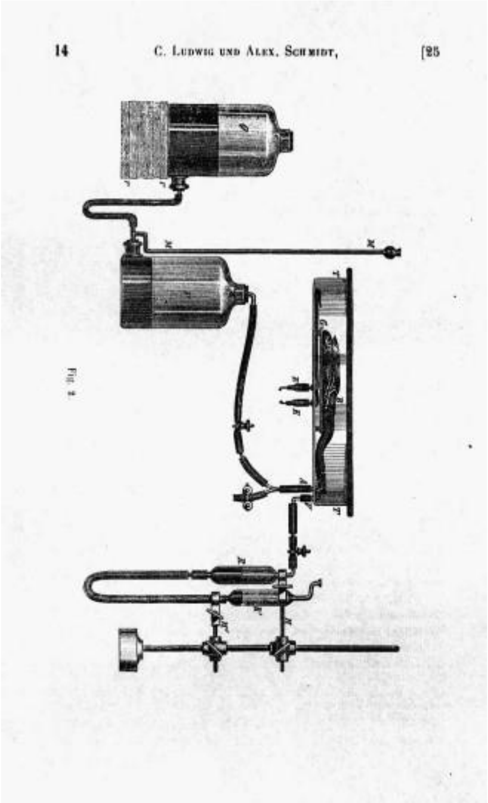
Basics:
- History
- Types
- ECMO circuit
- Indications & contraindications
- Evidence



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14.11.1400

تاریخچه گردش خون برون پیکری:

در سال ۱۶۹۳ میلادی پزشک فرانسوی Jean Baptiste Denis آزمایش انتقال خون انسان به گوسفند را برای تعیین قابلیت انتقال خون بین دو گونه انجام داد.

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1635–1703	Robert Hooke conceptualizes the notion of an oxygenator.
1869	Ludwig and Schmidt attempt to oxygenate blood by shaking together defibrinated blood with air in a balloon.
1882	von Schröder of Strasburg uses a bubble oxygenator to oxygenate an isolated kidney.
1882	Frey and Gruber describe the first 'two-dimensional', direct-contact extracorporeal oxygenator, which exposed a thin film of blood to air in an inclined cylinder, which was rotated by an electric motor.
1916	Discovery of heparin when Jay Maclean demonstrates that a phosphatide extracted from canine heart muscle prevents coagulation of the blood.
1929	First whole-body extracorporeal perfusion of a dog by Brukhonenko and Tchetchuline.
1930s	Gibbon and Kirkland further develop the concept of the oxygenator.
1948	Bjork describes the rotating disc oxygenator.
1952	All-glass bubble oxygenator by Clarke, Gollan and Gupta.
1953	First successful human intracardiac operation under direct vision using a mechanical extracorporeal pump oxygenator.
1955	Kirklin and colleagues at the Mayo Clinic further developed the Gibbon-type stationary screen oxygenator into the Mayo–Gibbon pump oxygenator apparatus, and made it available for commercial use.
1955	Lillehei and colleagues then begin to use the DeWall bubble oxygenator clinically.
1958	Clowes, Hopkins and Neville use 25 m^2 of permeable ethylcellulose (soon replaced by the mechanically stronger polytetrafluoroethylene or Teflon) in multiple sandwiched layers to form the first clinical membrane oxygenator.
1972	Hill reports the first adult survivor on ECMO.
1972	Editorial in the *New England Journal of Medicine* by Zapol: 'Buying time with artificial lungs'.

First Heart - Lung Machine (Roller pump)

Gibbon 1953

First clinical application of ECLS

Used for an ASD repair

First Adult Clinical Application

Hill 1971

Used for a trauma patient post car accident

First Neonatal Clinical Application

Bartlett 1975

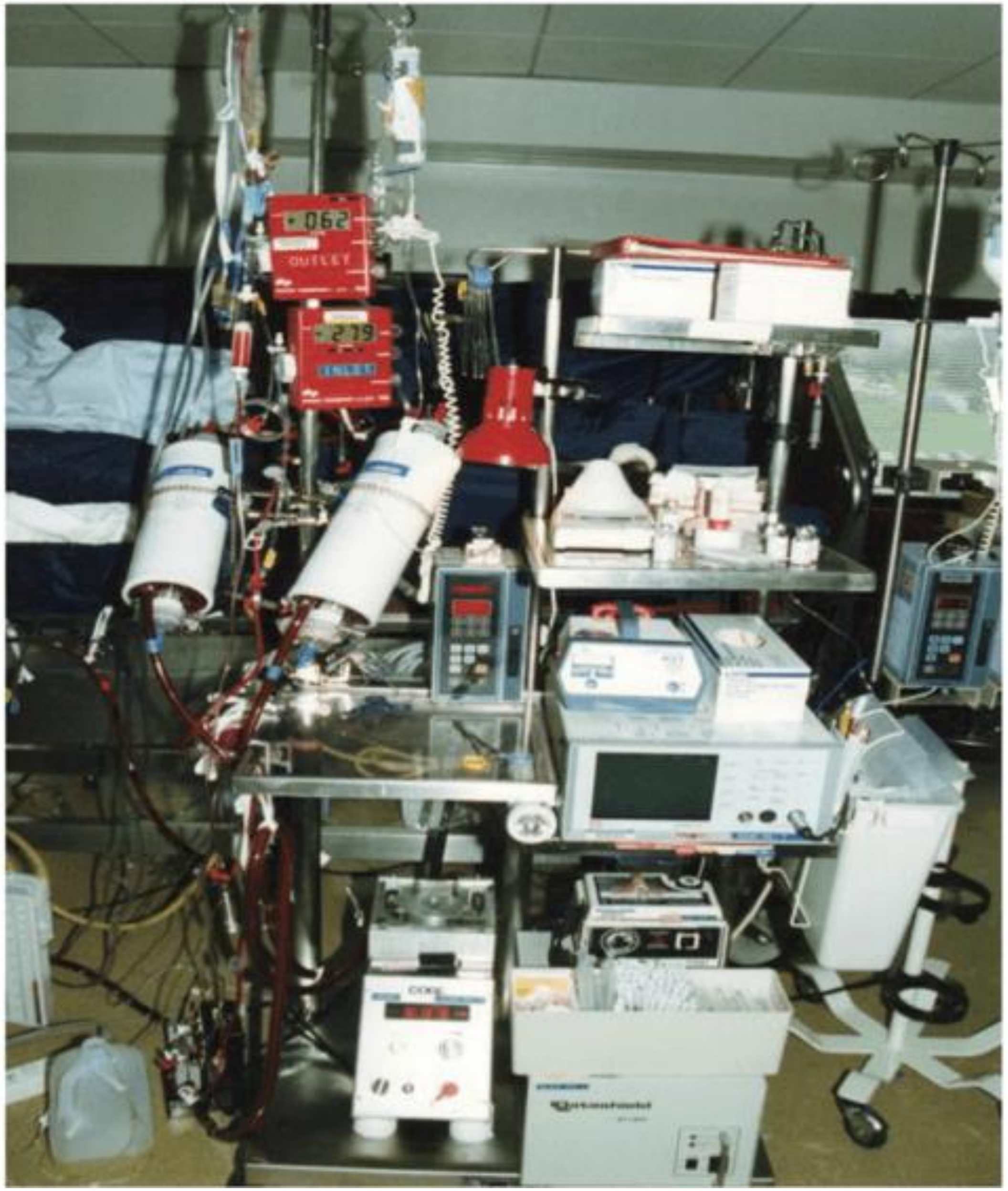
Neonate treated for meconium aspiration

Robert Bartlett 1975

ECLS:

- An artificial heart (**pump**) and lung (membrane **oxygenator**)
- Indications for ECLS are acute, severe **heart or lung failure**

Year	Event
1976	Bartlett reports the successful use of ECMO on an abandoned newborn nicknamed Esperanza by the nursing staff.
1978	Kolobow and Gattinoni describe using extracorporeal circulation to remove carbon dioxide, allowing a potential decrease in ventilation harm.
1979	Publication of a randomized controlled trial in adult patients with acute respiratory distress syndrome (ARDS) by the National Heart, Lung and Blood Institute: disappointing results with 10% survival in either group.
1989	Founding of the Extracorporeal Life Support Organization (ELSO).
2009	H1N1 influenza pandemic and data relating to clinical success with ECMO are widely disseminated, including in the lay press.
2009	'Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomized controlled trial', published in *The Lancet*.
2011	The National Health Service (England) commission a national respiratory ECMO service.
2014	Publication of 'Position paper for the organization of extracorporeal membrane oxygenation programs for acute respiratory failure in adult patients' in the *American Journal of Respiratory and Critical Care Medicine*.

