Considerations in Circuit Miniaturization

The AmSECT 40th International Conference

Pediatric Track

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Objectives

- Investigate the long held dogma is "smaller is better".
  - Motivations for miniaturization
- Discuss techniques to miniaturize the neonatal and pediatric CPB circuits.
- Explore "Second Generation" concepts of pediatric pump oxygenators
  - Safety considerations

The Problem - A matter of proportions

	Pt. Blood Volume	Circuit Prime Volume	% diff
75 kg Adult	4500 ml	1500 ml (7059 ml)	33%
3 kg Neonate	255 ml	400 ml (84.1 ml)	157%

Motivation for circuit miniaturization

- √ Avoidance of donor blood
  - risk of infection
  - immunological problems
  - metabolic problems
  - Availability and cost
  - Parental preference
- √ Avoidance of hemodilution
  - capillary leak/edema
  - clotting mechanisms disturbed
- √ Reduction of synthetic surface area

Martin Elliott
Perfusion: 1993;8:81-86

Motivation for circuit miniaturization

T Gourlay, Perfusion; 2001; 16:381-390, *Biomaterial development for Cardiopulmonary bypass*.

Blood-biomaterial interaction studies using a rodent recirculation model.

Does reducing the expanse of exposed biomaterial reduce the inflammatory response?

Reducing surface area of PVC tubing produced less CD11b Integrin expression on neutrophils.

Motivation for circuit miniaturization

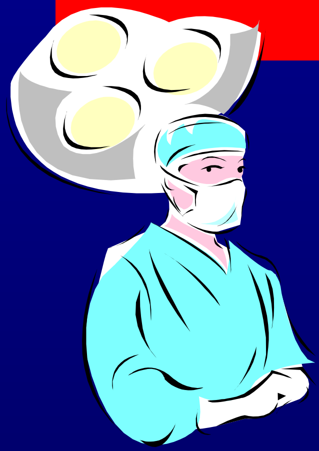
F De Somer et al, Perfusion 1996; 11: 455-460, *"Low extracorporeal priming volumes for infants: a benefit?*

80 infants (mean 4.6 ± 1.6 kg) studied with small circuit
Total prime volume = 205 ml
Mean RBCs used in prime = 93.5 ± 60 ml (25% asaunginious)
Mean post-op RBCs used = 202 ± 67 ml (3.7% no RBCs)

Mean FFP used in prime = 2 ± 19 ml (85% no FFP)
Mean post-op FFP used = 62 ± 72 ml (37% no FFP at all)

No MUF used

The Spectrum of Thought



Optimal Conditions

Blood use is inevitable. Circuitry should be reasonably small using available components and historical perfusion parameters & norms.

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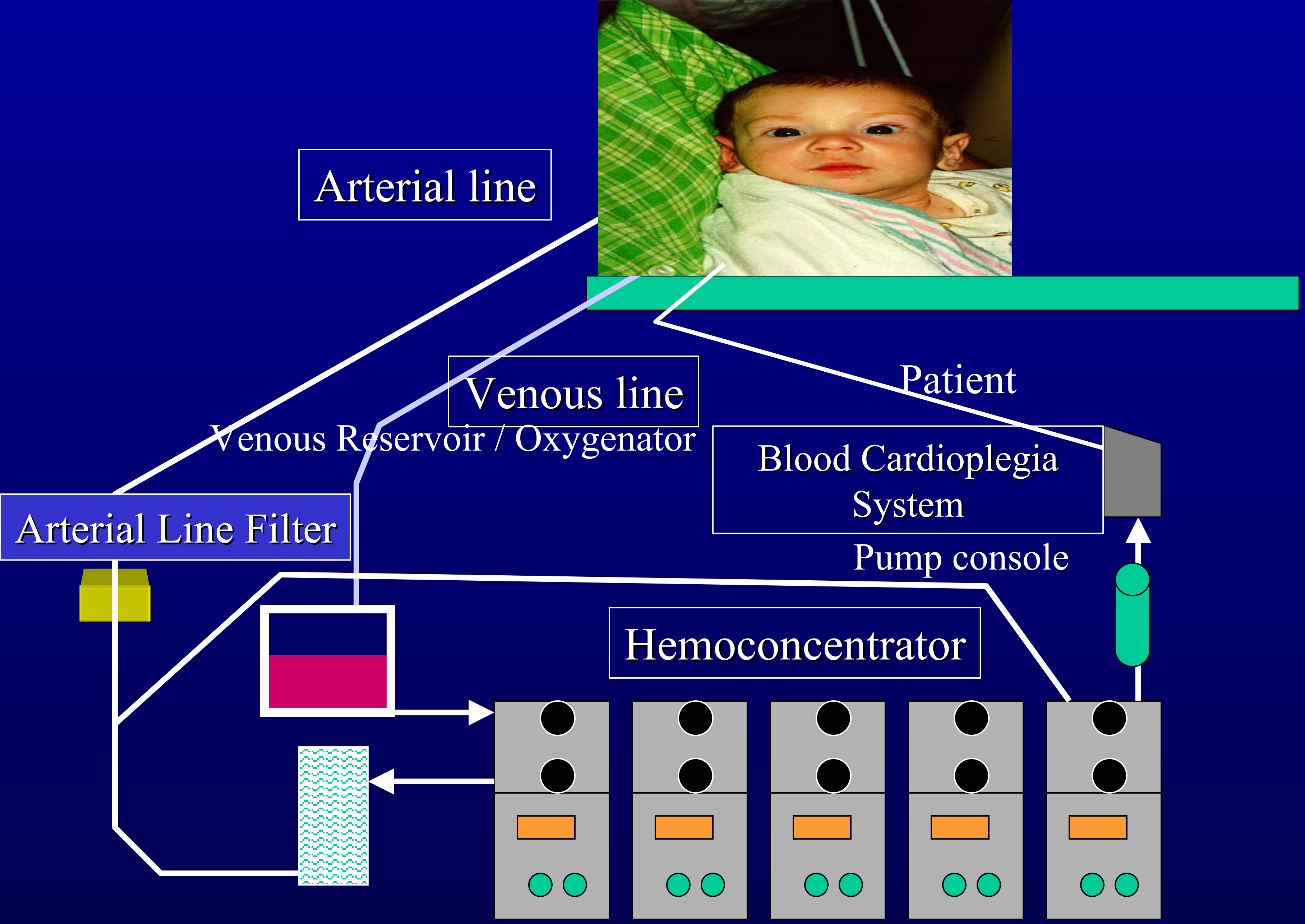
Smaller is better. Bloodless CPB in infants is possible, we should work toward this. Apply new concepts to attain miniaturization

