Pediatric extracorporeal life support systems and Pediatric cardiopulmonary perfusion systems: Now and future

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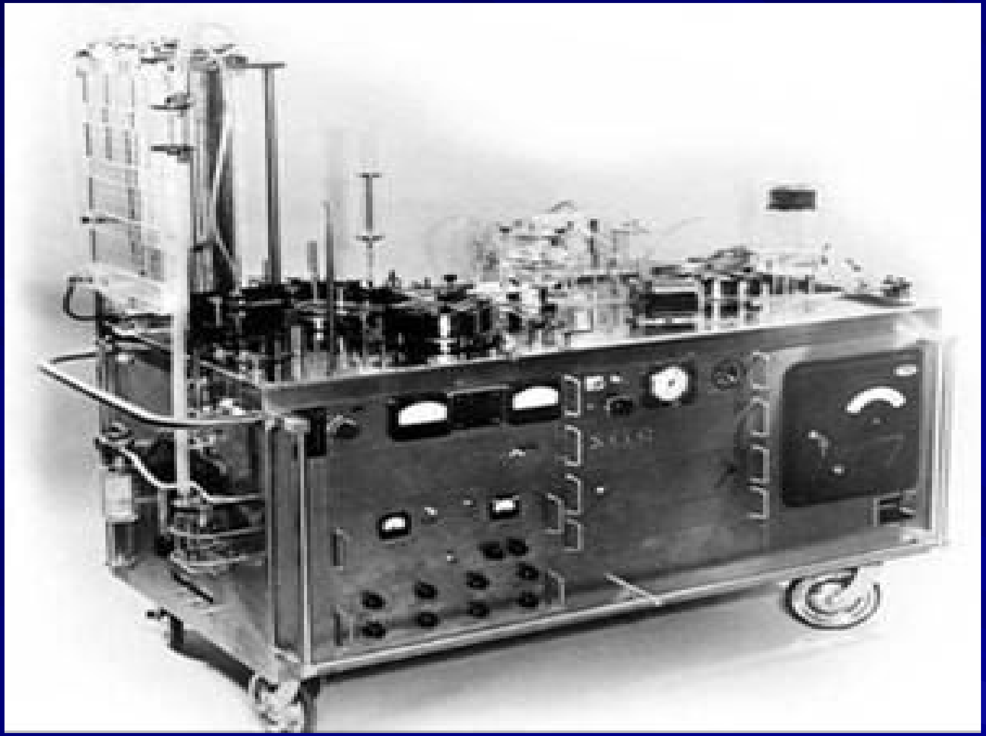
Background - History