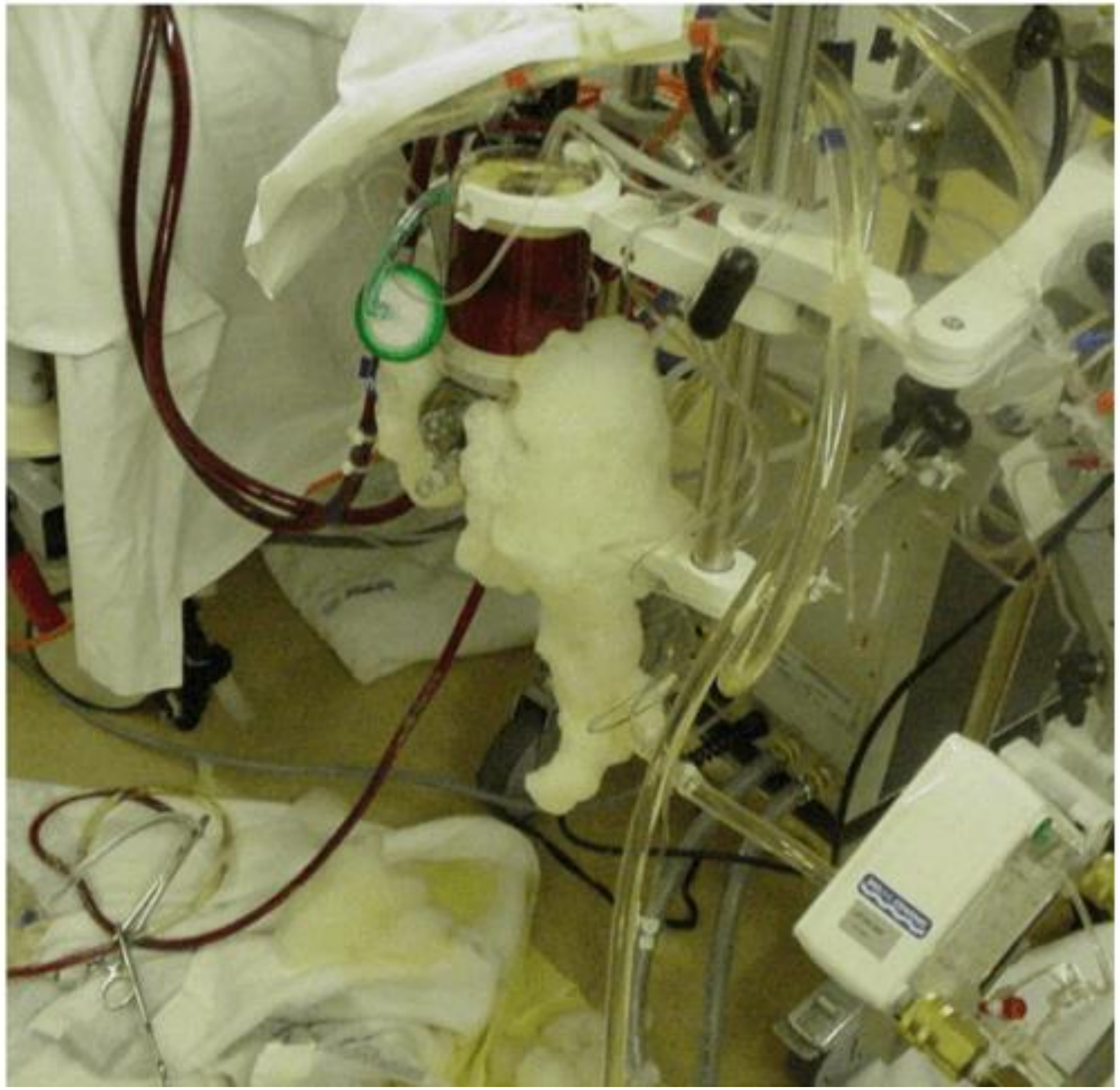


1992

Silicone membrane

Roller pump

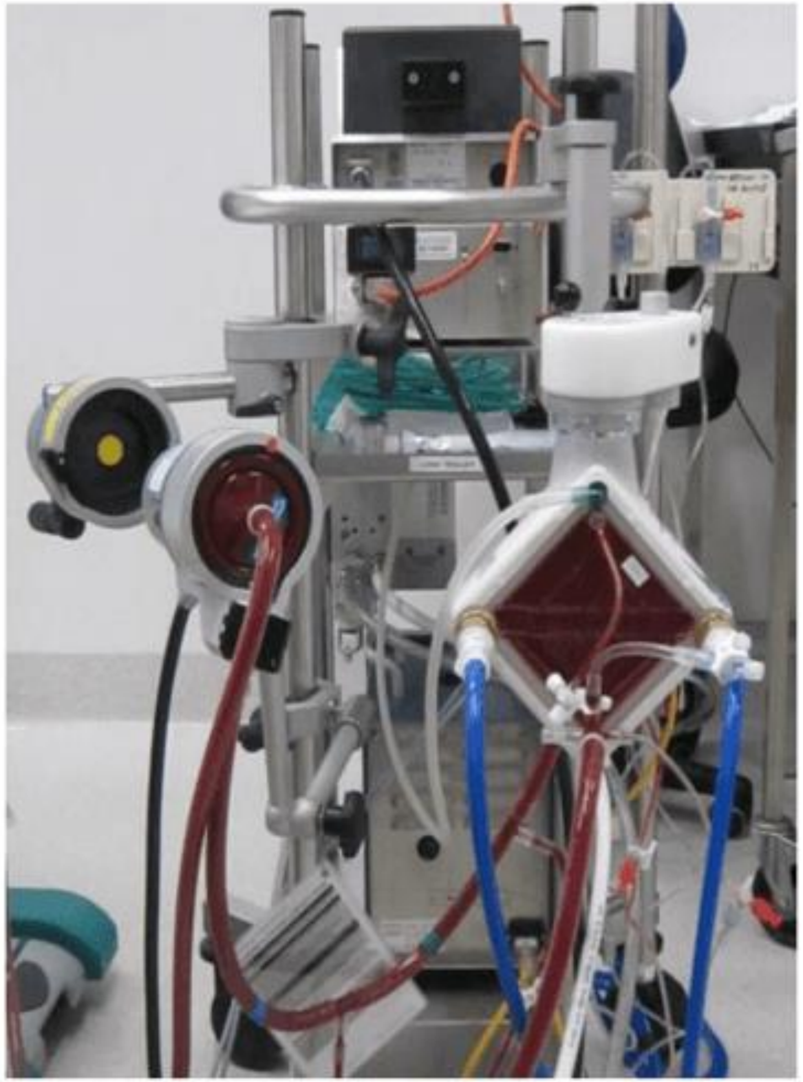
Plasma Leak



1998

Oxygenator failure prior to introduction of polymethylpentene (PMP) oxygenators

2-3 oxygenators used per patient run

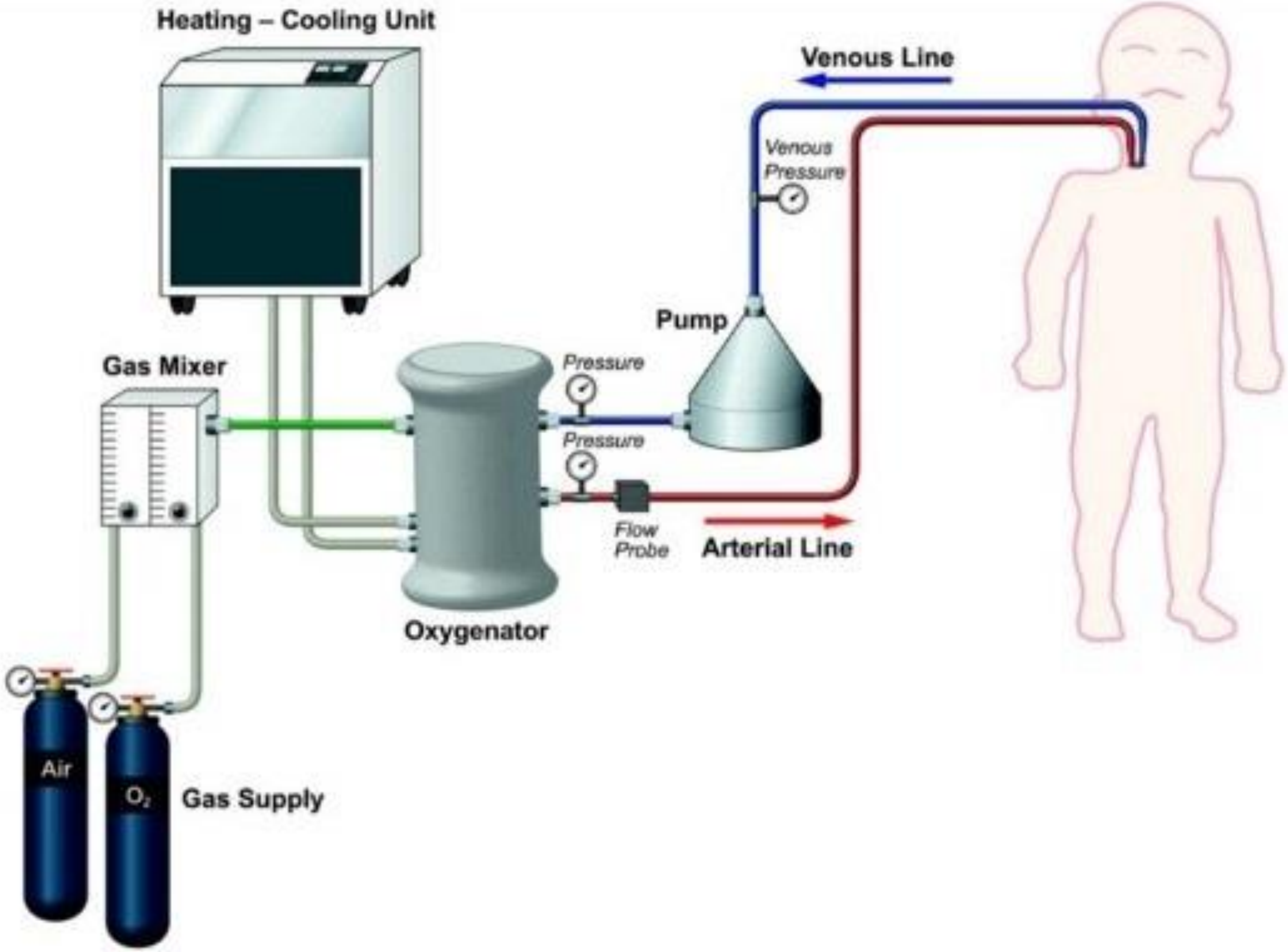


2010

Centrifugal pump

PMP membrane

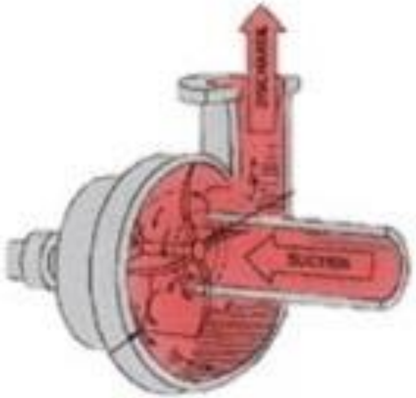
Basic ECMO Circuit



Pumps

- Drain blood from patient and drive it through oxygenator
- Two types
  - Roller
  - Centrifugal

Ultrasonic Flow Sensor



Centrifugal Pump

Roller Pump

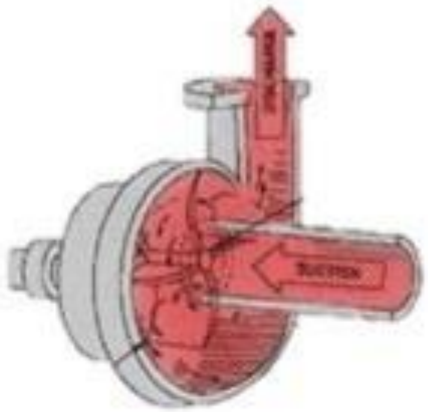
Roller Pump Characteristics

- Preload dependent
  - Requires forward flow at inlet
  - Risk of "cavitation"
- Afterload independent
  - Pump flow continues despite high afterload
  - Risk of circuit rupture
- Flow determined by pump revolutions per minute (RPM) and tubing diameter

