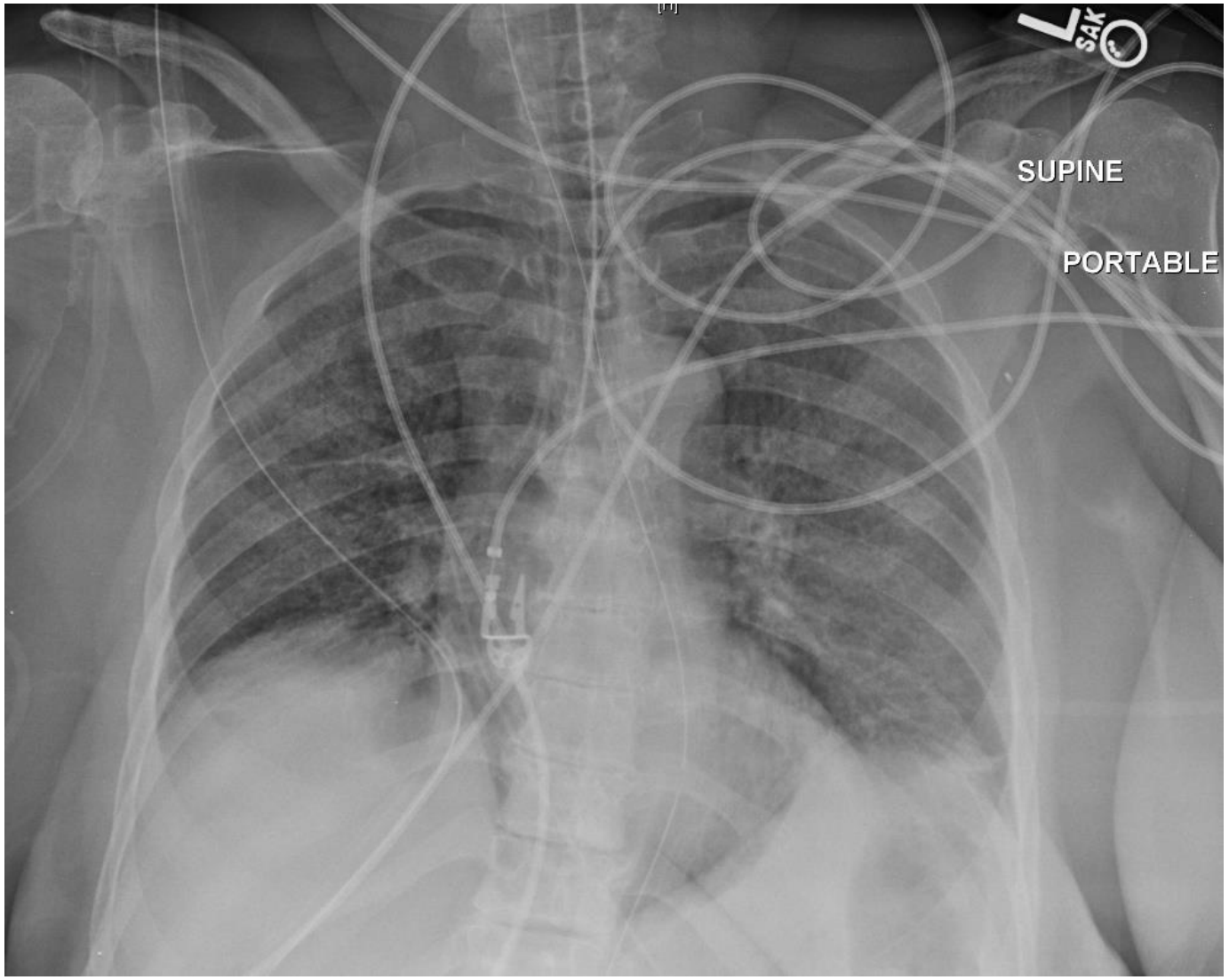
Pearl #1: Chronotropy

- CO = HR x Stroke Volume

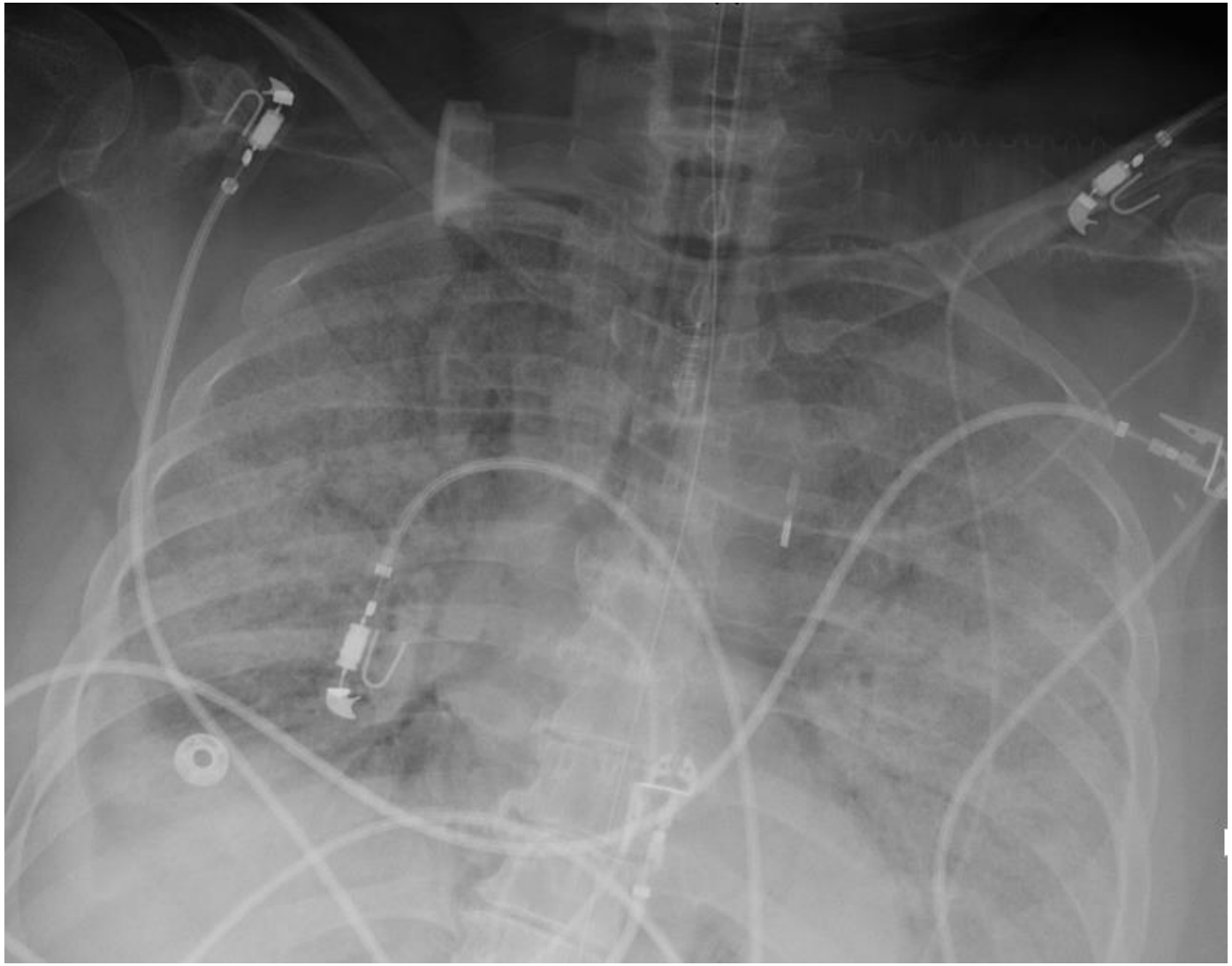
-Thus, if you DOUBLE the heart rate you will DOUBLE the cardiac output

-Increasing the HR is much easier than increasing the stroke volume--but requires a high energy price

Post-Arrest CXR



Post-Cath Lab



Data Summary

- Post – VF arrest, complete heart block
- Abciximab and RV temp wire started
- Prox LAD thrombus, PCI → sinus tach
- 3.5 x 15 mm Xience DES
- Diagonal angioplasty Trek 2.5 x 8 mm
- TIMI 3 flow
- IABP with improved hemodynamics
- Evolving respiratory failure / shock

Pearl # 2: Trajectory

“Nothing stays the same in the ICU”

- Acute, severe respiratory failure
- Rising pressor / inotrope requirement
- Post-PCI shock
- End-organ hypoperfusion

Pearl #3: Assess “Vitals”

- Obvious: Temp, HR, BP, O2 Sat
- Less Obvious: mental status, UOP, breathing pattern, pulse pressure
- Vital monitoring: 12L EKG, telemetry
- Vital labs: pH (VBG often faster than ABG) lactate, BUN, LFTs, INR, trop, CK
  - CORRELATE TIMING OF LABS WITH SITUATION

Options

A. Continue IABP, Mech. Vent, vasopressors

B. Return to cath lab for Impella 2.5

C. Go to the OR for HeartMate II

D. Go to the OR for axillary Impella 5.0

E. Initiate extracorporeal membrane oxygenation (ECMO)

F. Consult palliative care

“To do nothing for the gomers was to do something, and the more conscientiously I did nothing the better they got.”

-Samuel Shem

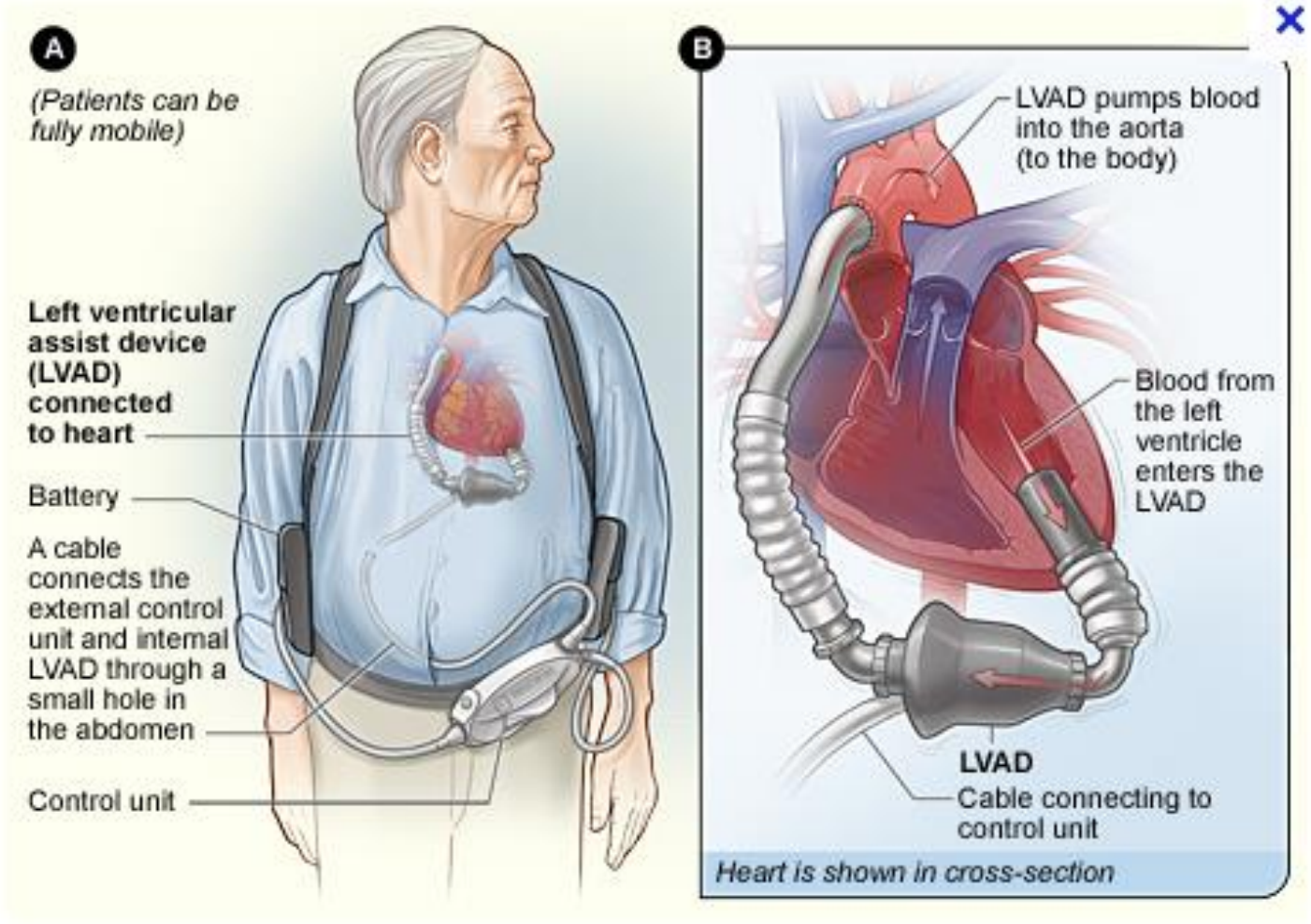
The House of God

The Mechanical Revolution

- First year of medical school (2003)
  - PA catheter + IABP (Pre-ESCAPE, SHOCK II)
- Internship (2007)
  - Occasional Tandem Heart, Impella
  - Durable LVAD uncommon
- Advanced HF Fellowship (2012-2014)
  - Axial and centrifugal CF-LVADs exploding
  - One-year survival approaching 90%
  - Impella 2.5, Impella 5.0, VA-ECMO common

