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Colorado Review of Anesthesia for Subspecialties And Hospitals
Guiding the future of patient care

Mechanical Support Devices in Non-Cardiac Anesthesia

Kenji Tanabe, MD Sam Gilliland, MD

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Commercial Disclosures: none

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Learning Objectives

- Describe the mechanism, perioperative indications, and contraindications of veno-venous (VV) and veno-arterial (VA-ECMO)
- Explore the limited clinical indications for the intra-aortic balloon pump
- Review the mechanism and clinical role of microaxial flow pumps
- Review the perioperative considerations for left-ventricular assist devices for non-cardiac surgery

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The New York Times

The Race to Reinvent CPR

A new, high-tech approach called ECPR can restart more hearts and save more lives. Why aren't more hospitals embracing it?

FOX43

Life-saving ECMO treatment helps York County mom survive rare birth complication | Health Smart

THE NEW YORKER
ANNALS OF MEDICINE

HOW ECMO IS REDEFINING DEATH

A medical technology can keep people alive when they otherwise would have died. Where will it lead?

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FOX43

Life-saving ECMO treatment helps York County mom survive rare birth complication | Health Smart

After a rare complication nearly took her life, a York County mom says advanced ECMO technology and the team behind it gave her a second chance.

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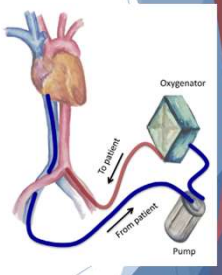
ECMO Overview

- ECMO can act as important **salvage therapy** for otherwise fatal perioperative emergencies
- Functions as a **bridge to recovery**
- ECMO therapy **increasing**
- Plan to discuss the **two major types of ECMO**, **how it works**, and broad perioperative **clinical indications**



Foong TW, Ramanathan K, Chan KKM, MacLaren G. Extracorporeal Membrane Oxygenation During Adult Noncardiac Surgery and Perioperative Emergencies: A Narrative Review. *J Cardiothorac Vasc Anesth*. 2021;35(1):281-297.

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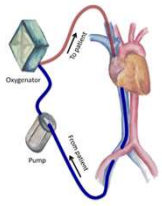
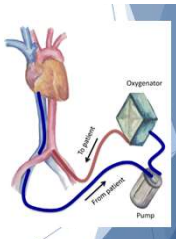
Veno-venous (VV) ECMO



Pulmonary support

Veno-arterial (VA) ECMO



Pulmonary & cardiac support

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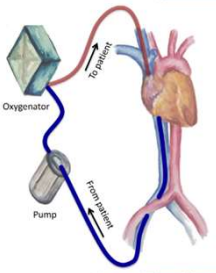
Veno-venous (VV) ECMO



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Veno-venous (VV-ECMO)

Function	• Directs blood **outside of the body** (extra-corporeal) using large, venous cannulas to perform gas exchange
Broad Clinical Indications	• Refractory hypoxemic or hypercapnic respiratory failure • Bridge to **recovery** or additional life-saving intervention (i.e. lung transplant)
Common ICU Indications	• ARDS (i.e. COVID-pneumonia causing ARDS) • Status asthmaticus • Severe pulmonary disease before lung transplant

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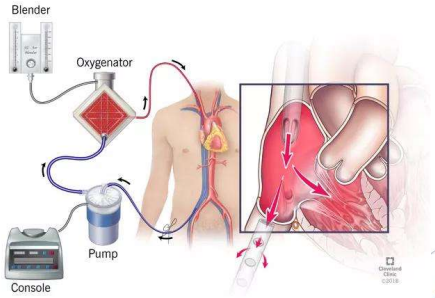
VV-ECMO Circuit Overview



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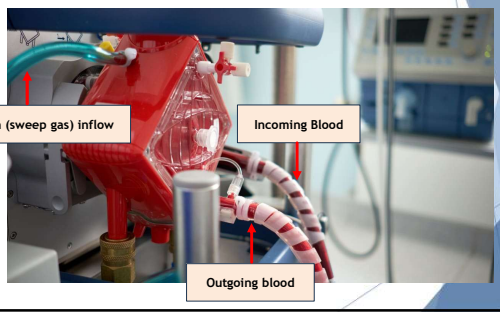
ECMO Oxygenator



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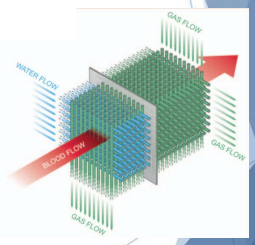
ECMO Oxygenator

- Comprised of overlapping, hollow microfiber network (non-porous) permeable to gas exchange
- Countercurrent blood & gas flow allows for O_2 and CO_2 exchange
- Oxygenator surface area = 0.8-2.5 m^2 (lungs ~ 50 m^2)



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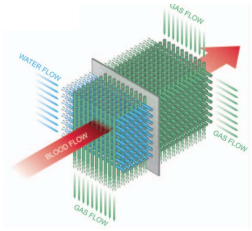
VV-ECMO Setting #1: Sweep



Sweep Gas Flow

- Rate (L/min) that gas in infused into oxygenator
- Sweep akin to **minute ventilation**
- ↑ sweep ∝ ↓ partial pressure CO_2

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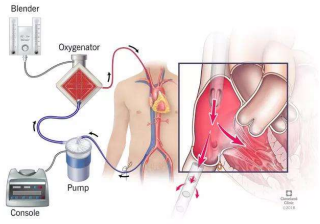
VV-ECMO Setting #2: ECMO Flow



ECMO Flow Rate

- **ECMO flow rate:** Determined primarily by pump RPM's (L/m)
- ↑ ECMO flow ∝ ↑ oxygenation

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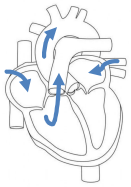
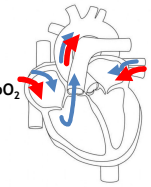
ECMO Flow and Oxygenation

Hypoxic Failure



Hypoxic Failure with VV-ECMO

ECMO blood with 100% SpO_2



↑ ECMO flows = ↑ proportion of cardiac output comprised by well oxygenated ECMO blood

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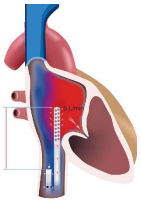
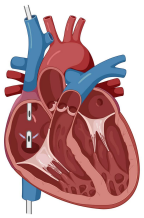
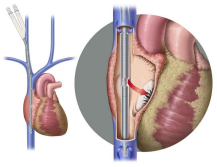
VV-ECMO Cannula Configurations



Femoral-femoral cannulation



Femoral-jugular cannulation



Dual lumen (IJ) cannulation

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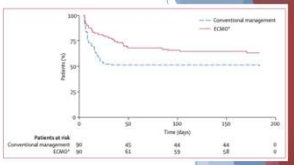
VV-ECMO and ARDS Outcomes

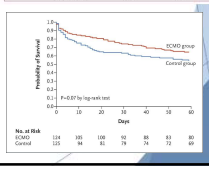
LANCET **CESAR Trial (2009)**

- 180 patients with severe ARDS
- Conventional mechanical ventilation versus transfer to specialized center for ECMO consideration



EOLIA Trial (2018)

- 249 patients with severe ARDS
- Conventional mechanical ventilation versus transfer to specialized center for ECMO consideration



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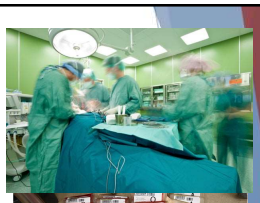
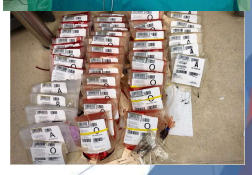
Clinical Vignette

- 25 year old male s/p auto-pedestrian collision
- Blunt abdominal trauma, OR for emergent ex-lap
- Undergoes massive transfusion
- After two hours in the OR, bleeding subsides and abdomen packed
- Ventilation getting more difficult…





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Perioperative Case (continued)

VV-ECMO?

