대한심장혈관흉부외과학회
The Korean Society for Thoracic & Cardiovascular Surgery

2025 전공의 연수교육

ECMO support for post-cardiotomy

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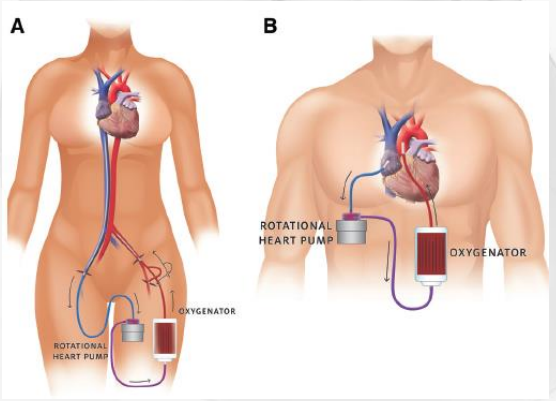
Introduction

- Extracoporeal membrane oxygenation (ECMO)

  → Extrocoporeal life support (ECLS)

- Post-cardiotomy ECMO support
  - Severe respiratory or cardiac failure after cardiac surgery
  - VA, VV, V-AV or V-VA mode
  - Prevalence of ECMO implantation following cardiac surgery; 0.3 - 3.6%
  - Posttransplant cardiac graft failure; 2-26%
  - RV failure after LVAD implantation; 25%
  - 10% - 15% of patients after HTx or LVAD
  - Peripheral vs. Central



The NEW ENGLAND JOURNAL of MEDICINE

Prolonged Extracorporeal Oxygenation for Acute Post-Traumatic Respiratory Failure (Shock-Lung Syndrome) — Use of the Bramson Membrane Lung

J. Donald Hill, M.D., Thomas G. O'Brien, M.D., James J. Murray, M.D., Leon Dontigny, M.D., M. L. Bramson, A.C.G.I., J. J. Osborn, M.D., and F. Gerbode, M.D.

N Engl J Med 1972; 286:629-634 | March 23, 1972 | DOI: 10.1056/NEJM197203232861204

1971, Dr. JD Hill, Extending extracorporeal support outside of the OR

24 y.o. trauma victim (ARDS)

Post-Cardiotomy Extracorporeal Life Support (PC-ECLS)

- Intraoperative failure to wean from cardiopulmonary bypass (CPB)
- Delayed refractory cardiogenic shock
- Postoperative cardiac arrest
- Intractable postoperative ventricular arrhythmias
- Refractory hypoxia with or without associated global cardiac hypocontractility

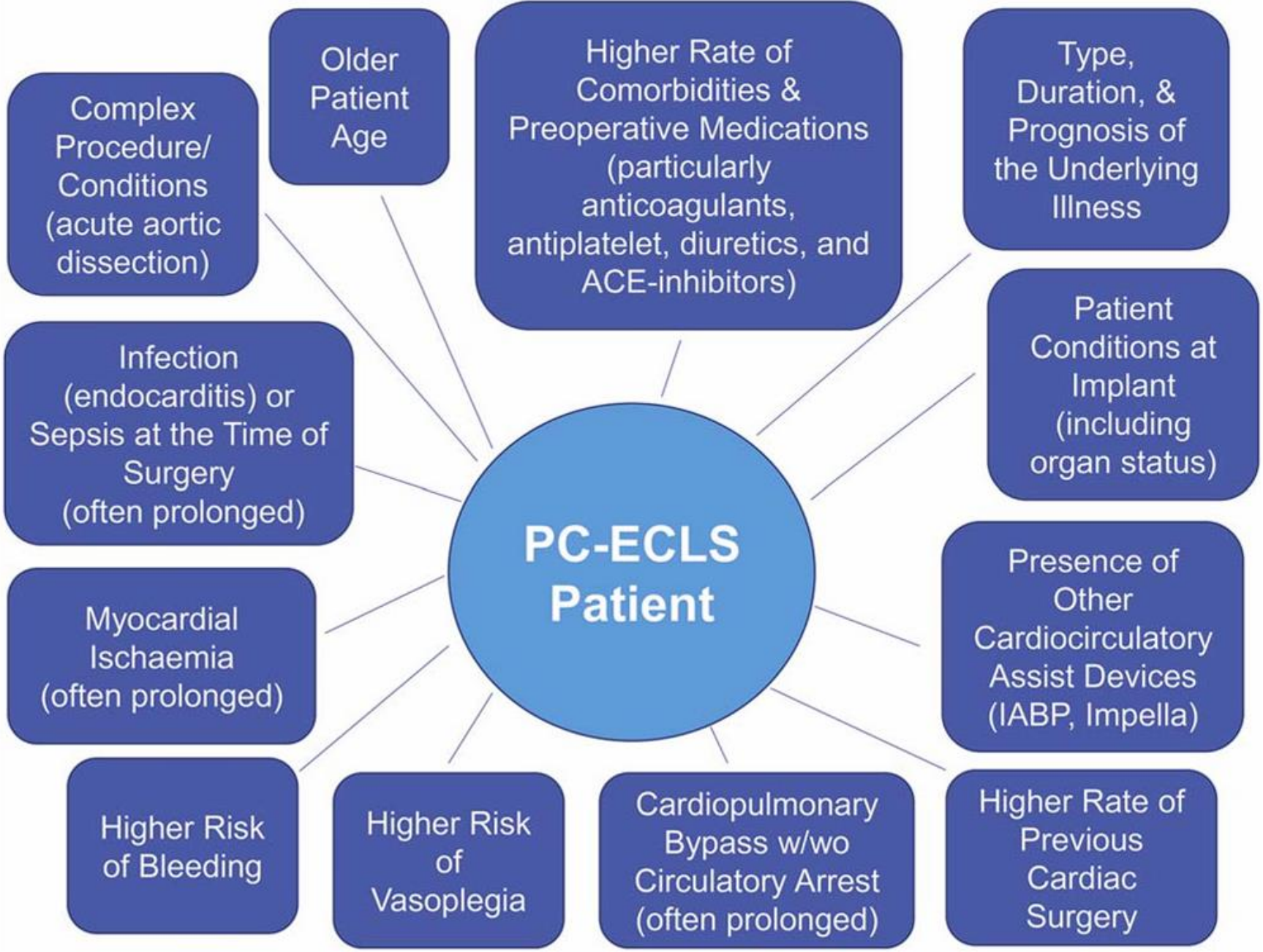


FIGURE 1. Characteristics of the PC-ECLS patient that, in many instances, differ from those of other potential recipients and clinical settings, all of which impact outcome. *ACEI*, Angiotensin-converting enzyme inhibitors; *PC-ECLS*, post-cardiotomy extracorporeal life support; *IABP*, intra-aortic balloon pump.

Consideration factors, Timing

- Patient comorbidities and age
- Degree and trajectory of post-bypass myocardial dysfunction
- Satisfaction with the procedure just performed including whether myocardial recovery was optimized
- Ongoing bleeding concerns
- Preoperative discussions that may have taken place regarding the patient's wishes for aggressive support

- Unresponsive LCOS due to uni- or biventricular failure during or after CPB
- Earliest signs of end-organ injury, or at the onset of anaerobic metabolism
- Prediction for application (Scoring system, TTE parameters)

Indications

- Persistent cardiogenic shock despite optimal inotropic support following cardiac surgery procedures
- Refractory respiratory failure despite optimal ventilator support

- The use of "multiple inotropes" as the indication for PC-ECLS; Vasoact
- Based on the risks a
inotropes and LCO c
associated complica

Inotropic Score (IS) = dopamine dose (μg/kg/min)
+ dobutamine dose (μg/kg/min)
+ 100 × epinephrine dose (μg/kg/min)

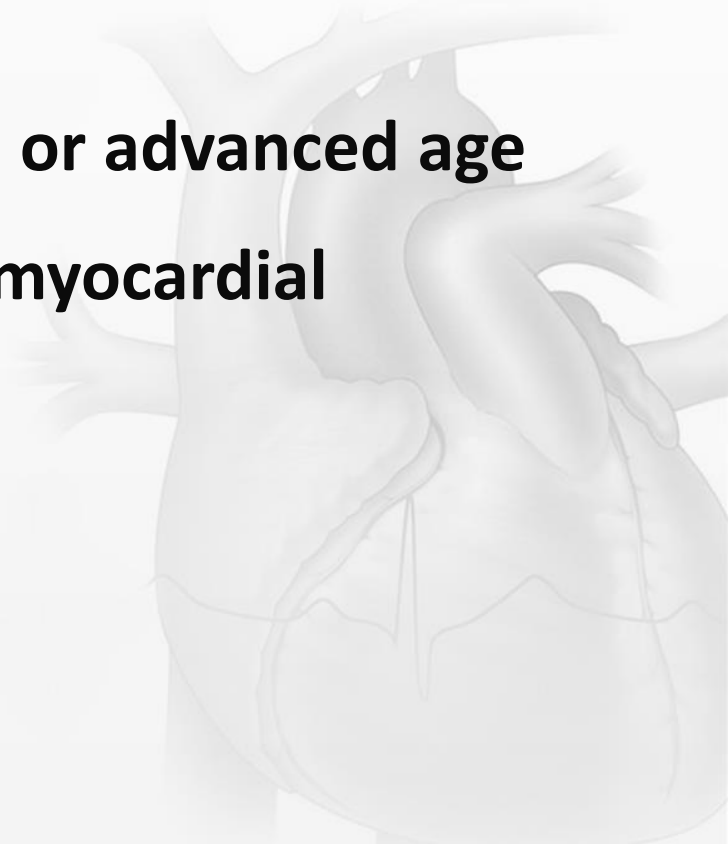
Vasoactive-Inotropic Score (VIS) =

IS + 10 × PDE inhibitor (milrinone or olprinone) dose (μg/kg/min)
+ 100 × norepinephrine dose (μg/kg/min)
+ 10000 × vasopressin dose (U/kg/min)