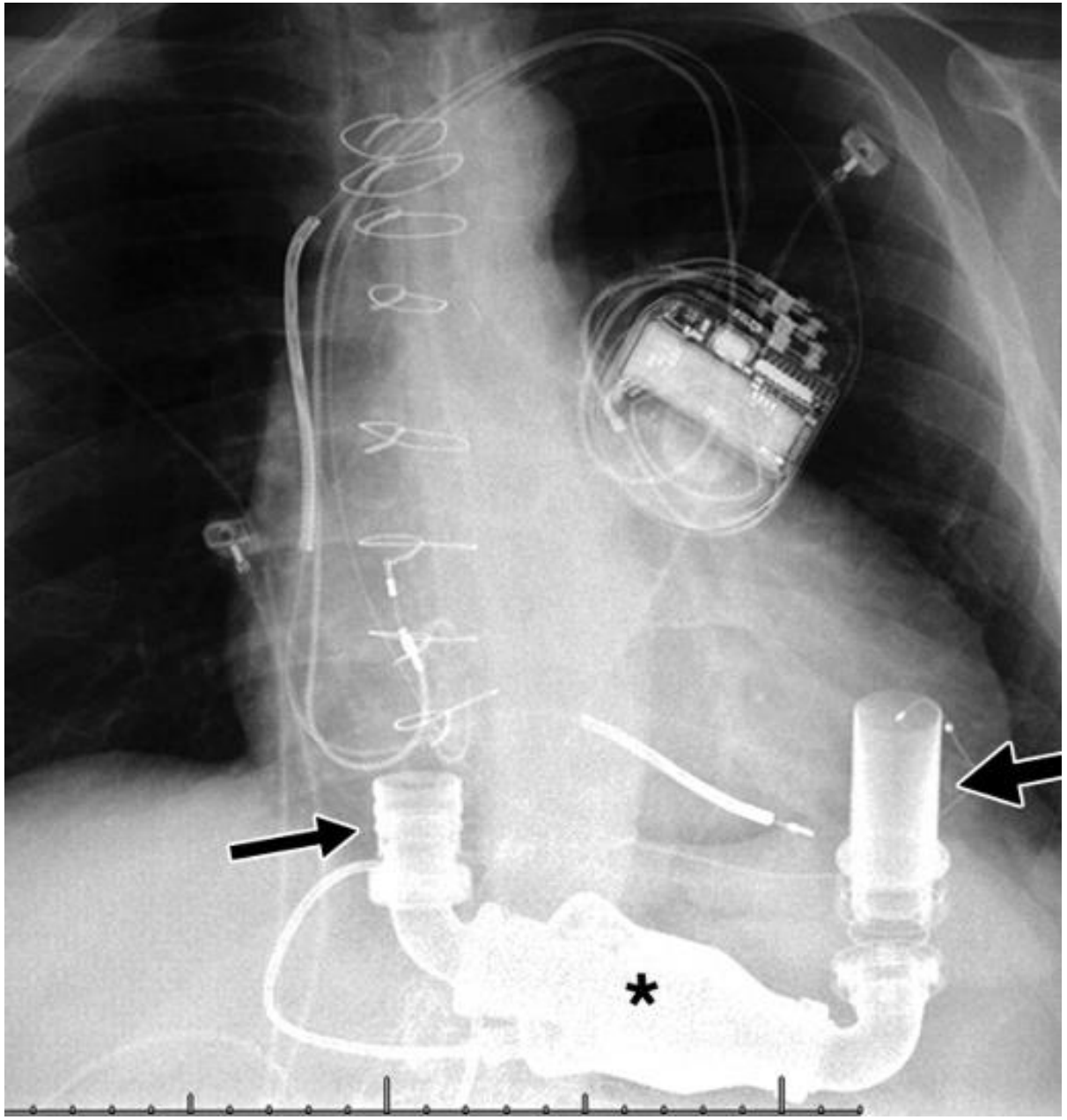
Left Ventricular Assist Devices

Low-Profile Long-Term Support

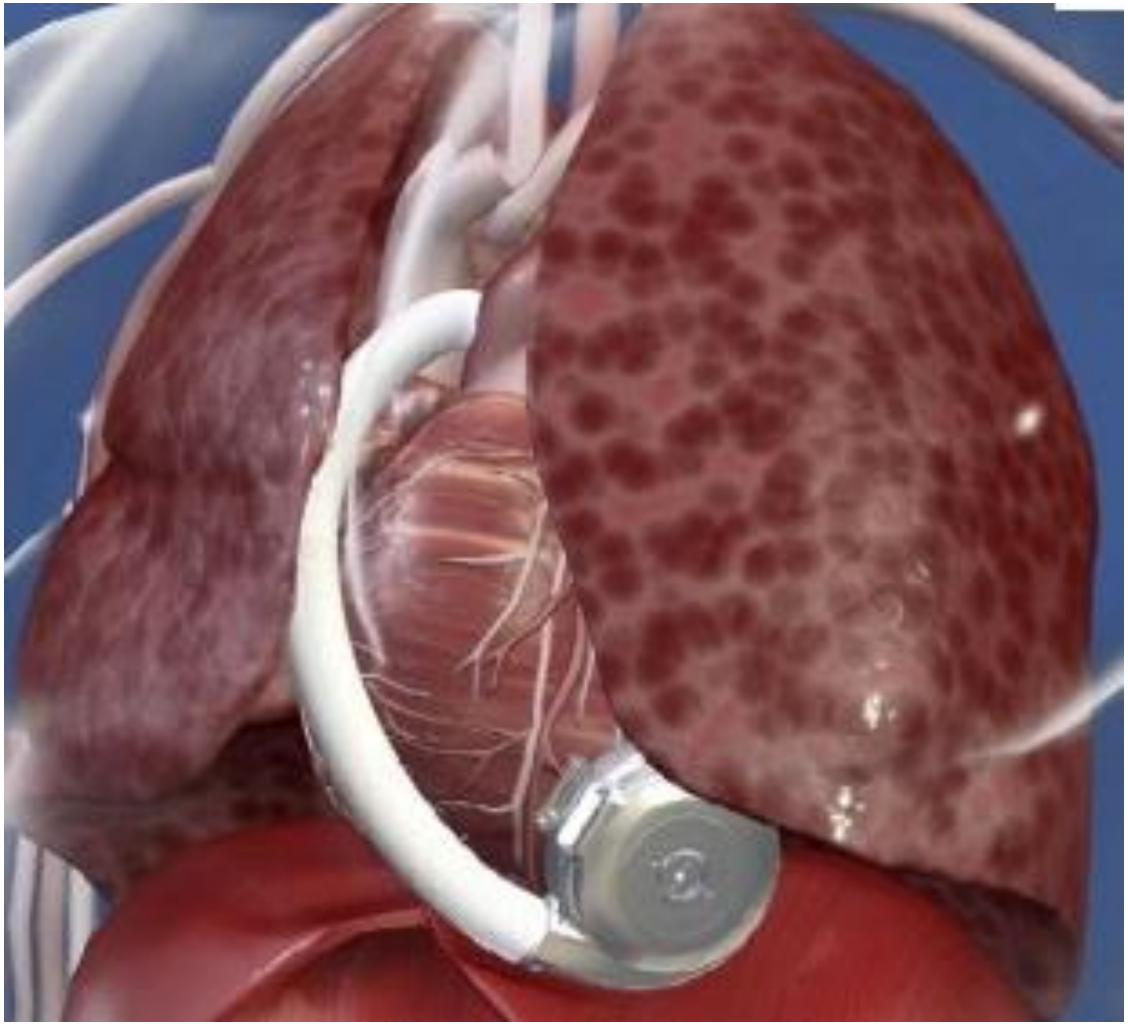


Bridge or Destination Therapy

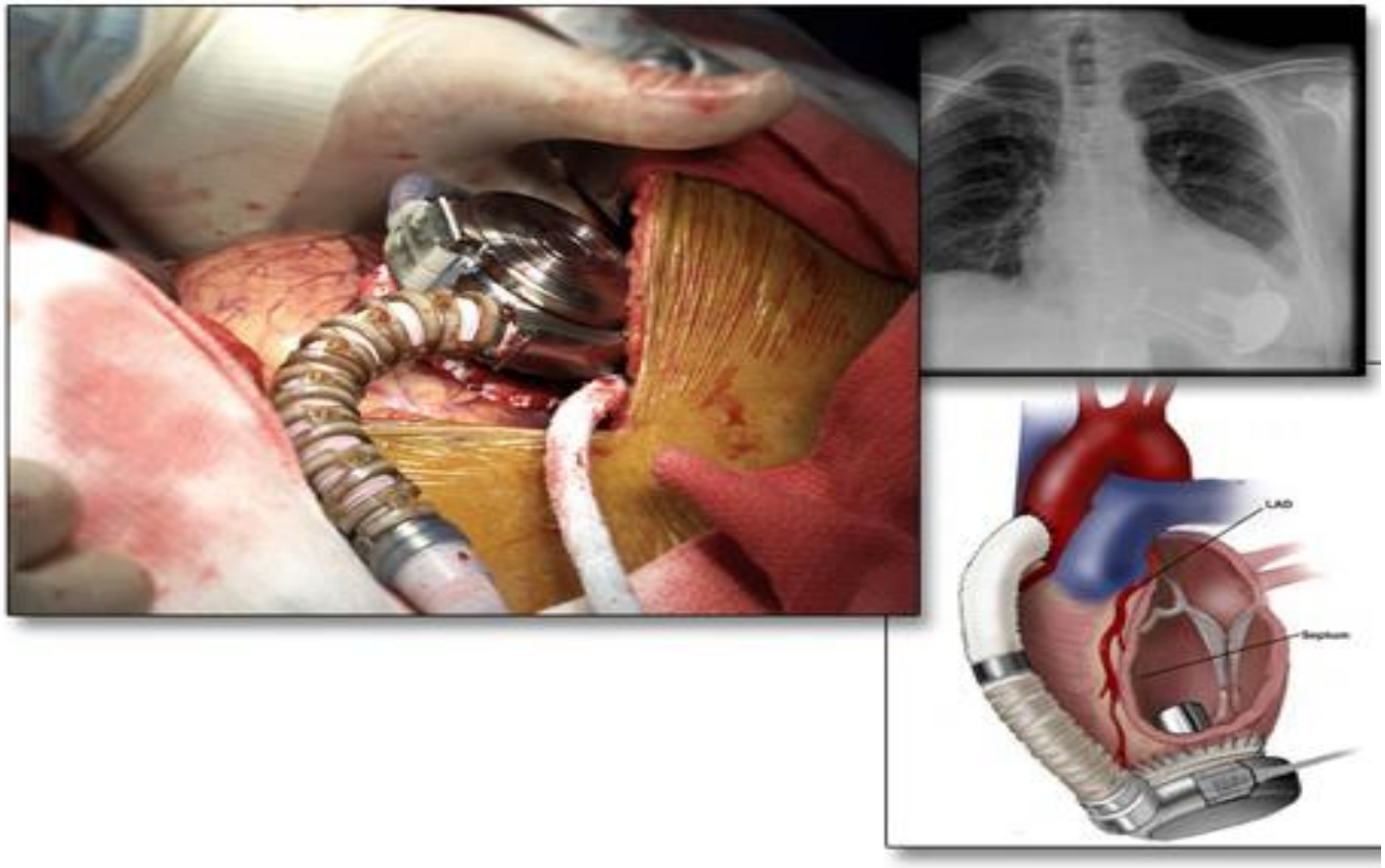
Can you spot the LVAD?