- Stable hemodynamics on minimal pressor
- Stiff lungs, poor oxygenation
- FiO_2 100%; peak pressure 40 cm H_2O
- SpO_2 88%
- 7.22 / PaO_2 55 / $PaCO_2$ 55 / -4
- Ruled out bronchospasm, mainstem intubation, pneumothorax

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VV-ECMO Indications and Contraindications

Indication

Acute hypoxic or hypercarbic respiratory failure

Bridge to recovery (i.e. reversible lung injury)*

Strict Contraindications

- Do Not Resuscitate / patient preference
- Advanced cancer
- Significant intracranial hemorrhage
- Irreversible lung injury

Relative Contraindications

- Age > 70
- Severe, multi-organ failure (i.e. anoxic brain injury)
- Time on ventilator > 7 days
- *Contraindication to anti-coagulation*

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Key Considerations for VV ECMO Candidacy

- Reversible lung injury?
- Otherwise survivable injuries and intact non-pulmonary organ function?
- Will tolerate eventual AC for VV-ECMO circuit?
- Institutional ECMO infrastructure
  - Team to cannulate (cardiothoracic surgeons, general surgeons, some intensivists in adult population)
  - ICU setting familiar with ECMO
  - Ultimate destination for transfer?

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Perioperative Case (continued)

- Stable hemodynamics on minimal pressor
- Stiff lungs, poor oxygenation
- FiO_2 100%; peak pressure 40 cm H_2O
- SpO_2 88%
- 7.22 / PaO_2 55 / $PaCO_2$ 55 / -4
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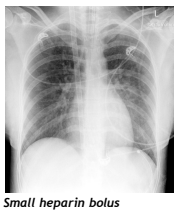
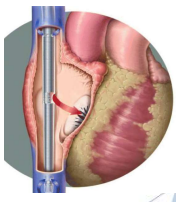
Emergent Intraoperative ECMO Cannulation



Small heparin bolus



Dual-Lumen Cannula. The Alfred. Oct 2020.
Zhang, James Z, et al. "Fibroadipose Tissue Ring Causing ECMO Catheter Obstruction: An Unusual Complication of Avalon Elite Catheter Insertion." Case Reports 3.3 (2021): 464-468.

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Clinical Case: Before and After ECMO

Pre-ECMO	Post-ECMO
7.22 / PaO_2 55 / $PaCO_2$ 55 / -4	7.30 / PaO_2 123 / $PaCO_2$ 39 / -3
Lung-*damaging* ventilator settings	Ultra-lung protective ventilation

Poor oxygen delivery to cells, organ failure

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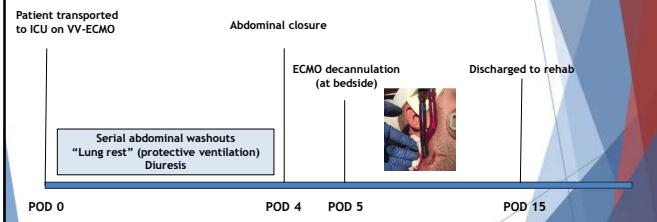
Perioperative Case (continued)



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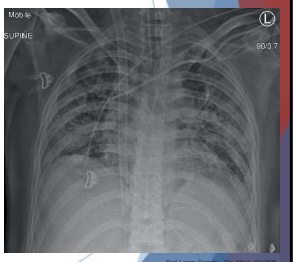
Emergent Perioperative VV-ECMO Indications

Severe **hypercarbic** or **hypoxic** respiratory failure

- Induction/extubation aspiration
- Fat embolism (severe hypoxemia)
- Anaphylaxis (severe bronchospasm)
- TRALI / severe pulmonary edema
- Aspiration pneumonitis / pneumonia



Dual Lumen Cannula. The Alfred. Oct 2020.

Foong TW, Ramanathan K, Chan KKM, MacLaren G. Extracorporeal Membrane Oxygenation During Adult Noncardiac Surgery and Perioperative Emergencies: A Narrative Review. J Cardiothorac Vasc Anesth. 2021;35(1):280-287.

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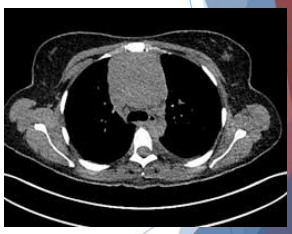
Non-Emergent Perioperative VV-ECMO

- **Complex thoracic surgery** (complex tracheobronchial operations, complex lung resection, TE fistula repair)
- **Certain anticipated difficult airway** (mediastinal mass, airway compressing tumor, etc.)

Cannulation before induction



Simionis L, Stimmon G, Lizo JA, Efthymiou A, Rouiller R. Case report: awake Chamberlain mediastinotomy under hypnosis to prevent complete airway obstruction and cardiovascular collapse. Mediastinum. 2021;5:29. Published 2021 Sep 30.

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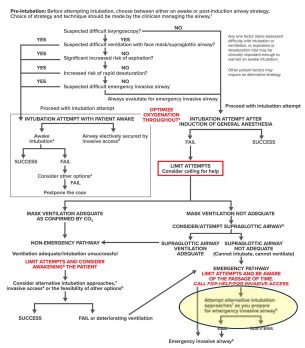
2022 Difficult Airway Algorithm



...rgical tracheostomy. Elective invasive airway techniques ...omy. Also consider rigid bronchoscopy and ECMO. *Cons... ...irways may improve the ability to ventilate. †Alternative d... ...v, alternative laryngoscope blades, combined techniques.

Apfelbaum J, Hagberg L, ... et al. "2022 American Society of Anesthesiologists practice guidelines for management of the difficult airway." Anesthesiology. Vol 136(1): 31-81.

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VV-ECMO Summary

- **VV-ECMO provides oxygenation and CO_2 removal for patients with hypoxic or hypercarbic respiratory failure**
- **Utilized frequently in ICU, growing utilization for non-cardiac perioperative emergencies**
- **Key considerations for VV-ECMO candidacy: reversible lung injury & otherwise intact/survivable organ function**
- **Critical to consider institutional ECMO availability and staffing**

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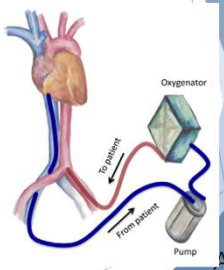
Veno-arterial (VA) ECMO



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Veno-arterial (VA-ECMO)

Function

- Directs blood outside of the body using large venous "drainage" cannula and arterial "return" catheter
- Performs **gas exchange and provides pressurized, arterial flow**

General Clinical Indications

- Circulatory failure +/- respiratory failure
- Bridge to **recovery** or additional life-saving intervention (i.e. LVAD, heart transplant)

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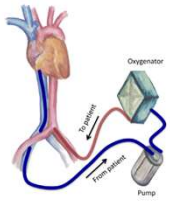
VA-ECMO



- Blood drains from **venous system**
- Directed through **pump** (pressurizes) and **oxygenator** (oxygenation & ventilation)
- Returned to patient's **arterial system**

Pulmonary & cardiac support

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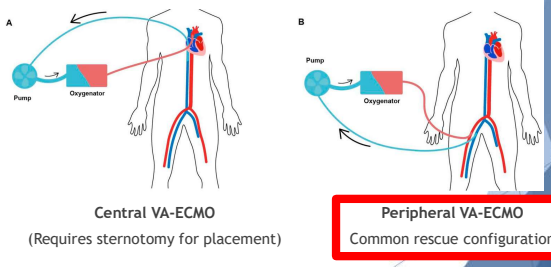
VA-ECMO Configurations



Central VA-ECMO
(Requires sternotomy for placement)

Peripheral VA-ECMO
Common rescue configuration

Ruzsel N, Kielbowski K, Piotrowska M, et al. Central, peripheral ECMO or CPB? Comparison between circulatory support methods used during lung transplantation. J Cardiothorac Surg. 2021;16(1):341. Published 2021 Nov 27.

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Primary VA-ECMO Setting: Pump Speed

Pump Speed

- Programmed pump RPM's are primary determinant of ECMO flow (L/m)

Management of Penetrating Cardiac Injury and Tricuspid Regurgitation With ECMO. Perfusion Times. April 2024.

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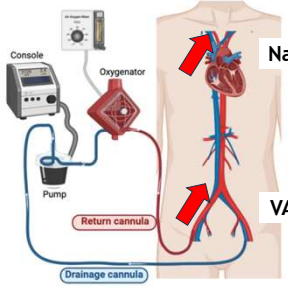
VA ECMO: Cardiopulmonary Support



Native cardiac output

+

VA-ECMO Flow

= Total cardiac output

Trieu, N.H.K., Pham, H.M., Huynh, D.Q. et al. Peripheral VA-ECMO: from Evolving Indications to Perioperative Implications. Anesthesiol. Perioper. Sci. 3, 16 (2025).