Conventional approaches to miniaturization

"Priming Volume" - defined

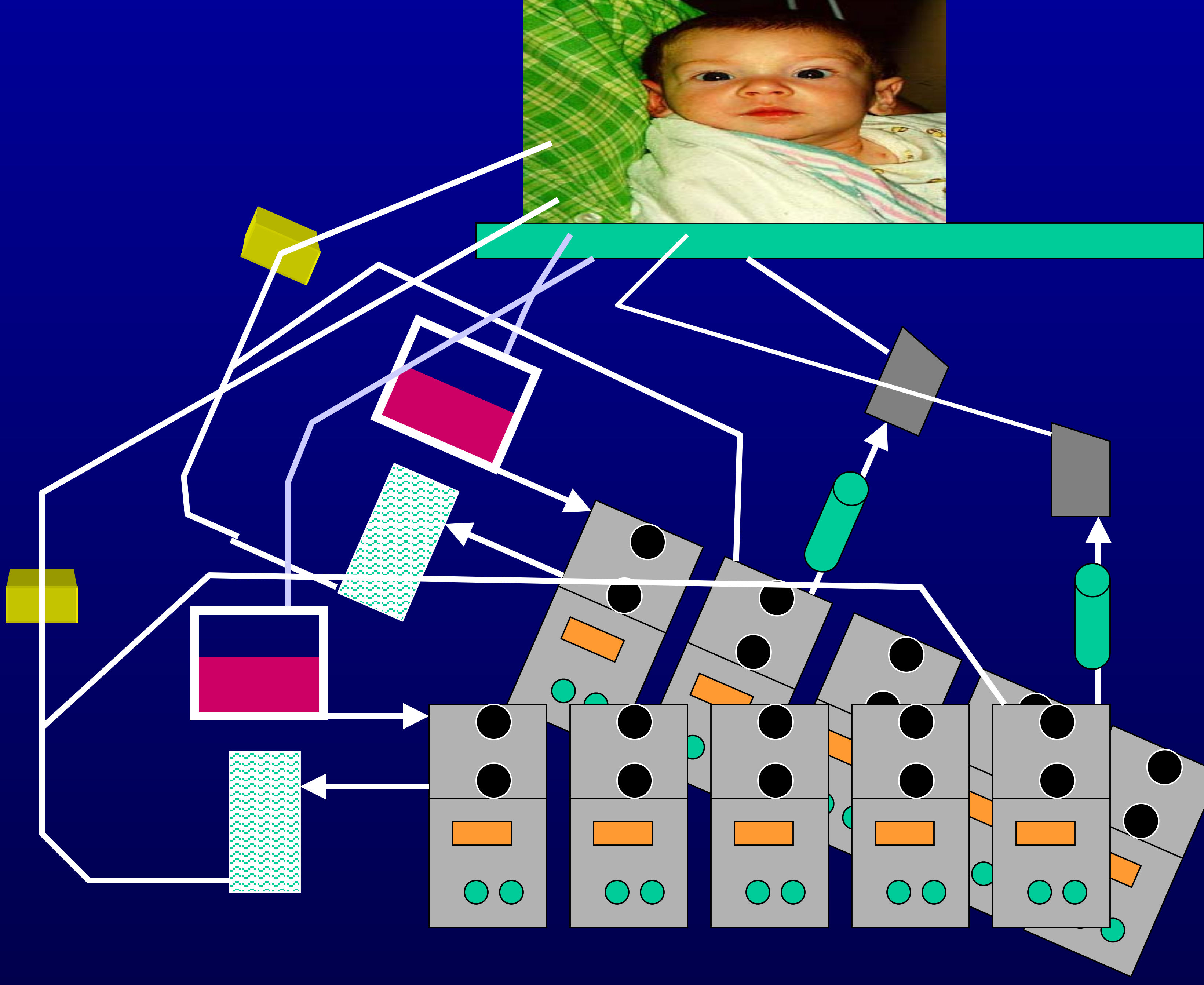

Arterial line
Venous line
Patient
Venous Reservoir / Oxygenator
Blood Cardioplegia System
Arterial Line Filter
Pump console
Hemoconcentrator

How can we reduce the priming volume?

