UNIVERSITY OF MICHIGAN MEDICAL CENTER
C. S. MOTT CHILDREN'S HOSPITAL

PROTOCOLS and GUIDELINES for PEDIATRIC PERFUSION

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SECTION 1: Principles

Purpose

This manual has been developed, overseen, and approved by all appropriate attending physicians. The purpose of *Protocols and Guidelines for Pediatric Perfusion* is to improve the continuity and quality of care provided by perfusion services at the University of Michigan Medical Center. To that end, this manual presents the basic information necessary for the safe and effective conduct of pediatric perfusion as suggested by the *Essentials and Guidelines for Perfusion Practice* of the American Society of Extracorporeal Technology. Accordingly, the *Essentials and Guidelines for Perfusion Practice* are included as a reference and serve only as basis for the protocols and guidelines which follow. The procedural information contained herein is not intended to replace common sense and good judgment. The appropriate course of action in any situation is dictated by a combination of policy, common sense, and experience. Meaningful communication, however, between the perfusionist, the attending surgeon, and anesthesiologist is essential whenever a serious departure from established protocols and guidelines is undertaken.

Essentials and Guidelines for Perfusion Practice of the American Society of Extracorporeal Circulation

Essential I: An accurate perfusion record must be maintained according to an established protocol.

Practice Guidelines

A. The perfusion record should include the following patient information:
1. Hospital ID
2. Age
3. Gender
4. Height
5. Weight
6. Body Surface Area (BSA)
7. Allergies
8. Blood Type
9. Pre-op Laboratory Data
10. Diagnosis/History

B. Additional procedure information should include:
1. Date
2. Procedure
3. Perfusionist(s)
4. Surgeon(s)
5. Anesthesia Personnel
6. Comments/Events

C. The following disposable lot numbers should be recorded:
1. Oxygenator
2. Cardiotomy Reservoir
3. Tubing Pack/Arterial Filter
4. Cardioplegia set
5. Ultrafiltration set
6. Cell washing set
7. Centrifugal pumphead and flow probe

D. The following patient parameters should be documented at a frequency determined by institutional perfusion protocol:
1. Blood flow rates
2. Arterial blood pressure
3. Central venous/Pulmonary artery pressure
4. Arterial/Venous blood gases
5. Venous oxygen saturation
6. Potassium concentration
7. Ionized calcium concentration
8. Sodium concentration
9. Activated Clotting Times (ACT) and/or Heparin/Protamine assay results
10. At least one of the following patient temperatures which may include:
    - Bladder
    - Esophageal
    - Rectal
    - Nasopharygeal

- Tympanic

11. Additional Temperature may include:
    - Venous blood
    - Arterial blood
    - Cardioplegic solution
    - Myocardium
    - Water bath(s)
12. Oxygenator gases including flow rate and concentration
13. Input fluid volumes:
    - Prime
    - Blood products
    - Asanguineous fluids
    - Cardioplegic solution
    - Autologous components
14. Output fluid volumes including:
    - Urine output
    - Ultrafiltrate
15. Medications and/or inhalational anesthetic agents administered via extracorporeal circuit

E. The perfusion record should be signed by the primary perfusionist and retained as part of the patient's medical record. Additional copies of the perfusion record may be retained in the perfusion department and/or patient database.
F. Patient parameters that are monitored/measured during the conduct of cardiopulmonary bypass should be documented.

Essential II: The perfusionist shall employ a checklist(s) according to an established protocol.

Practice Guidelines

A. The perfusion checklist(s) according to an established protocol.
B. Checklist(s) should be retained.

Essential III: Extracorporeal circulation shall be conducted by a knowledgeable and competent perfusionist.