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VA-ECMO Indications and Contraindications

Indication

Cardiogenic shock

Acute cardiopulmonary failure

Strict Contraindications

Do Not Resuscitate / patient preference

Severe, irreversible organ failure (i.e. anoxic brain injury)

Severe aortic insufficiency, aortic dissection

End stage malignancy

Relative Contraindications

Age > 70

Limited vascular access, severe PAD

Contraindication to anti-coagulation

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Key Considerations for VA ECMO Candidacy

- **Reversible cardiopulmonary injury (or candidate for heart transplant/LVAD?)**
- **Otherwise survivable injuries and intact neurologic, renal, and liver function?**
- **Will tolerate eventual AC for VV-ECMO circuit?**
- **Institutional ECMO infrastructure**
  - Team to cannulate (cardiothoracic surgeons, general surgeons, some intensivists in adult population)
  - ICU setting familiar with ECMO
  - Ultimate destination for transfer?

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VA-ECMO and Cardiogenic Shock Outcomes

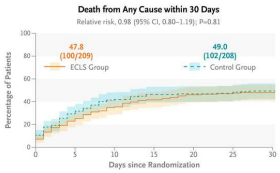
The NEW ENGLAND JOURNAL of MEDICINE

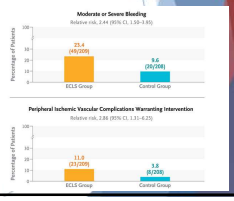
RESEARCH SUMMARY

Extracorporeal Life Support in Infarct-Related Cardiogenic Shock

Thiele H et al. DOI: 10.1056/NEJMoa2307227

- 420 patients with ACS-related cardiogenic shock pending revascularization
- Fairly severe cardiogenic shock: mean pH 7.2, median lactate 6.8





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VA-ECMO Perioperative Case Presentation

- 27 year old G1P0 presenting for elective 41 week induction of labor at satellite hospital in the community
- Developed non-reassuring fetal heart tones, rushed to OR for emergent C/S
- Unremarkable C/S facilitated by anesthesia from epidural catheter
- At fascial closure, developed shortness of breath…

Obstetric and Gynecologic Society of Minnesota. Intensive Course in Obstetric Emergencies, 2023

Mascaro M, Caudill A, Mesiguda AS, et al. Defying the Odds: Survival After Amniotic Fluid Embolism and Extracorporeal Membrane Oxygenation Support. Am J Case Rep. 2021;22:e932213. 10.12659/AJCR.932213

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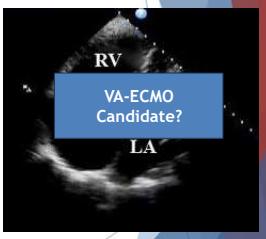
VA-ECMO Perioperative Case Presentation

- Patient devolved into PEA
- ROSC after 5 cycles of CPR
- Urgent transthoracic echocardiography demonstrated *severe* right ventricular dysfunction
- Requiring near code dose epinephrine, norepinephrine
- Plt 87, fibrinogen <60, lactate 13.2
- Diagnosed with **amniotic fluid embolism**



Dresden, Scott, et al. "Right ventricular dilatation on bedside echocardiography performed by emergency physicians aids in the diagnosis of pulmonary embolism." Annals of emergency medicine 63.1 (2014): 10-16.

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VA-ECMO Indications and Contraindications

Indication
Cardiogenic shock
Acute cardiopulmonary failure

Strict Contraindications

- Do Not Resuscitate / patient preference
- Severe, irreversible organ failure (i.e. anoxic brain injury)
- Severe aortic insufficiency, aortic dissection

Relative Contraindications

- Age > 70
- Limited vascular access, severe PAD
- *Contraindication to anti-coagulation*

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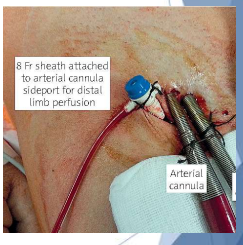
VA-ECMO Perioperative Case Presentation

- ECMO consult placed to affiliate tertiary hospital
- Mobile cannulation team placed the patient on femoral VA-ECMO
- Patient stabilized, epinephrine and norepinephrine weaned
- Transferred to tertiary academic medical center



Noc, Marko. "Time line for veno-arterial extracorporeal membrane oxygenation in 24-7 interventional cardiology center?." Advances in interventional Cardiology/Postepy w kardiologii interwencyjnej 11.4 (2015): 362.

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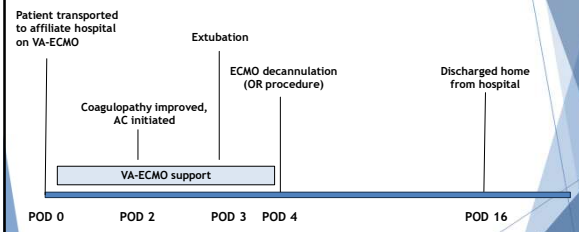
VA-ECMO Perioperative Case Presentation



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Two Critical Post-VA ECMO Cannulation Considerations

1. Ensure adequate left ventricular forward flow (**"venting/unloading"**)
2. Femoral VA-ECMO requires **right radial arterial line**

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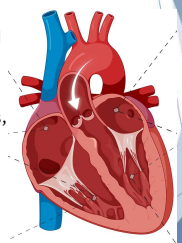
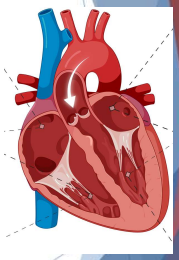
Left Ventricular Venting/Unloading

- **Retrograde flow** coming into left ventricle from aorta **significantly increases afterload**
- **Retrograde flow** can cause multiple issues
  1. Prevent AV from opening (AV thrombosis, LV thrombus)
  2. Increased left ventricular diastolic pressure → pulmonary edema
- Ensure **pulsatility** on arterial line



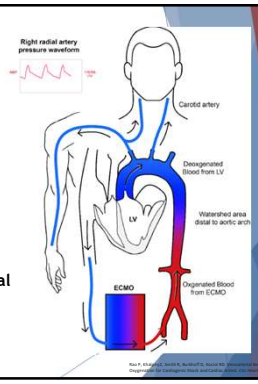
45



46

North-South Syndrome

- With concomitant lung failure, **native ejected blood is deoxygenated**
- Competitive flow from the heart (poorly oxygenated) and femoral ECMO (well oxygenated) establishes an aortic **mixing cloud**
- **Critical to maintain a right radial arterial line** to assess cerebral oxygenation

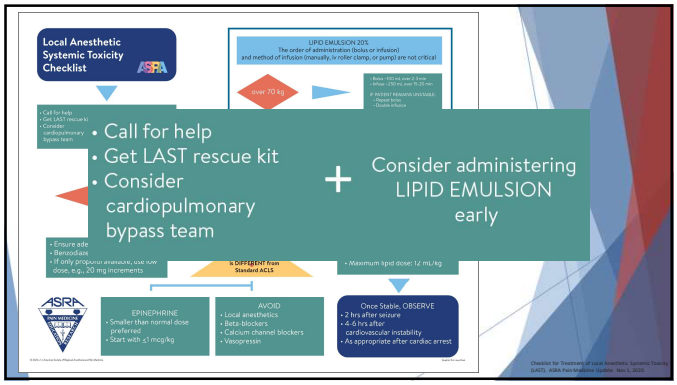


47

Emergent Perioperative VA-ECMO Examples

- **Amniotic fluid embolism**
- **Stabilization during pulmonary embolism mechanical thrombectomy**
- **LAST**
- **Intraoperative takotsubo cardiomyopathy**
- **Pregnancy with pulmonary hypertension**
- **Severe anaphylaxis**

48



49

VA-ECMO Summary

- **VA-ECMO provides cardiac and respiratory support for reversible cardiopulmonary failure**
- **Frequently employed in ICU, growing utilization for non-cardiac surgeries**
- **Key considerations for VV-ECMO candidacy: reversible cardiopulmonary injury, otherwise survivable organ function**
- **After rescue femoral VA-ECMO, critical to establish right radial arterial line and monitor for pulsatility (AV opening)**

50

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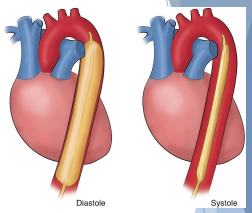
Intra-aortic Balloon Pump