Contraindications

- Uncontrollable bleeding

- Contra-candidate for advanced cardiac therapy, eg, Long term-MCS or HTx
- Preoperative chronic organ failure or advanced age
- Expect irreversible of recovery of myocardial dysfunction
- Aortic valve insufficiency



Prognostication, mortality

Table 44-1. Published series of extracorporeal membrane oxygenation implanted in postcardiotomy patients.

Author	Ref	Pts (nr.)	Prevalence° (%)	ECMO Duration (mean±SD, hrs if available)	Weaning (%)	Survival to Hospital Discharge (%)	Predictors of Hospital Mortality
Ko	1	76	2.6%	132±139^^ 118±57§§ 99±33#	46,7%	26.3%**	Acute renal failure requiring dialysis on ECMO
Smedira	38	97	0.48%	48-72¶	39.2%¶¶	35%	na
Rastan	39	517	1.2%	78,7±68.4	63.3%	24.8%	Age>70 years, Diabetes, Obesity, Preop chronic renal failure, Operative lactate >4 mmol/L, Logistic Euroscore >20
Elsharkawy	40	239	0.58%	na	na	36%	Older age, Higher preoperative albumin, Diabetes history, CABG surgery, Longer CPB time
Wu	42	110	2.6%	143±112	60.9%	43.6%	Age >60 yrs,CVVH, Total Bilirubin>6 mg/dl, ECMO duration >110hrs
Saxena	43	45*	na	103±74.3	53.3%	24.4%	Preop atrial fibrillation, Chronic renal failure, Lactic acidosis on ECMO, Persistent coagulopathy on ECMO
Fiser	44	51	0.9%	85±12.5^ 64.7±9.2§	31%	16%	Age >65 years, LVEF< 30% after 48 hours on ECMO
Zhang	45	32	na	64.8±40.8	43.7%	25%	CK-MB relative index as the ratio of CK-MB to total CK
Unosawa	46	47	na	na	61.7%	29.7%	Incomplete sternal closure, ECMO support >48 hours

Prognostication, mortality

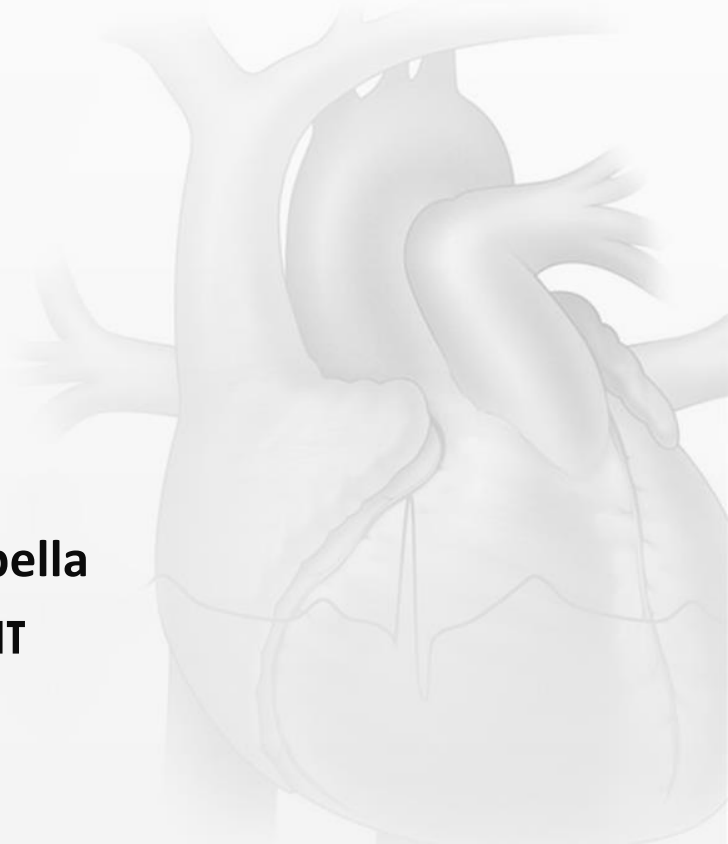
- Large single-center; survival 25-42%
  - end-organ injury, lactate levels
- Large meta-analysis; survival to discharge 34%
  - age, pre-ECLS lactate levels
- Lactate clearance during the initial period of support

Recommendations for indications, contraindications, and prognostication of PC-ECLS

Recommendations	Class*	Level†
It is recommended that PC support be initiated prior to end-organ injury or onset of anaerobic metabolism (lactate level <4 mmol/L) in patients with likelihood of myocardia recovery and in the absence of uncontrollable bleeding not amenable to surgical repair.[14,33]	I	B
When the likelihood of native myocardial recovery is low, PC ECLS is recommended in patients who are eligible for LT-MCS or a HTx.	I	C
The early use of ECLS after cardiac surgery in a patient with an IABP and optimal medical therapy, with failure to wean from CPB or marginal hemodynamics is recommended.[33]	I	B
Significant comorbidities, advanced age, elevated lactate level, and renal injury are risk factors associated with death and should be considered prior to ECLS initiation.[27,25,33]	IIa	B
Preoperative implant of ECLS may be considered in patients in very poor condition (hemodynamic or metabolic) or with structural cardiac anomalies (postacute MI VSD, severe lung edema, or dysfunction due to underlying cardiac disease) to facilitate perioperative management (bridge to surgery).	IIb	C
It should be considered that the type and modality of ECLS (uni or biventricular failure, right or left ventricular compromise, preoperative, intraoperative or postoperative cardiocirculatory failure, acute or chronic cardiac dysfunction, cardiogenic shock or cardiac arrest, including alternative mechanical support device) are discussed based on the type of hemodynamic condition and patient characteristics.	IIa	C

Mode

- VA mode; cardiac and respiratory support
- VV mode; respiratory support
- Hybrid ECLS; V-AV or V-VA mode, VV-A mode
  - North-South or Harlequin syndrome; differential oxygenation between the lower and upper parts of the body
  - Inadequate flow
  - Parallel circuits
- Peripheral vs. Central
- Oxy-RVAD; postoperative RV failure
- Femoral vs. another artery
- Left heart vent
- ECPELLA; ECMO + Impella, ECMELLA; ECLS + Impella
  - ECMO weaning off → Impella removal or LVAD, HT