CPB
ECMO-ECLS
VAD
TAH

The first heart-lung machine (HLM) which was made by Gibbon

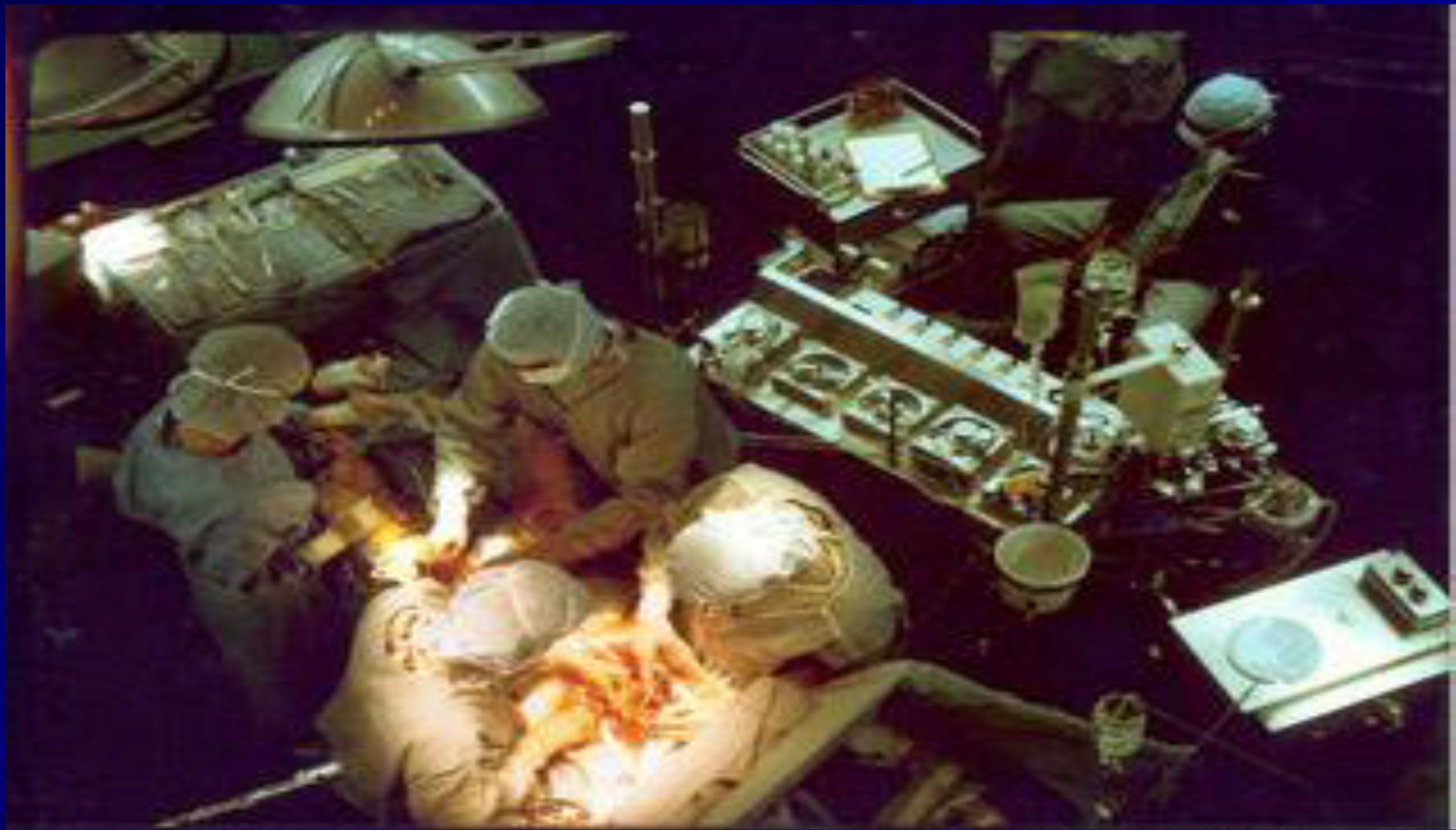


CPB
ECMO-ECLS
VAD
TAH

The new HLM machines

One of the first machines and surgical team

Now



Differances between pediatric and adult Cardiopulmonary Perfusion

- Pediatric organ sytems are not developed sufficiently as adults.
- The size of the organs are smaller than the adults
- The rate of metabolism is higher than adults ↔ higher perfusion rate is needed.
- The frequent need of intracardiac access
- Presence of abnormal anatomy and physiology

Differances between pediatric and adult cardiopulmonary bypass (CPB) procedures

- Extreme hypothermia, hemodilution and perfusion flow rate values
- Pathological anatomy →operation technical changes
- CPB circuit extremely large compared to body mass index
- The prime volume is more than the total blood of newborns and infants.
- Large body mass index differences observed in the cases→selection of appropriate materials required in each case.

Pediatric CPB Complications ↑↑↑↑↑

- We must lower the prime volume ↓
- We must lower the surface area which the blood contacts. ↓
- We must reduce the size of the circuit components ↓

Prime Volume

- Adults → 25-30 % Of the total blood volume
- Neonates → 2-3 times Of the total blood volume
- To prevent excessive hemodilution → Donor blood can be add to prime volume