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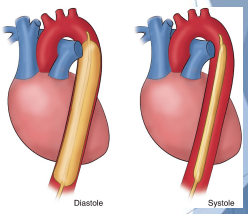
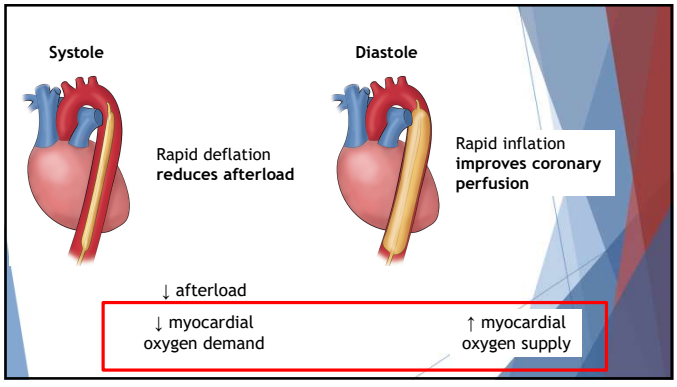
IABP Overview

- Endovascular catheter and polyurethane balloon positioned in descending thoracic aorta
- Placed by interventional cardiologist or cardiothoracic surgeon through femoral artery
- Rapid helium inflation and deflation (*counterpulsation*) augments cardiac cycle



52



53

IABP Indications

Cardiogenic shock (left ventricular failure or mechanical complications of an acute myocardial infarction)
Low cardiac output after cardiopulmonary bypass
Prophylaxis in patients with severe left main coronary arterial stenosis in whom surgery is pending
Intractable myocardial ischemia awaiting further therapy
Refractory heart failure as a bridge to further therapy

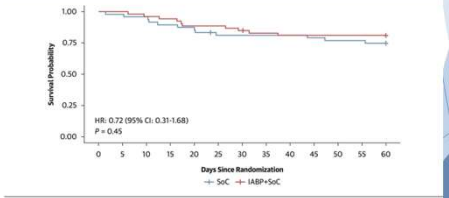
54

Questionable Benefit

JACC

Early Intra-Aortic Balloon Support for Heart Failure-Related Cardiogenic Shock

FIGURE 2 Kaplan-Meier Curve for 60-Day Survival or Successful Bridge to HRT



HRT = heart replacement therapy; IABP = intra-aortic balloon pump; SoC = standard of care.

55

Questionable Benefit

The NEW ENGLAND JOURNAL of MEDICINE

Intraaortic Balloon Support for Myocardial Infarction with Cardiogenic Shock

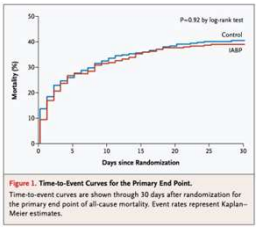


Figure 1. Time-to-Event Curves for the Primary End Point.
Time-to-event curves are shown through 30 days after randomization for the primary end point of all-cause mortality. Event rates represent Kaplan–Meier estimates.

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Microaxial Flow Pumps for the Uninitiated

Anesthesiology
University of Colorado Anschutz Medical Campus

57

Objectives

- Introduce microaxial flow pumps and examine benefits and limitations of each device
- Discuss the data supporting the use of impella for cardiogenic shock and ventricular unloading in concert with other MCS
- Review perioperative considerations for management including hemodynamic goals and waveform analysis

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Characteristics

- Non-pulsatile
- Axial flow
- Percutaneous insertion (femoral or axillary arterial)

59

Mechanics

Draws blood from LV and ejects into ascending aorta

Hemodynamic effects

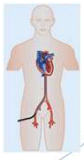
Increased MAP	Reduced LVEDP	Reduced PAP	Decreased MvO2

60

Types of Devices - CP

	Impella CP (Current)
Indication	HR-PCI and CS
Access	Percutaneous femoral or axillary
Motor Size (Fr)	14
Catheter Size (Fr)	9
Sheath Size (Fr)	14
Max Flow Rate (L/min)	3.7
Max Speed (rpm)	51,000
Performance Levels	P0–P9
Duration of support	HR-PCI: ≤6h/ CS: ≤4d
SmartAssist	Yes
Pressure Sensor	Optical sensor

Guide Wire	0.018" diameter × 260 cm placement guidewire
Anticoagulation (AC)	Heparin purge + systemic AC or BBPS alone [2]
Common Complications	Hemolysis, limb ischemia, bleeding, stroke, infection
Contraindications (CI)	Severe AS/AR, mechanical AV, LV thrombus, CI to AC



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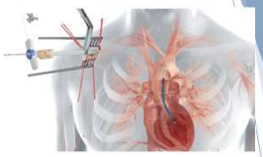
Types of Devices – 5.5

	Impella 5.5 (Current)
Indication	CS
Access	Axillary cutdown or direct insertion into AA
Motor Size (Fr)	19
Catheter Size (Fr)	9
Sheath Size (Fr)	23
Max Flow Rate (L/min)	5.5
Max Speed (rpm)	33,000
Performance Levels	P0–P9
Duration of support	14 days
SmartAssist	Yes
Pressure Sensor	Optical sensor



Guide Wire	0.018" diameter × 260 cm placement guidewire
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Contraindications

- Relative
  - Severe AI
  - VSD
  - HOCM
  - Severe PAD
- Absolute
  - Mechanical aortic valve prosthesis
  - Mobile LV thombi or ruptured papillary muscles
  - Aortic dissection or severe calcification

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Unfavorable Criteria –		+ Favorable Criteria
Severe PAD	1	Young age
< 1-year life expectancy	2	No comorbidities
Biventricular failure	3	Left-predominant failure
Clinical frailty /Advanced age	4	ACS/STEMI presentation
Cardiac arrest > 10 min	5	No severe valvulopathies
Glasgow Coma Scale < 8	6	No cardiac arrest or < 10 min
Aortic dissection, intracardiac thrombi	7	No history of previous DCM
Active bleeding or severe coagulopathy	8	

Figure 1. Factors to be considered for patient selection for pMCS placement. pMCS: percutaneous Mechanical Circulatory Support, ACS: Acute Coronary Syndrome, STEMI: ST-elevation Myocardial Infarction, DCM: Dilated Cardiomyopathy, PAD: Peripheral Artery Disease.

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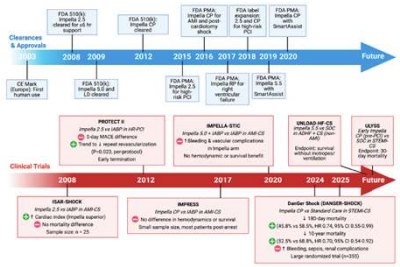
Data Progression



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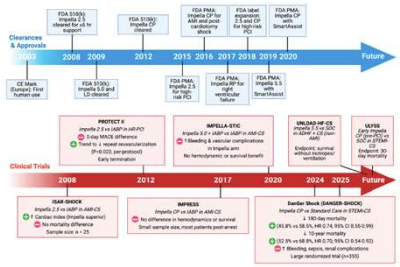
Data Progression



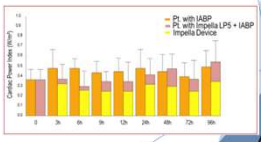
67

IMPELLA-STIC

- Acute MI <24h post-revascularization
- Small study (12 total)
- IABP v IABP + Impella 5.0
- Increased in significant bleeding
- No change in CPI

CLINICAL RESEARCH

Mechanical circulatory support with the Impella® LP5.0 pump and an intra-aortic balloon pump for cardiogenic shock in acute myocardial infarction: The IMPELLA-STIC randomized study



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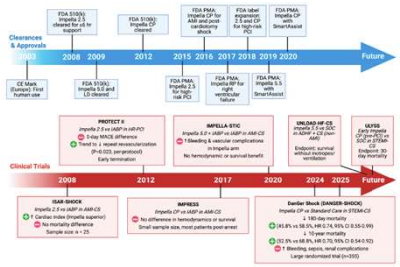
Data Progression



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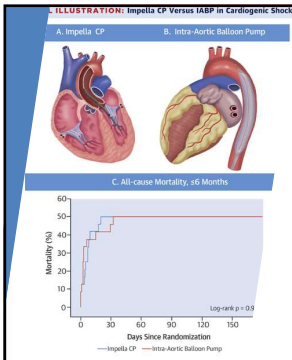
IMPRESS

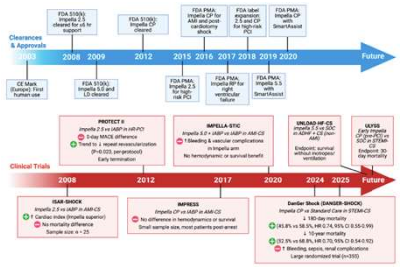


- Larger cohort
- Impella CP v IABP
- No change in mortality
- More bleeding, hemolysis in pMCS arm

Ouweneel, D.M. et al. J Am Coll Cardiol. 2017;69(3):278-87.