- Modify tubing dimensions
  - Length
  - Diameter

Shorten line lengths

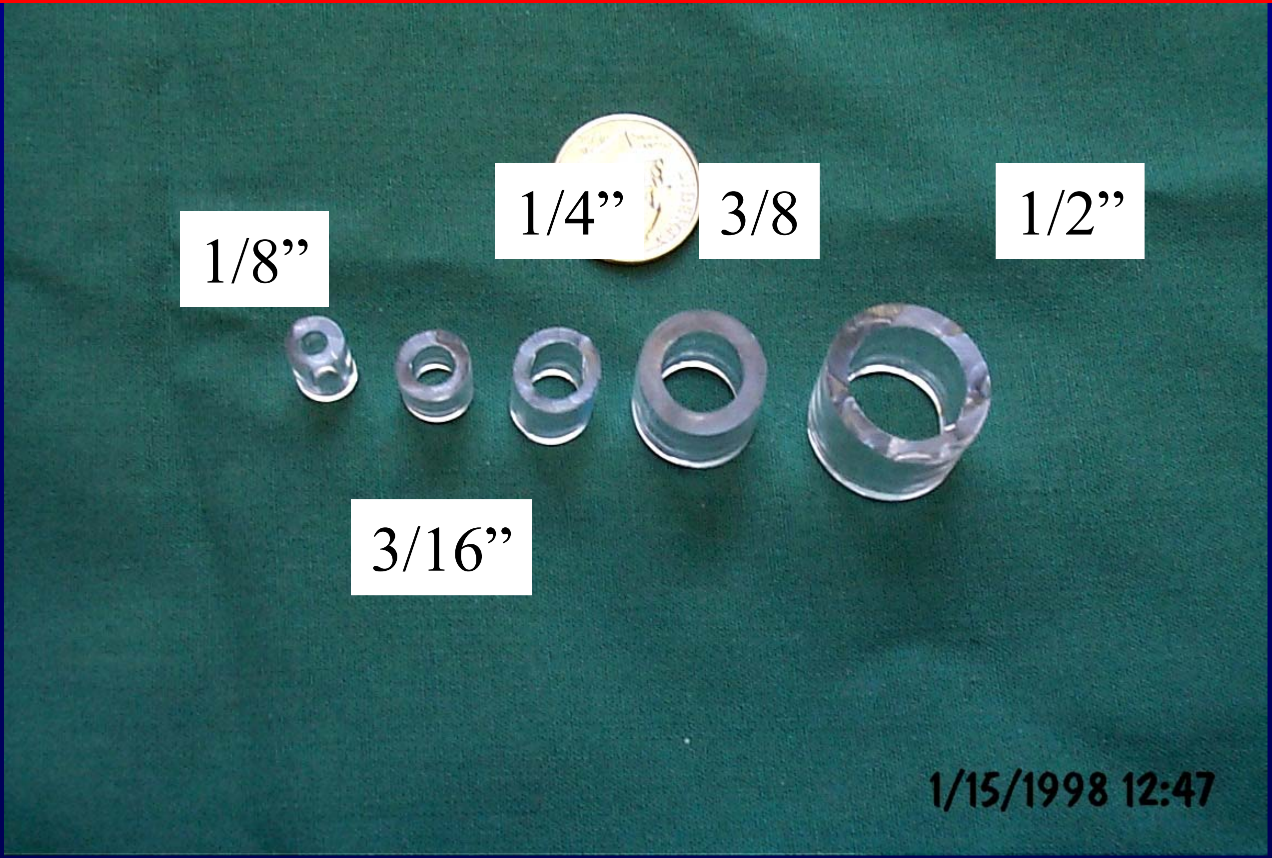
- √ Minimize the deadspace in the circuit
- √ Reposition to optimize tubing lengths



Decrease tubing diameters

Tubing I.D.	Volume cc/foot
1/8”	2.5
3/16”	5.0
1/4”	9.65
3/8”	21.7
1/2”	38.6

Tubing Diameter



Tubing flow ranges

Arterial Line

1/8”	300 - 400	cc/min
3/16”	400 - 1000	cc/min
1/4”	1000 - 2200	cc/min

Disclaimer:Values advocated by other centers. We are not necessarily recommending this

Venous Line

Most centers will use 1/4” venous line up to about 1500 ml/min.

Augmented venous drainage has changed that paradigm

How can we reduce the priming volume?

- Modify tubing dimensions
  - Length
  - Diameter
- Component selection
  - Oxygenator
  - Arterial line filter
  - Cardioplegia system

Components

- Oxygenator Unit
- Arterial Line Filter
- Cardioplegia System

Components - Oxygenators Unit

CONSIDERATIONS

- **Venous reservoir**
- **Design**
- **Versatility**
- **Biocompatability**

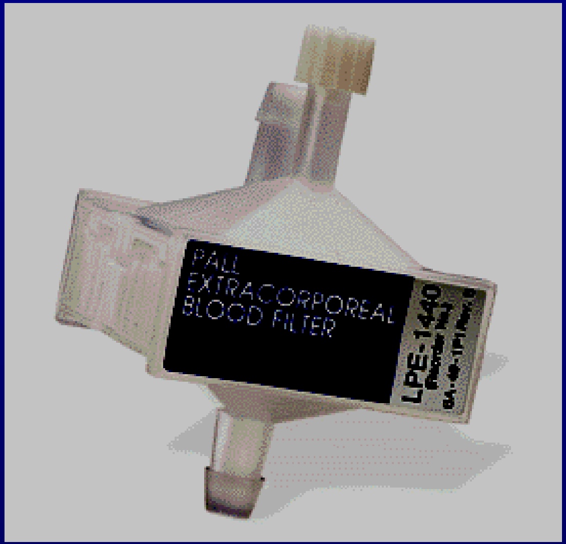
	Priming Vol. (ml)	Q Rating (ml/min)	Memb. Area (m^2)
Cobe Micro	52	800	0.33
Sorin Lilliput I	60	800	0.34
Medtronic MiniMax	140	1500	0.6
Terumo 308	80	800	0.8

Cobe Micro

Sorin Lilliput I

Arterial Line Filters

Pall LPE 1440



Capiox AFO2

How can we reduce the priming volume?