Centrifugal Pump Characteristics

- Centrifugal action creates pressure differential between center and periphery of pump

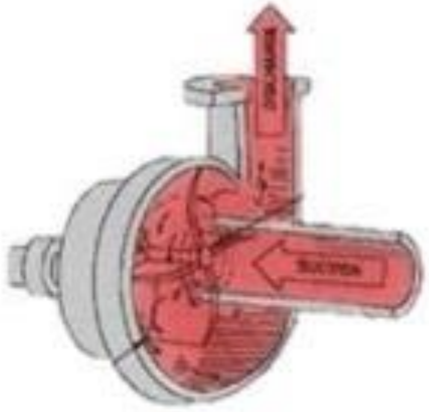
- Non-occlusive pump
  - Clamp lines when pump off, to prevent backflow from the patient



Centrifugal Pump

Centrifugal Pump Characteristics

- Preload dependent
  - Sensitive to volume available to the pump inlet
- Afterload dependent
  - Sensitive to the resistance at the pump outlet
- Flow meter required – cannot predict flow from RPM



Centrifugal Pump

BOX 32.2 CENTRIFUGAL PUMPS

- Operate on the constrained vortex principle.
- Blood flow is inversely related to downstream resistance.
- Flow rate is determined using an ultrasonic flow meter.
- Increase in centrifugal pump revolutions per minute may result in heat generation and hemolysis.
- If the centrifugal pump is stopped, the line must be clamped to prevent retrograde flow.