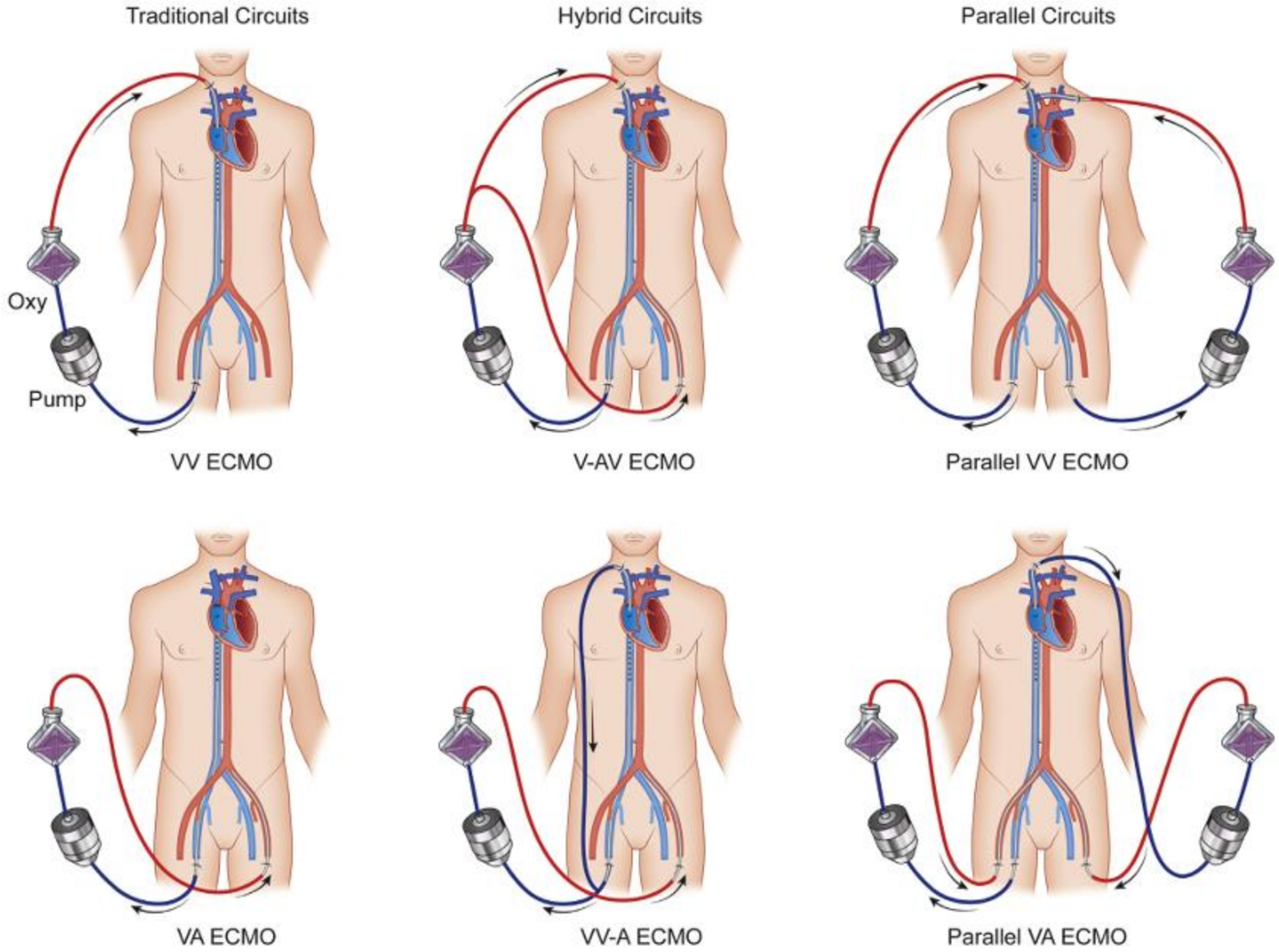


FIGURE 1. Various extracorporeal membrane oxygenation configurations including standard, hybrid and parallel circuits. *Oxy*, Oxygen; *VV ECMO*, venovenous extracorporeal membrane oxygenation; *V-AV ECMO*, veno-arteriovenous extracorporeal membrane oxygenation; *VA ECMO*, venoarterial extracorporeal membrane oxygenation; *VV-A ECMO*, venoveno-arterial extracorporeal membrane oxygenation.

Recommendations for ECLS modes and configurations

Recommendations	Class*	Level†
Peripheral cannulation approach should be considered in patients with PCS and for V-A ECLS in the presence of LV or biventricular failure.[41,43-45]	IIa	B
Oxy-RVAD configuration may be considered in the presence of PC refractory isolated RV failure.	IIb	C
In the presence of limb ischemia despite antegrade perfusion, contralateral femoral artery, axillary artery, or central access should be considered.	IIa	C
Axillary/subclavian artery or central aortic cannulation for patient inflow may be considered as an alternative to femoral artery cannulation.	IIb	C
Direct cannulation of the LV through the apex may be considered for LV drainage and for conversion to an LVAD-like configuration (LV apex-subclavian artery).	IIb	C
Alternative, hybrid, ECLS configurations (VV-A, V-VA, or other configurations, including additional devices) may be considered in patients on V-V ECLS or V-A ECLS with cardiac failure, differential oxygenation (also known as Harlequin syndrome), respiratory failure, refractory hypoxemia, insufficient venous drainage, and/or LV stasis.	IIb	C
In the presence of infrequent hemodynamic or structural cardiac conditions, the use of associated devices (ECLS + IABP or transseptal or transaortic suction device) should be considered.	IIa	C

TABLE 4. Principles to consider when choosing non-conventional post-cardiotomy ECLS system modes and configurations

Underlying disease (preoperative or intraoperative) (ischemic/inadequate myocardial protection, valve disease with mechanical prosthesis, associated lung dysfunction, or edema)
Preoperative uni- or biventricular function (isolated RV versus isolated LV or biventricular dysfunction)
Adequacy of ECLS venous return
Adequacy of ECLS output (septic state) (if higher flow is required)
State of global cardiac contractility (very poor or absent contractility with high risk of intracardiac thrombosis)
Extent of left chamber stasis and distension
Adequacy and efficacy of aortic valve opening under ECLS support
Pulmonary insufficiency/congestion
Adequacy of upper body and/or coronary oxygenation
Presence and extent of peripheral arterial atherosclerosis
Presence of limb ischemia (peripheral cannulation)
Presence of limb hyperperfusion (axillary artery perfusion with "chimney technique")
Likelihood of ECLS weaning (bridge to VAD or HTx) (a prophylactic "VAD-like" configuration for a prolonged temporary assistance with short-term mechanical assistance without oxygenator)
Possibility of patient mobility on ECLS (if prolonged support expected)

RV, Right ventricle; *LV*, left ventricle; *ECLS*, extracorporeal life support; *VAD*, ventricular assist device; *HTx*, heart transplant.