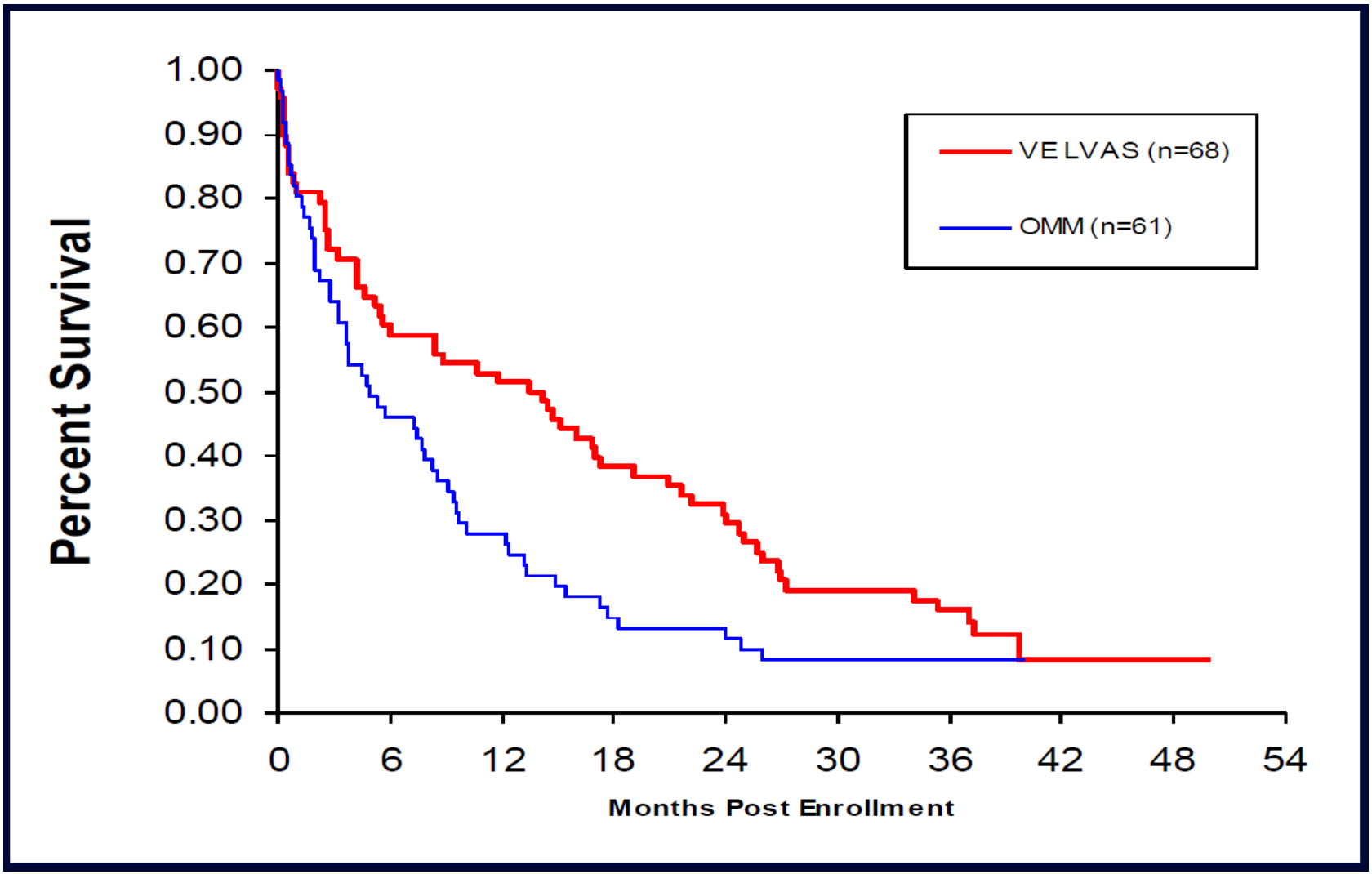
Heart Ware HVAD



Heart Ware HVAD

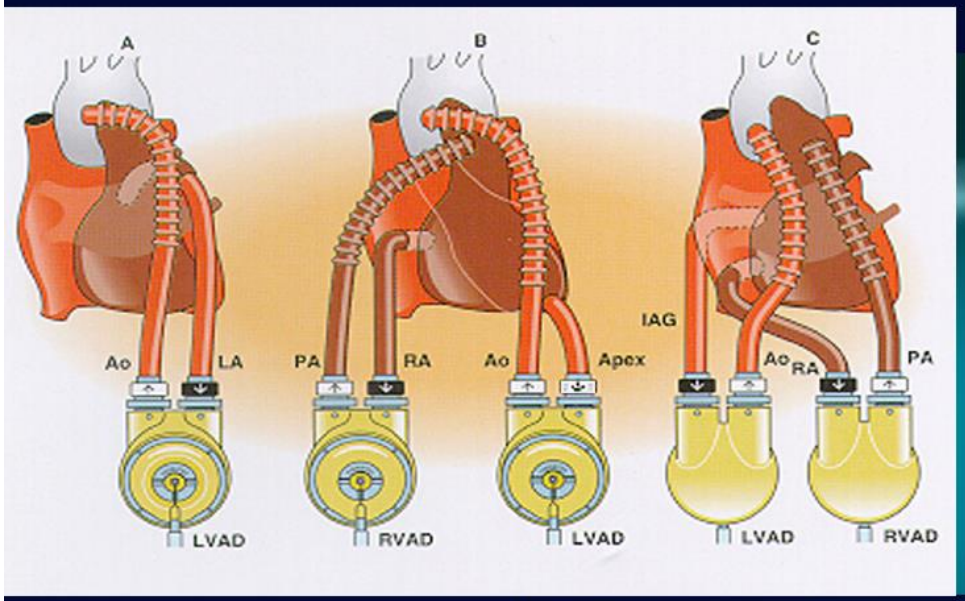


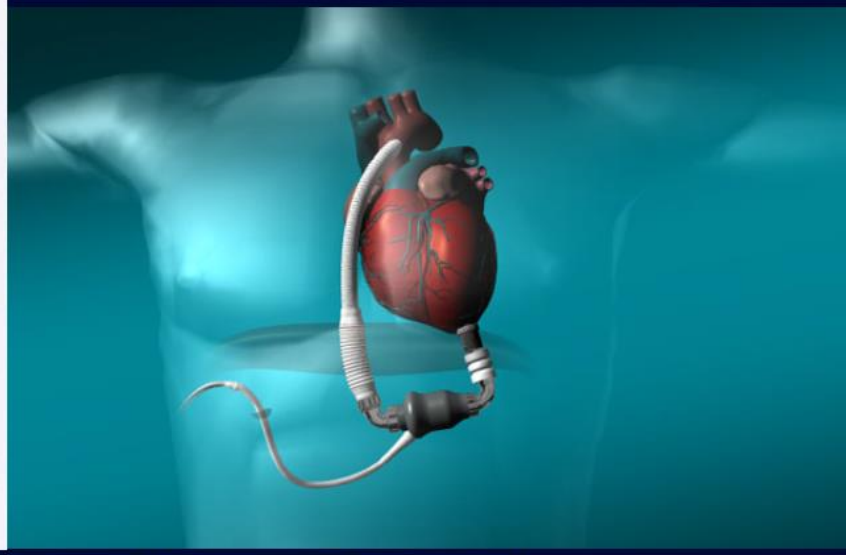
MCS vs Medical Therapy

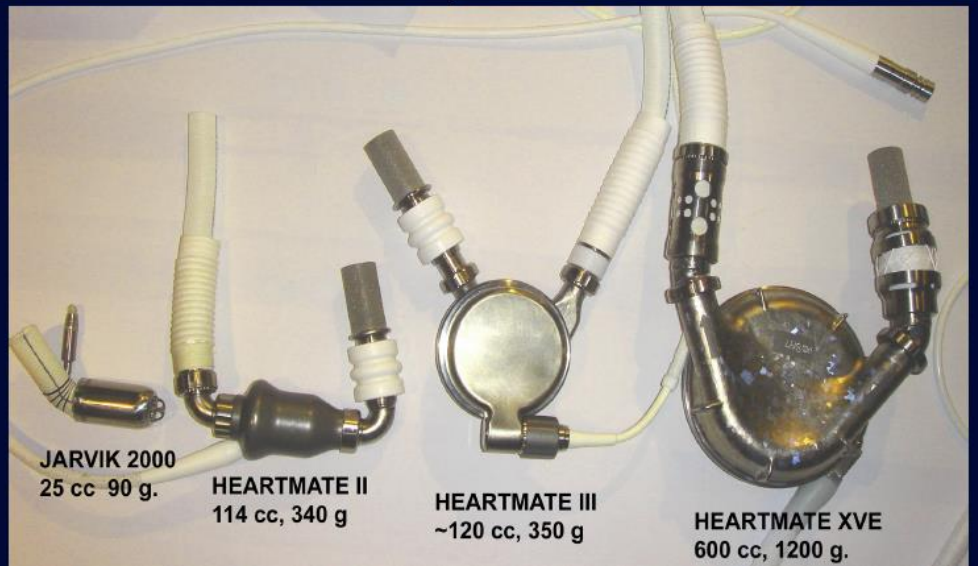


N Engl J Med 2001; 345:1435-43

Evolution of Devices

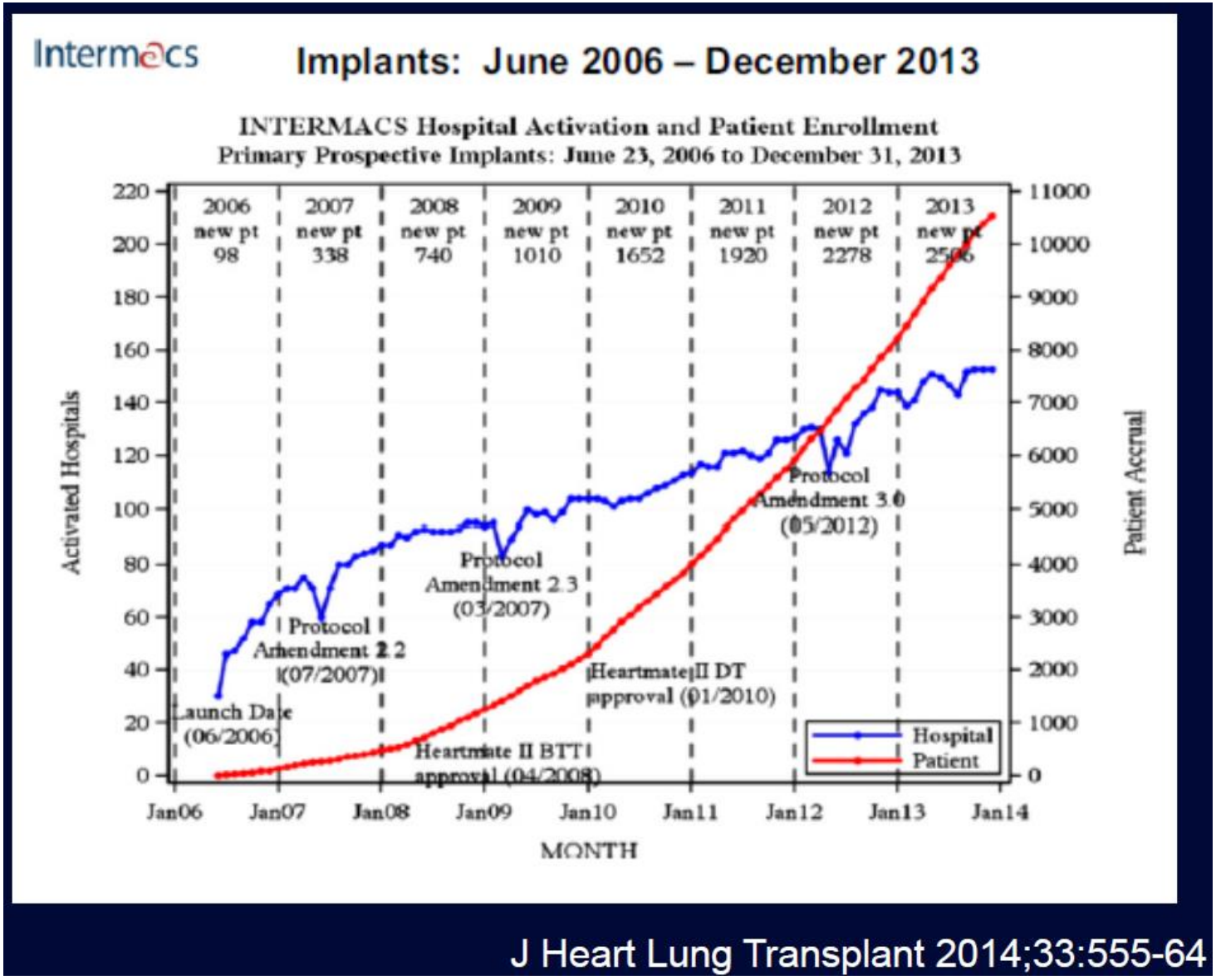






Today's LVAD Patient

Rise in Mechanical Devices

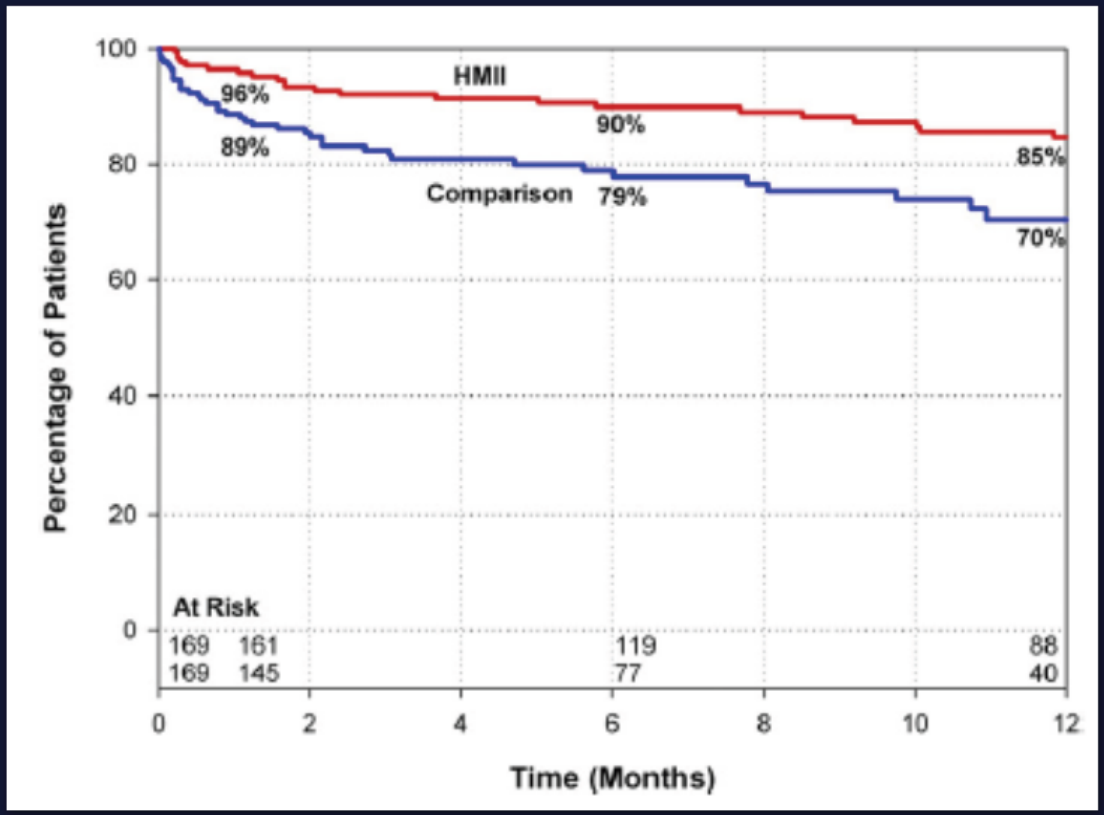


J Heart Lung Transplant 2014;33:555-64

HeartMate II Post-Approval Study

- The post-approval study examined outcomes of patients treated with HMII (n=169) vs an INTERMACS control group comprised of:
  - HM XVE (n=135) and
  - Thoratec IVAD (n=34)

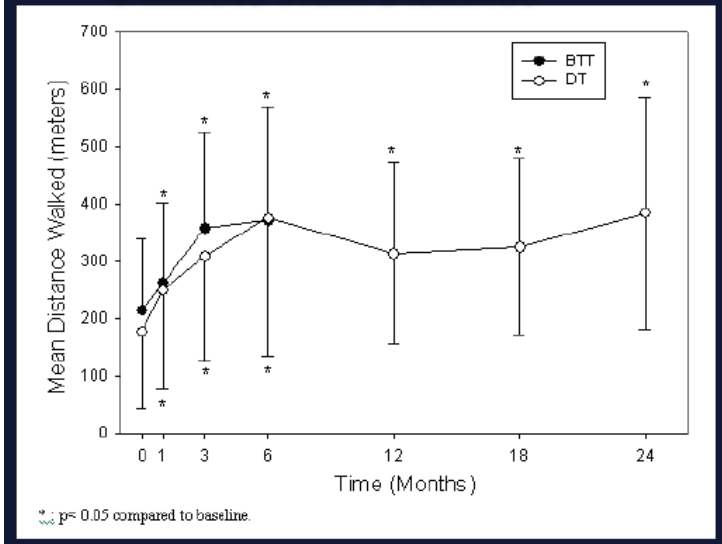
  and consisted of concurrent controls (n=55) and historical controls (n=114)
- Enrolled April-August 2008 at 77 US centers



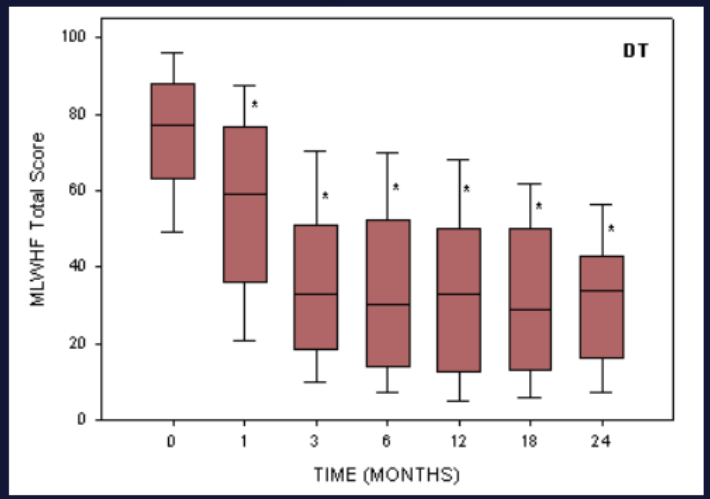
J Am Coll Cardiol 2011;57:1890-8

Quality of Life (at 6 months)

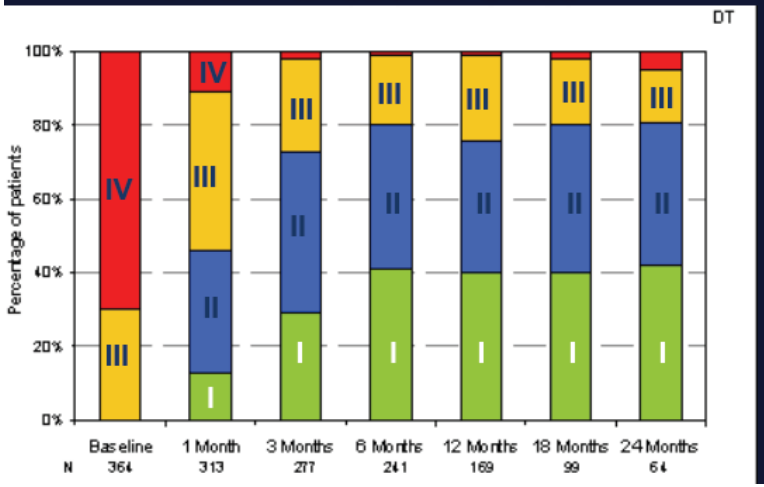
6 Minute Walk Distance



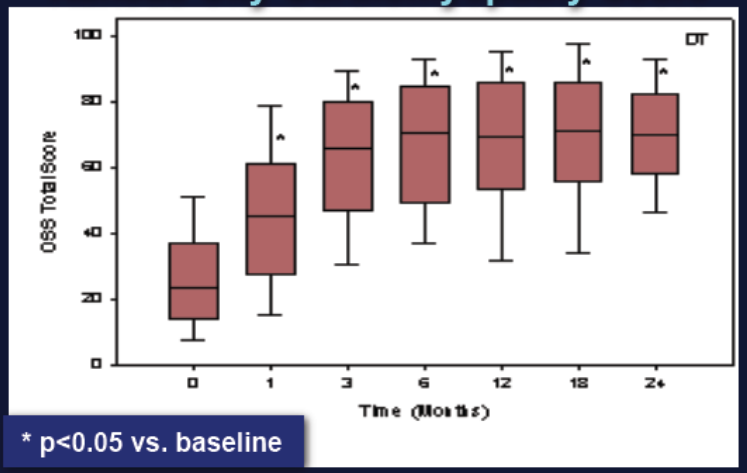
Minnesota Living with Heart Failure



NYHA Functional Class



Kansas City Cardiomyopathy Score



J Am Coll Cardiol 2010; 55: 1826-34

LVAD Candidates?