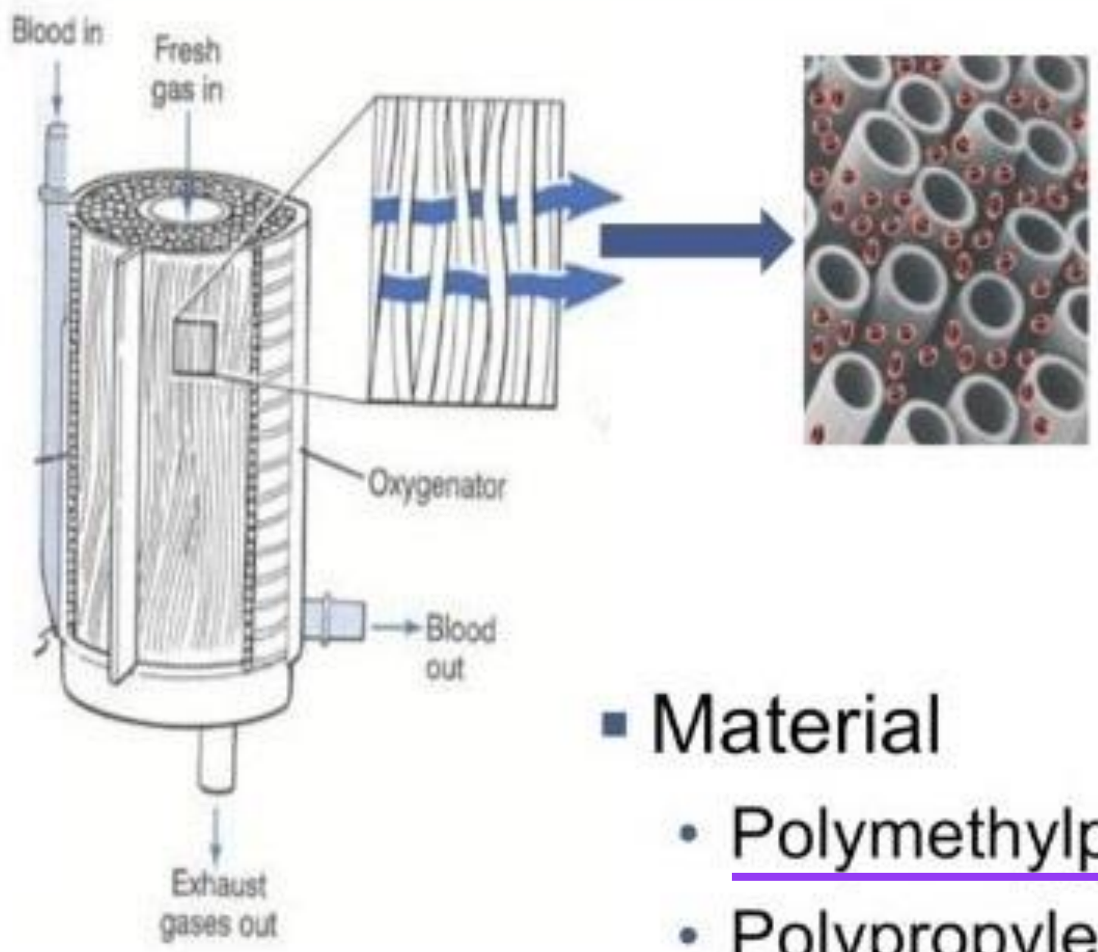
Revolution centrifugal pump disposable

Blood Flow Monitor

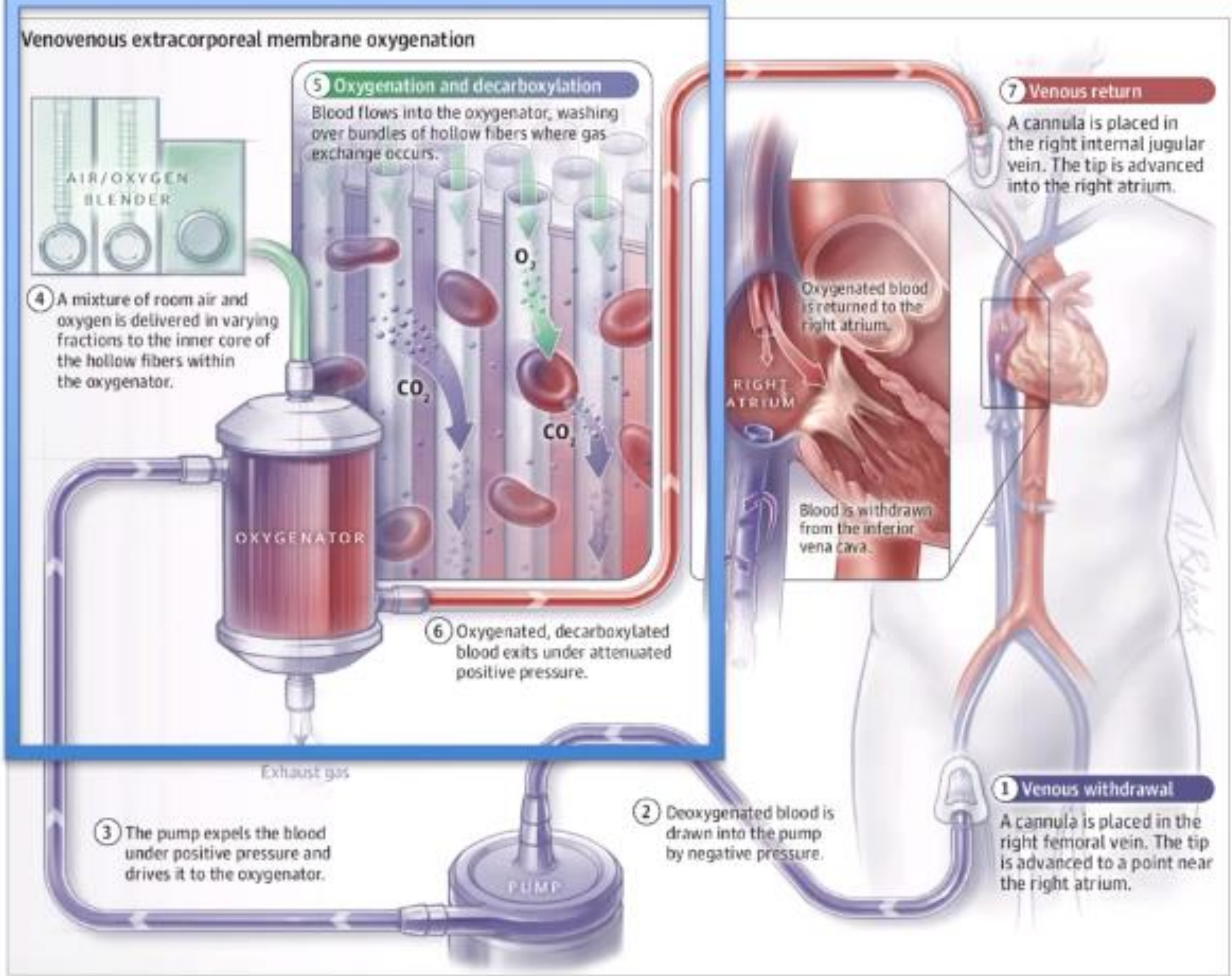
- Measurement of blood flow

- Position
  - Incorporated into the machine
  - External device

Oxygenators



- Hollow fiber membrane
- Gas exchange by diffusion
- Material
  - Polymethylpentene (PMP)
  - Polypropylene