- Modify tubing dimensions
  - Length
  - Diameter
- Component selection
- Elimination(??)

arterial line filter

hemoconcentrator/MUF circuit

BCPS system

Elimination of Arterial Line Filter?

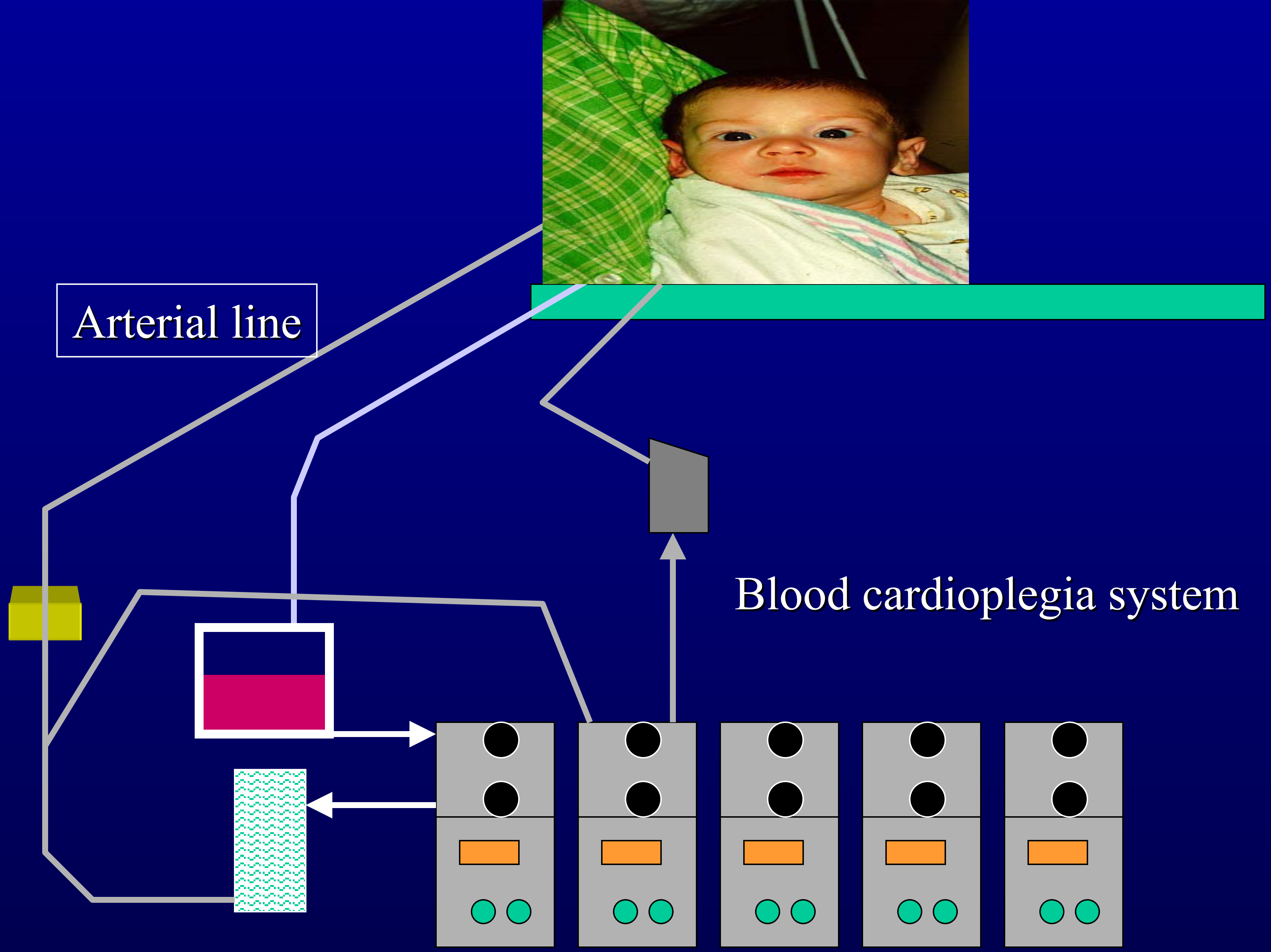
The ALF can represent
10 - 20% of the entire
Priming volume of a
Pediatric CPB circuit

96% of pediatric centers use arterial line filtration

Groom R, 1995, Perfusion 10(6):393-401

Blood Cardioplegia Systems

What are the options?


Arterial line
Blood cardioplegia system

Next Generation

... In the long-term the whole basic concepts of venous return and arterial pumping must be re-addressed.

Martin Elliott
Perfusion
1993: 8:81-86

Re-design the pump console

What is the current “standard” CPB console?