Peripheral vs. Central

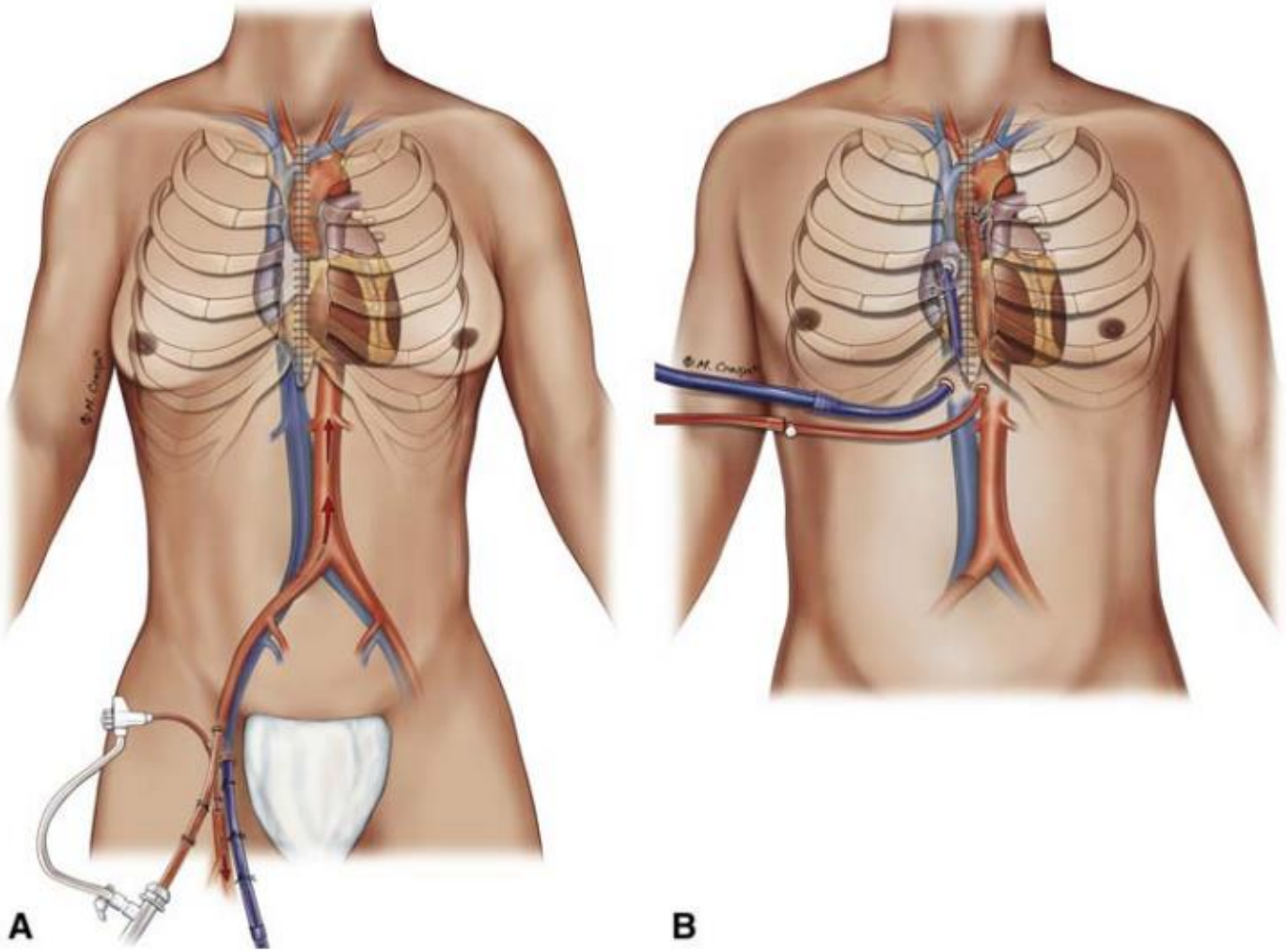
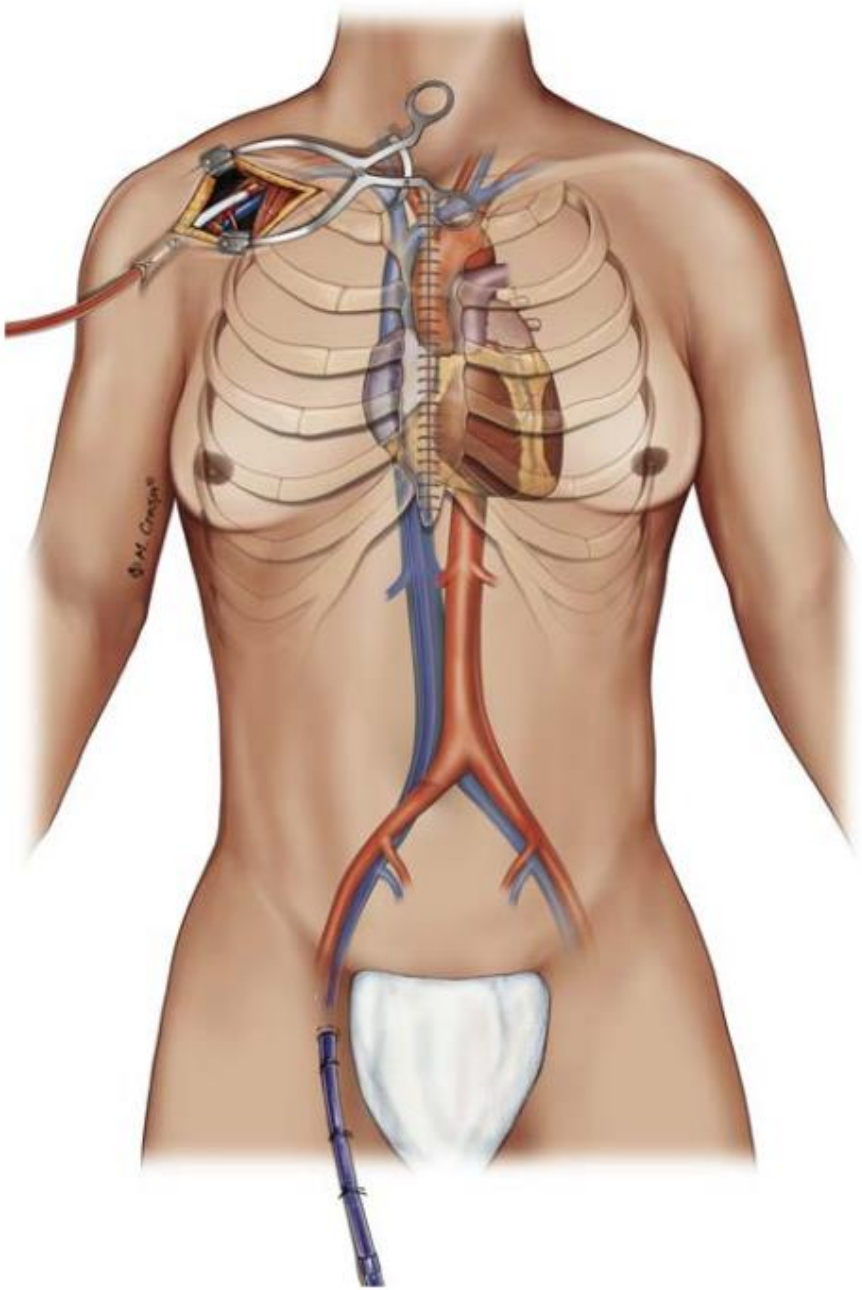


FIGURE 2. Several configurations of veno-arterial extracorporeal membrane oxygenation in post-cardiotomy patients. (A) Peripheral (femoral vessel) approach with distal perfusion cannula and (B) subxipoid cannula tunneling with central approach.



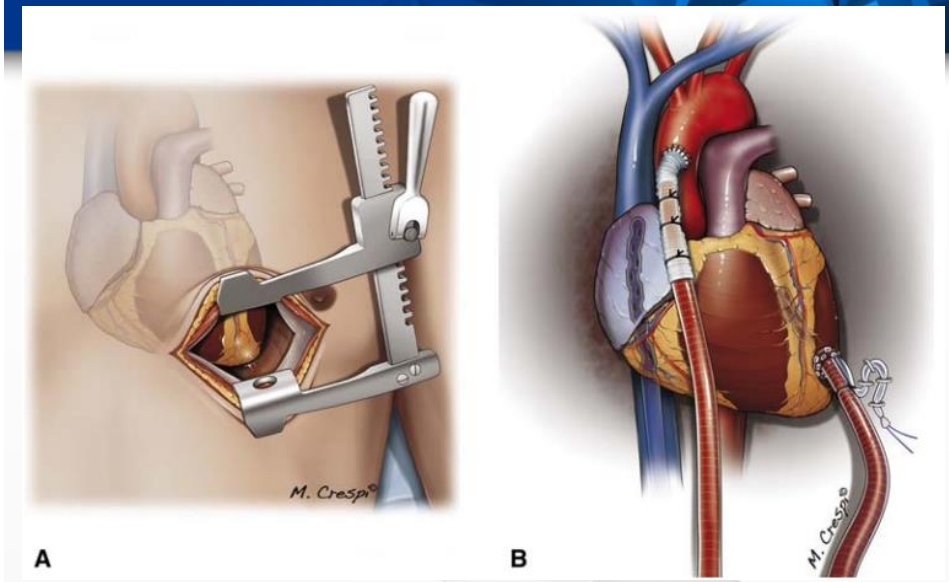


FIGURE 3. Peripheral veno-arterial extracorporeal membrane oxygenation with axillary artery ("chimney technique" with graft interposition) as the perfusion port.