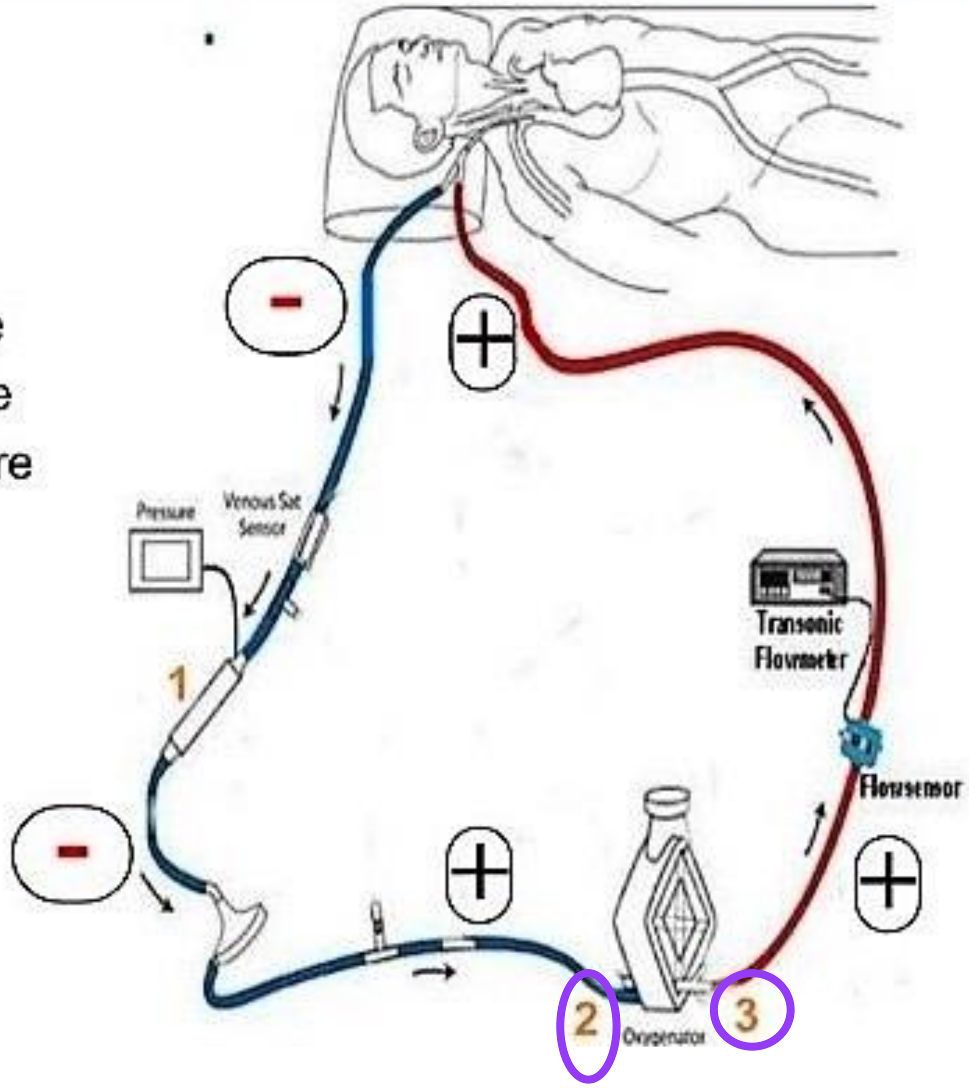

Venovenous extracorporeal membrane oxygenation
AIR/OXYGEN BLENDER
4 A mixture of room air and oxygen is delivered in varying fractions to the inner core of the hollow fibers within the oxygenator.
5 Oxygenation and decarboxylation
Blood flows into the oxygenator, washing over bundles of hollow fibers where gas exchange occurs.
O_2
CO_2
CO_2
OXYGENATOR
Exhaust gas
6 Oxygenated, decarboxylated blood exits under attenuated positive pressure.
3 The pump expels the blood under positive pressure and drives it to the oxygenator.
PUMP
2 Deoxygenated blood is drawn into the pump by negative pressure.
7 Venous return
A cannula is placed in the right internal jugular vein. The tip is advanced into the right atrium.
Oxygenated blood is returned to the right atrium.
RIGHT ATRIUM
Blood is withdrawn from the inferior vena cava.
1 Venous withdrawal
A cannula is placed in the right femoral vein. The tip is advanced to a point near the right atrium.

Oxygenator Models

Circuit Pressure Monitors

LEGEND

1 Venous Access Pressure
2 Pre-Oxygenator Pressure
3 Post-Oxygenator Pressure
+ Gravity drainage
- Suction applied



Pre-Oxygenator Pressure

- Reflects resistance due to any component downstream of the sensor
  - Oxygenator
  - Return tubing & cannula
  - Patient

- Used to calculate delta membrane pressure

- High pressure alarm, assess:
  - Oxygenator clot
  - Return tubing & cannula for position, kink, or clot

Post-Oxygenator Pressure

- Reflects resistance due to any component downstream of the oxygenator
  - Return tubing & cannula
  - Patient

- High pressure alarm, assess:
  - Return tubing & cannula for position, kink, or clot
  - Hypertension in patient (VA ECMO)

Delta Membrane Pressure

- ΔP = pre-oxygenator pressure – post-oxygenator pressure
- Reflects resistance of oxygenator
- Varies with blood flow
- Rising trend in ΔP indicates clotting in oxygenator

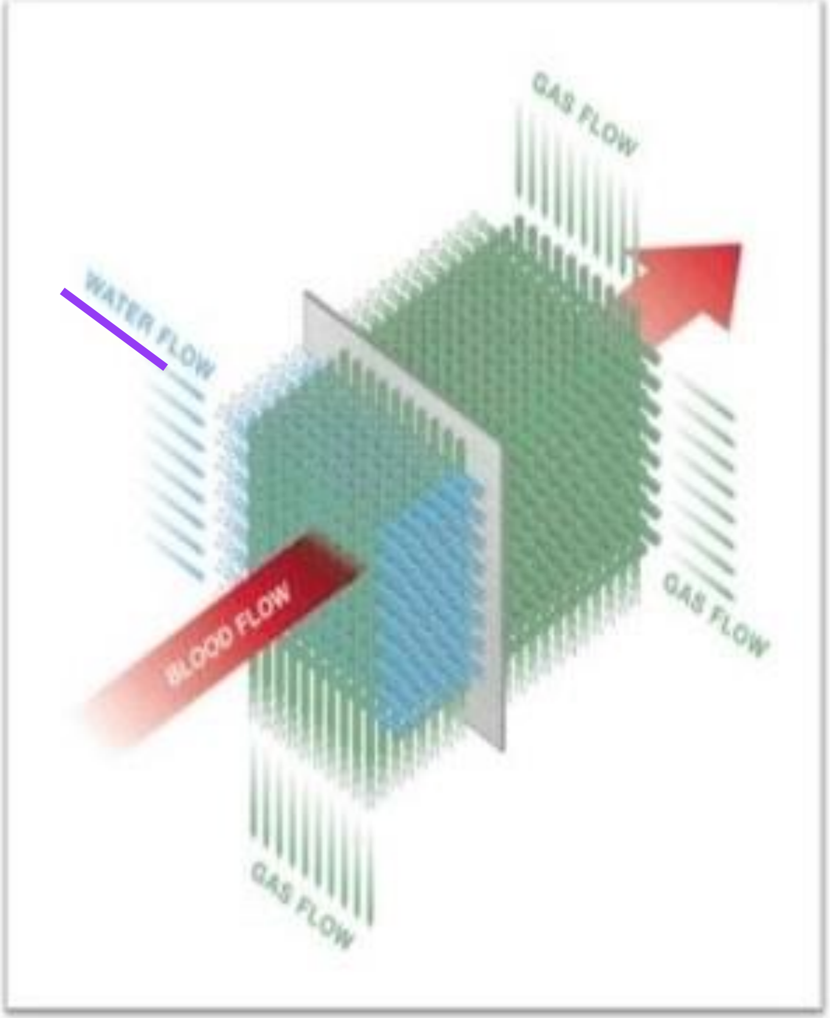
Heat Exchangers

- External sources of heat loss for patients
  - Ambient air
  - Sweep gas flow
  - Blood in tubing
  - Transfusion