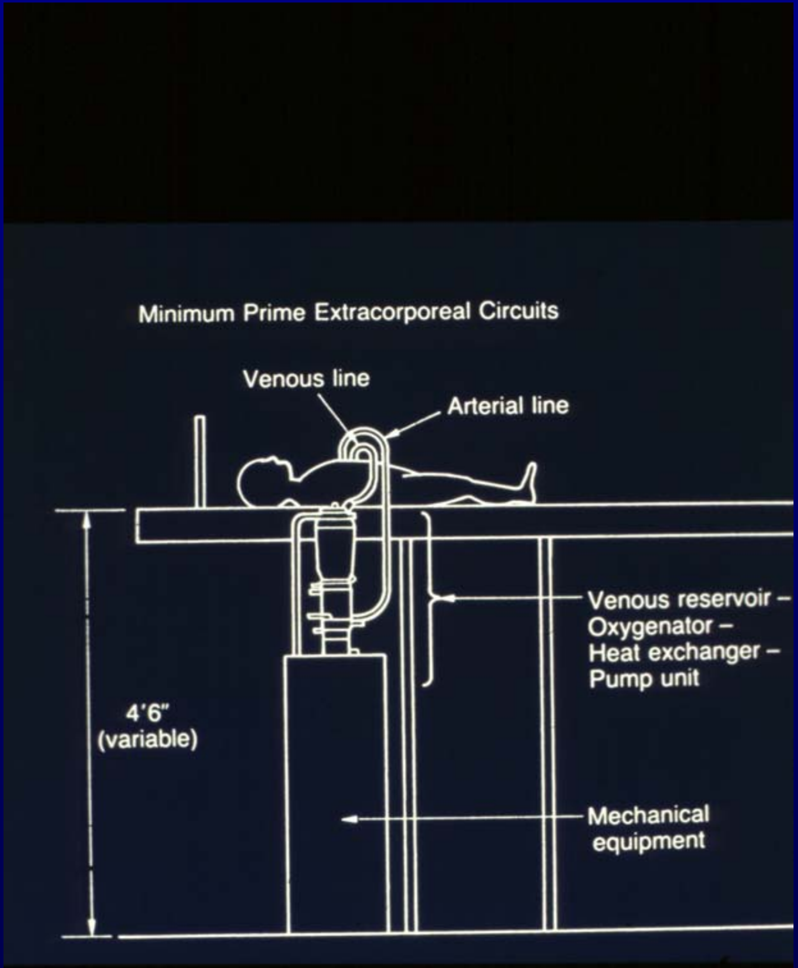
"Second generation pump oxygenator"

CARDIOPULMONARY BYPASS IN NEONATES, INFANTS and YOUNG CHILDREN

Jonas R and Elliott M

Chapter 16 Kirklin, Raible, Blackstone

Priming volume and other aspects of pump oxygenators for neonates and infants



The Duke mini-circuit

Oxygenator and Pumps at patient Level.

Requires the use of Vacuum assisted Venous drainage.