- **Inclusion criteria:**
  - LVEF ≤ 25%
  - Peak VO2 <14 ml/kg/min (or 50% age- and sex-predicted)
  - And either
    - *NYHA class IIIb-IV symptoms for at least 45 of the prior 60 days on maximally tolerated oral heart failure medications, or*
    - *Dependence on IV inotropes for at least 14 days, or*
    - *Dependence on an IABP for at least 7 days*
  - Not a candidate for transplantation
- **Exclusion criteria:**
  - Irreversible renal, pulmonary or hepatic dysfunction or active infection

LVADs Of The Future

Pipeline: getting bigger by getting smaller

	HVAD™	MVAD™	IV-VAD™
Procedure	Surgical	Minimally Invasive	Catheter Delivery System
Flow	10 L/min	10 L/min	3 L/min
Patient Class	Late Class IV	Class IV	Class III / Early Class IV
Treatable Pop.	100,000	350,000	1,000,000

Common Complications of LVADs

- Driveline infections / sepsis
- Ventricular arrhythmias (suck-down, RV fail)
- GI bleeding (any common cause + AVMs)
- Nose bleeds
- Neurologic events (hemorrhagic / ischemic)
- LVAD failure (electrical, mechanical, thrombus)
- Right heart failure
- Aortic Insufficiency (de novo)
- Hemolysis (baseline vs in setting of thrombus)

Pearl #4: Assess Risk

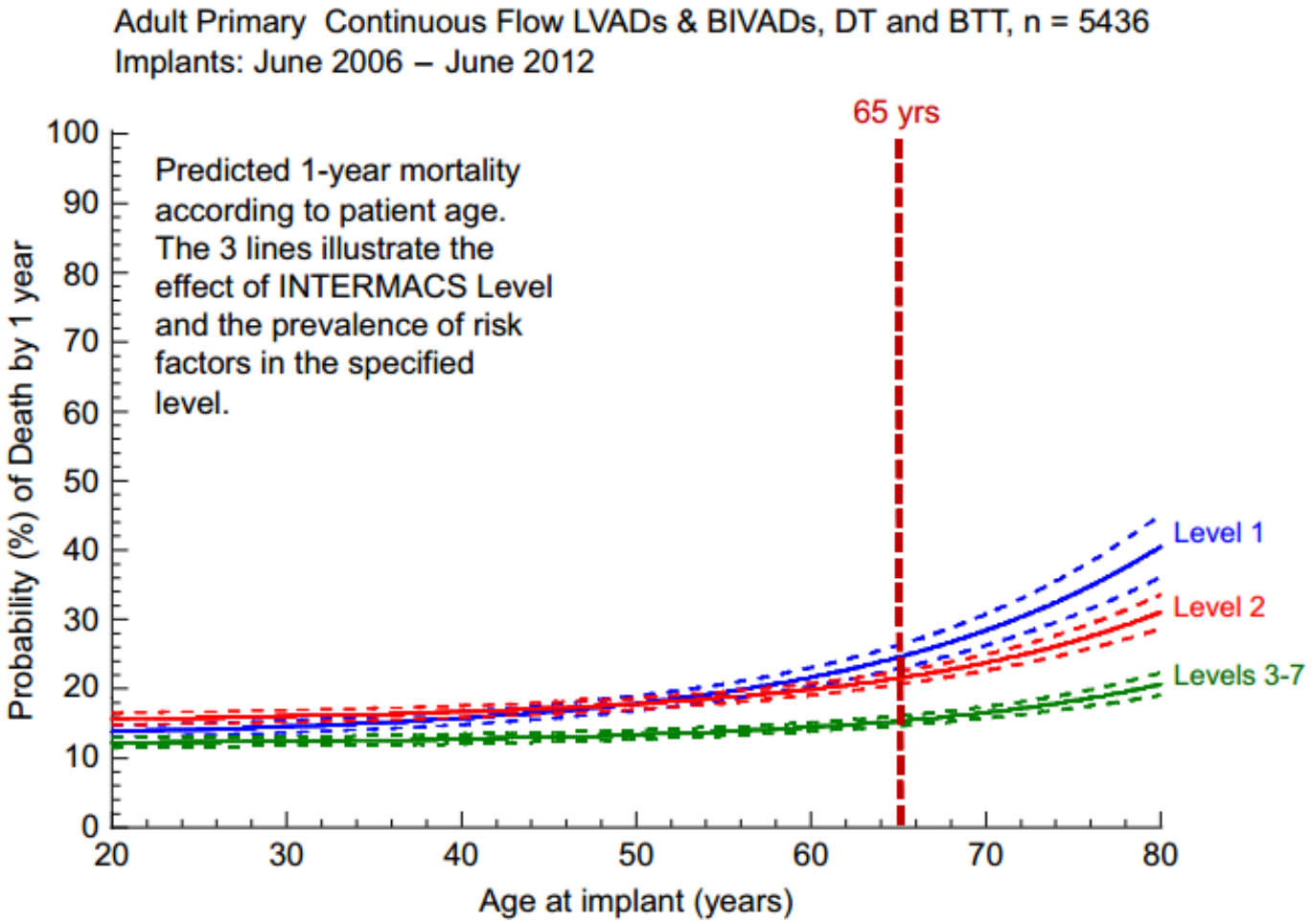
- Considerations for Mechanical Support
  - Nobody dies from LV dysfunction alone
  - Assess end-organs !!! -cause, acuity, severity
  - Trajectory, trajectory, trajectory… (UOP)
  - Evaluate the RV, relationship with LV, lungs
  - Oxygenation, Ventilation, Acid-Base
  - Arterial, Venous Access (potential pitfalls)
  - Define the Goals of Care
    - Bridge to recovery, durable support, transplant

Why Not Just Throw in LVAD?

- INTERMACS profile 1 avoided

	Implant Date Period							
	Pre 2001		2001		2012 (Jan-Jun)		Total	
Patient Profile at Time of Implant	n	%	n	%	n	%	n	%
Unspecified	1	0.0%	.	.	6	0.6%	7	0.1%
1 Critical Cardiogenic Shock	860	22.1%	298	16.0%	148	16.6%	1307	19.7%
2 Progressive Decline	1627	41.9%	708	38.0%	329	36.7%	2664	40.1%
3 Stable but Inotrope dependent	750	19.3%	519	27.8%	246	27.4%	1515	22.8%
4 Resting Symptoms	441	11.3%	233	12.5%	117	13.0%	791	11.9%%
5 Exertion intolerant	91	2.3%	66	3.5%	27	3.0%	184	2.7%
6 Exertion limited	59	1.5%	31	1.6%	14	1.5%	104	1.5%
7 Advanced NYHA Class 3	47	1.2%	6	0.3%	8	0.8%	61	0.9%
Total	3876	100.0%	1861	100.0%	896	100.0%	6633	100.0%

Targeting INTERMACS Level 3

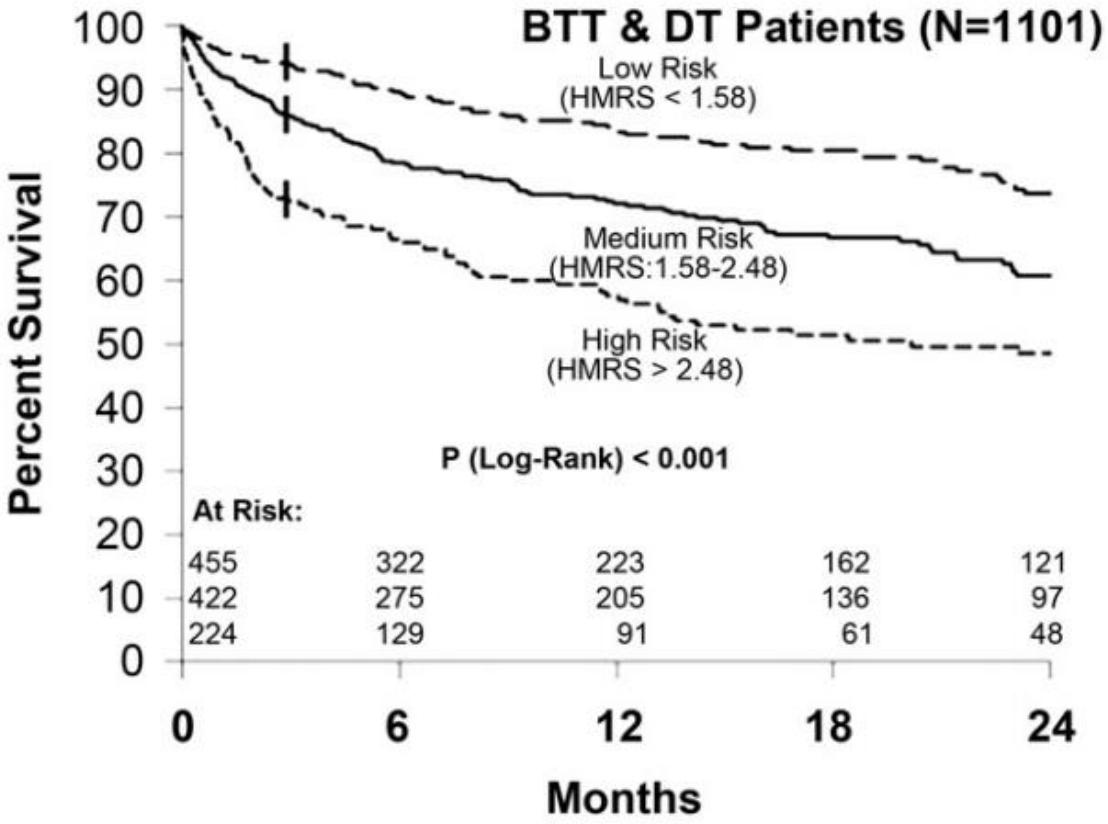


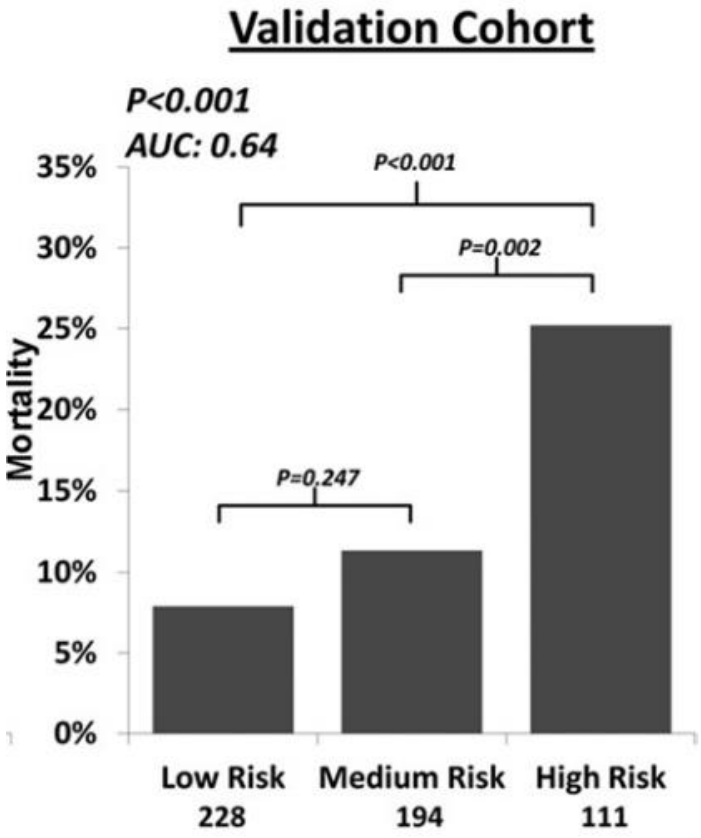
Maybe Organ Function is Key?