Heat Exchangers

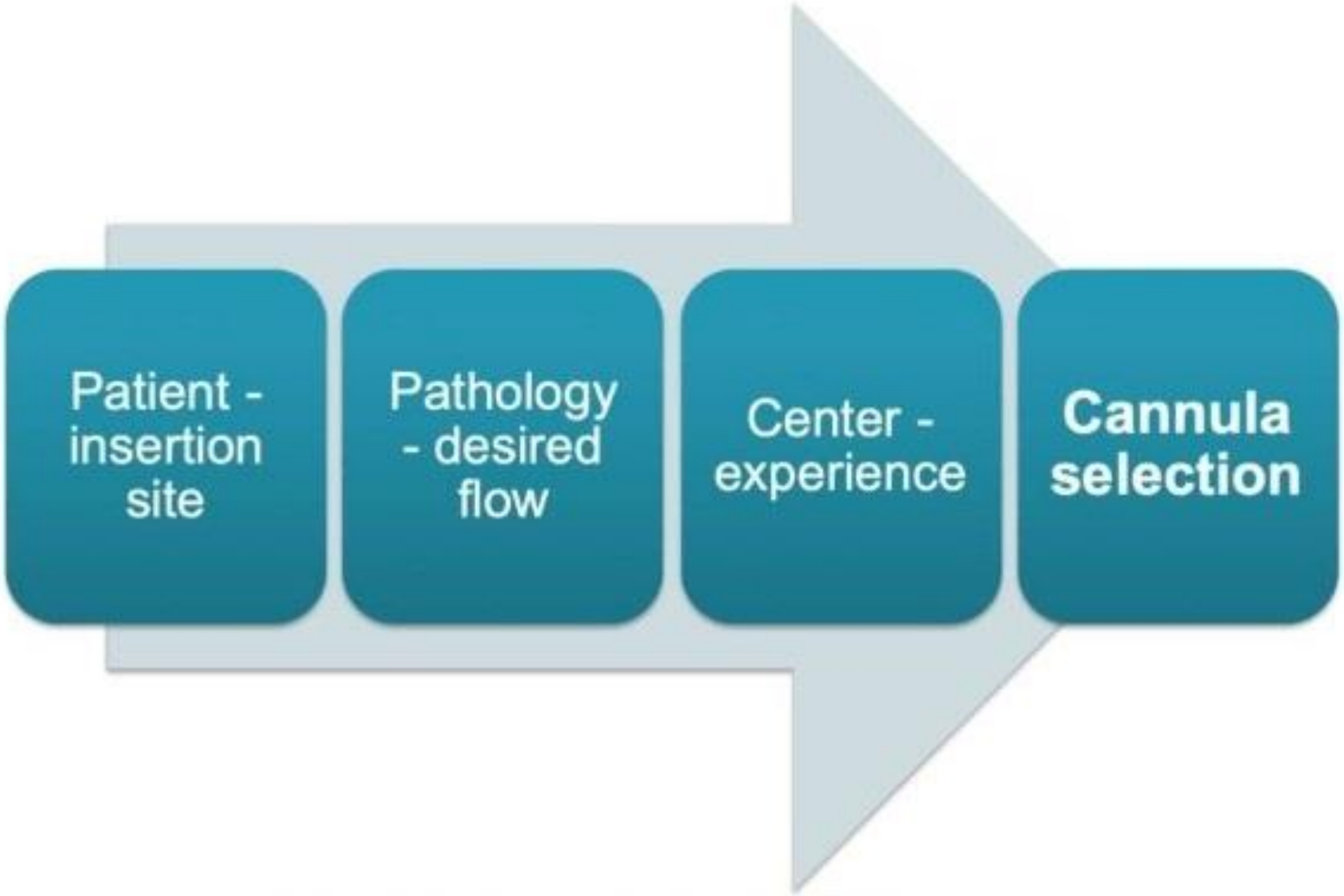
- Warmed by external water bath
  - Bath temp set 36-38.5°C
- Can be utilized for cooling
  - Decrease VO_2
  - Neuroprotection
  - Fever control

Heat Exchangers

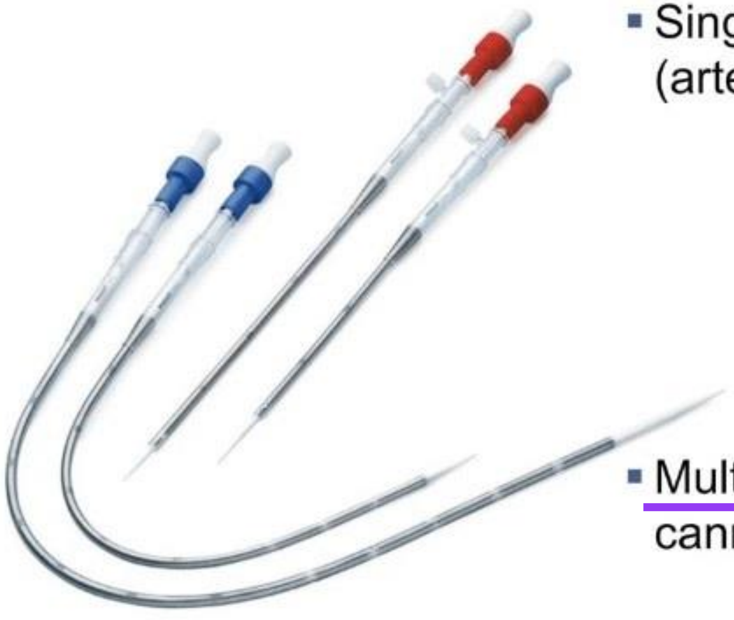


- Integrated as a component into hollow fiber membrane

Cannula Selection



Cannula Selection



- Single-stage (arterial) cannulae
- Multi-stage (venous) cannulae

Cannula Selection

- Wire reinforced

- Dual lumen

Tubing

- Tubing Material
  - Polyvinyl chloride (PVC)
  - Biocompatible surface coatings

- Tubing Size
  - Neonates – 1/4 inch
  - Pediatrics – 3/8 inch
  - Adults – 3/8 inch

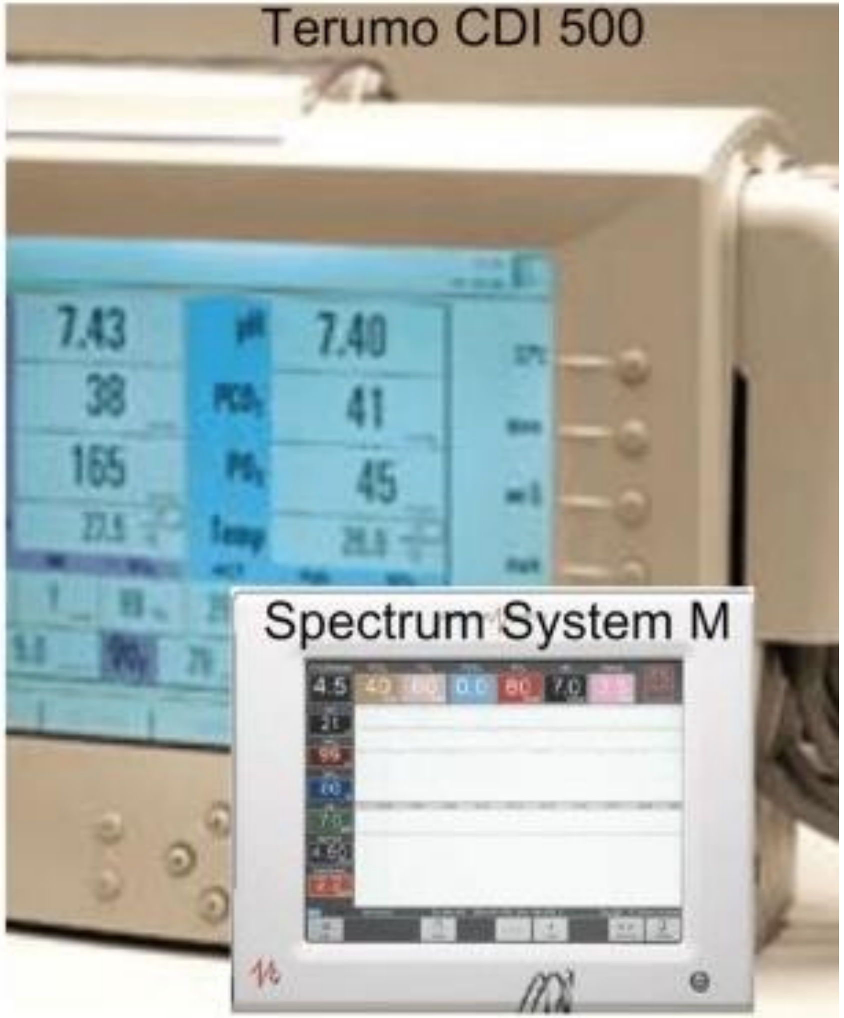
Gas Blenders and Flowmeters

- Gas Blender
  - Air/O_2 mixed to deliver different FiO_2
  - Inlet 30-70 PSI

- Dual Flowmeter
  - "Sweep" gas flow
  - 0-10 L/min

Blood Monitoring Systems

- Continuous in-line blood gas & venous sat monitoring
- Aids in early recognition of patient or ECMO problems



Summary

- Pump types
  - Roller: preload dependent, flow driven by RPMs
  - Centrifugal: preload and afterload dependent, most commonly used
- Oxygenator
  - Made of PMP in hollow fiber architecture
  - Gas exchange by diffusion

Summary

- Pressure monitor
  - Aid in identifying impending complications
- Cannula
  - Drainage cannula: multi-stage
  - Return cannula: single-stage
  - Single or double lumen
- Gas blender and oxygen supply

ECMO Indications

- ELSO Guidelines:
  - Acute severe cardiac failure or respiratory failure
  - High predicted risk of mortality
  - Non-responsive to optimal conventional therapy
  - Reversible or as a bridge to device / transplant