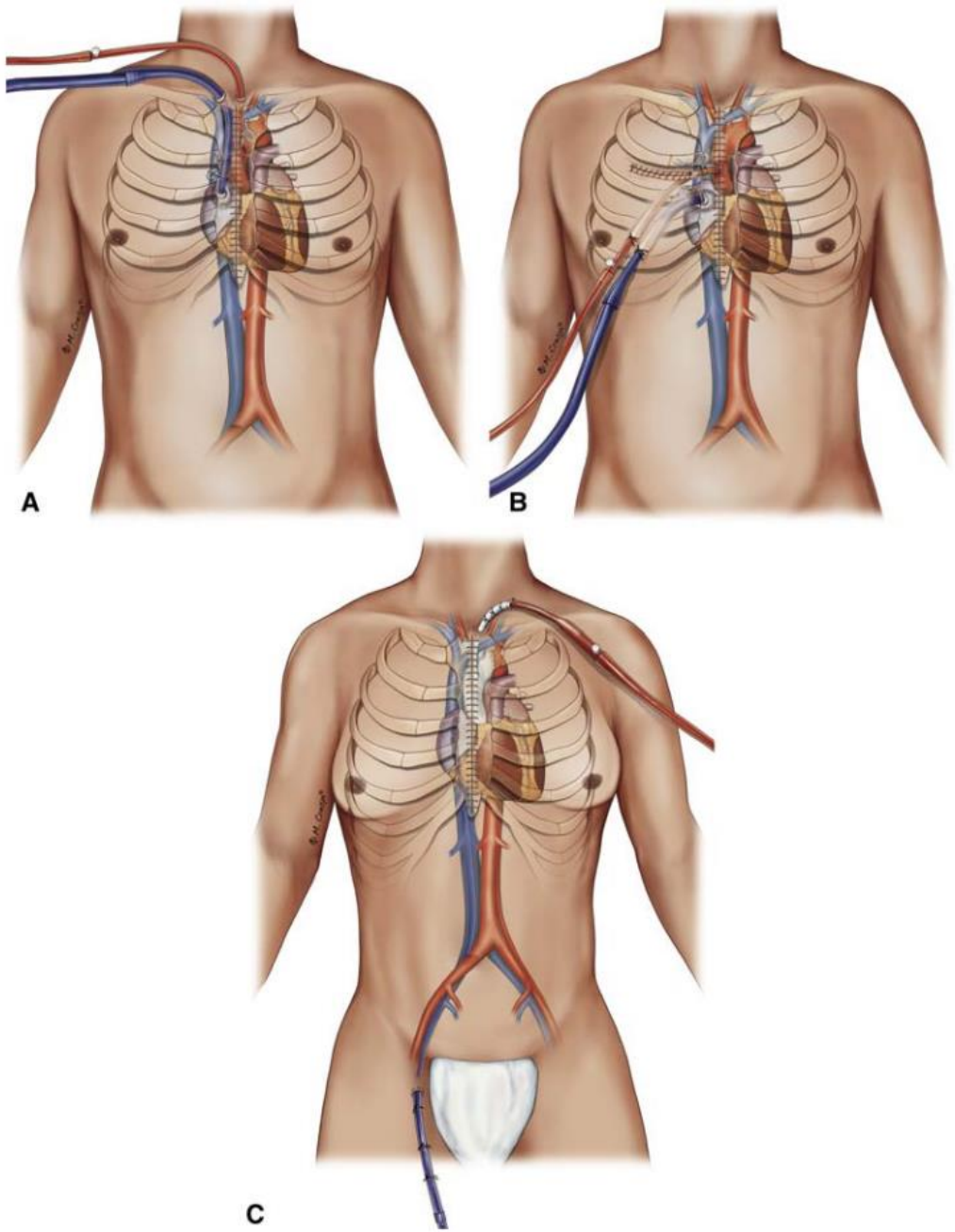
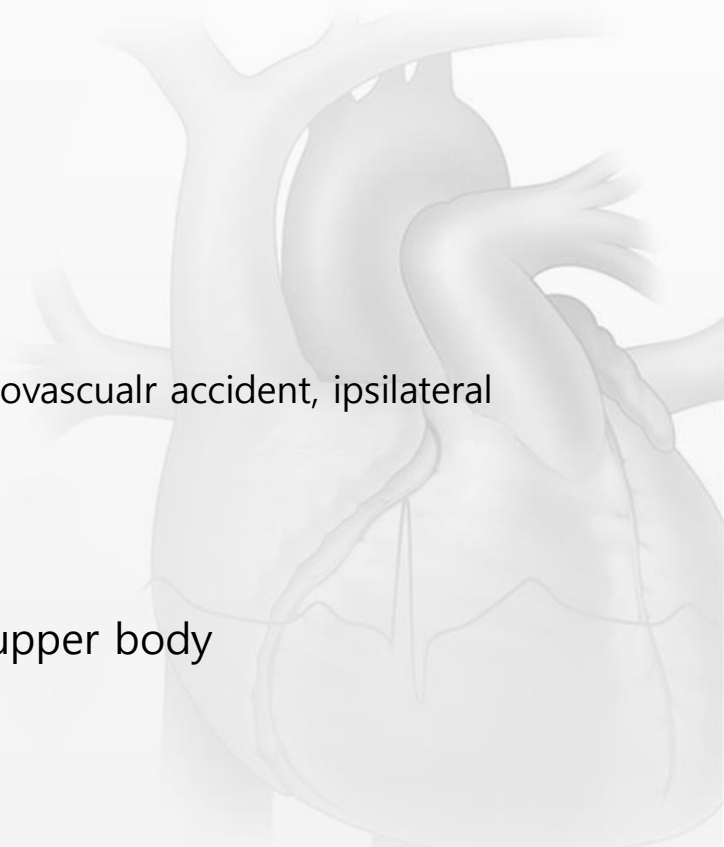


FIGURE 10. Alternative externalization of extracorporeal life support (ECLS) arterial and venous cannulae. (A) Jugular tunneling of the arterial and venous cannulae at the jugular site, allowing sternal closure. (B) Externalization of the ECLS cannulae through intercostal spaces. (C) Externalization of the arterial outflow port of a veno-arterial ECLS through a prosthetic graft anastomosed at the aortic prosthesis; this approach may allow a central configuration, sternal closure, and cannula withdrawal in case of weaning without reopening the sternum.

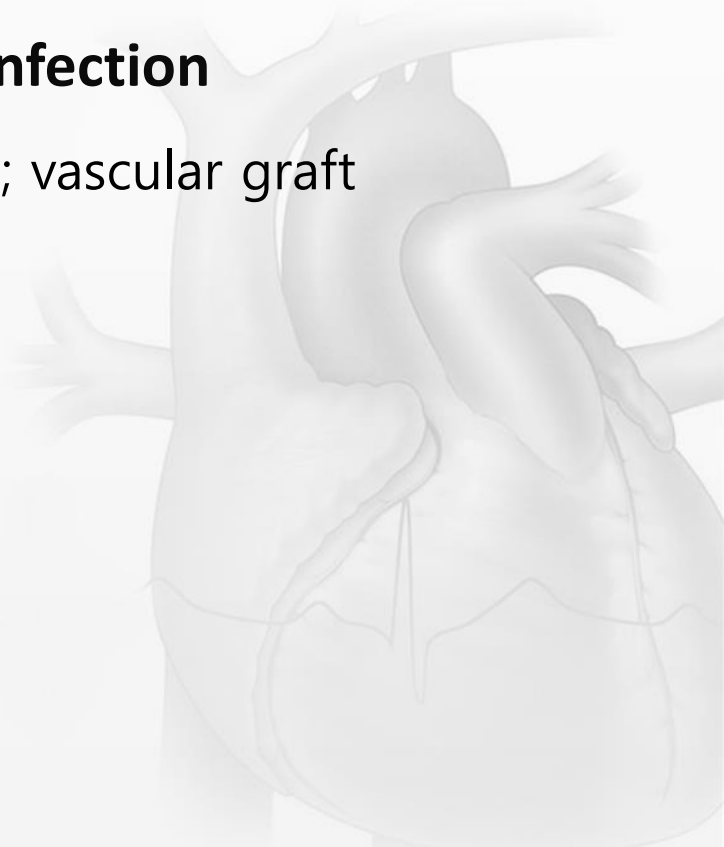
Peripheral vs. Central

- **No survival advantage**
- **Peripheral cannulation**
  - **More common; 79%**
  - **Percutaneous; allow sternal closure → less infection**
  - **Less sternal bleeding, blood transfusion**
  - **More limb ischemia**
    - Small femoral a.; distal perfusion, vascular graft
    - Axillary or subclavian a.
      - Pseudocentral flow
      - More vascular access complication; bleeding, cerebraovascualr accident, ipsilateral hyperperfusion, compartment synd.
  - **Increased afterload; retrograde flow**
    - LV distension, stasis
    - Differential oxygenation between the lower and upper body



Peripheral vs. Central

- **Central cannulation**
  - **Directs antegrade flow into the aorta**
  - **Utilizing the cannulas already in place for CPB**
  - **Opened sternum; more bleeding and infection**
    - Cardiac compression from the cannulas; vascular graft
  - **Reoperation for weaning**
    - Direct LV venting through RUPV



Oxy RVAD

- Isolated RV failure
- Surgical or percutaneous cannulation of the PA

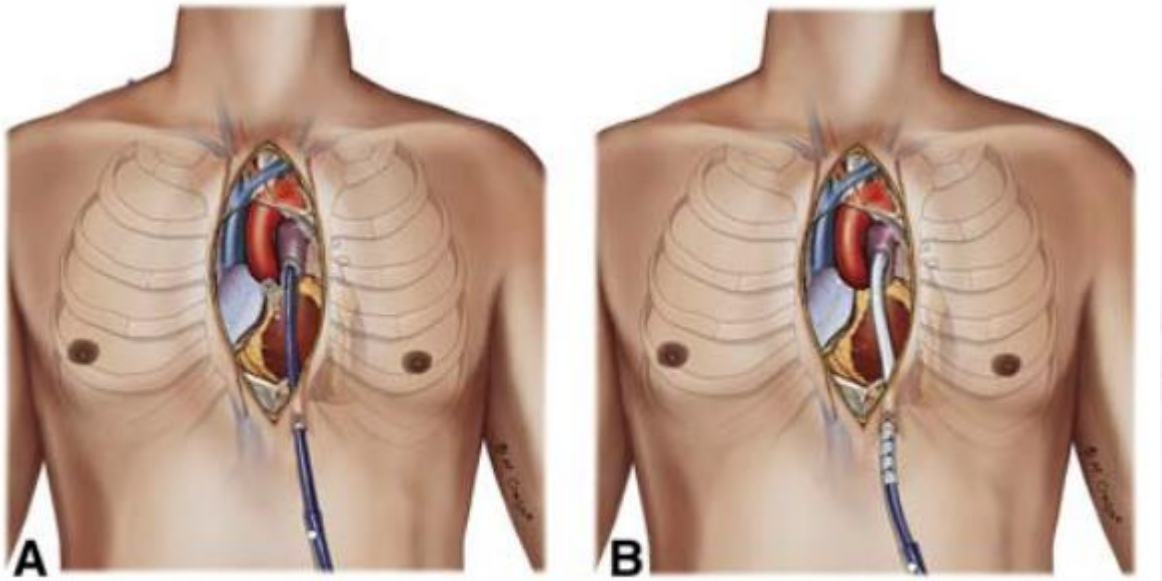
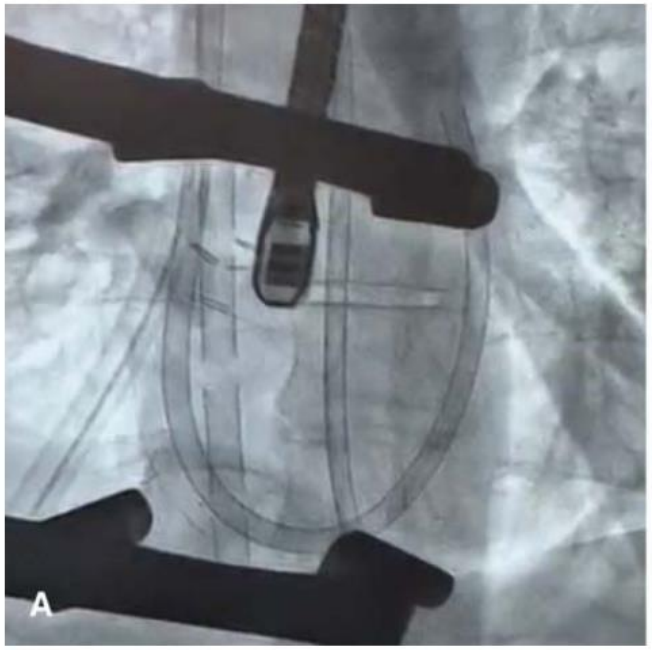