Sanguineous prime volume

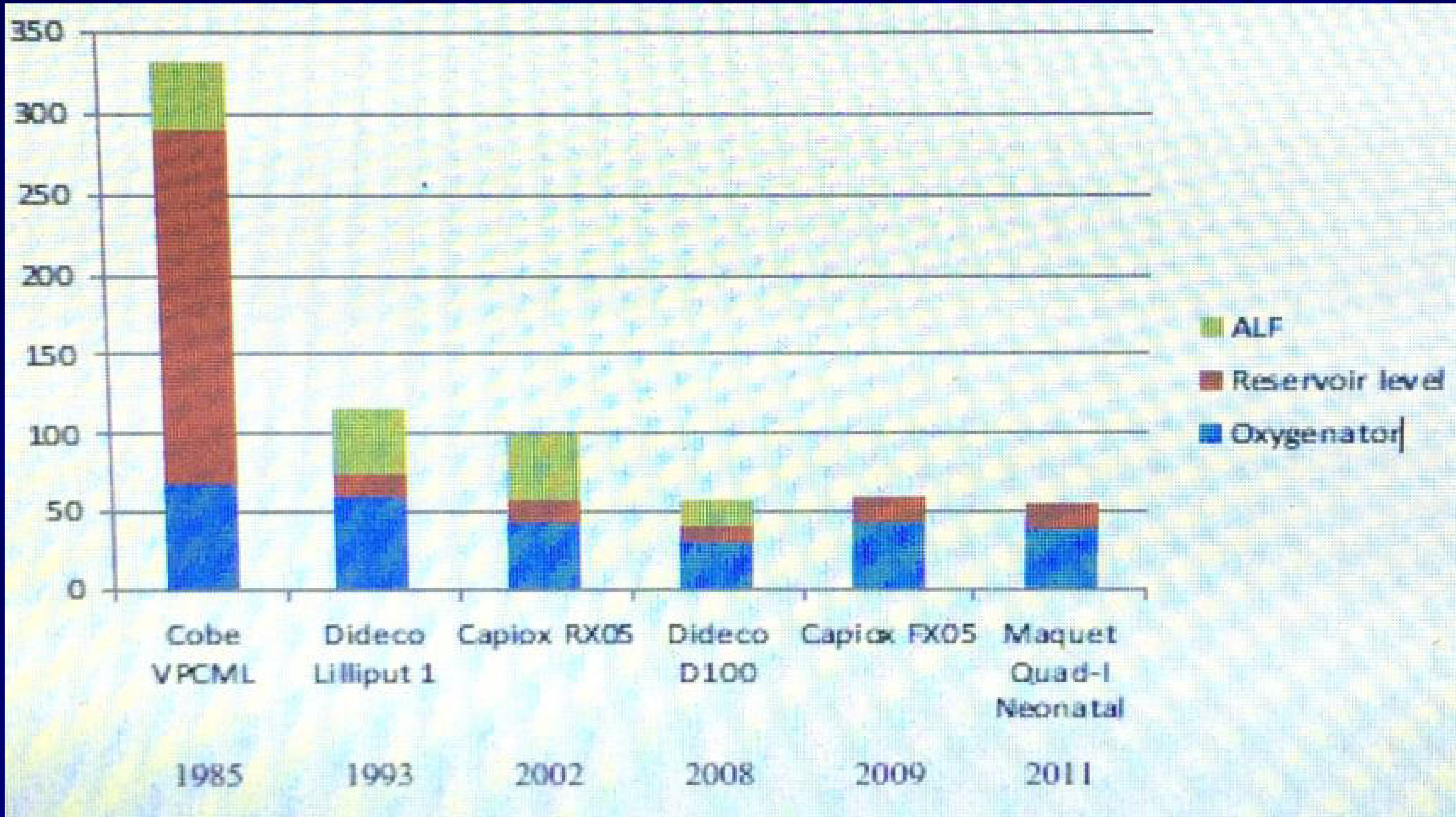
- Blood-borne infections
- Reinforcement of inflammatory reaction
- Transfusion-induced acute lung injury
- Pulmonary hypertension
- The organ perfusion disorders due to rheological properties
- Low cardiac index

Our Target :

- Lower prime oxygenator volume
- Reducing the size of the venous line
- Reducing the size of the circuit
- Arterial line filter
- Venous Reservoir Level