Parameter	Estimate	SE	OR (95% CI)	p Value
Age (per 10 yrs)	0.274	0.12	1.32 (1.05–1.65)	0.018
Albumin (per g/dl)	−0.723	0.23	0.49 (0.31–0.76)	0.002
Creatinine (per mg/dl)	0.740	0.22	2.10 (1.37–3.21)	<0.001
INR (per unit)	1.136	0.32	3.11 (1.66–5.84)	<0.001
Center volume <15	0.807	0.34	2.24 (1.15–4.37)	0.018

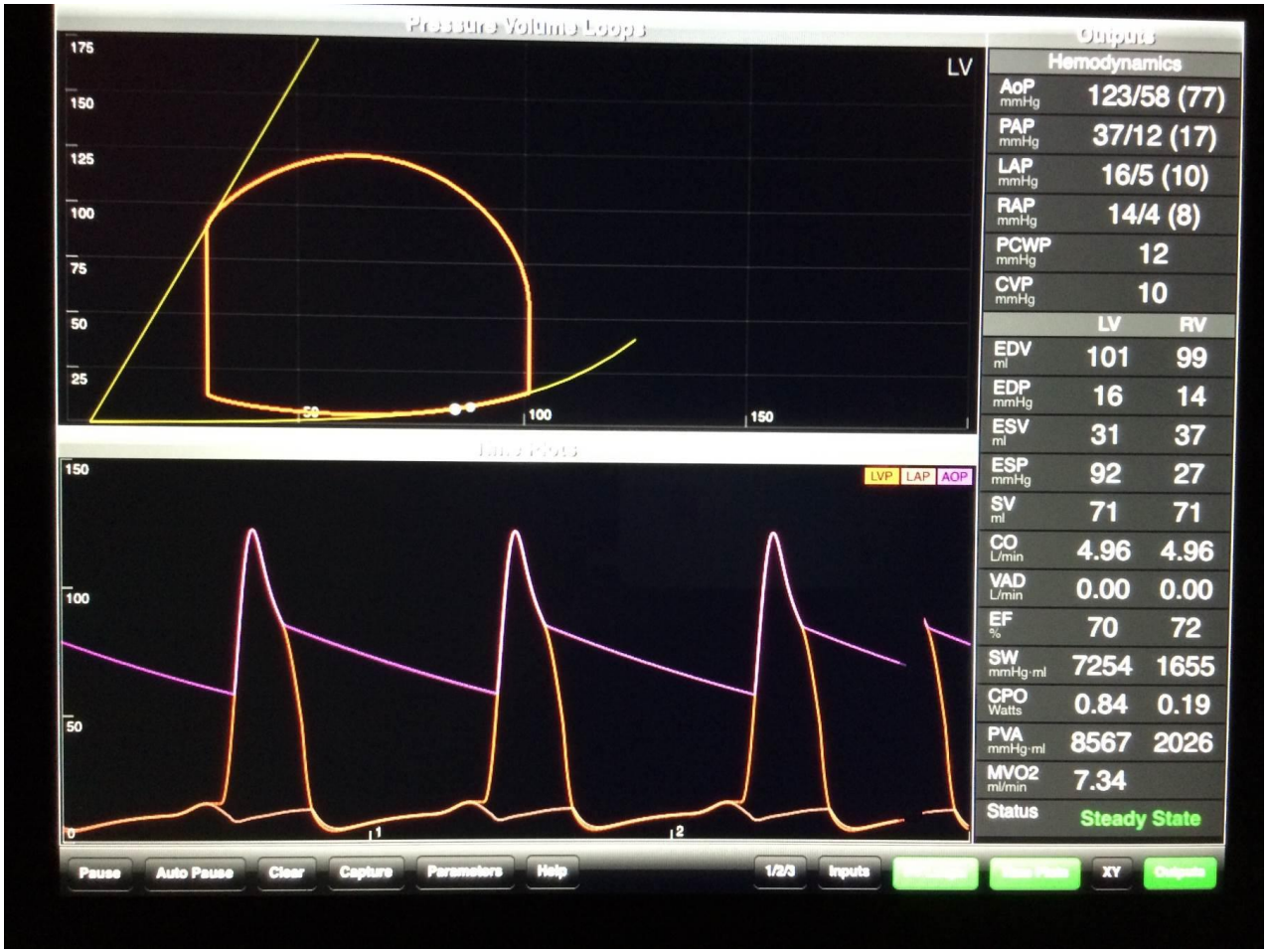
Multivariable predictors ($p < 0.05$) of 90-day mortality in the derivation cohort and the formula for calculating the HeartMate II Risk Score (HMRS). Calculation of HMRS: HMRS = (0.0274 × [age in years]) − (0.723 × [albumin g/dl]) + (0.74 × [creatinine mg/dl]) + (1.136 × [INR]) + (0.807 × [center LVAD volume <15*]). *Enter value of 1 if total center LVAD volume is <15 and 0 if ≥15. Other variables entered into multivariable analysis (all $p > 0.05$ in final model): sex, LVAD indication, pre-operative inotrope, vasopressor and/or vasodilator use, pre-operative ventilator support and/or IABP support, RVSWi, hematocrit, platelets, aspartate aminotransferase, total bilirubin, and implant era. Model fit was inferior when blood urea nitrogen was entered in place of creatinine into the aforementioned model. Likewise, entering right atrial pressure and/or mean pulmonary artery pressure in place of RVSWi did not improve modeling.