70

Data Progression



71

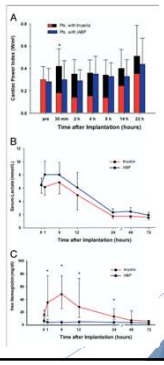
ISAR-SHOCK

- Impella 2.5 v IABP
- Superior hemodynamic support (30 minutes post-placement)

A Randomized Clinical Trial to Evaluate the Safety and Efficacy of a Percutaneous Left Ventricular Assist Device Versus Intra-Aortic Balloon Pumping for Treatment of Cardiogenic Shock Caused by Myocardial Infarction

Melchior Seyfarth, MD,*† Dirk Sibbing, MD,* Iris Bauer, MS,* Georg Fröhlich, MD,† Lorenz Bott-Flügel, MD,† Robert Byrne, MB, MRCPI,* Josef Dirschinger, MD,† Adnan Kastrati, MD,* Albert Schömig, MD*†

Munich, Germany



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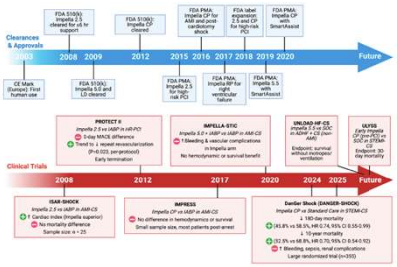
Data Progression



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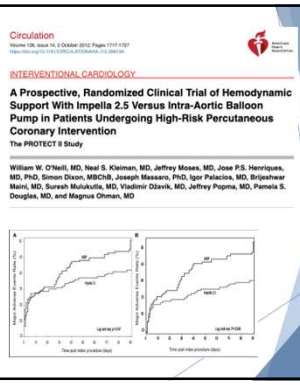
PROTECT II

- Larger study
- High risk PCI with percutaneous support
- Comparable to surgical outcomes
- No mortality difference IABP v Impella 2/5


Circulation

INTERVENTIONAL CARDIOLOGY

A Prospective, Randomized Clinical Trial of Hemodynamic Support With Impella 2.5 Versus Intra-Aortic Balloon Pump in Patients Undergoing High-Risk Percutaneous Coronary Intervention

The PROTECT II Study

William W. O'Neill, MD, Neal S. Kleiman, MD, Jeffrey Moses, MD, Jose P.S. Henriques, MD, PhD, Simon Dixon, MBChB, Joseph Massaro, PhD, Igor Palacios, MD, Brijeshwar Maini, MD, Suresh Mulukutla, MD, Vladimir Dzavik, MD, Jeffrey Popma, MD, Pamela S. Douglas, MD, and Magnus Ohman, MD

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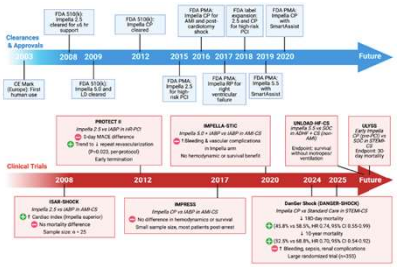
If at first (or second, or third, or fourth…) you don't succeed, TRY TRY AGAIN!

75

Data Progression



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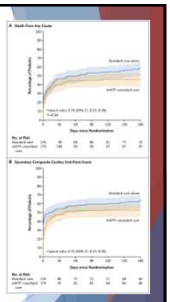
DAN-SHOCK

- STEMI with cardiogenic shock
- Standard therapy vs standard + Impella CP
- Decreased all cause mortality (45.8% v 58.5%, p = 0.04)
- Higher complication rate (24% vs 6.2%)
  - Bleeding
  - Limb ischemia
  - Hemolysis
  - Renal replacement therapy
  - Sepsis



The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Microaxial Flow Pump or Standard Care in Infarct-Related Cardiogenic Shock

J.E. Møller, T. Engstrøm, L.O. Jensen, H. Eiskjær, N. Mangner, A. Polzin, P.C. Schulze, C. Skurk, P. Nordbeck, P. Clemmensen, V. Panoulas, S. Zimmer, A. Schäfer, N. Werner, M. Frydland, L. Holmvang, J. Kjærgaard, R. Sørensen, J. Lønborg, M.G. Lindholm, N.L.J. Udesen, A. Junker, H. Schmidt, C.J. Terkelsen, S. Christensen, E.H. Christiansen, A. Linke, F.J. Woitek, R. Westenfeld, S. Möbius-Winkler, K. Wachtell, H.B. Ravn, J.F. Lassen, S. Boesgaard, O. Gerke, and C. Hassager, for the DanGer Shock Investigators*

77

Future Pathways

- ECMELLA
- Pre-revascularization unloading
  - Decreased MVO2
  - Reduction in infarct size
- RP Flex
  - RECOVER RIGHT
- STEMI_DTU, NCSI-II, ANCHOR, UNLOAD ECMO

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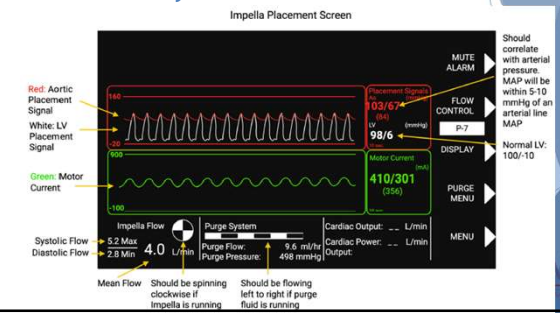
Waveform Analysis



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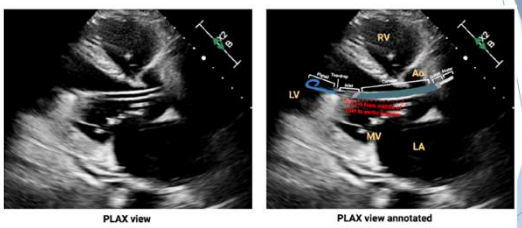
Transthoracic Echocardiography

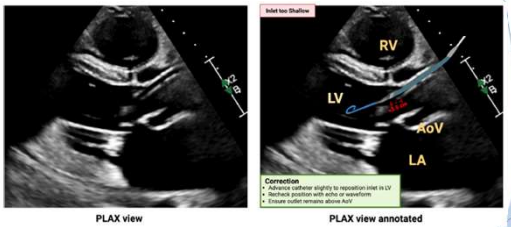


PLAX view

PLAX view annotated

80

Transthoracic Echocardiography



PLAX view

PLAX view annotated

81

Complications

- Malrotation
- Thrombosis
- Hemolysis
- Vascular Access
  - Bleeding
  - Limb ischemia

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LVAD Management in Non-Cardiac Sugery

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83

Objectives

- Examine the history of durable mechanical support for the heart failure population
- Explore indications and patient selection for left ventricular assist device (LVAD) implantation
- Identify types of LVADs and their similarities and differences
- Describe the LVAD-specific preoperative evaluation process
- Identify monitoring considerations
- Discuss perioperative hemodynamic and device goals
- Trouble shoot LVAD-specific issues

84

A Case!

"Roger"

- 53M presents for upper "push" endoscopy for persistent melena and anemia
- LVAD implanted in 2021
- VAD coordinator says "He can't cough or bad things happen"

85

OK…but what is an LVAD?

- **(L)**eft **(V)**entricular **(A)**ssist **(D)**evice
- Ideal state
  - Assist LV in pumping blood
  - Avoid major thrombosis
  - Implantable
  - Portable
  - Electrically powered
- Implanted as bridge to transplant (BTT) or destination therapy (DT)

Dalia AA, Cronin B, Stone ME, Turner K, Hargrave J, Vidal Melo MF, Essandoh M. Anesthetic Management of Patients With Continuous-Flow Left Ventricular Assist Devices Undergoing Noncardiac Surgery: An Update for Anesthesiologists. J Cardiothorac Vasc Anesth. 2018 Apr;32(2):1001-1012. doi: 10.1053/j.jvca.2017.11.038. Epub 2017 Nov 22. PMID: 29306620.

86

OK…but that's probably super rare…right?

No!

- >100,000 devices currently implanted

87

OK…but I probably won't need to take care of one of these patients…right?

Also no!