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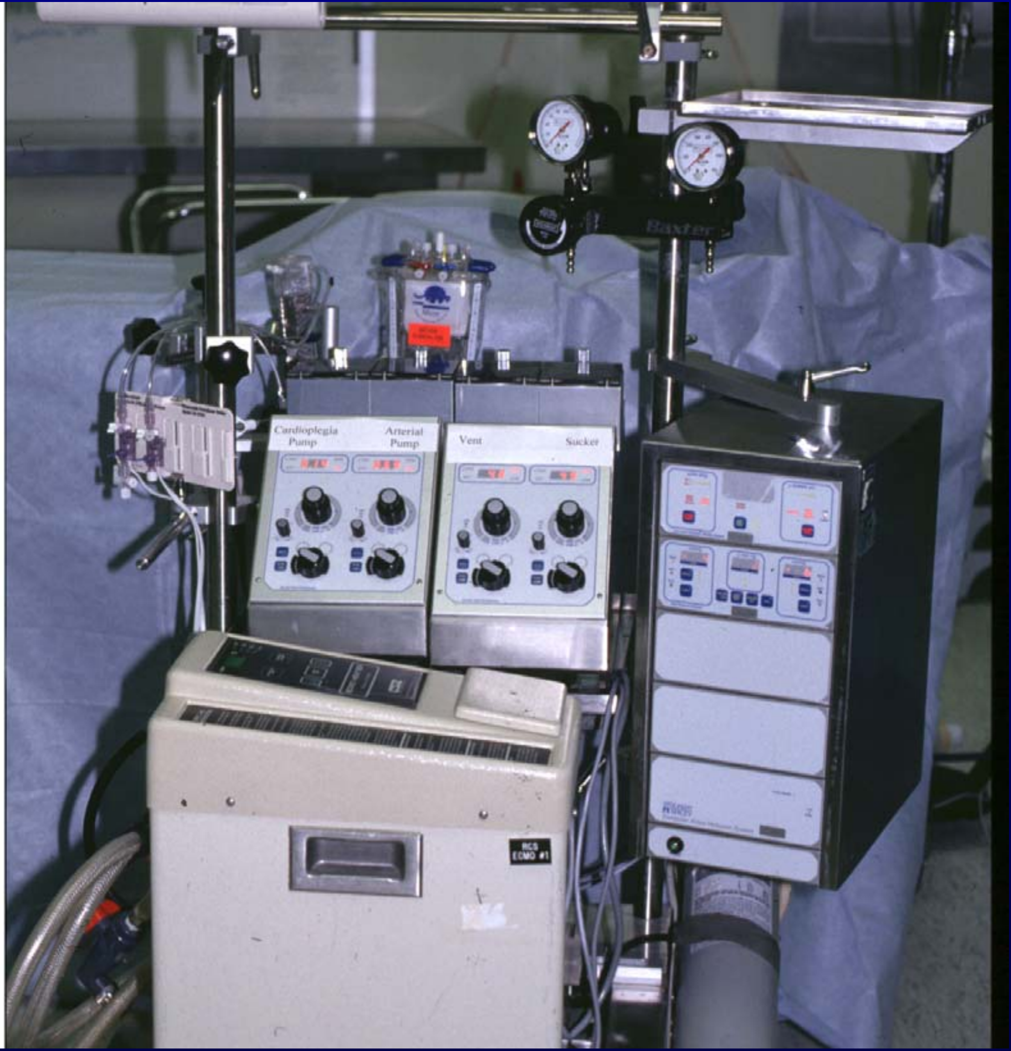
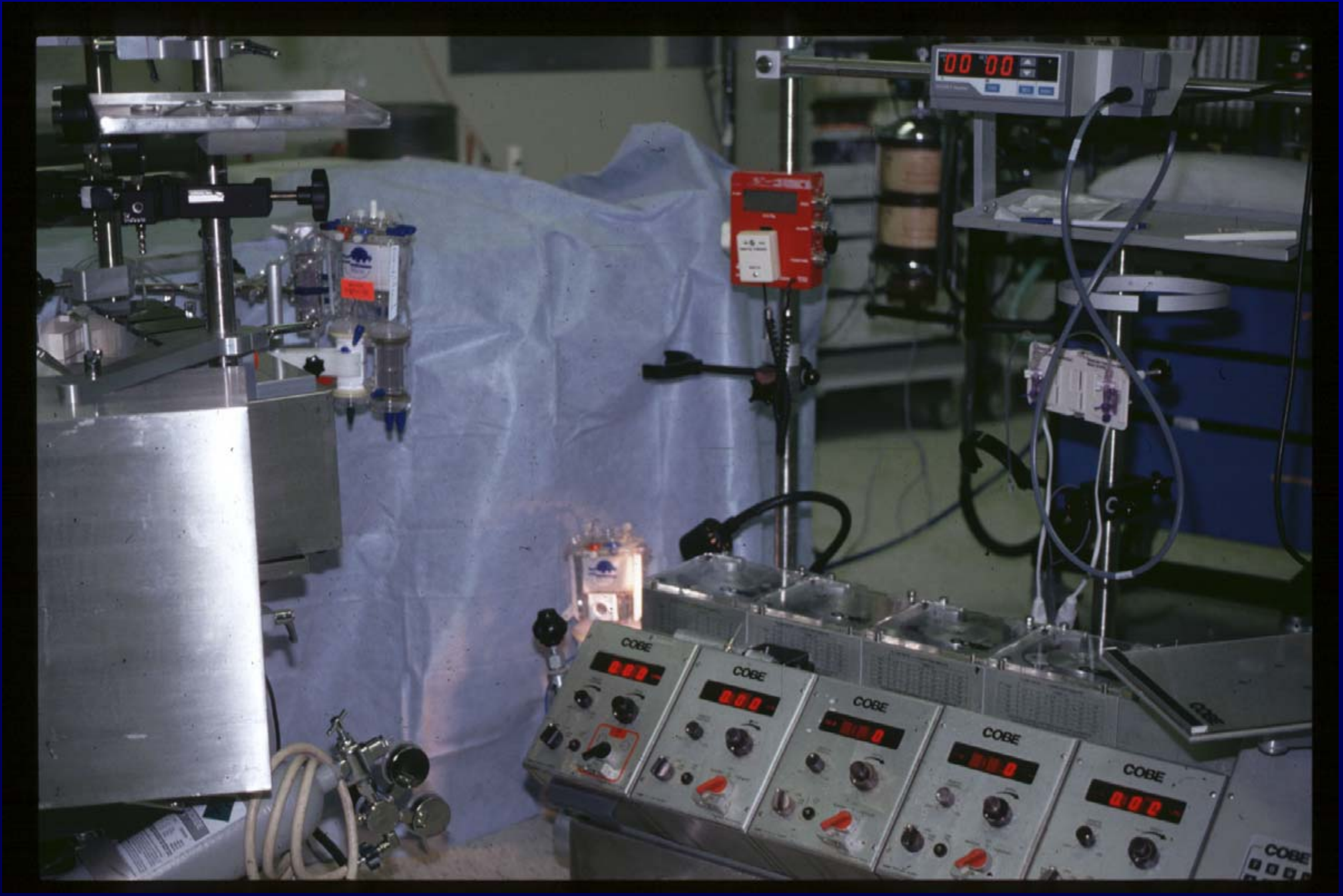
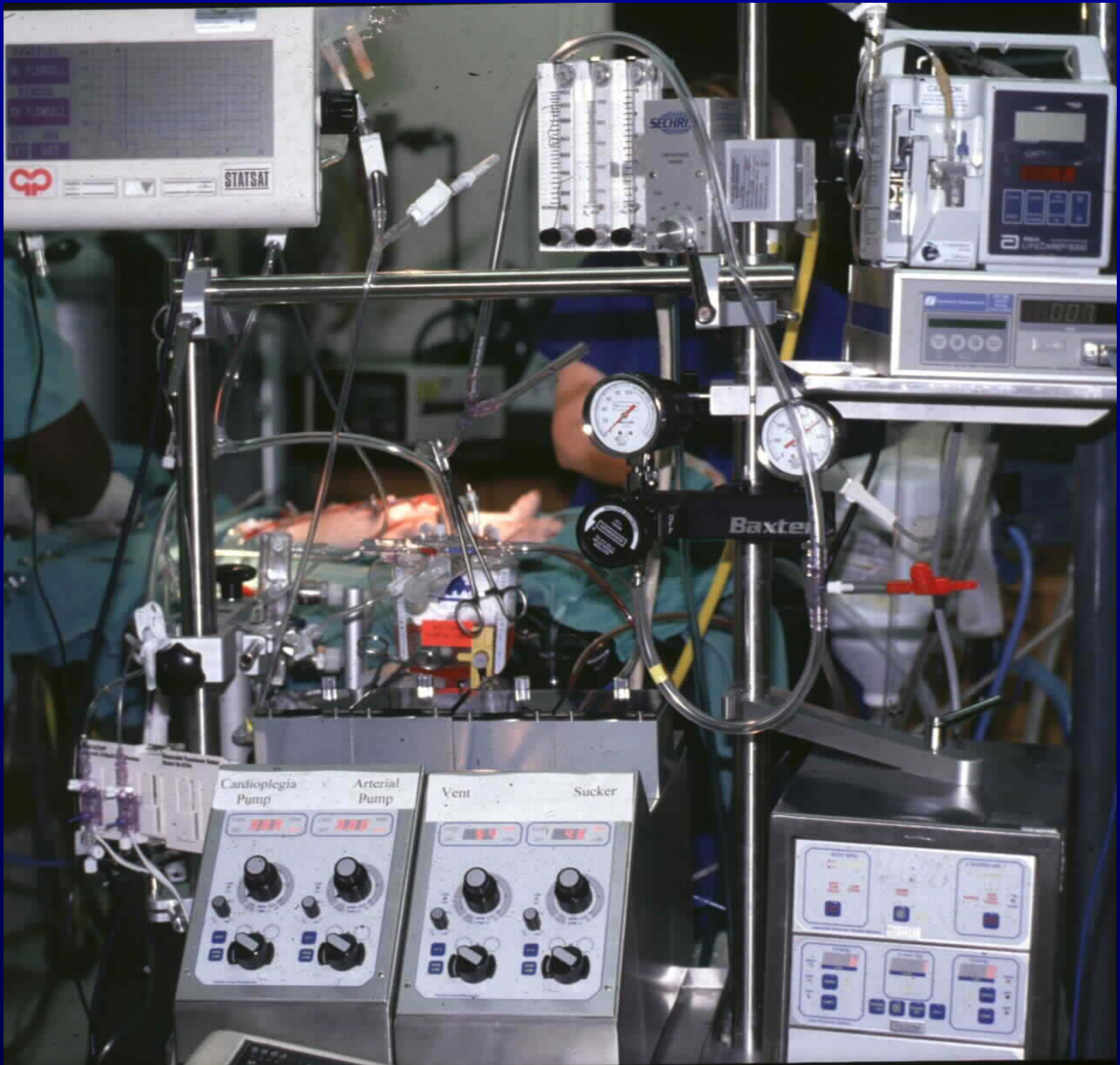