FIGURE 4. (A) Direct pulmonary artery cannulation. (B) Pulmonary artery cannulation through a prosthetic graft.



Oxy RVAD

- Limited or absent recirculation with RV support
- Totally bypassing the RV; RV failure
  - Avoiding retrograde flow of LV
- Additional left heart drainage; LV unloading
- Removal of the oxygenator; normal lung function, decrease anticoagulation and oxygenator-related complications(hemolysis and clot formation)

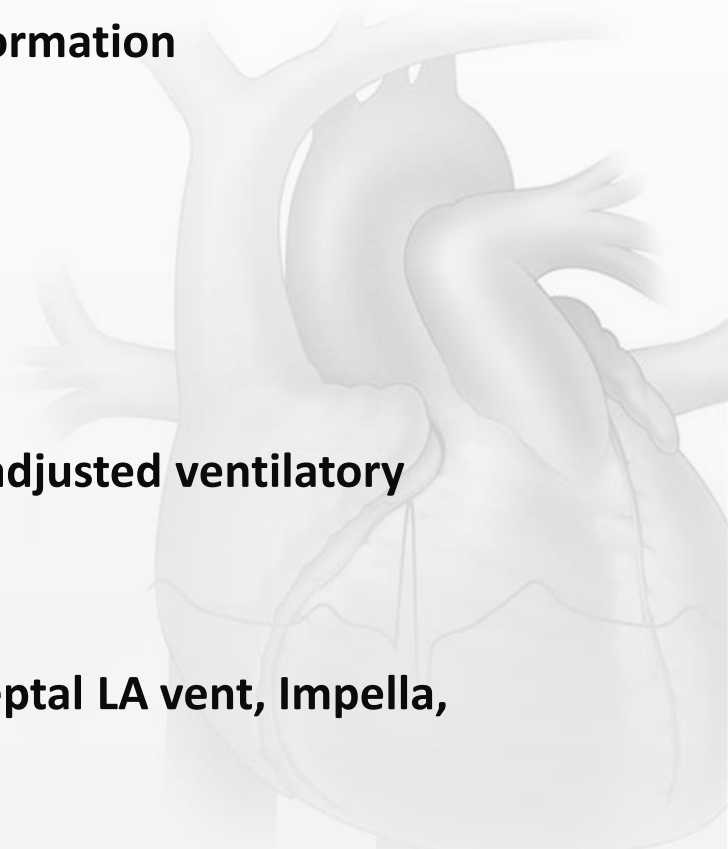
Recommendations for an oxygenator in the RV assist device circuit of the ECLS system (Oxy-RVAD)

Recommendations	Class*	Level†
The use of an Oxy-RVAD may be considered in patients with isolated preoperative or postoperative RV dysfunction and concomitant respiratory compromise.	IIb	C
The use of an Oxy-RVAD may be considered in patients with preoperative lung compromise at high risk for postoperative V-V ECLS or who need other forms of respiratory support.	IIb	C
The use of an Oxy-RVAD in patients undergoing acute pulmonary artery embolectomy with preoperative, intraoperative, or postoperative RV failure occurrence is recommended.	I	C
The use of an Oxy-RVAD in patients undergoing pulmonary artery endarterectomy with preoperative, intraoperative, or postoperative RV failure occurrence may be considered.	IIb	C

Oxy-RVAD, External right ventricular-ventricular support with an oxygenator; *RV*, right ventricular; *V-V ECLS*, veno-venous extracorporeal life support. *Class of recommendation. †Level of evidence.

Left heart venting

- LV distension
  - Subendocardial ischemia; impair ventricular recovery
  - Progressive pul. congestion
- Failure of the aortic valve opening
  - Increase the risk of blood stasis and thrombus formation
- Initial signal
  - Blood pressure pulsatility; < 15mmHg
  - Echo; LV swirling (smoke like)
- Non-aggressive strategies
  - Reduce ECLS flow, vasodilation, Inotropic drug, adjusted ventilatory setting (enhance RV drainage), IABP
- More aggressive strategies
  - Catheter- or device-based interventions (transseptal LA vent, Impella, direct LV vent, PA vent)



Method	Factor	Grade of severity		
Arterial line				
	Arterial Pulsatility	Mild weakness	Moderate weakness	Almost Pulseless
Central venous Line				
	$ScvO_2$	75-55%	55-45%	<45%
	CVP	8-12 mmHg	12-16 mmHg	> 20 mmHg
Echocardiogram				
	AV	Opening every 2 bpm	Opening every 3-4 bpm	Closure
	LV distension	Mild	Moderate	Severe
	LA distension	Mild	Moderate	Severe
	"Smoke like" effect	Mild	Moderate	Severe
	IVC dilatation[1]	1.5 to 2.5 cm	>2.5 cm	>2.5 cm
	IVC collapse[2]	<50%	<50%	No change
Swan Ganz Catheter				
	PCWP	13-18 mmHg	18-25 mmHg	>25 mmHg
Chest X-ray				
	Congestion[3]	Alveolar edema	Interstitial edema	Redistribution

$ScvO_2$: central venous blood oxygen saturation; CVP: central venous pressure, AV: aortic valve; bpm: beats per minute; LV: left ventricle; LA: left atria, PCWP: post capillary wedge pressure.

Less Invasive LV Unloading Manoeuvers To Be Applied

IABP + Less Invasive LV Unloading Manoeuvers To Be Applied

Invasive Catheter-Based LV Unloading Manoeuvers To Be Applied

FIGURE 6. Criteria to be used for the assessment of left ventricular unloading need (modified from Meani et al[101]). *LV*, Left ventricle; *$ScvO_2$*, central venous blood oxygen saturation; *CVP*, central venous pressure; *AV*, aortic valve; *IABP*, intra-aortic balloon pump; *LA*, left atria; *IVC*, inferior vena cava; *PCWP*, post-capillary wedge pressure.