- ECMO is considered at 50% predicted mortality risk and indicated at 80% risk

Indications for VV ECMO

- Hypoxemic respiratory failure
  - 50% mortality risk is associated with a $P_aO_2/F_iO_2 < 150$ on $F_iO_2 > 0.9$ and/or Murray Lung Injury Score 2-3
  - 80% mortality risk is associated with a $P_aO_2/F_iO_2 < 100$ on $F_iO_2 > 0.9$ and/or Murray Lung Injury Score 3-4
- Hypercapneic respiratory failure
  - pH < 7.20 despite best-practice ventilatory strategies

(for > 6h)

- Bridge to recovery or transplant

VV ECMO Diagnostic Examples

Pathologic conditions that may require VV ECLS:

- ARDS
- Severe air leak syndrome
- Pulmonary contusion
- Inhalation injuries (Gastric contents, near drowning , smokes)
- Status asthmaticus, airway obstruction
- Acute graft failure following lung transplant
- Alveolar proteinosis

Absolute contraindications in ARDS
Moribund state with established multiple organ failure
Prolonged cardiac arrest
Severe anoxic brain injury
Massive intracranial hemorrhage
Severe chronic respiratory failure with no possibility of lung transplantation
Metastatic malignancy or hematological disease with poor short-term prognosis
Other advanced comorbidities with poor short-term prognosis

Relative contraindications in ARDS
Invasive mechanical ventilation for more than 7–10 days
Contraindication to anticoagulation
Severe coagulopathy
Advanceed age
Salvage ECMO (referred to as "rescue" in EOLIA), i.e., employing ECMO when severe right heart failure, or other severe decompensation occurs

Evidence for VV ECMO

- 2 RCTs and some case control studies
- Mostly in the context of ARDS

November 16, 1979

Extracorporeal Membrane Oxygenation in Severe Acute Respiratory Failure

A Randomized Prospective Study

Warren M. Zapol, MD; Michael T. Snider, MD, PhD; J. Donald Hill, MD; et al

Author Affiliations

JAMA. 1979;242(20):2193-2196. doi:10.1001/jama.1979.03300200023016

- Mortality for all patients with ARDS was 66%, and the mortality for severe ARDS was 90%, with or without ECLS
- ECLS attempted by inexperienced teams, in VA mode for 1 week without protecting the lung from ventilator injury, did not improve the ultimate survival in severe ARDS
- we developed a name for the technology
- **Clinical research on ECLS in adults essentially stopped for a decade**

Extracorporeal circulation in neonatal respiratory failure: A prospective randomized study

R. H. Bartlett, D. W. Roloff, R. G. Cornell, A. F. Andrews, P. W. Dillon, J. B. Zwischenberger

Department of Surgery, Penn State College of Medicine

- 12 infants with birth weight greater than 2 kg
- 11 patients were randomly chosen for ECMO, All survived

Clinical Trial > Pediatrics 1989 Dec;84(6):957-63.

Extracorporeal membrane oxygenation and conventional medical therapy in neonates with persistent pulmonary hypertension of the newborn: a prospective randomized study

P P O'Rourke [1], R K Crone, J P Vacanti, J H Ware, C W Lillehei, R B Parad, M F Epstein

- **39 Newborn infants** with severe persistent PHT and RF who met criteria for 85% likelihood of dying
- Overall survival of ECMO-treated infants was **97%** (28 of 29) compared with 60% (6 of 10) in the CMT group

ECMO became standard treatment for severe neonatal respiratory failure by 1986, and **standard treatment for severe cardiac failure in children by 1990.**

Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial

Giles J Peek, MD • Prof Miranda Mugford, DPhil • Ravindranath Tiruvoipati, FRCSEd • Prof Andrew Wilson, MD
Elizabeth Allen, PhD • Mariamma M Thalanany, MSc • et al. Show all authors

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- **180 adults (from 766) in a 1:1 ratio to receive continued conventional management or referral to consideration for treatment by ECMO**

- **Exclusion criteria were:** high pressure (>30 cm H_2O of peak inspiratory pressure) or high FiO_2 (>0·8) ventilation for more than 7 days

- **63% of ECMO treated survived to 6 months** without disability compared with 47% of Control group

- **Recommendation:**
  - **Transferring of adult patients with severe but potentially reversible respiratory failure [Murray score exceeds 3·0 or who have a pH of less than 7·20] on optimum conventional management to ECMO center**

Murray Lung Injury Score

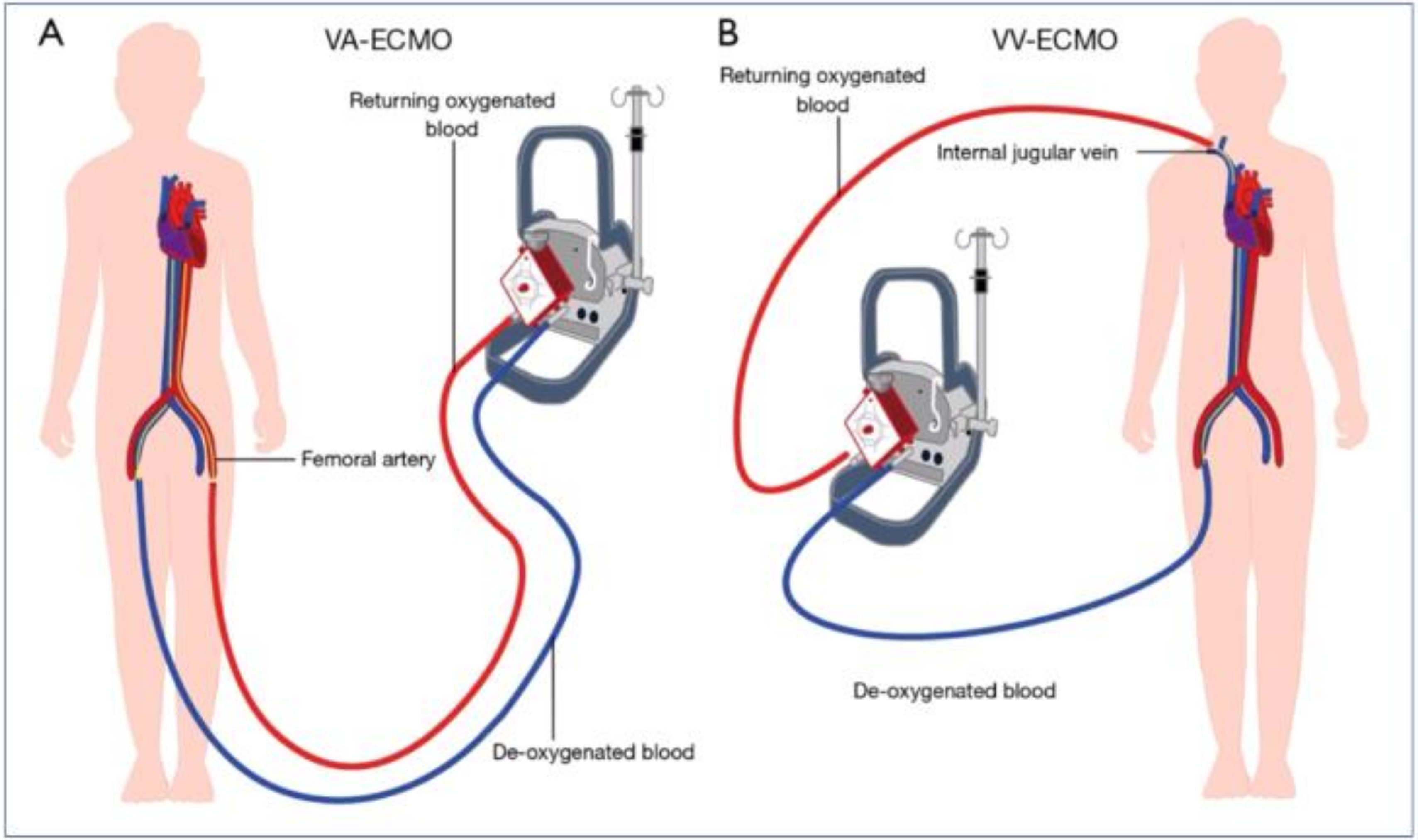
Score	P_aO_2/F_iO_2	Infiltrates on chest radiograph	PEEP (cmH_2O)	Compliance (mL / cmH_2O)
0	≥300	No	≤5	≥80
1	225-299	1 quadrant	6-8	60-79
2	175-224	2 quadrants	9-11	40-59
3	100-174	3 quadrants	12-14	20-39
4	<100	4 quadrants	≥15	<20