↓↓↓↓

The circuit prime volume reduction
and **non *sanguineous prime* volume**

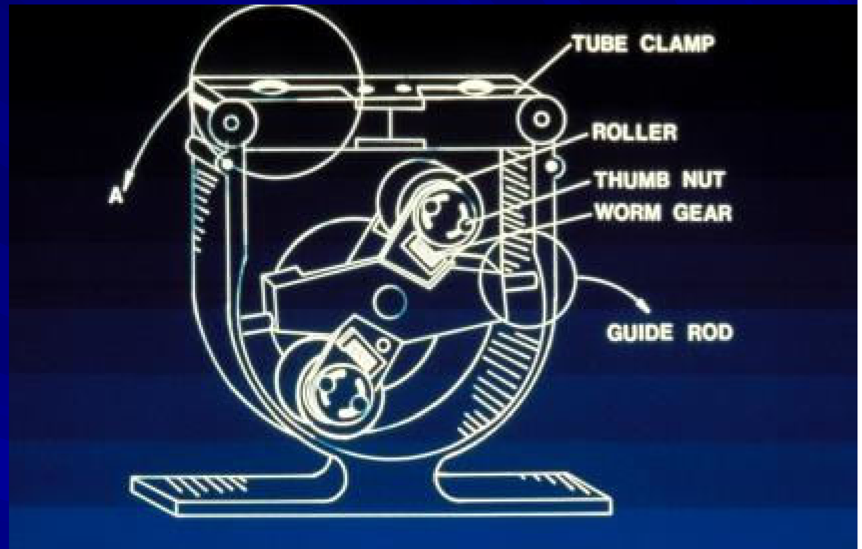


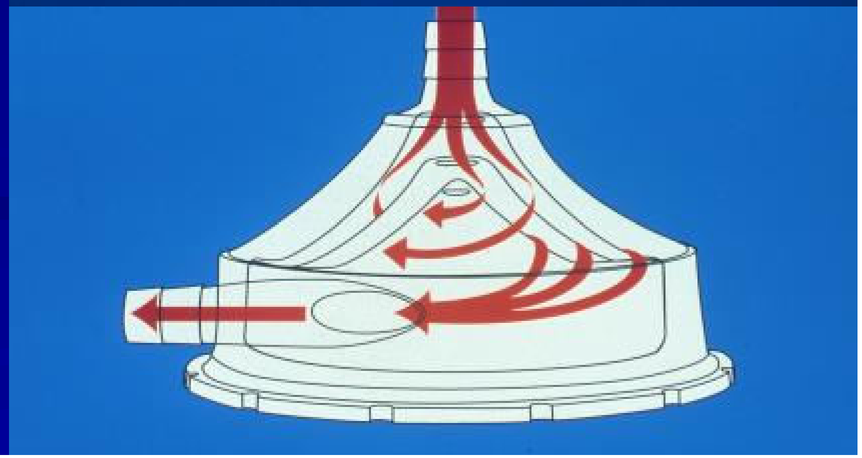
ALF:Arterial line filter

McRobb CM, Mejak BL, Ellis WC, Lawson DS, Twite MD. Recent Advances in Pediatric Cardiopulmonary Bypass. Semin Cardiothorac Vasc Anesth . 2014;18(2):153–60.

Pediatric CPB pumps

- Roller Pumps
- Centrifugal Pumps





Roller Pumps

- +++ With small diametered lines, the prime volume is low
- +++ Sensitive flow control even at low flow rates
- --- Hemolysis or damage to the other formed elements of the blood
- --- Roller pump induced tubing tear of polyvinylchloride and silicone rubber tubing
- --- Inability to provide appropriate position → The new generation heart lung machine can be given the required position.

Centrifugal Pumps

- +++ More mobile
- +++ Less hemolysis or damage to the other formed elements of the blood
- +++ Reducing the flow line to prevent the high pressure in arterial line obstructions
- --- High prime volume
- --- Insufficient sensitivity at low flow rates

New generation centrifugal pumps

	Prime volume (ml)	**Max Flow (L/min)**	Connector
Medos Deltastream DP3	**16**	8	3/8”
Medos s.pump	**17**	8	3/8”
Levitronix CentriMag	31	10	3/8”
Maquet ROTAFLOW	32	10	3/8”
Medtronic Affinity CP	40	10	3/8”
Terumo CAPIOX SP	45	8	3/8”
Medtronic BP-50 Bio-Pump	48	**1.5**	**1/4”**
Sarns disposable centrifugal pump	48	10	3/8”
Sorin RevOlution	52	8	3/8”