Contemporary 90-Day Risk

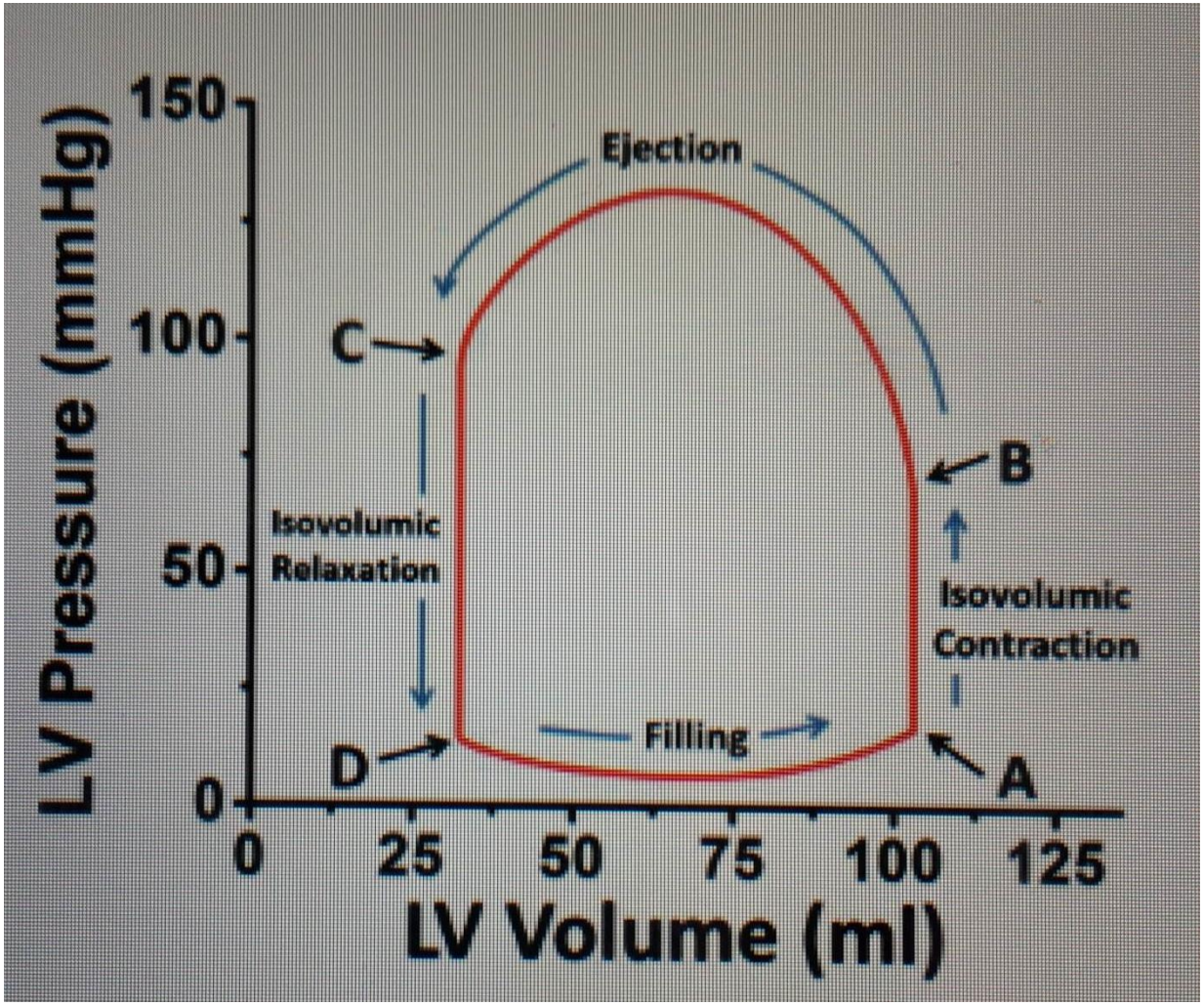




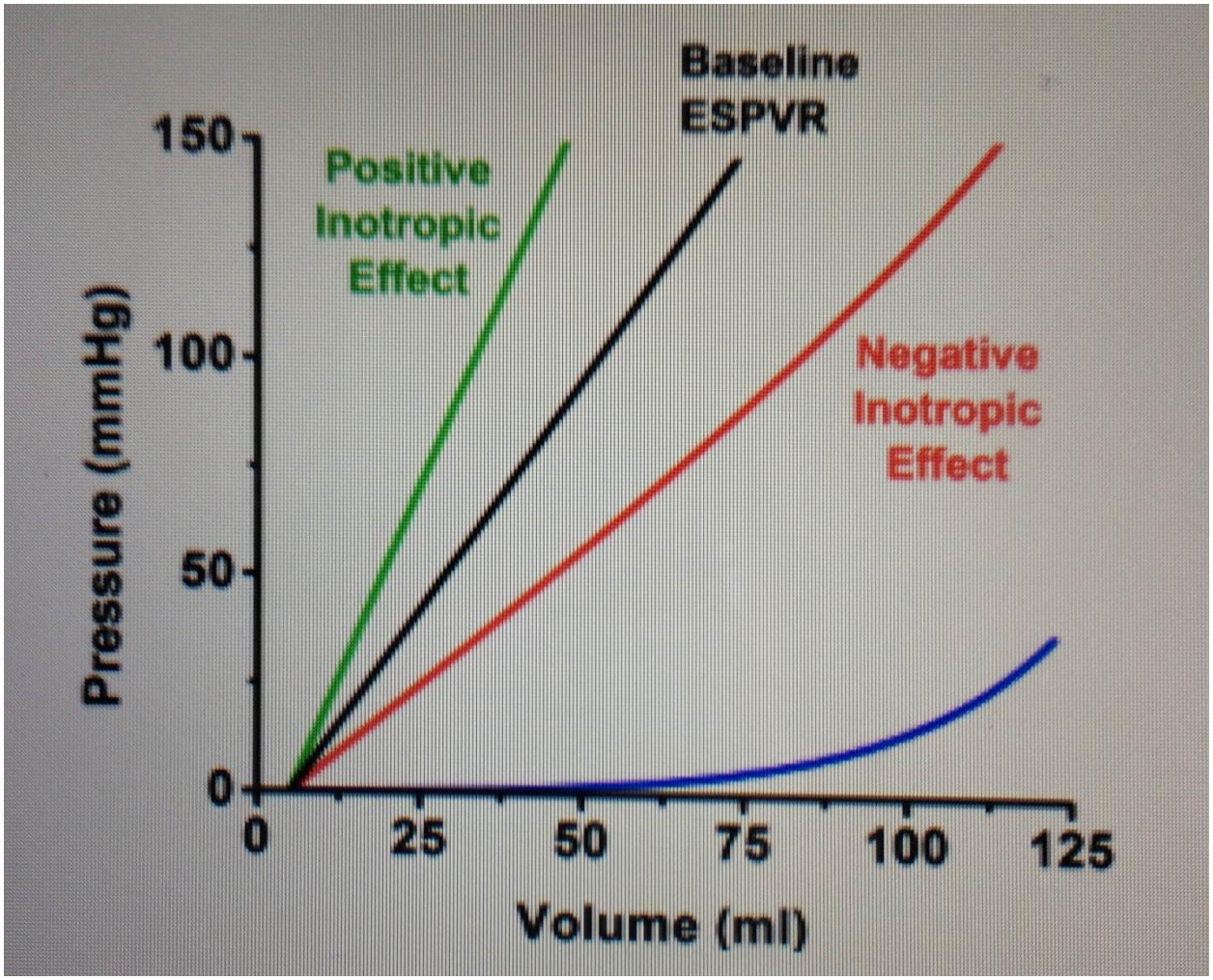
Pearl #5: Know Thy Device



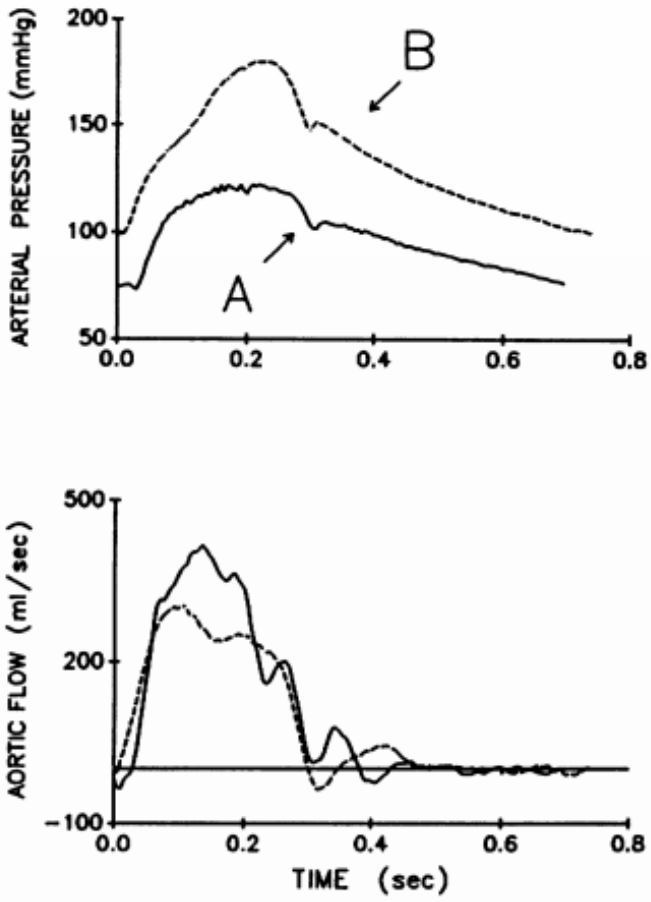
Pressure-Volume Relationship

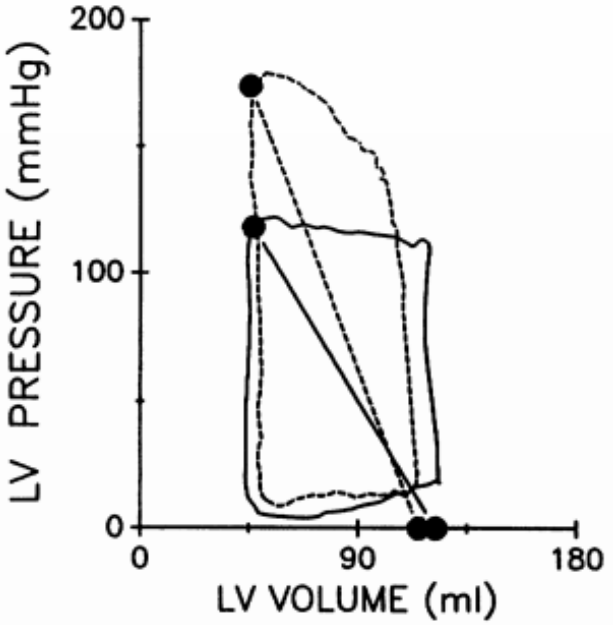


End-Systolic Pressure-Volume

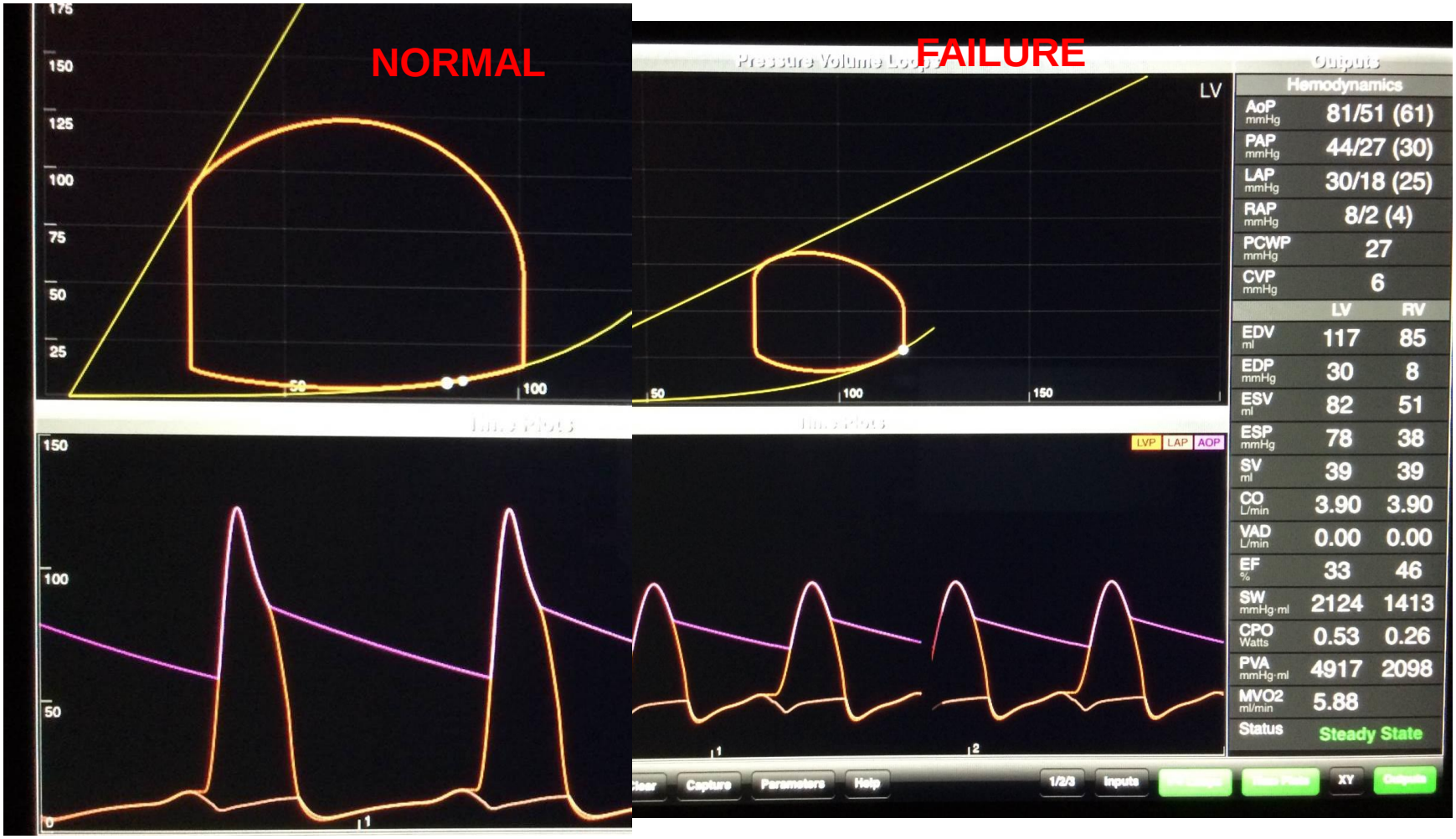


Effective Arterial Elastance (Ea)





Acute Heart Failure



Acute Heart Failure

- Loss of contractility
- Rightward shift in end-diastolic relation
- Loss in LV compliance, “overload” state
- Increased LV diastolic pressures
  - Reduced Ao to coronary pressure gradient
  - Reduced coronary flow, increased injury
- Decrease in stroke volume
- Increase in mitral regurgitation

Beyond the IABP…

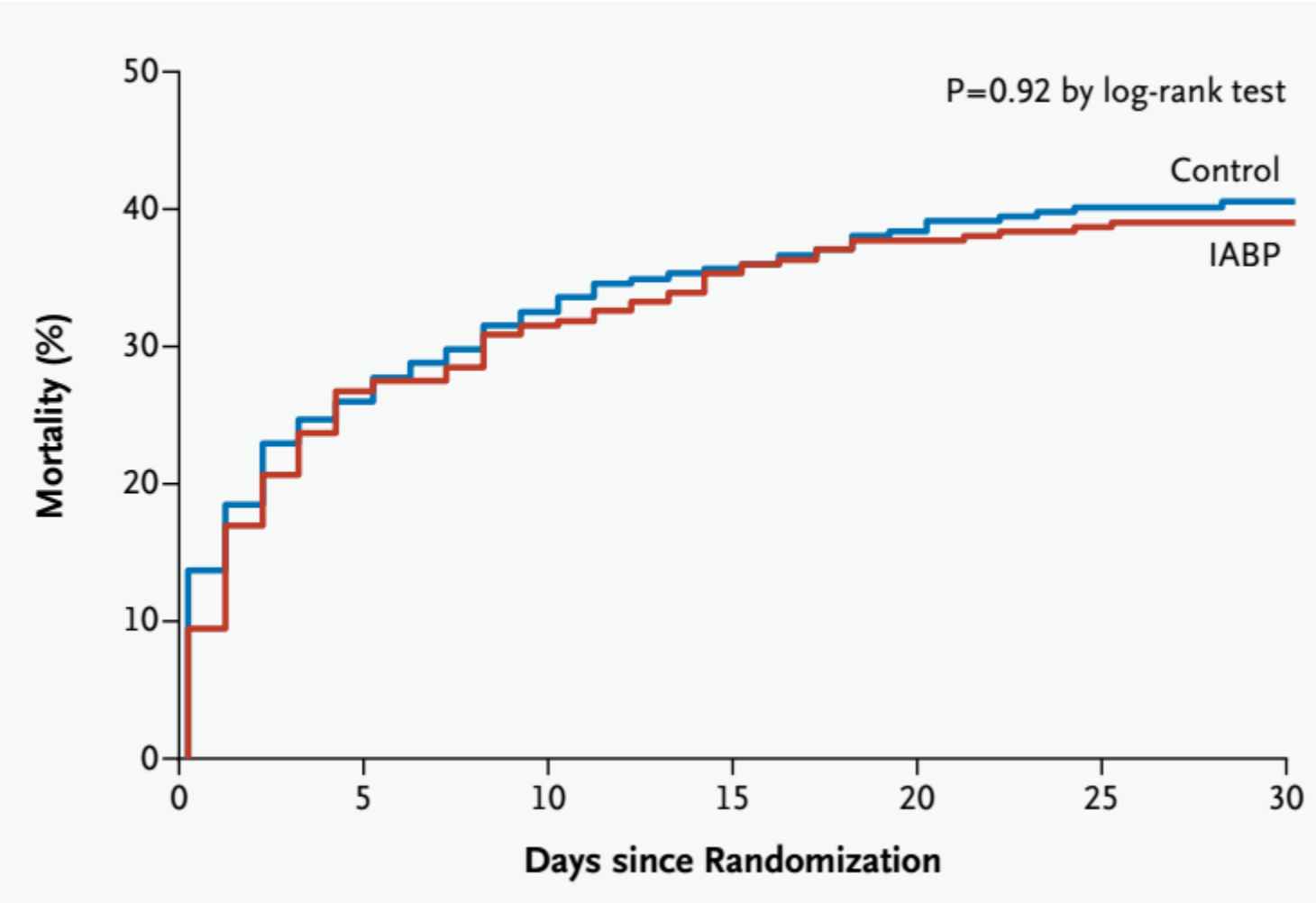
The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Intraaortic Balloon Support for Myocardial Infarction with Cardiogenic Shock

Holger Thiele, M.D., Uwe Zeymer, M.D., Franz-Josef Neumann, M.D., Miroslaw Ferenc, M.D., Hans-Georg Olbrich, M.D., Jörg Hausleiter, M.D., Gert Richardt, M.D., Marcus Hennersdorf, M.D., Klaus Empen, M.D., Georg Fuernau, M.D., Steffen Desch, M.D., Ingo Eitel, M.D., Rainer Hambrecht, M.D., Jörg Fuhrmann, M.D., Michael Böhm, M.D., Henning Ebelt, M.D., Steffen Schneider, Ph.D., Gerhard Schuler, M.D., and Karl Werdan, M.D., for the IABP-SHOCK II Trial Investigators*

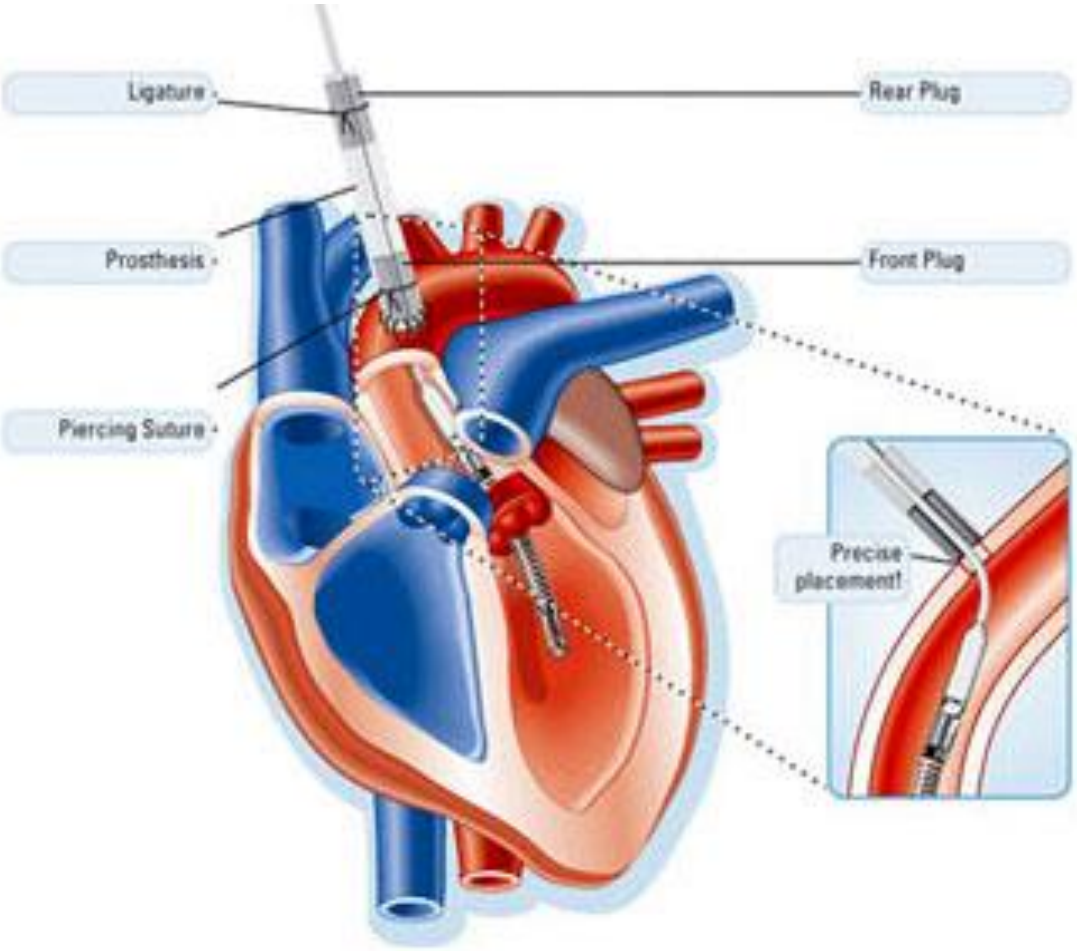
PCI + IABP – SHOCK II



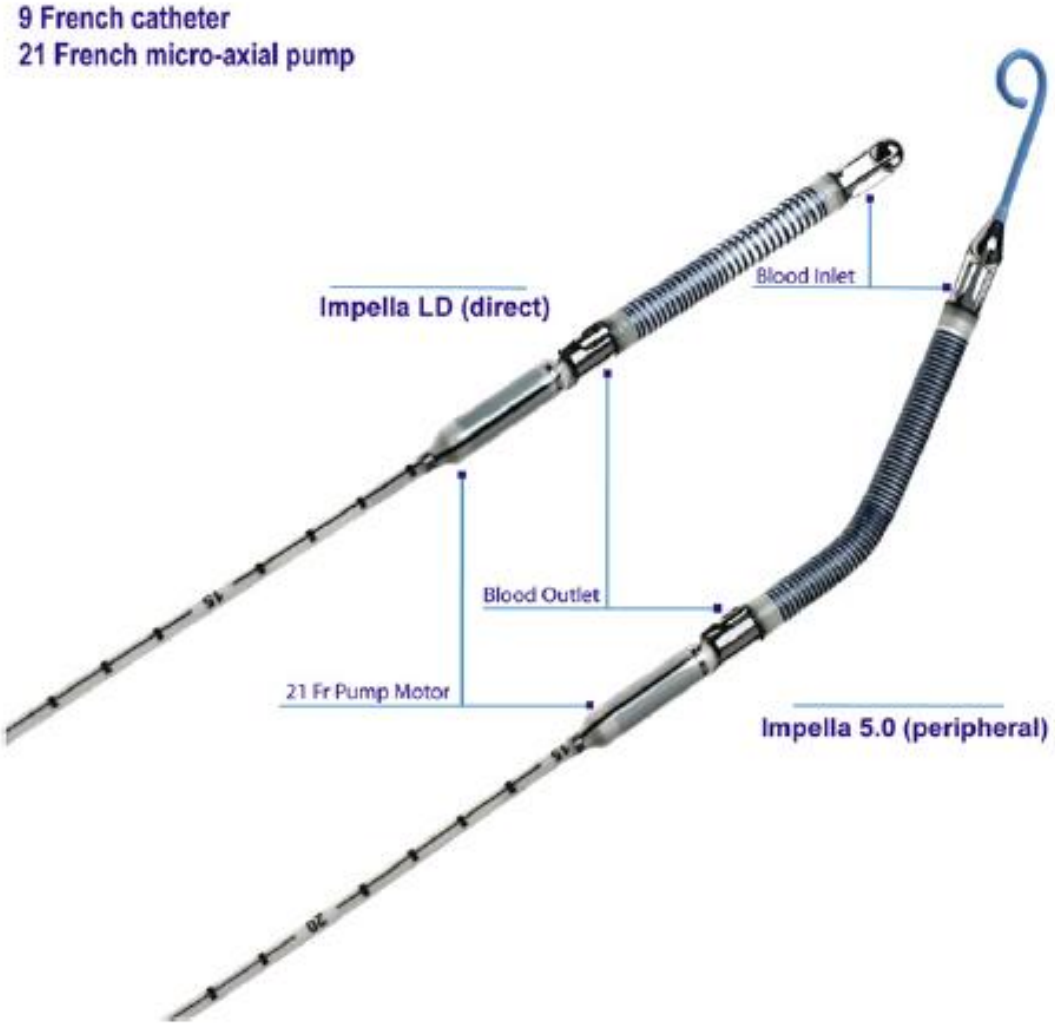
IABP: Completely Obsolete?