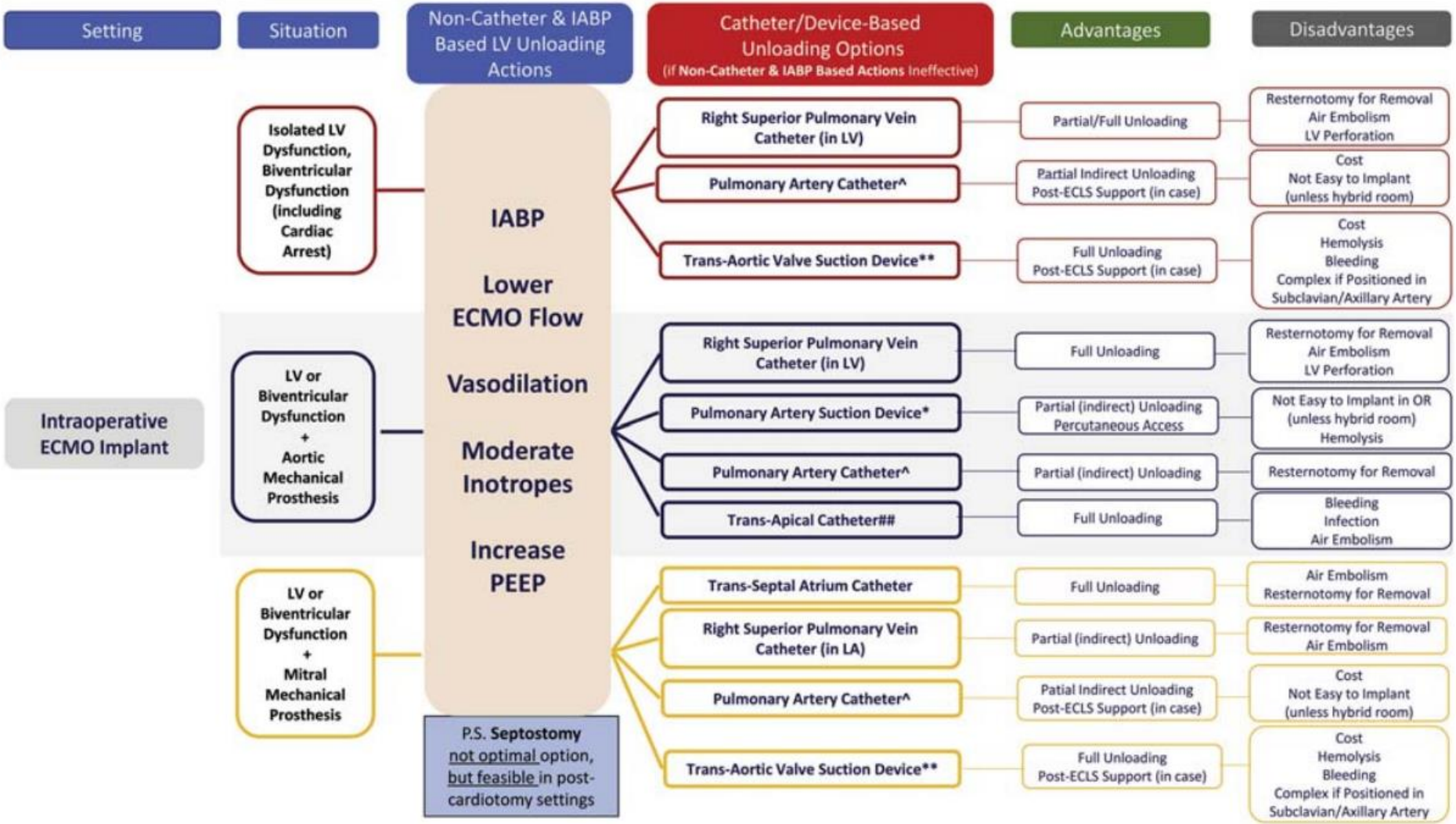


FIGURE 7. Procedures to enhance left ventricular unloading during veno-arterial ECMO in intraoperative post-cardiotomy shock. **Impella (Abiomed Inc, Danvers, Mass), *Impella RP (Abiomed Inc), ^single-lumen cannula; ##single- or double-lumen cannula. *IABP*, Intra-aortic balloon pump; *LV*, left ventricle; *ECMO*, extracorporeal membrane oxygenation; *PEEP*, positive end expiratory pressure; *ECLS*, extracorporeal life support.

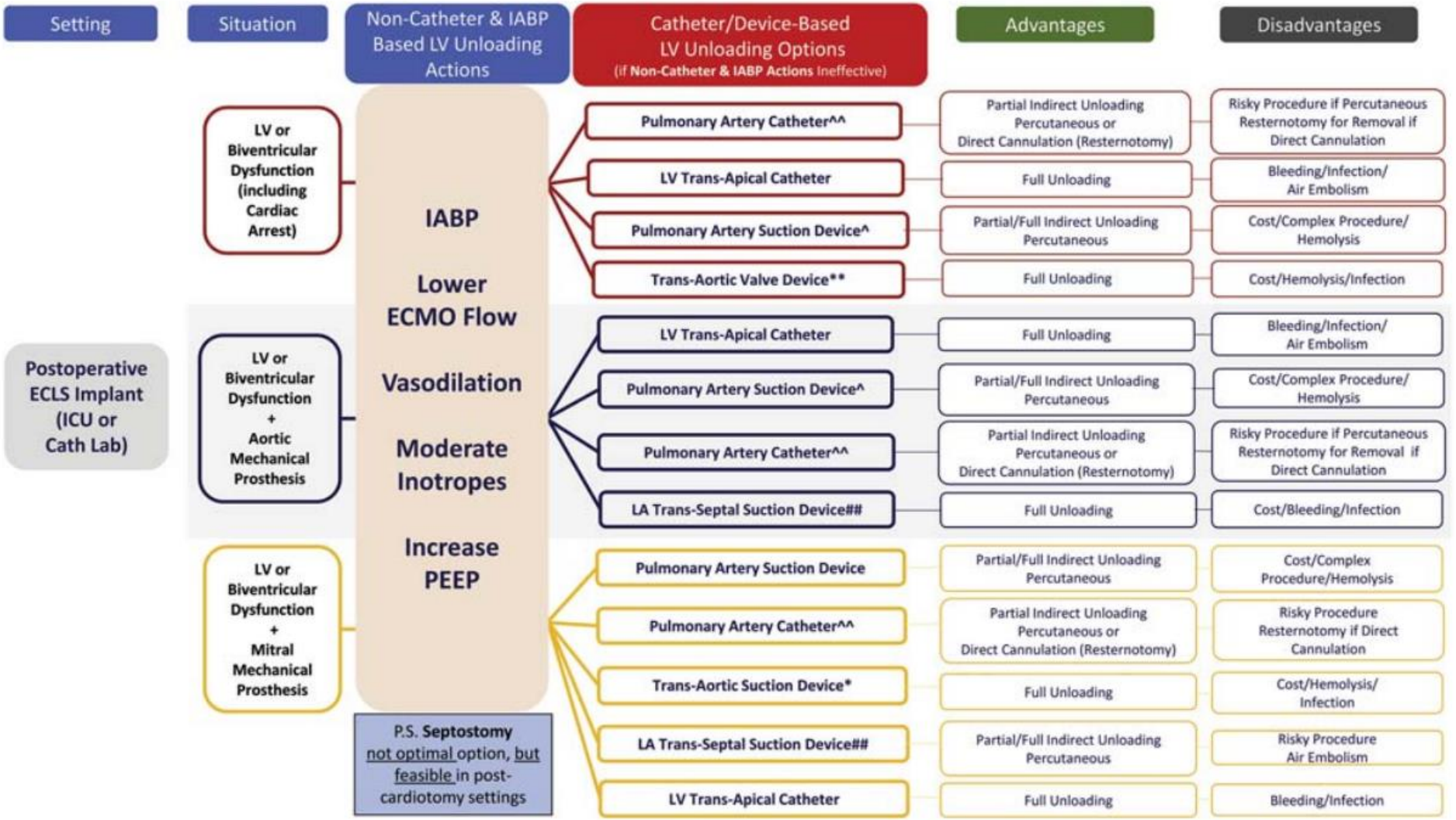
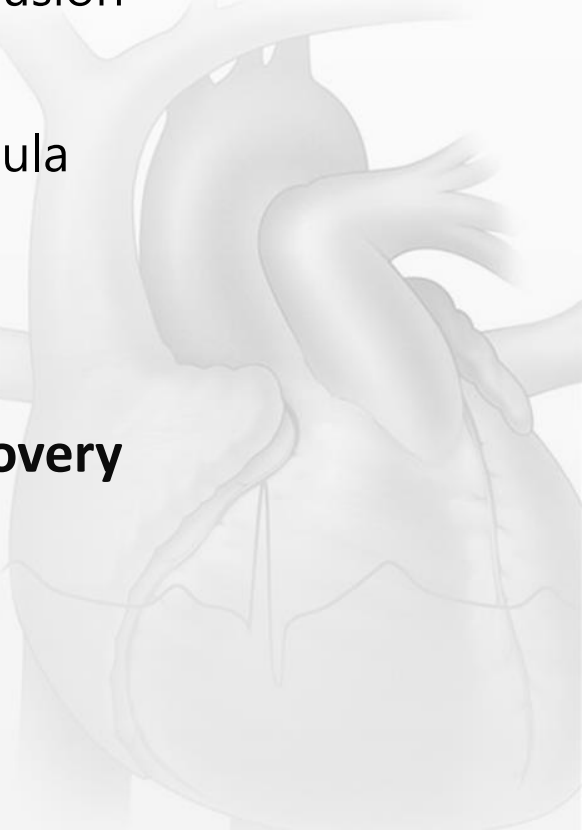


FIGURE 8. Procedures to enhance left ventricular unloading during veno-arterial ECMO in postoperative post-cardiotomy shock. **Impella (Abiomed Inc, Danvers, Mass); *Impella RP (Abiomed Inc); ^^single- or double-lumen cannula. *IABP*, Intra-aortic balloon pump; *LV*, left ventricle; *ECLS*, extracorporeal life support; *ICU*, intensive care unit; *ECMO*, extracorporeal membrane oxygenation; *PEEP*, positive end expiratory pressure.