- ~30% of all LVAD supported patients will require non-cardiac surgery
- 20-40% will require endoscopic intervention for GI bleeding

Mathis MR, Sathishkumar S, Kheterpal S, etal. Complications, risk factors, and staffing patterns for noncardiac surgery inpatients with left Ventricular assist devices. Anesthesiology 2017;126:450-60.

Cushing K,KushnirV. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

88

Durable Mechanical Support

- Ideal state
  - Assist LV in pumping blood
  - Avoid major thrombosis
  - Implantable
  - Portable
  - Electrically powered

Dalia AA, Cronin B, Stone ME, Turner K, Hargrave J, Vidal Melo MF, Essandoh M. Anesthetic Management of Patients With Continuous-Flow Left Ventricular Assist Devices Undergoing Noncardiac Surgery: An Update for Anesthesiologists. J Cardiothorac Vasc Anesth. 2018 Apr;32(2):1001-1012. doi: 10.1053/j.jvca.2017.11.038. Epub 2017 Nov 22. PMID: 29306620.

89

- LVAD Pump
- Inflow Cannula
- Outflow Cannula
- Driveline
- Controller
- Battery

Abbott. (2022). HeartMate 3 Left Ventricular Assist System Instructions for Use. https://www.cardiovascular.abbott/us/en/hcp/products/heart-failure/left-ventricular-assist-devices/heartmate-3/manuals-resources.html

90

How did we get here?

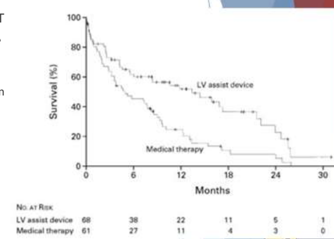
- First LVAD placed in 1966 by DeBakey
- Three case series published in 1971 describing prolonged wean from cardiopulmonary bypass

DeBakey ME. Left ventricular bypass pump for cardiac assistance. Clinical experience. Am J Cardiol. 1971 Jan;27(1):3-11. doi: 10.1016/0002-9149(71)90076-2. PMID: 5538711.

91

Pneumatic

- First device approved by the FDA in 1994 for BTT
- Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) 2001
  - NYHA Type IV ineligible for cardiac transplantation
  - 48% risk reduction death from all causes LVAD vs. medical management
  - 52% vs. 25% at one year, 23% vs 8% at 2 years
  - Improve in quality of life
  - Adverse events x2.35 in LVAD group
    - Infection
    - Bleeding
    - Device malfunction



Rose EA, Gelijns AC, Moskowitz AJ, Heitjan DF, Stevenson LW, Dembitsky W, Long JW, Ascheim DD, Tierney AR, Levitan RG, Watson JT, Meier P, Ronan NS, Shapiro PA, Lazar RM, Miller LW, Gupta L, Frazier OH, Desvigne-Nickens P, Oz MC, Poirier VL; Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) Study Group. Long-term use of a left ventricular assist device for end-stage heart failure. N Engl J Med. 2001 Nov 15;345(20):1435-43. doi: 10.1056/NEJMoa012175. PMID: 11794191.

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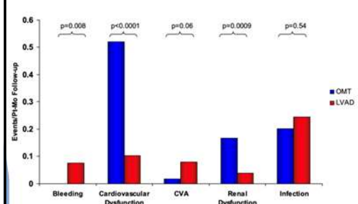
Pneumatic



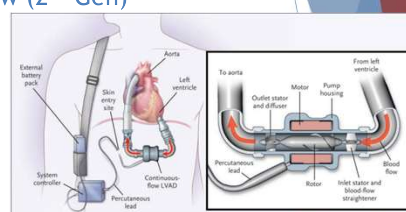
- Investigation of Nontransplant-Eligible Patients Who Are Inotrope Dependent (INTREPID) 2007
  - Not randomized but statistically matched to OMT
  - Sicker cohort
  - Worse survival than REMATCH but reinforced superiority over medical management (27% vs 11%)

Rogers JG, Butler J, Lansman SL, Gass A, Portner PM, Pasque MK, Pierson RN 3rd; INTrEPID Investigators. Chronic mechanical circulatory support for inotrope-dependent heart failure patients who are not transplant candidates: results of the INTrEPID Trial. J Am Coll Cardiol. 2007 Aug 21;50(8):741-7. doi: 10.1016/j.jacc.2007.03.063. Epub 2007 Aug 6. PMID: 17707178.

93

Continuous Flow (2nd Gen)

- Rotary pump
- Smaller
- Improved durability with only one moving part
- Significant reductions in SAEs and improvement in mortality



Miller LW, Pagani FD, Russell SD, John R, Boyle AJ, Aaronson KD, Conte JV, Naka Y, Mancini D, Delgado RM, MacGillivray TE, Farrar DJ, Frazier OH; HeartMate II Clinical Investigators. Use of a continuous-flow device in patients awaiting heart transplantation. N Engl J Med. 2007 Aug 30;357(9):885-96. doi: 10.1056/NEJMoa067758. PMID: 17761592.

Slaughter MS, Rogers JG, Milano CA, Russell SD, Conte JV, Feldman D, Sun B, Tatooles AJ, Delgado RM 3rd, Long JW, Wozniak TC, Ghumman W, Farrar DJ, Frazier OH; HeartMate II Investigators. Advanced heart failure treated with continuous-flow left ventricular assist device. N Engl J Med. 2009 Dec 3;361(23):2241-51. doi: 10.1056/NEJMoa0909938. Epub 2009 Nov 17. Erratum in: N Engl J Med. 2018 Aug 16;379(7):697. PMID: 19920051

94

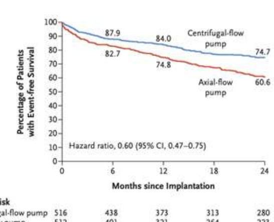
Third Generation

- HeartMate 3 (HM3) and HVAD
- Intrapericardial, directly implanted
- HVAD – centrifugal impeller with hybrid magnetic/hydrodynamic impeller suspension
- HM3 – fully magnetically levitated

Berardi C, Bravo CA, Li S, Khorsandi M, Keenan JE, Auld J, Rockom S, Beckman JA, Mahr C. The History of Durable Left Ventricular Assist Devices and Comparison of Outcomes: HeartWare, HeartMate II, HeartMate 3, and the Future of Mechanical Circulatory Support. J Clin Med. 2022 Apr 5;11(7):2022. doi: 10.3390/jcm11072022. PMID: 35407630; PMCID: PMC9000165.

95

Third Generation



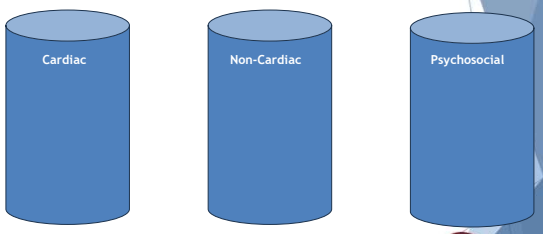
- Interagency Registry for Mechanical Assisted Circulatory Support (INTERMACS)
  - 140pts. HVAD noninferior to HM2 (180d survival 94%)
- MOMENTUM 3 (Multicenter Study of MagLev Technology in Patients Undergoing Mechanical Circulatory Support Therapy with HeartMate 3) HM2 v HM3
  - 366 BTT and DT
  - Survival free of disabling stroke or free of reoperation 77.9% to 56.5% at two years
  - Pump thrombosis exceedingly rare
  - Ischemic stroke significantly less

Molina EJ, Shah P, Kiernan MS, Cornwell WK 3rd, Copeland H, Takeda K, Fernandez FG, Badhwar V, Habib RH, Jacobs JP, Koehl D, Kirklin JK, Pagani FD, Cowger JA. The Society of Thoracic Surgeons Intermacs 2020 Annual Report. Ann Thorac Surg. 2021 Mar;111(3):778-792. doi:

Mehra MR, Goldstein DJ, Cleveland JC, Cowger JA, Hall S, Salerno CT, Naka Y, Horstmanshof D, Chuang J, Wang A, Uriel N. Five-Year Outcomes in Patients With Fully Magnetically Levitated vs Axial-Flow Left Ventricular Assist Devices in the MOMENTUM 3 Randomized Trial. JAMA. 2022

96

Who gets an LVAD?