- May still have a practical niche:
  - Mild slowly progressing low-output heart failure (defined by invasive hemos)
  - Anticipate short need while going to OR for definitive therapy, closely monitored
  - Post-operative low-output “boost”
  - UNOS Status 1A categorization
  - Vascular access “issues” warranting lower profile indwelling device

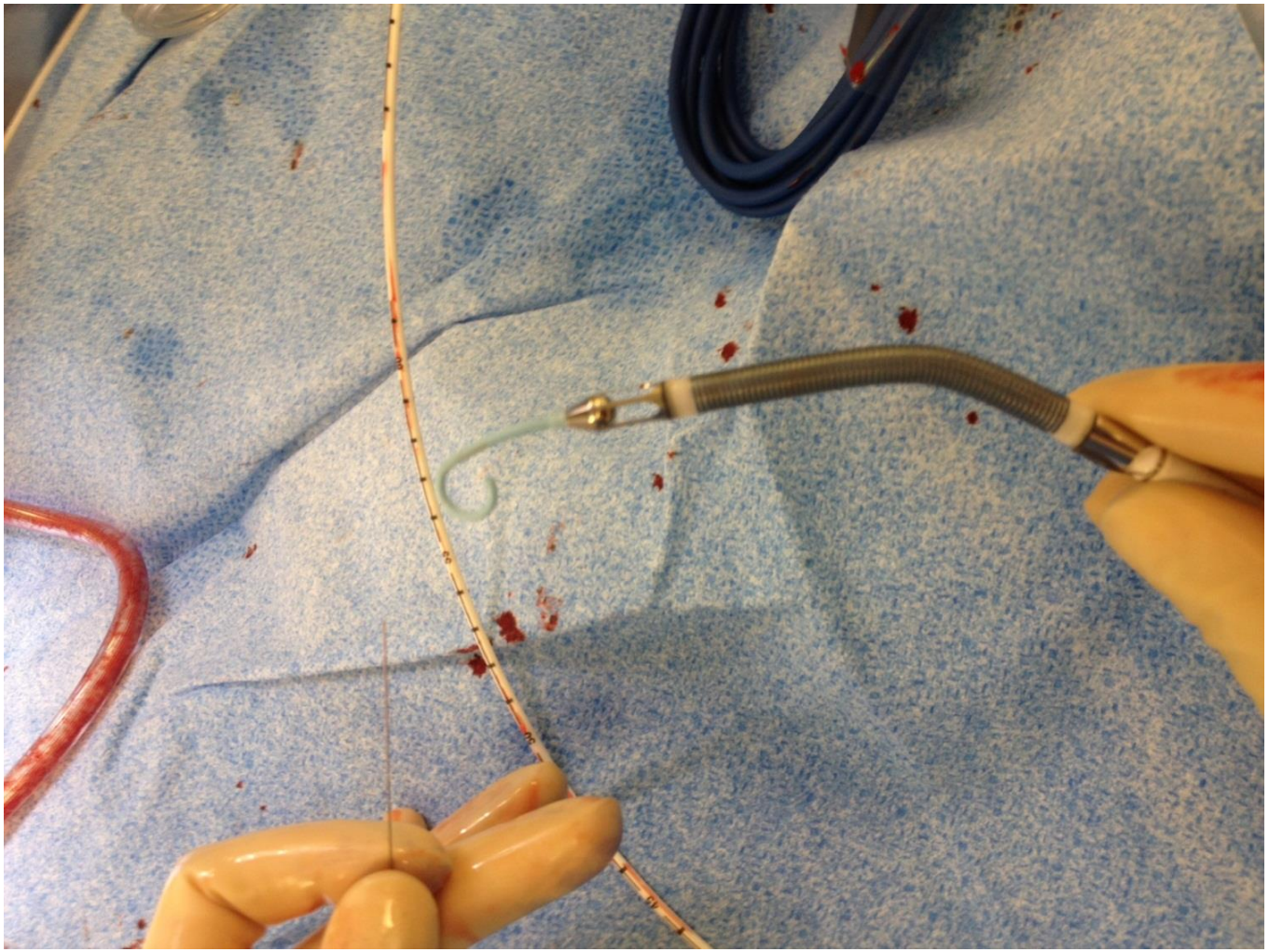
Impella Axial Flow Pump



Impella Axial Flow Pump

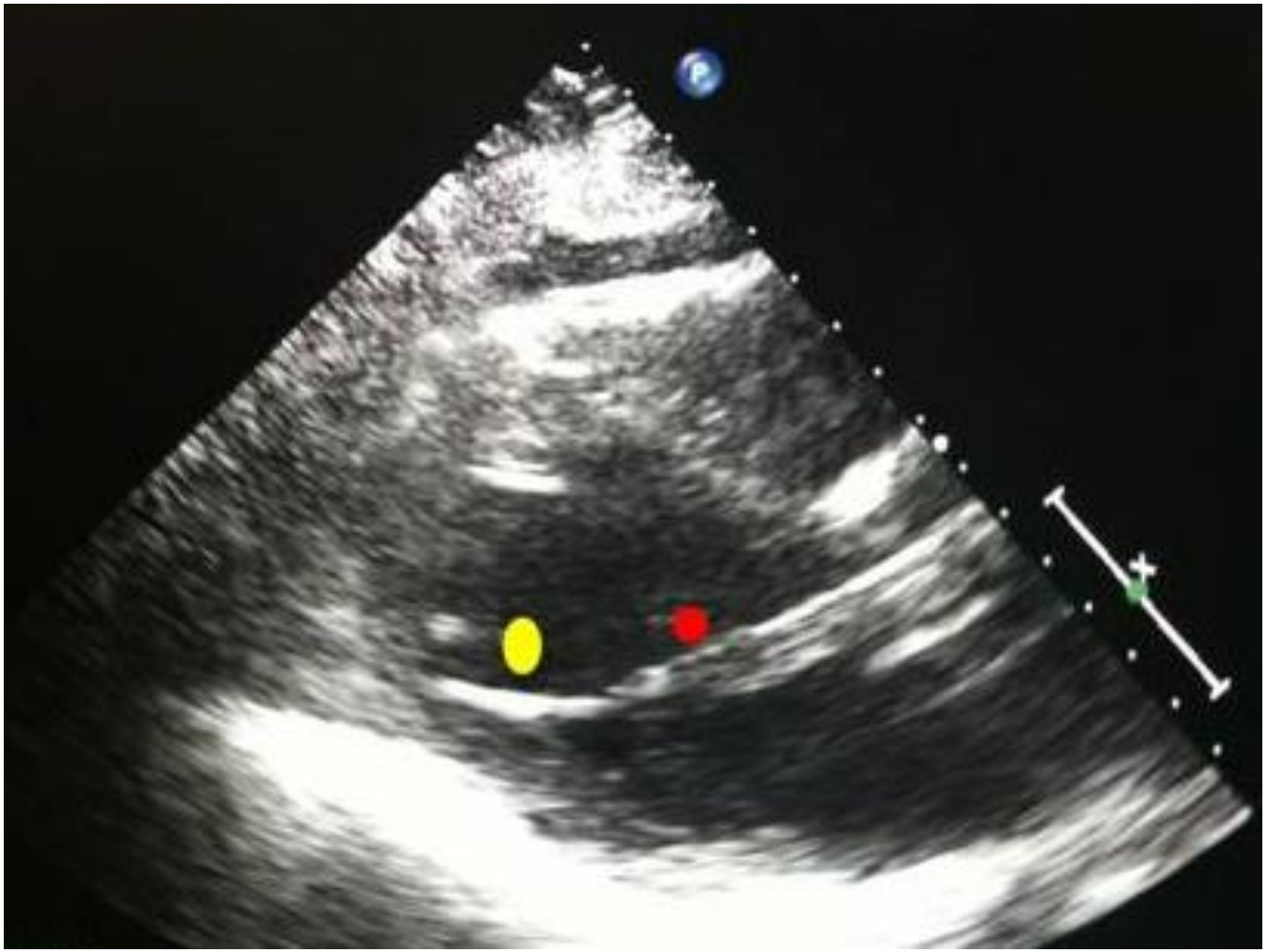


Impella Axial Flow Pump

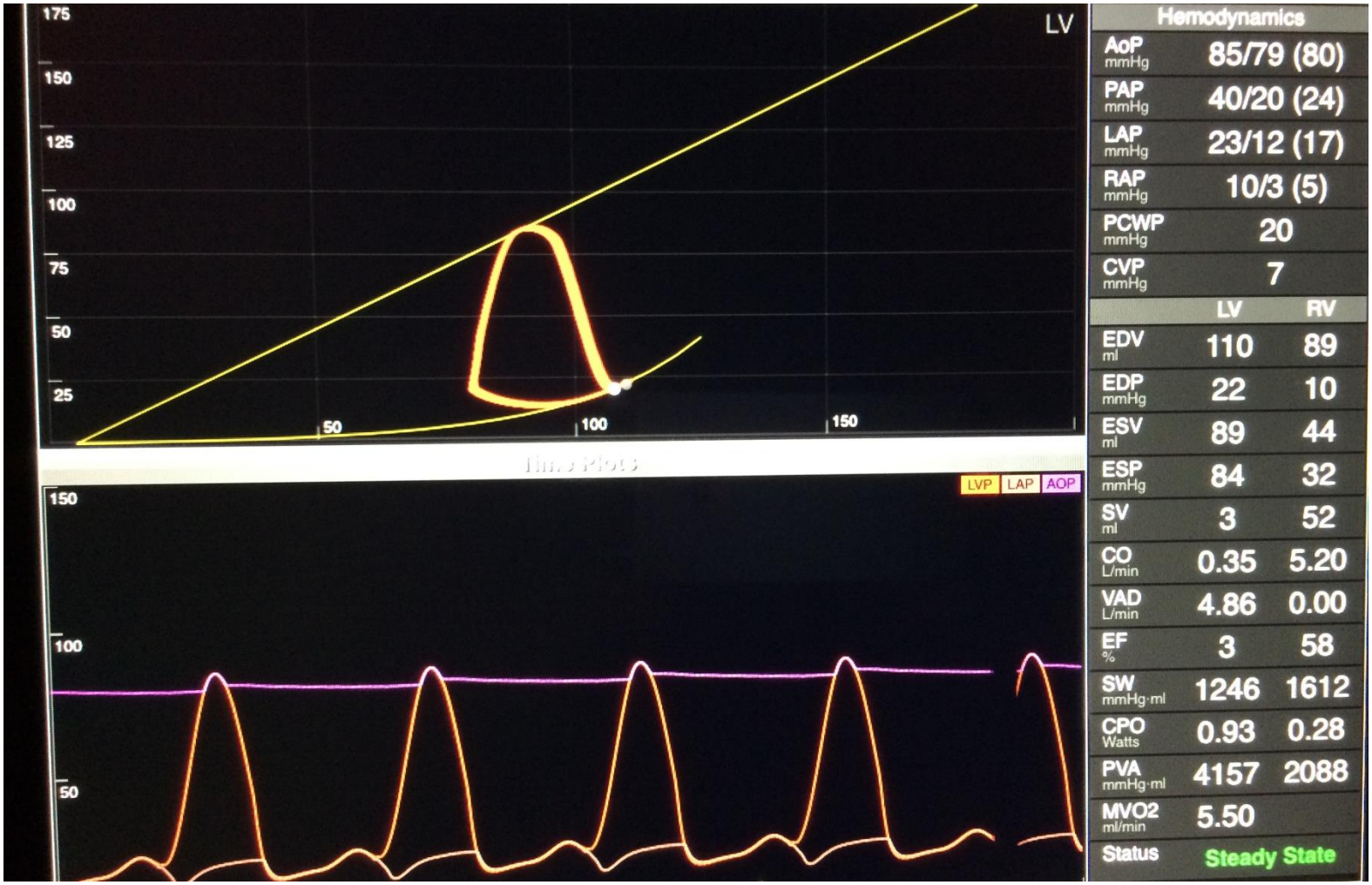


Axillary Access: Advantage?

Inlet Cage 3.5-4.0 cm from AV



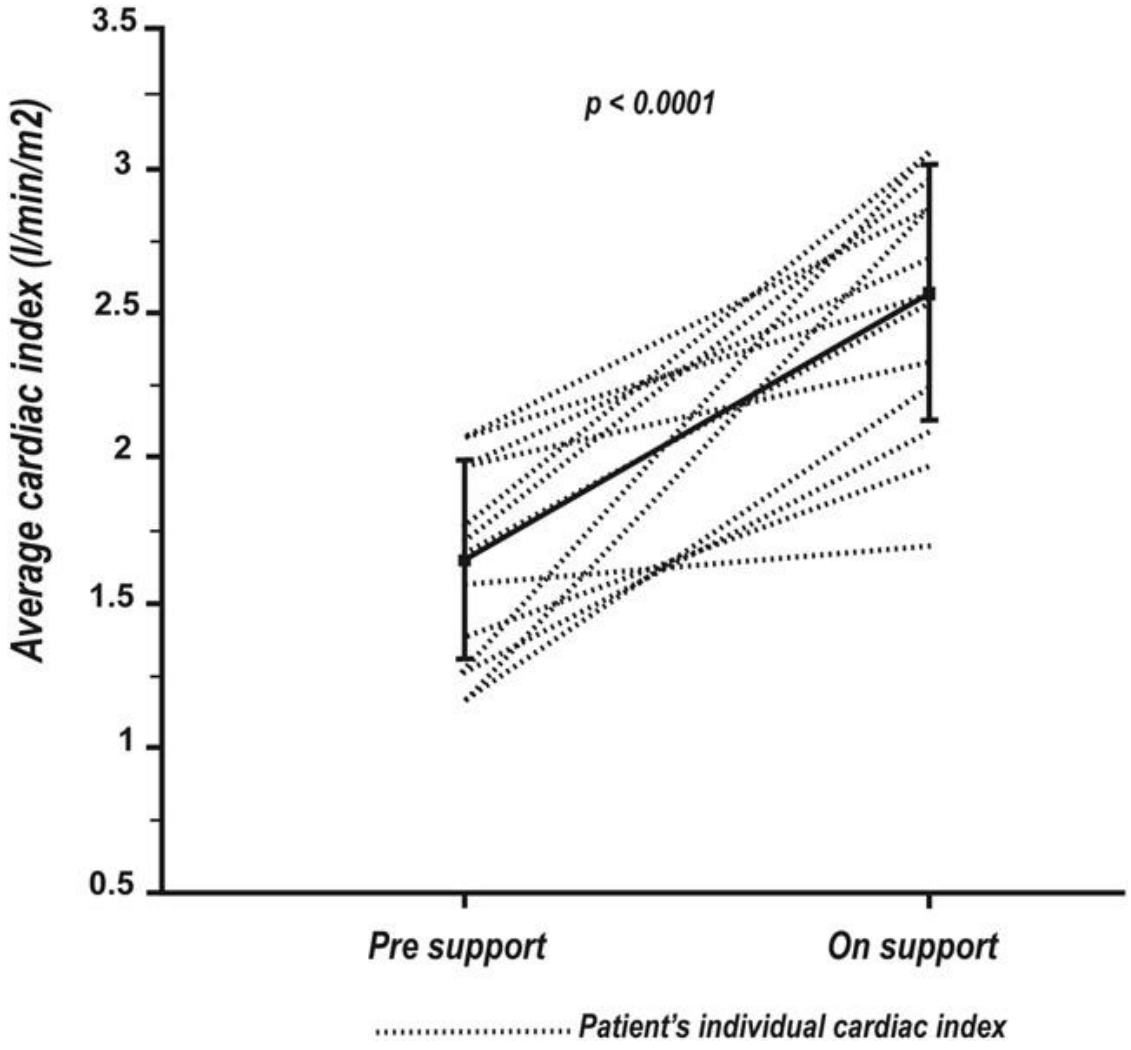
Impella (5.0)