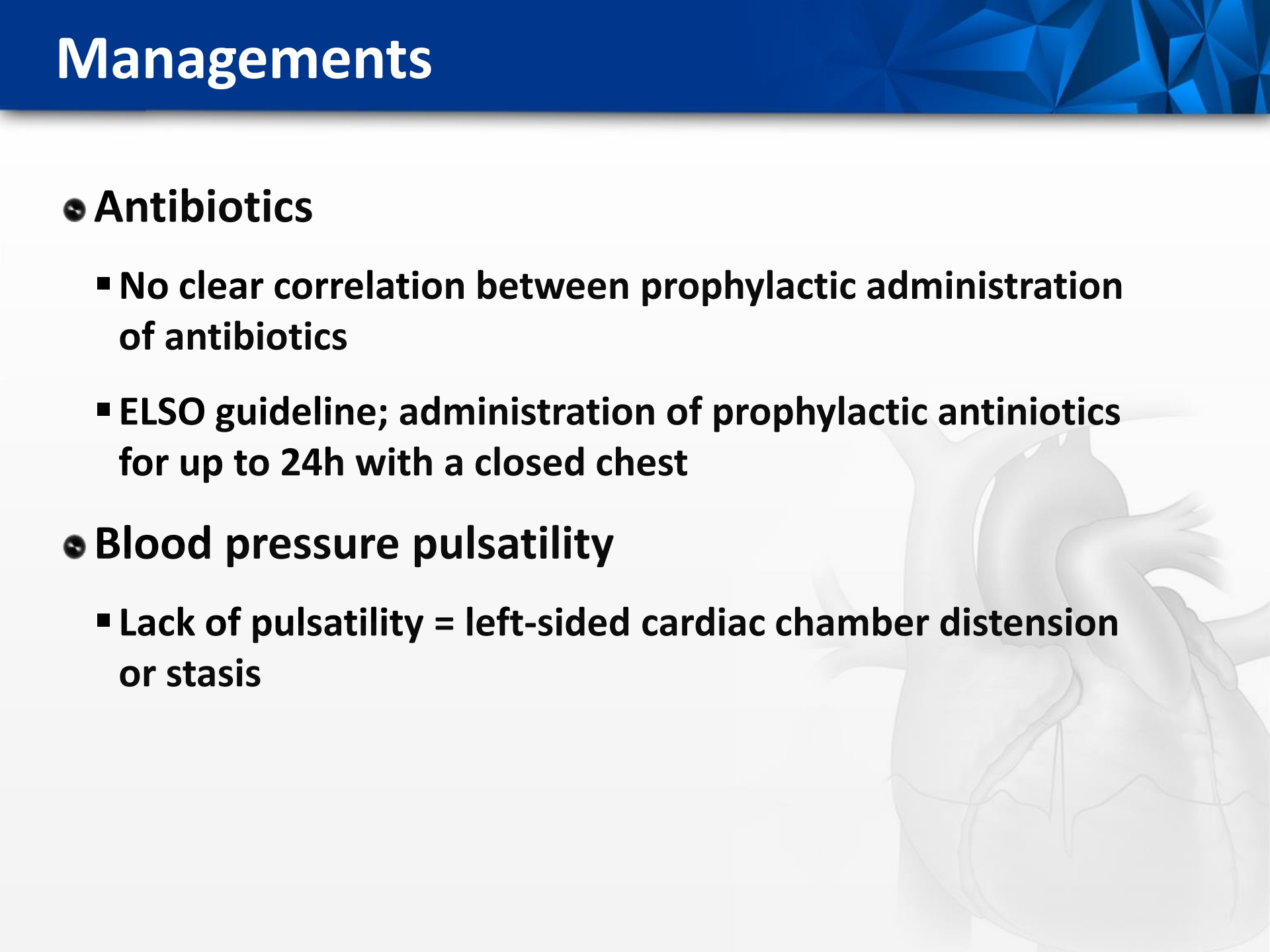
Managements

- **Sternum management**
  - **Sternal open; if short duration of support is anticipated**
  - **Sternal closure**
    - Minimization of blood loss, infection, and transfusion
    - Perioperative mobility; Awake EMCO
    - tamponade, cardiac compression from the cannula
- **Inotropes, Vasoconstrictors**
  - **Cardiac contraction and improving ejection**
  - **Expense of myocardial work that may delay recovery**
  - **The degree is unclear**
  - **Prevent LV distension and stasis**



Managements

- **Antibiotics**
  - **No clear correlation between prophylactic administration of antibiotics**
  - **ELSO guideline; administration of prophylactic antiniotics for up to 24h with a closed chest**
- **Blood pressure pulsatility**
  - **Lack of pulsatility = left-sided cardiac chamber distension or stasis**



Managements

- **Peripheral arterial/pulse oximetry**
  - **Peripheral cannulation; mixture of retrograde ECLS blood and native CO**
  - **Poor native lung function**
  - **Right and left hand-based oximetry; mixing point**
- **Pul. artery catheter**
  - **Pul. capillary wedge pressure = LA pressure = LV end-diastolic pressure = LV filling pressure ≒ diastolic pul. artery pressure**
  - **Mixed venous saturation; organ perfusion**

Managements

- **Near-infrared spectroscopy (NIRS)**
  - **No improvement of clinical results**
  - **Cerebral oxygen delivery**
  - **Extremity malperfusion**
  - **> 25% decline from baseline**
- **Anticoagulation**
  - **Partial heparin reversal with limited protamine**
  - **Infusion of heparin is typically delayed until a hemostasis is achieved, often within 24-48h (chest tube drainage <100cc/hr)**
  - **Monitoring; ACT, aPTT, antifactor Xa, thromboelastography**
    - ACT; 160-220s, aPTT; 50-80s
  - **Massive transfusion for bleeding; 6:6:1 = pRBC, FFP, Plts**

Recommendations for postoperative anticoagulation management

Recommendations	Class*	Level†
Heparin is recommended as the anti-coagulant of choice for PC-ECLS.	I	C
If HIT is suspected, it is recommended to change anticoagulation to DTIs.[130,131,34]	I	B
In the postoperative period, it is recommended to withhold anticoagulation until bleeding has diminished to acceptable levels.	I	C
It is recommended to monitor anticoagulation using the following tests: • ACT 160–220 s • aPTT 50–80 s	I	C
A TEG-driven algorithm should be considered for anticoagulation management.	IIa	C

PC-ECLS, Post-cardiotomy extracorporeal life support; *HIT*, heparin-induced thrombocytopenia; *DTI*, direct thrombin inhibitor; *aPTT*, activated partial thromboplastin time; *ACT*, activated clotting time; *TEG*, thromboelastography. *Class of recommendation. †Level of evidence.

Weaning

TABLE 5. Criteria and clues for weaning from veno-arterial ECLS (modified from ELSO Red Book[110])

Types of ECLS systems	Criteria for weaning
V-A ECLS	Stable hemodynamic conditions for at least 24 h
	Mean arterial pressure >60 mm Hg in the absence of or with low levels of vasopressors/inotropes
	Low arterial lactate levels (<2 mmol/L)
	PaO_2 >100 mm Hg with ECLS FiO_2 <21% and FiO_2 40% on the mechanical ventilator
	Aortic flow velocity time integration >10–12 cm at an ECLS flow of 1–1.5 L/min
	Left ventricular ejection fraction >20%–25%
	Doppler lateral mitral annulus peak systolic velocity ≥6 cm/s
	LV and RV adequate contractile response to volume challenge
	Venous and arterial patency and lack of distal thrombi should be checked after decannulation
	Use of other temporary assist device, like a transaortic suction device, may be used to enhance weaning from ECLS
	Transition to a VAD may be considered once hemodynamic stability has been achieved; however, in the presence of liver dysfunction, systemic inflammation, or obesity, mortality will be high
From Oxy-RVAD ECLS (isolated RV support)	No sweep gas flow to the oxygenator for at least 2 h and maintain acceptable systemic arterial O_2 saturation (>90%) with normal respiratory parameters
	Stable hemodynamics with low doses of inotropes for at least 24 h
	Weaning trial should parallel prophylactic inotropic infusion (levosimendan)
	No signs of liver (transaminase increase) or renal (oliguria, anuria) stasis or evidence of steady and/or marked decrease
	TAPSE >10 mm with ECLS flow at 1–1.5 L/min
	Off-pump long-axis/short-axis ratio <0.55
	Lack of thrombi at the pulmonary artery level should be checked after decannulation

ECLS, Extracorporeal life support; *V-A*, veno-arterial; *ELSO*, Extracorporeal Life Support Organization; *LV*, left ventricle; *RV*, right ventricle; *Oxy-RVAD*, right ventricular assist device with oxygenator; *TAPSE*, tricuspid annular plane systolic excursion.

References

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