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Cardiac Evaluation

Testing	High Risk Features	Contraindications
Right heart catheterization	- Elevated PVR - Elevated TPG	
Left heart catheterization	- Significant multivessel obstructive CAD	
Transthoracic Echocardiogram	- Valvular disease - RV dysfunction	
Electrocardiogram	- Refractory ventricular arrhythmia	
Cardiopulmonary exercise test	- Significant pulmonary disease	

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Noncardiac Evaluation

System	Testing	High Risk	Contraindications
Renal	Basic metabolic panel	- eGFR < 30	Hemodialysis*
Gastrointestinal	EGD/Colonoscopy	- Significant ulcers, AVMs	Malignancy with poor 5yr survival
Hepatic	Liver panel, liver ultrasound If needed to r/o cirrhosis: liver bx, portal pressures	- Chronic liver dz with bili 1-3 g/dL - Acute liver injury without improvement in 48h prior to implant	- Chronic liver dz with bili >3g/dL - E/o cirrhosis* - MELD >17
Hematology	CBC, coags, HIT panel (selected pts)	Pro-thrombotic state	
Oncology	Age-appropriate screening	H/o prior malignancy	Active malignancy*

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Noncardiac Evaluation

System	Testing	High Risk Features	Contraindication
Vascular	Vascular ultrasound Ankle-brachial index	- Significant lower extremity vascular dz - Ascending aorta calcifications, significant carotid plaque	
Pulmonary	Pulmonary function test Lung imaging	- Low FEV1 and FVC, DLCO < 50% predicted - Extensive pulmonary pathology (increases risk of post-op RV failure)	
Infectious Disease	Dependent on history and physical exam	- Recent treated infection, esp nosocomial	Active infection

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Noncardiac Evaluation

System	Testing	High Risk Features	Contraindication
Endocrine	TSH HbA1c	- Poorly controlled diabetes	
Nutrition	Albumin, pre-albumin	- BMI < 20, BMI > 40 - albumin < 3.2 mg/dL - pre-albumin <15 mg/dL	
Neurologic	CTH or MRI brain Neurocognitive evaluation	- h/o prior CVA	Substantial neurologic deficits or neurocognitive disabilities impairing functional status
Dental	XR or CT as indicated	- Active dental infection	

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Psychosocial Evaluation

Testing	High Risk Features	Contraindications
SIPAT score Comprehensive psychosocial and substance abuse history	- Active substance use - Untreated or newly dx'd psychiatric dz - H/o noncompliance - Lack of caregiver support - Lack of insurance coverage	Poor psychosocial profile with no viable plan for improvement in a short timeframe, lack of stable housing, at risk for incarceration

102

Surgical Technique

- Sternotomy or bilateral thoracotomies
- Easier via sternotomy
- Lower incidence of RV failure and preserves sternum in event of BTT via thoracotomy

Anschutz

Hanke JS, Rojas SV, Avsar M, Haverich A, Schmitto JD. Minimally-invasive LVAD Implantation: State of the Art. Curr Cardiol Rev. 2015;11(3):246-51. doi: 10.2174/1573403x1103150514151750. PMID: 25981314; PMCID: PMC4558356.

103

Devices

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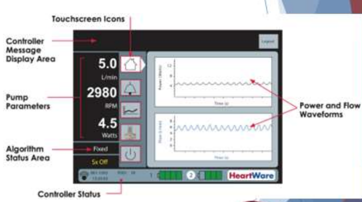
HVAD Controller Parameters

- Pump Speed (RPM)
- Power (W)
- Flow (L/min)
- Waveform

LVAD Type	HVAD
Speed (RPM)	2.4K-3K
Flow (L/min)	4-6
Power (W)	3-7
Pulsatility	2-3

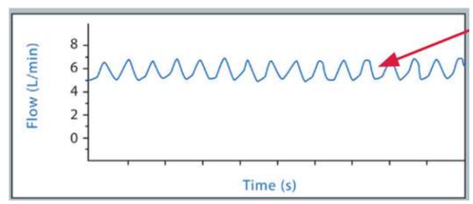


CRASH

Heartware. (2017). HeartWare HVAD System Instructions for Use. https://www.accessdata.fda.gov/cdrh_docs/pdf10/P100047S090D.pdf

105

Waveform Analysis

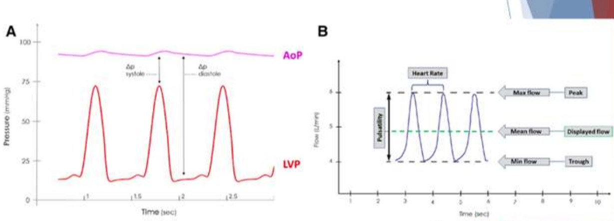


CRASH

Heartware. (2017). HeartWare HVAD System Instructions for Use. https://www.accessdata.fda.gov/cdrh_docs/pdf10/P100047S090D.pdf

106

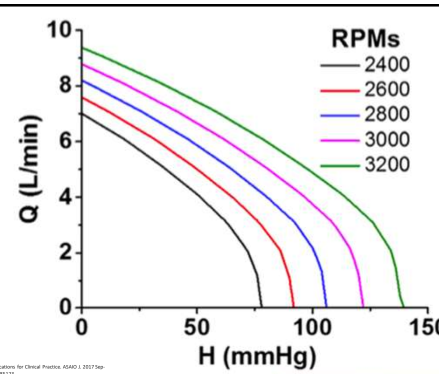
Waveform analysis



Rich JD, Burkhoff D. HVAD Flow Waveform Morphologies: Theoretical Foundation and Implications for Clinical Practice. ASAIO J. 2017 Sep-Oct;63(5):526-535. doi: 10.1097/MAT.0000000000000557. PMID: 28323662; PMCID: PMC5585123.

107

Flow vs Gradient



Rich JD, Burkhoff D. HVAD Flow Waveform Morphologies: Theoretical Foundation and Implications for Clinical Practice. ASAIO J. 2017 Sep-Oct;63(5):526-535. doi: 10.1097/MAT.0000000000000557. PMID: 28323662; PMCID: PMC5585123.

108

Controller Parameters HeartMate 2/3

- Pump Speed (RPM)
- Power (W)
- Flow (L/min)
- Pulsatility Index

LVAD Type	HM 2	HM 3
Speed (RPM)	8K-10K	5K-6K
Flow (L/min)	4-7	4-6
Power (W)	5-8	4.5-6.5
PI	5-8	3.5-5.5

Abbott. (2022). HeartMate 3 Left Ventricular Assist System Instructions for Use. https://www.cardiovascular.abbottcan/en/hcp/products/heart-failure/left-ventricular-assist-device/heartmate-3/manuals-resources.html

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Pulsatility Index

- Dimensionless
- Indicative of
  - Contractility
  - LV preload
  - Afterload

$$10\ x\frac{(Qmax\ -Qmin)}{Qavg}$$

Anschutz

Mossaini N, Fukamachi K, Kobayashi M, Smedira NG, Hoercher KJ, Massiello A, Lee S, Horvath D, Starling RC. Axial and centrifugal continuous-flow rotary pumps: a translation from pump mechanics to clinical practice. J Heart Lung Transplant. 2013 Jan;32(1):1-9. doi: 10.1016/j.healun.2012.09.001. PMID: 23260035

110

Device Parameters

LVAD Type	HM 2	HM 3	HVAD
Speed (RPM)	8K-10K	5K-6K	2.4K-3K
Flow (L/min)	4-7	4-6	4-6
Power (W)	5-8	4.5-6.5	3-7
PI/pulsatility	5-8	3.5-5.5	2-3

Anschutz

Roberts SM, Hovord DG, Kodavatiganti R, Sathishkumar S. Ventricular assist devices and non-cardiac surgery. BMC Anesthesiology. 2015;15(1)

111

Ok so you have your LVAD…

- Trading one pathology for another
  - ~30% of all LVAD supported patients will require non-cardiac surgery
  - 20-40% will require endoscopic intervention for GI bleeding

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112

Case

Roger had a HeartMate 3 placed via bilateral thoracotomy two years earlier

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113

Preoperative Assessment - Patient

- Reason for presentation
  - Bleeding
  - Surgical technique/requirements
- Co-morbidities
- Medication review
- Cardiac Status
  - Signs/symptoms of RHF
- Labs
- Recent imaging
- Additional hardware
  - AICD/pacemaker

nschutz

Roberts SM, Hovord DG, Kodavatiganti R, Sathishkumar S. Ventricular assist devices and non-cardiac surgery. BMC Anesthesiology. 2015;15(1)

114

LVADs in GI

- Bleeding Triad
  - Anticoagulation
  - AV malformations
  - Acquired vWF deficiency

Cushing K,Kashyrl V. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

115

Case

- Roger has had persistent melena for the last month. He has required intermittent transfusions as an outpatient but was admitted last night with anemia and multiple suction alarms
- LVAD was implanted for NICM but his RV function never normalized
- On Coumadin at home, INR was 3.5 on presentation, not reversed given ability to keep up with transfusion requirement
- AICD in place prior to LVAD implantation

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Preoperative Assessment - Device

- Hardware
  - Manufacturer/model
  - Date of implantation
  - Contact Info
- Interrogation
  - Alarms
  - Suction events
- Complications
  - Bleeding
  - Driveline infection
  - Thrombosis
  - Urine color change

Roberts LM, Howard DG, Kodavatiganti R, Sathishkumar S. Ventricular assist devices and non-cardiac surgery. BMC Anesthesiology. 2015;15(1).