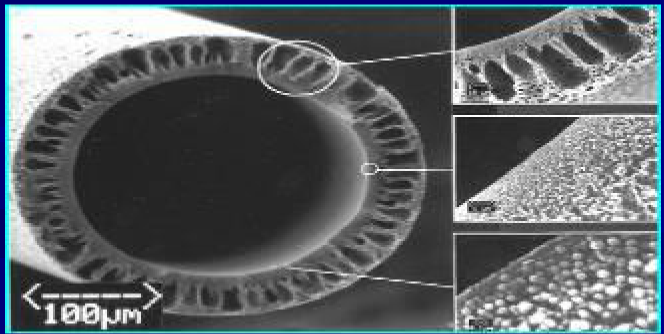
Pediatric Oxygenators

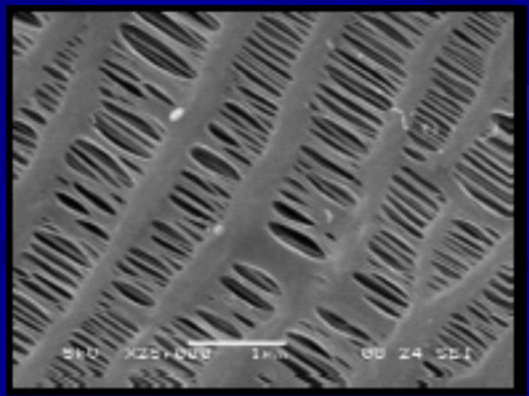
Structure → Holow fiber

Gas exchange surface → porous polypropylene

Gases transmit from the pores → through blood

Erythrocytes and plasma does not transmit !!





Pediatric Oxygenators

Wide temperature range (10 °C - 40 °C)
Wide flow range (0 - 200 ml / kg / min)
Htc wide range (15% - 40%)
Wide range of line pressure

Wide gas flow range

↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓

Despite its small surface area, effective gas exchange, even at high flow.

Pediatric Oxygenators	Priming volume (ml)	Surface area (m2)	Max Flow (L/min)
Sorin D100 Kids	**31**	0.22	0.7
Maquet QUADROX-i Neonatal	38	0.38	1.5
Terumo CAPIOX BabyRx	43	0.50	1.5
Medtronic Affinity Pixie	48	0.67	2
Medos Hilite 1000	57	0.39	1
Sorin Lilliput I	60	0.34	0.8
Maquet QUADROX-i Pediatric	81	0.80	2.8
Sorin D101 Kids	87	0.61	2.5
Medos Hilite 2800	98	0.80	2.8
MedtronicMinimax Plus	**149**	0.80	2.3

Pediatric Tubing Sets

- Tubing sets → 75 % of the prime volume
- The most important step in reducing the tubing set volume →Reducing the length and diameter of the tubing set:

  ------Approximation of the pump to the patient → about 29% reduction in the volume of prime
- Tubing set diameter reduction → the resistance to flow increase → assisted venous drainage
- Shortening of the tubing set → decrease of the resistance

Pediatric Arterial Filters

- Disadvantages:

--------High prime volume

--------A large foreign surface

--------The difficulty of removing the air bubbles

Pediatric Arterial Filters	Priming volume (ml)	Max Flow (L/min)	Pore (µm)
Sorin D130 Kids ALF	**16**	**0.7**	40
Sorin D131 Kids ALF	28	2.5	40
Medtronic Affinity Pixie ALF	39	3.2	**30**
Terumo CAPIOX ALF AF02	40	2.5	**32**

Integrated products

- Only reducing the component size→ insufficient to reduce prime volume
- We need integrated component products → oxygenator + arterial filter

	Priming volume (ml)	Max Flow (L/min)	Pore (µm)
Maquet QUADROX-i Neonatal	**38**	1.5	33
Terumo CAPIOX FX05	43	1.5	32
Maquet QUADROX-i Pediatric	81	2.8	33
Terumo CAPIOX FX15	144	5.0	32

Integrated products

- No need for an extra prime volume for the arterial filters
- The captured gas bubbles are transferred to the oxygenator gas reservoir by the pressure difference.
- Particulate emboli capture efficiency is similar to standard filters

- Gas emboli capture efficiency is higher than standard filters

Pediatric cardioplegia

- Standard blood cardioplegia
- Del Nido cardioplegia
- Crystalloid cardioplegia

------St. Thomas solution

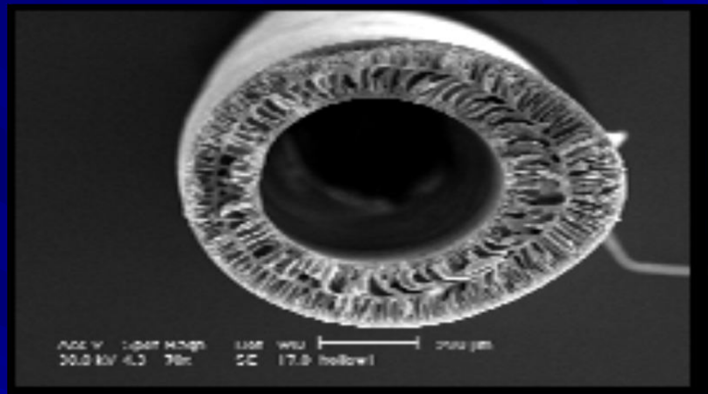
------Custodiol (Histidine-Tryptophan-Ketoglutarate)

- Microplegia

------Quest Biomedical MPS2 Myocardial Protection System (prime 7-35 mL)

Pediatric Ultrafiltration

It has a porous hollow fiber structuremade with polysulfone, molecules Weighting <50-65 kDa can pass .