Compared to standard console



Mini circuit - small roller pumps


STATSAT
SECHRIST
Baxter
Cardioplegia Pump
Arterial Pump
Vent
Sucker

Mini-circuit cardiopulmonary bypass with vacuum assisted venous drainage: feasibility of an asanguineous prime in the neonate

- C Lau et al. *Perfusion 1999*; 14: 389-396
- 10 x 1-week old piglets
  - 5 conventional circuit
  - 5 “mini-circuit”
- Results
  - Blood requirements less (47 ± 5.8 ml vs. 314 ± 31.6)

Clinical Applications

Dr. Y Takahashi
Sakakibara Heart Institute
100 infants (3.3 - 4.9 kg)
VSD/PH
Mean lowest Hct = 15%
Post-op Day 2 = 28%

94% had no blood transfusions

No neurological complications
Psychomotor development index scores near normal.

Technowood® System

Barrier sheet

Technowood® System

Safety issues in Miniaturization

Wilcox TW: JECT 34(1): 2002

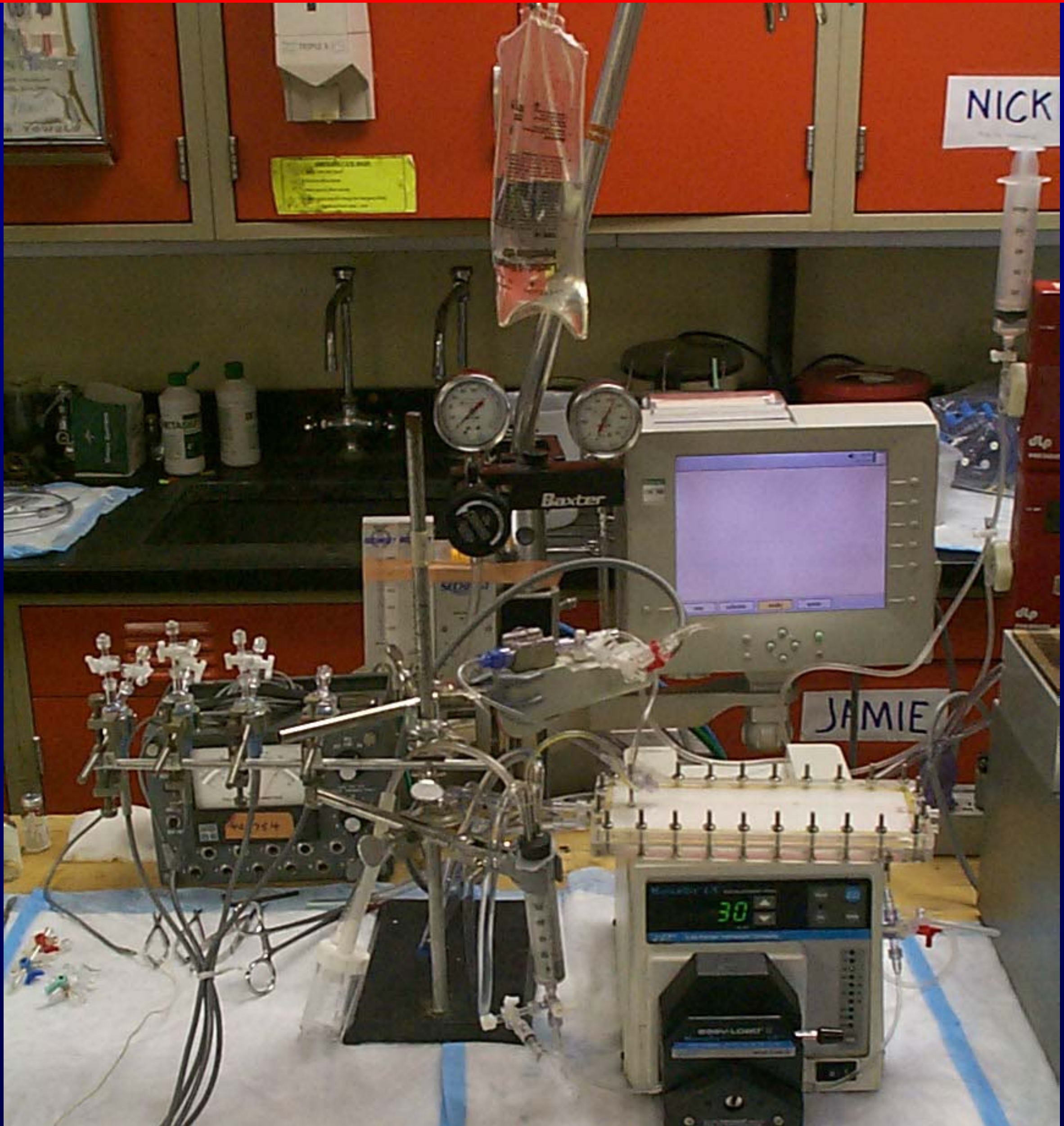
Vacuum-Assisted Venous Drainage: To Air or Not to Air, That is the Question. Has the Bubble Burst?