Murray score = sum of individual scores / 4

- For patients with a 50% risk of death (ie, PaO2/FIO2 <150 on FIO2 >90% and/or Murray score of 2–3), ECMO should be considered.
- When the anticipated risk of death approaches 80% (PaO2/FIO2 <100 on FIO2 >90% and/ or Murray score 3–4 despite optimal care for ≥6 hours), VV ECMO is indicated


MAQUET
GETINGE
CARDIOHELP

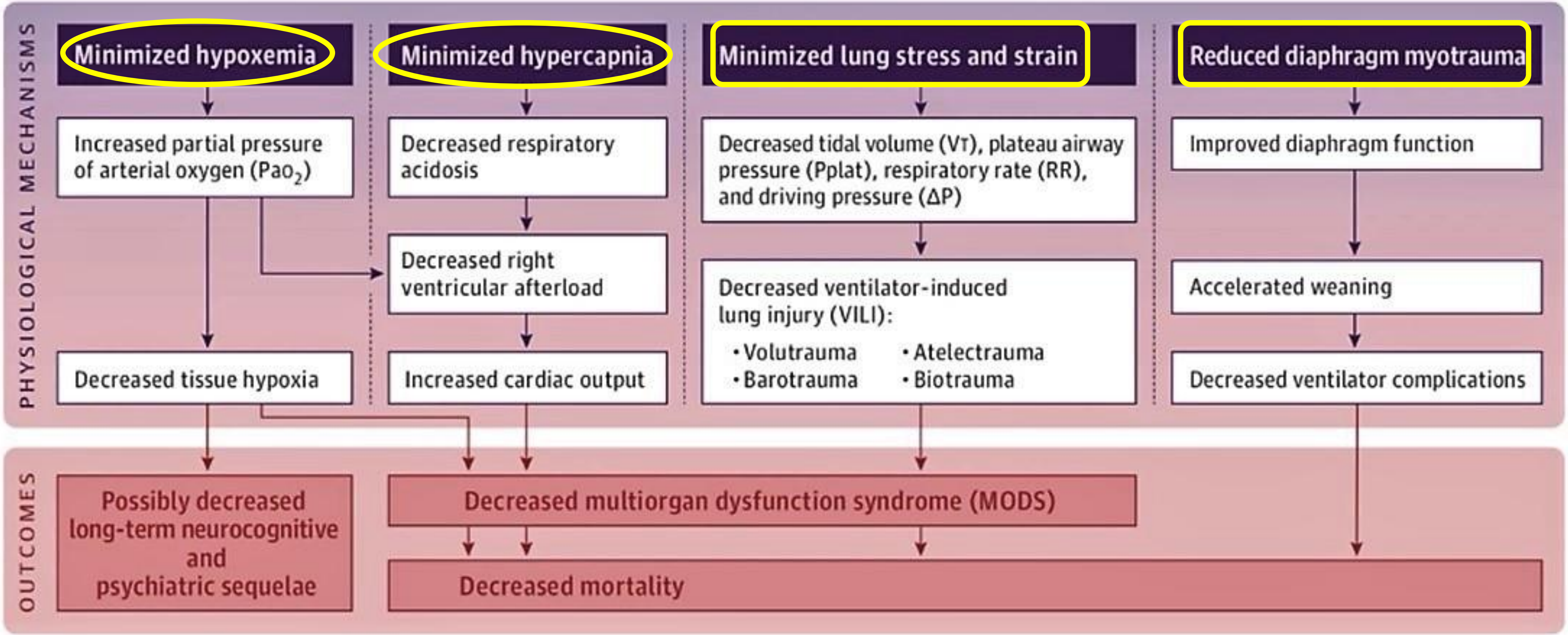

Cardiohelp
Emergency Drive Holder
Battery pack for at least 90 min
Display: user-friendly
touchscreen
Alarm output, e.g., ward call
Main power supply: together
with the DC device socket, the
Cardiohelp device can be used
with common voltages and
currents worldwide.
Equipotential bonding
connection
Adjustment of
flow and speed
The protective frame
protects the Cardiohelp
Device against crushing
USB port type A and
USB port type B
Emergency button
DC device socket
MAQUET
GETINGE
CARDIOHELP



Parallel Circulation
ECMO BF diverted from Pulmonary Circulation
Oxygenated Blood to Arterial Side

In Series Circulation
All BF goes to Pulmonary Circulation
Oxygenated Blood through Lungs

Potential Physiologic Mechanisms of Benefit of Extracorporeal Life Support (ECLS) for Respiratory Failure



MEDICAL OR MECHANICAL COMPLICATIONS

Neurologic
- All CNS hemorrhage (3.4%)
- CNS infarction (1.8%)
- Brain death (1.3%)
- Seizures (1.2%)

Pulmonary
- Pneumothorax (5.8%)
- Pulmonary hemorrhage (3.9%)

Cardiac
- Cardiac arrhythmia (7.9%)
- CPR required (4.1%)
- Tamponade (1.0%)

Renal
- Increased creatinine (20.6%)
- Renal replacement therapy (3.0%)

Infections
- Culture-proven infection (11.1%)
- Cannula insertion site infection
- Bloodstream infection

Hematologic
- Hemolysis (4.8%)
- Disseminated intravascular coagulation (2.0%)
- Fibrin or coagulation factor consumption
- Acquired Von Willebrand disease
- Thrombocytopenia
- Heparin-induced thrombocytopenia
- Epistaxis
- Venous thromboembolism

Anticoagulation therapy

Bleeding
- Cannula site bleeding (7.8%)
- Surgical site bleeding (6.8%)
- Gastrointestinal bleeding (5.5%)
- Pulmonary hemorrhage (3.9%)
- Retroperitoneal hematoma

DEVICE COMPLICATIONS

Circuit-related
- Circuit component clots (13.1%)
- Oxygenator failure (5.9%)
- Circuit change (2.4%)
- Clots in hemofilter (1.3%)
- Air in circuit (1.2%)
- Pump failure (1.0%)
- Altered pharmacokinetics
- Air embolism
- Hypothermia

Cannula-related
- Cannula site bleeding (7.8%)
- Cannula problems (4.8%)
- Limb ischemia (1.7%)
- Compartment syndrome, fasciotomy, or amputation (1.4%)
- Cannula-associated thrombosis
- Cardiac or vascular perforation
- Cannula insertion site infection

Daily monitoring of Patients under ECMO

- To avoid a drop in $PaCO_2 > 20$ mm Hg/h over the first 24-h of ECMO in most patients

- Platelet count, fibrinogen, anticoagulation levels

Awake or walking ECMO
use of ECMO without mechanical ventilation

نکات کلیدی

۱–اکمو به عنوان درمانی برای نارسایی حاد قلبی–ریوی پیشرفته به کار می رود.

۲–اکمو VA باید برای نارسایی حاد قلبی یا نارسایی توام قلبی و تنفسی مد نظر باشد.

۳–اکمو VV برای مبتلایان به ARDS شدید مقاوم به درمان با عملکرد قلبی کافی اندیکاسیون دارد (Murray score 3–4 for ≥ 6h despite optimal care) .

۴– خونریزی و ترومبوز دو عارضه مهم همراه اکمو هستند.

۵–اکمو می تواند در فارماکوکینتیک داروهای لیپوفیل و با اتصال زیاد به پروتیین ها تغییر ایجاد کند.

۶–اکمو در بیماران هوشیار (Walking ECMO) می تواند درمانی موقتی تا زمان پیوند باشد.