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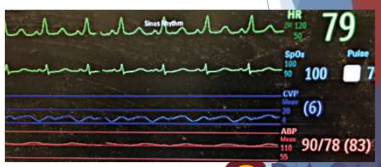
Intraoperative Management

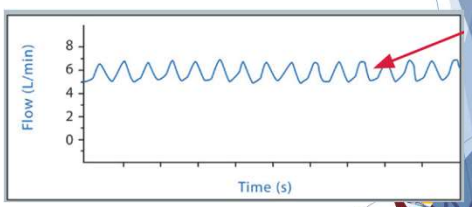
- Monitoring
  - Standard ASA Monitors
  - Blood pressure
    - Noninvasive v Arterial line
  - Oxygenation
    - SpO2 may be unreliable
    - Serial ABG
    - Cerebral oximetry
  - LVAD console
  - PAC, CVP
  - TEE/TTE



Cushing K,Kashyrl V. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

118

Waveform Analysis



Heartware. (2017). HeartWare HVAD System Instructions for Use. https://www.accessdata.fda.gov/cdrh_docs/pdf10/P100047S000D.pdf

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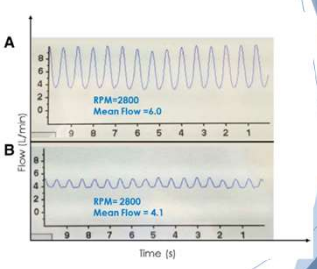
Volume Status

- Hyper
  - High Flow
  - High Pulsatility
- Hypo
  - Low Flow
  - Low Pulsatility



Cushing K,Kashyrl V. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

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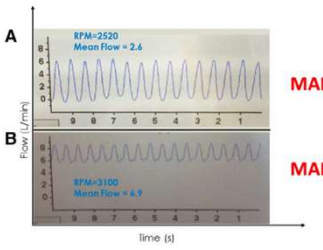
Afterload



MAP = 110mmHg

- Hyper
  - Low Flow
  - High Pulsatility

MAP = 60 mmHg

- Hypo
  - High Flow
  - Low Pulsatility

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Cushing K,Kushnir Y. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

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	Lower Mean Flow	Higher Mean Flow
Lower pulsatility	RV failure, hypovolemia, tamponade, occlusion, Vfib/rapid VT	Hypotension/vasodilation, aortic regurgitation, pump thrombosis (falsely elevated)
Higher pulsatility	HTN (with low trough), low RPMs, continuous suction	Hypervolemia, ?recovery

Cushing K,Kushnir Y. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

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Case

- Standard ASA monitors
- Pre-sedation arterial line but no central access
- Connected to LVAD console to monitor for line-of-sight monitoring

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123

Hemodynamic Goals

- Blood pressure
  - Goal MAP 70-90mmHg
  - HTN
    - Increases risk of pump thrombosis
    - Decreases flow especially in centrifugal pumps
  - HoTN
    - May precipitate suction events
    - "pushing on an open door"
- RV function
  - Avoid hypoxia, hypercarbia, acidosis
  - Avoid (as able) rapid shifts in RV afterload
- Rhythm
  - Maintain sinus native rhythm, sinus in possible

Anschutz

Robertson M, Havood DC, Kodeuzgansi K, Sathishkumar S. Ventricular assist devices and non-cardiac surgery. BMC Anesthesiology. 2015;15(1).

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Case

- Did not place pads - no magnet for AICD
- Diluted epinephrine, push dose vasopressin
- Minimized fluids, blood available
- Endoscopy performed through a mask

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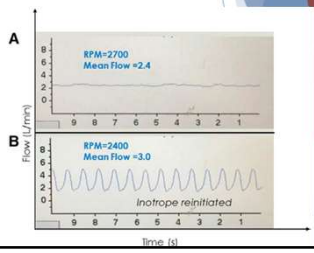
Right Heart Failure

- Low flow
- Low pulsatility
- Must correlate with physical exam findings/clinical situation



Cushing K,Kushnir Y. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

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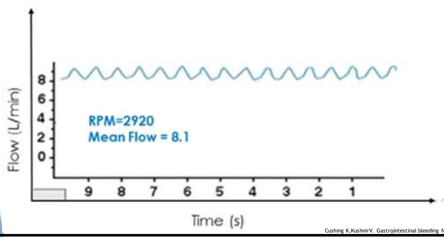
Aortic Regurgitation



- High flow
- Low pulsatility

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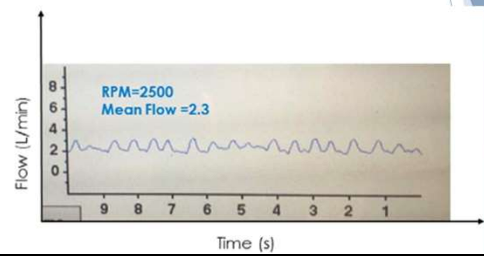
Cushing K,KushnirV. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

127

Cushing K,KushnirV. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

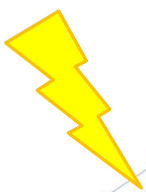
Cardiac Tamponade



128

Complications

- Suction Events
  - Hypovolemia (low LV preload)
  - RV failure / hypervolemia
  - High PVR
  - Vasoplegia
- Dysrhythmias
  - Poorly tolerated
  - May require cardioversion



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Roberts SM, Hovord DG, Kodavatiganti R, Sathishkumar S. Ventricular assist devices and non-cardiac surgery. BMC Anesthesiology. 2015;15

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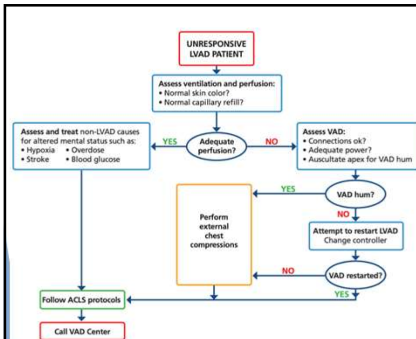


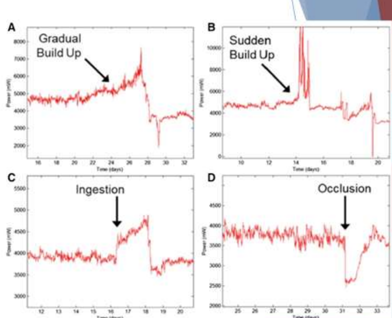
- Cardiac Arrest
  - OK for compressions but risk cannula dislodgement
- Power loss
  - Ensure battery charge
  - Access to working AC outlet

Anschutz

Peberdy MA, Gluck JA, Ornato JP, Bermudez CA, Griffin RE, Kasirajan V, Kerber RE, Lewis EF, Link MS, Miller C, Teuteberg JJ, Thiagarajan R, Weiss RM, O'Neil B; on behalf of the American Heart Association Emergency Cardiovascular Care Committee; Council on Cardiopulmonary, Critical Care, Perioperative, and Resuscitation; Council on Cardiovascular Diseases in the Young; Council on Cardiovascular Surgery and Anesthesia; Council on Cardiovascular and Stroke Nursing; and Council on Clinical Cardiology. Cardiopulmonary resuscitation in adults and children with mechanical circulatory support: a scientific statement from the American Heart Association. *Circulation*. 2017;135:e1115–e1134. doi: 10.1161/CIR.0000000000000504.

130

Pump Thrombosis



Cushing K,KushnirV. Gastrointestinal bleeding following LVAD placement from top to bottom. DigDisSci2016;61:1440-7.

131

Recovery

- Usual care for extubation
- Depending on center weigh PACU vs ICU

Roberts SM, Hovord DG, Kodavatiganti R, Sathishkumar S. Ventricular assist devices and non-cardiac surgery. BMC Anesthesiology. 2015;15

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