How do pediatric perfusion circuits handle entrained venous air?

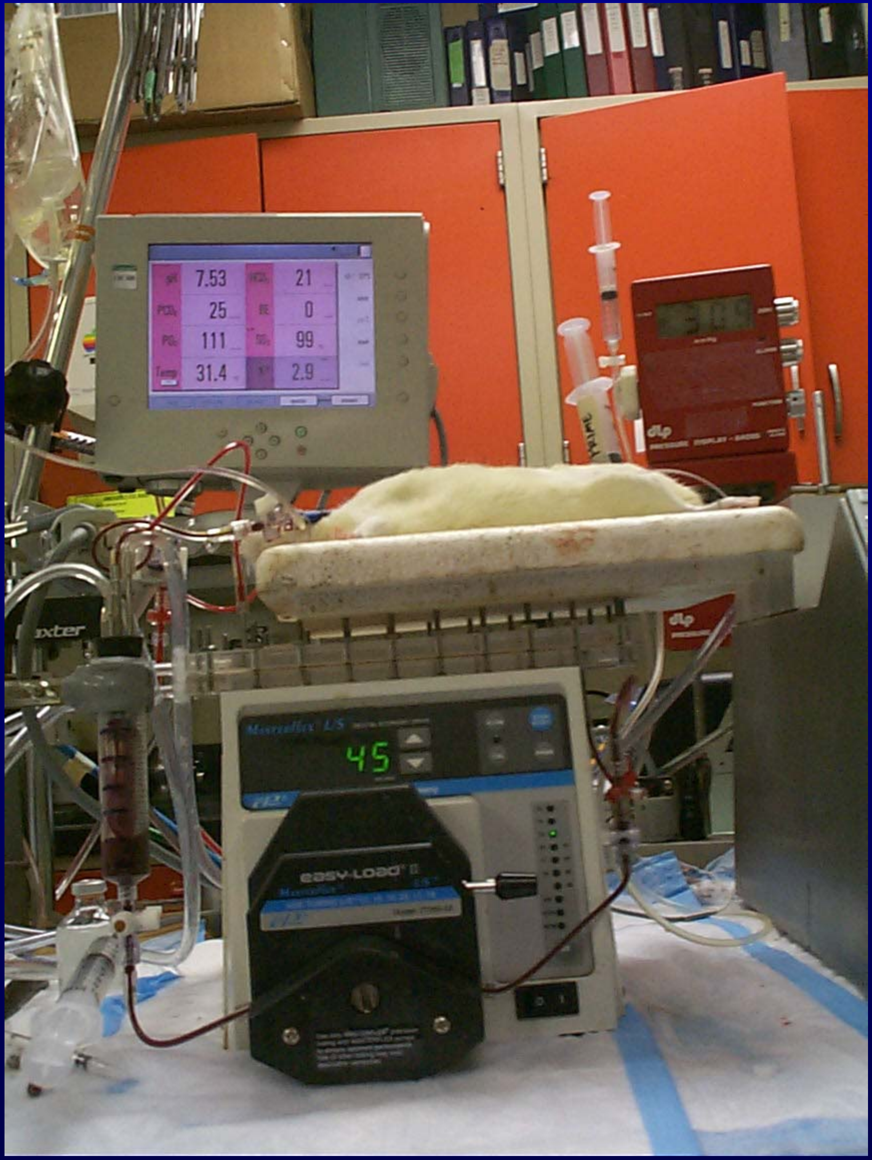
Air entrainment in venous line results in air emboli detection in the arterial line even under gravity conditions..

With VAVD, this effect to significantly more pronounced.

Limits of Miniaturization



Limits of Miniaturization



Limits of Miniaturization

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0.5 kg Rat	40 ml	10 ml	25%

Optimal CPB Conditions