175
150
125
100
75
50
25
LV
50
100
150
LVP
LAP
AOP
150
100
50
Hemodynamics
AoP mmHg 85/79 (80)
PAP mmHg 40/20 (24)
LAP mmHg 23/12 (17)
RAP mmHg 10/3 (5)
PCWP mmHg 20
CVP mmHg 7
LV RV
EDV ml 110 89
EDP mmHg 22 10
ESV ml 89 44
ESP mmHg 84 32
SV ml 3 52
CO L/min 0.35 5.20
VAD L/min 4.86 0.00
EF % 3 58
SW mmHg·ml 1246 1612
CPO Watts 0.93 0.28
PVA mmHg·ml 4157 2088
MVO2 ml/min 5.50
Status Steady State

Impella (5.0)

- Intrinsic contractility unchanged
- Increased mean arterial pressure
- Increased afterload
- Decreased preload
- Increased Ao-coronary gradient
  - Improved myocardial oxygen delivery
- Reduced stroke work (LV)
  - Possibly reduced infarct size

RECOVERY I Trial: Impella 5.0



Impella 5.0

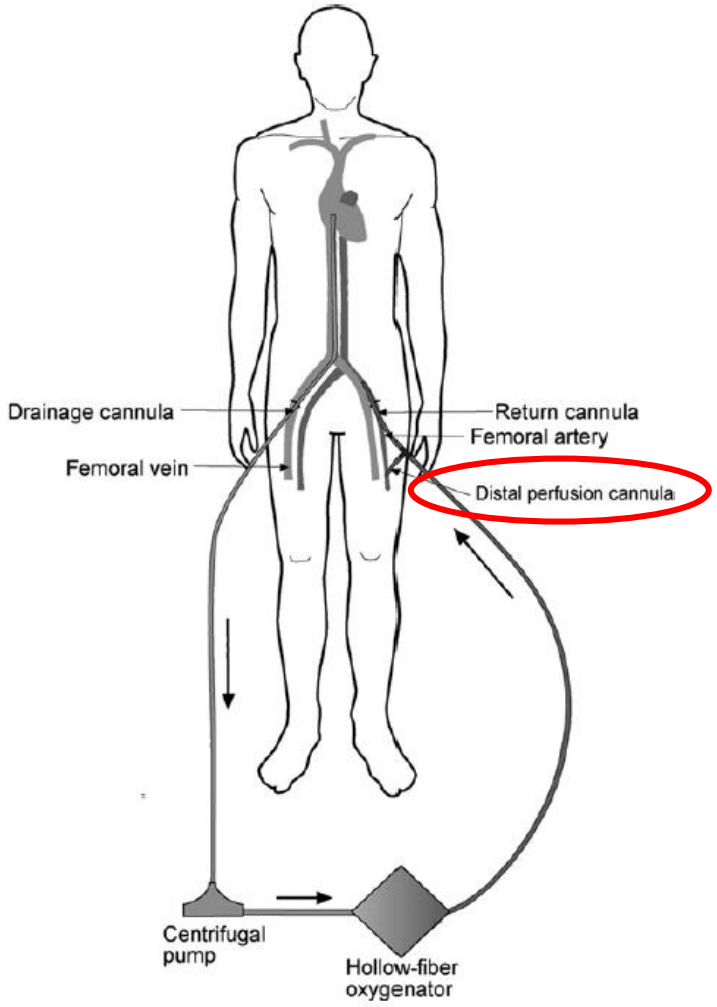
- The Ideal Patient: “Resting the LV”
  - Isolated LV failure due to CAD
  - Post-infarct / ischemic VT / VF
  - Post-cardiotomy / post-CABG
  - Expect reasonably quick recovery
  - Normal RV function
  - Normal pulmonary function
  - Available axillary access: allows HOB elevate

Impella 5.0

- Contraindications
  - Mechanical aortic valve
  - Ventricular septal defect
  - Hypertrophic cardiomyopathy
  - LV thrombus
  - Severe aortic insufficiency

VA-ECMO Circuit

- ICV-RA-Femoral vein
  - Cannula 23F-25F
- Centrifugal flow pump
- Oxygenator
- Femoral-iliac
  - Cannula 17F-21F
- Antegrade perfusion



VA-ECMO Circuit

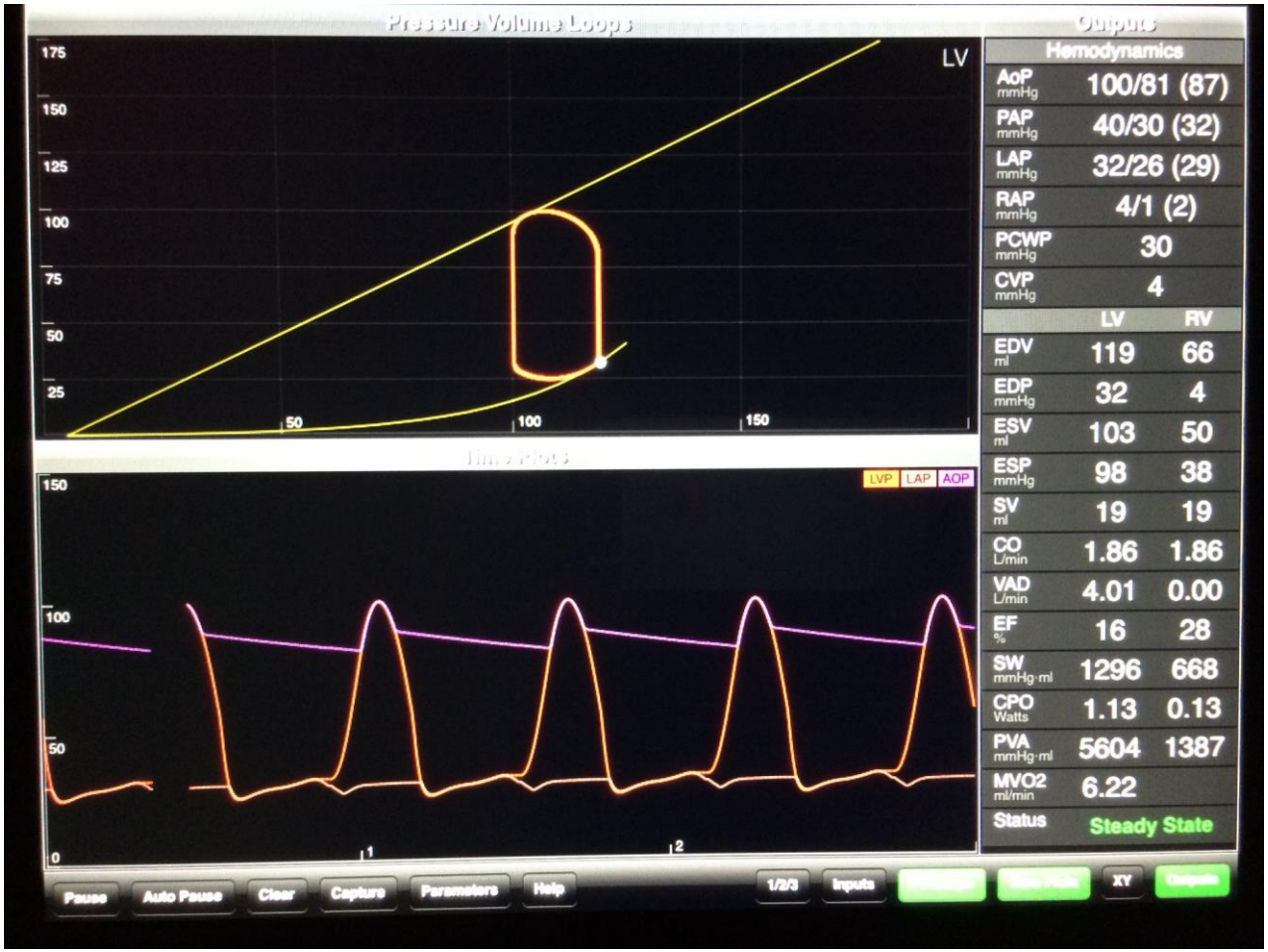
Oxygenator Technology

- 1st. involved “bubbling” O2 into blood
  - Allowed direct gas-blood interface
  - Blood trauma, hemolysis, microemboli
- 2nd gen. membrane oxygenators
  - Silicone membrane (non-micropores)
    - More durable but less efficient, lung injury
  - Polypropylene hollow-fiber (micropores)
    - Common in the OR, efficient but less durable
- 3rd gen. polymethylpentene (PMP)

VA-ECMO: Complications

Complication	Incidence (%)
Blood clots (oxygenator, pump, tubing, hemofilter)	3.2-22
Bleeding (surgical site, cannulation site, gastrointestinal tract, intracranial, tracheostomy)	5.3-79
Pump failure	4.7-20
Oxygenator failure	21
Neurologic complications (intracranial bleed, stroke, seizure, encephalopathy)	13-33
Limb ischemia	13-25
Problems during cannulation	0.8-8
Nosocomial infection	17-49
Renal failure	30-58

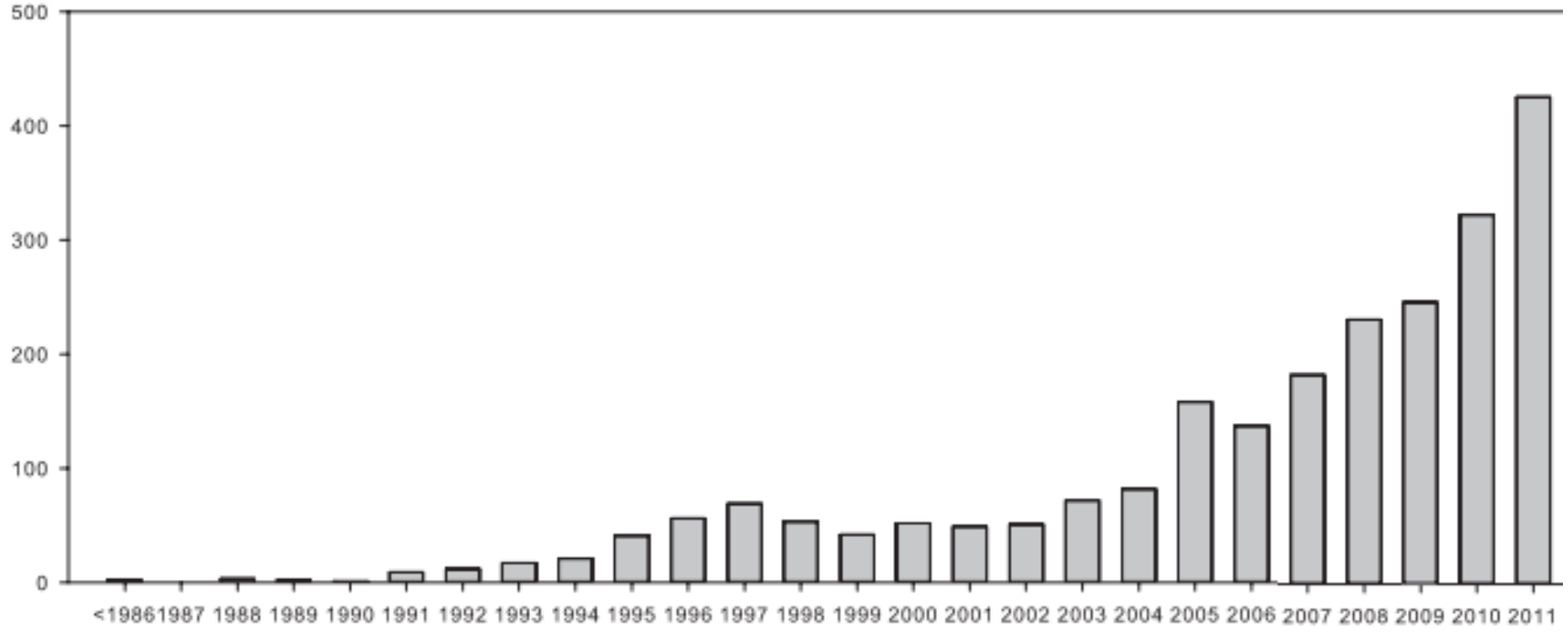
VA-ECMO: Pressure-Volume



VA-ECMO

- Hemodynamic Effects
  - Increased preload (LVEDP and PW will rise)
  - Increased MAP (improved BP support)
  - Increased LV afterload (LV can dilate)
  - Decreased intrinsic LV stroke volume
  - Decreased RA pressure
  - Decreased RV afterload and stroke work

Adult Cardiac Use VA-ECMO



VA-ECMO: Outcomes

Registry International Summary, July 2012

	Total Cases	Survive to Discharge or Transfer	
		Number	%
Neonatal			
Respiratory	25,746	19,232	75
Cardiac	4,797	1,912	40
ECPR	784	304	39
Pediatric			
Respiratory	5,457	3,061	56
Cardiac	5,976	2,913	49
ECPR	1,562	630	40
Adult			
Respiratory	3,280	1,808	55
Cardiac	2,312	891	39
ECPR	753	207	27
Total	50,667	30,958	61

VA-ECMO

- The “ECMO” Patient
  - Severe heart failure
  - Severe end-organ injury
  - Biventricular failure
  - Cardiopulmonary failure
  - Isolated RV failure
  - Pulmonary embolism

VA-ECMO

- Contraindications
  - Irreversible lung disease
  - Irreversible cardiac disease and contraindication to durable VAD or transplant
  - Inability to tolerate anticoagulation
  - Refractory septic shock (relative)
  - Severe coagulopathy, thrombocytopenia

Return to the Case

- Emergent broncoscopy showed DAH
- Rising inotrope / pressor requirement
- VA ECMO performed at bedside
- After 3 days of ECMO & IABP
  - A-line and echo: improved LV function
  - Oxygenation, acidosis resolved
  - End-organ function restored
  - Left leg vascular complications

Five Pearls

1. Consider Chronotropy
2. Define Trajectory
3. Respect the Vitals
4. Define Risk (including risk of doing nil)
5. Device (Know how they work and pitfalls)

ICU Management of VADs?

VAD Management Strategies

The LVAD patient is not that unique

Use invasive monitoring (PA and arterial lines)

Set the LVAD speed and “walk away”

Watch for RV failure, tamponade, volume shifts

Watch for arrhythmias

Watch for infections

Continue to follow the “five pearls”

Pearl # 6: CALL OUR TEAM

- Consult the Heart Failure Service
- Discussions ongoing for:
  - Cardiogenic shock response team