Aim:

- Reduction of Edema
- Raising hematocrit values
- Removal of electrolyte (potassium)
- Removal of Inflammation mediators, lactate and citrate

Pediatric Ultrafiltration	Prime(ml)
Medivator Hemocor HPH Jr	**8**
Medivator Hemocor HPH Mini	14
Maquet BC20 Plus	17
Medos Hemofilter Pro 20	17
Sorin Dideco DHFO.2 Hemoconcentrator	30
Medivator Hemocor HPH 400	34
Terumo CAPIOX Hemoconcentrator	35
Medos Hemofilter Pro 60	52
Maquet BC60 Plus	65

ECMO-ECLS

(Extracorporeal Membrane Oxygenation - ExtraCorporeal Life Support)

The aim is to provide sufficient time and appropriate environment for the restoration of myocardial and lung damage.

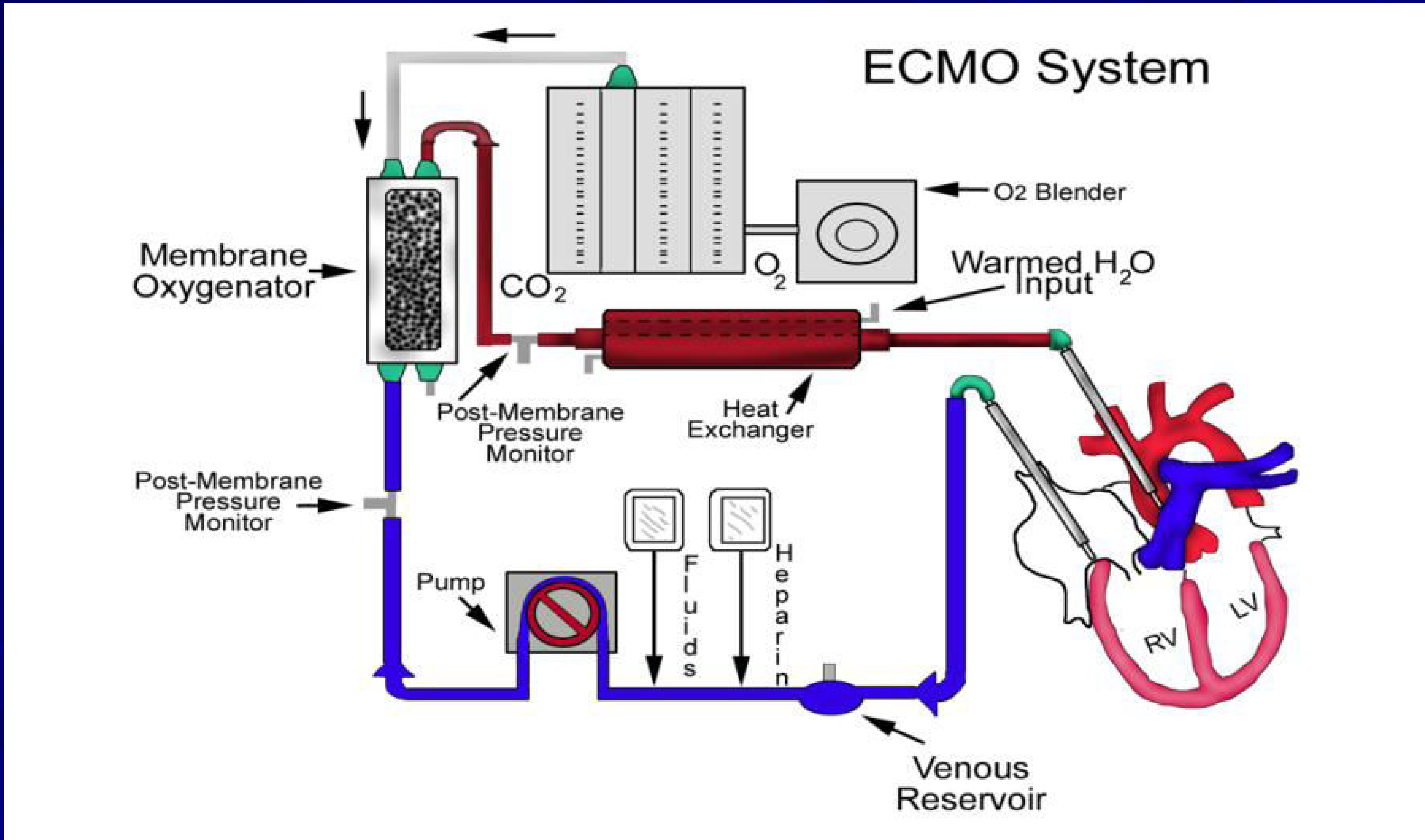
- ECLS

------ECMO

----ECCO2R (Extracorporeal carbon dioxide removal)

----VAD (*ventricular assist device*)

ECMO-ECLS


ECMO System
O2 Blender
Membrane
Oxygenator
CO_2
O_2
Warmed H_2O
Input
Post-Membrane
Pressure
Monitor
Heat
Exchanger
Post-Membrane
Pressure
Monitor
Pump
Fluids
Heparin
RV
LV
Venous
Reservoir

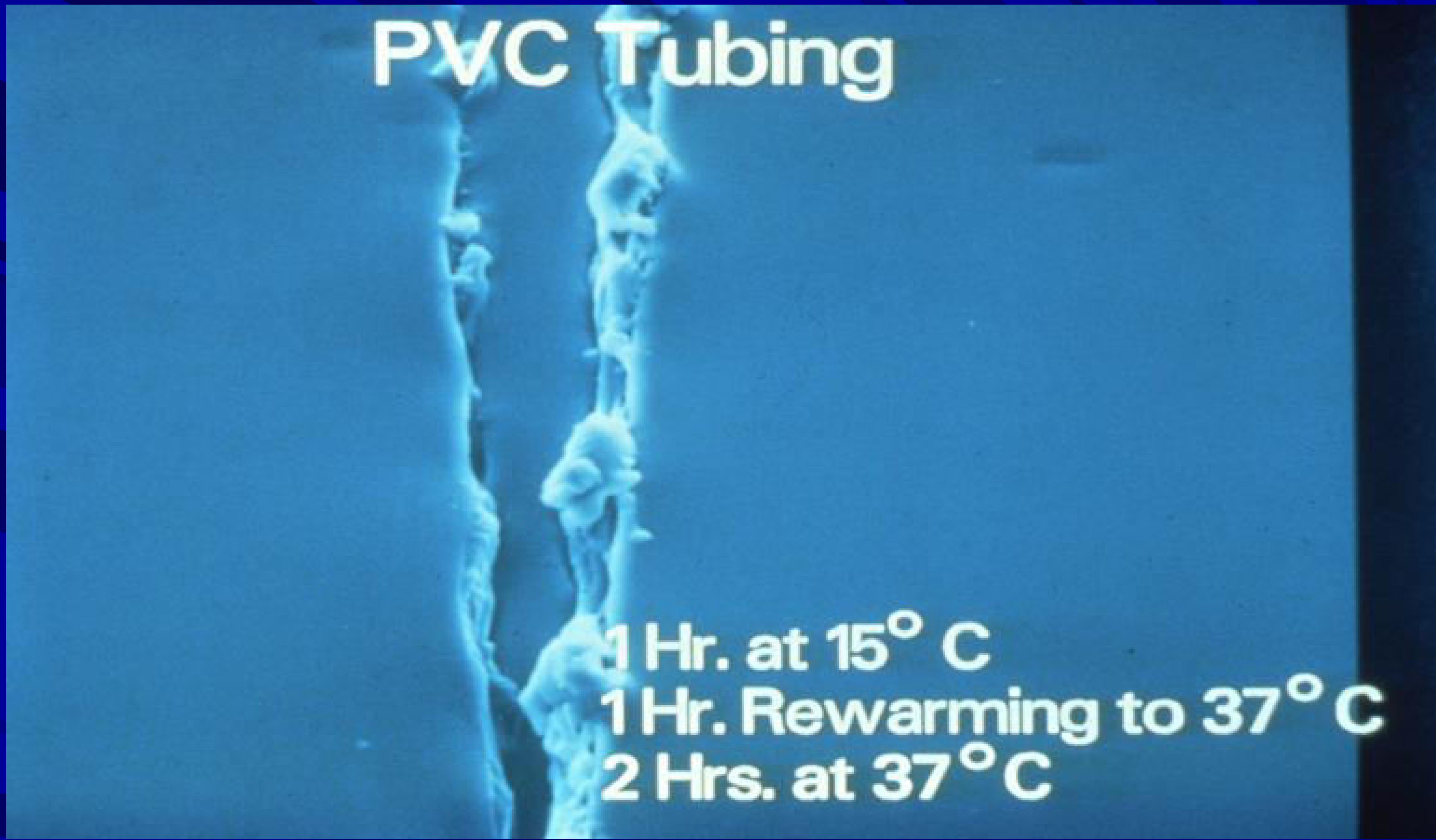
ECMO PUMPS

- Roller pumps are the most commonly used.
- ++++ Inexpensive
- ++++ Reliable
- ++++ Laminar flow
- ----- Hemolysis
- ----- Spallation and tube rupture

Spallation :

The sloughing off of plastic and silastic tubing particles into the lumens of tubing through the erosive and fatiguing action of rollers in the pump head.

Spallation and tube rupture



ECMO PUMPS

To prevent excessively high and low pressure formation → continuous measurement of arterial and venous pressure line

	Prime volume (mL)	Connector
Medtronic Bladder Reservoir R-14	35	**1/4”**
Medtronic Bladder Reservoir R-38	35	**3/8”**

ECMO PUMPS

- Centrifugal Pumps:
- ++++ Less traumatic to blood cells
- ------ Sensitive preload and afterload
- ------ Insufficient flow due to the high internal resistance of the silicon membrane oxygenators.
- ------ The risk of thrombosis in long-term use (5-7 days).

ECMO Oxygenators

- Porous polypropylene hollow fiber oxygenators→ In long-term use: wetting of the membrane structures, leakage of plasma, dysfunction.
- For long-term usage → non-porous silicon membrane oxygenators
- There are no holes in the silicon membrane. Gases diffuse through the blood from the silicon

ECMO Oxygenators

- Spiralcoiled structure → high resistance to blood flow → blood oxygenator transition speed slows down and increases gas transfer
- Internal heat exchanger available → also adding circuit heat exchanger unit → increase in the prime volume of the system

Silicone membrane oxygenators	Prime volume (mL)	**Surface area (m2)**	**Max Flow (L/min)**
Avecor/Medtronic 0800	100	0.8	1.2
Avecor/Medtronic 1500	175	1.5	1.8

ECMO Oxygenators

- Polymethylpentene porous hollow fiber oxygenator:

+++++Long-term use (up to 2 weeks) No largely plasma leakage

+++++ Internal heat exchanger →

No increase in prime volume

+++++ Centrifugal pump usage according to their low internal resistance

ECMO Oxygenators

Polymethylpentene oxygenator	Prime volume (mL)	**Surface area (m2)**	**Max Flow (L/min)**
Medos Hilite 800LT	**55**	0.32	0.8
Eurosets ECMO NEW BORN	90	0.69	1.5
Medos Hilite 2400LT	95	0.65	2.4
Sorin EOS ECMO	150	1.2	5
Maquet QUADROX-iD ECMO	250	1.8	7

ECMO Heat Exchangers

- Newborn ECMO → thermoregulation ability is underdeveloped

	Prime volume (mL)	**Max Flow (L/min)**
Gish Biomedical HE-3	20	2
Medtronic ECMOtherm II HE	50	2
Gish Biomedical HE-4	60	2

ECMO Tubing Sets

- **DEHP** in PVC tubes (di (2-ethylhexyl) phthalate) → infertility in long-term usage
- No abnormalities in clinical development for patients
- ECMO with the roller pump →PVC tube line in the pump head → spallation and tube rupture
- Tygon S-65 HL tubes are more resistant to spallation and tube rupture, they can be preferred.

Pediatric circulatory support

- Short-term (<30 days) assistance → ECMO, centrifugal pump or roller pump
- Long-term assistance → Ventricular assist devices (VAD):

Parakorporeal pneumatic pulsatile VAD

Newborns and infants→Berlin Heart, Medos HIA VAD

Adolescents→Thoratec VAD, Heartmate VAD

Axial flow devices→ MicroMed/DeBakey VAD

Good luck to all of our children, and Godspeed in now and future.

Thank You…

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