Practice Guidelines

A. Extracorporeal circulation should be conducted by a certified or board eligible perfusionist. Certification by the American Board of Cardiovascular Perfusion or its equivalent meets this requirement.
B. A perfusionist should conduct cardiopulmonary bypass with perfusion assistance available.
C. For emergency situations, a perfusionist should be available within 30 minutes of the hospital.
D. Perfusion department/services should maintain a policy and procedures manual which includes:

1. Routine and emergency procedures
2. Departmental policies
3. Continuing education policies

4. Catastrophic perfusion event management

E. Policy and procedures should be reviewed and revised on a periodic basis.

Essential IV: The perfusionist shall monitor the anticoagulation status of the patient according to an established protocol.

Practice Guidelines

A. Monitoring of the anticoagulation status of the patient intraoperatively should include the testing of activated clotting time (ACT). Other monitoring tests may include:

1. Platelet count
2. Heparin/Protamine assay
3. Prothrombin Time (PT)
4. Partial Thromboplastin Time (PTT)
5. Thromboelastogram

B. Patient specific initial heparin dose should be determined by one of the following methods:

1. Weight
2. Dose Response Curve, automated or manual
3. Blood Volume
4. Body Surface Area

C. Additional doses of heparin during cardiopulmonary bypass should be determined by using an ACT and/or Heparin/Protamine assay.

D. The perfusionist may determine the protamine dose.

Essential V: Appropriate gas exchange shall be maintained during extracorporeal circulation according to an established protocol.

Practice Guidelines

A. Appropriate oxygenator gas flow rate and concentration should be determined by using blood gas analysis which may include monitoring devices. Further determinations may be guided by oxygenator directions for use and perfusion parameters such as blood flow rate and temperature.

B. Blood gas analysis should be performed and recorded a minimum of every 30 minutes. Blood gas analysis may be performed at reasonable intervals as clinical conditions dictate.

Essential VI: The perfusionist shall maintain an appropriate blood flow rate during extracorporeal circulation according to an established protocol.

Practice Guidelines

A. Calculated blood flow rate should be determined prior to cardiopulmonary bypass using the patient's body surface area (BSA).

B. Appropriate blood flow rate should be determined by evaluation of a combination of:

1. Venous oxygen saturation
2. Body surface area
3. Arterial blood pressure
4. Temperature

C. Additional parameters that may guide blood flow rate include:
1. Base excess
2. Oxygen consumption
3. Venous pO_2
4. Arterial pO_2
5. Circuit volume
6. Physician request
7. Body weight
8. Anesthesia level
9. Arterial oxygen saturation

Essential VII: The perfusionist shall maintain an appropriate blood pressure during extracorporeal circulation according to an established protocol.

Practice Guidelines

A. Arterial blood pressure should be monitored and recorded.
B. Maintenance of arterial blood pressure may be influenced by factors other than the conduct of cardiopulmonary bypass.

Essential VIII: During extracorporeal circulation, the perfusionist must maintain a safe operational volume in the extracorporeal circuit according to an established protocol.

Practice Guidelines

A. The perfusionist should pre-determine a safe operational level for each perfusion circuit used.
B. A method of safe level detection should be employed. Appropriate blood volume should be maintained to allow for sufficient reaction time in the event of a decrease or loss of circulating volume.

Essential IX: Appropriate safety devices shall be employed.

Practice Guidelines

A. The following devices should be employed during cardiopulmonary bypass:
1. Arterial line filter with a one-way valved purge line
2. Bubble detector
3. Level sensor
4. Anesthetic gas scavenge line

B. Additional safety devices or techniques may include:
1. One-way valve in the intracardiac vent/sump line
2. Bubble trap
3. A method of preventing retrograde flow when using a centrifugal pump
4. Ventilating gas oxygen analyzer

Essential X: Appropriate monitoring devices shall be employed.

Practice Guidelines

A. The should include the following patient/circuit devices.
1. Blood flow indicator
2. Gas flow meter
3. Physiologic monitor(s)
4. Hematologic monitor(s)
5. Temperature monitors
6. Timers

B. These may also include:
1. Blood gas analyzer
2. Oxygen saturation monitor(s)
3. Chemistry monitor(s)

Essential XI: The perfusionist shall make a reasonable effort at cost containment.

Practice Guidelines

The perfusionist should actively participate in cost containment processes as they relate to the delivery of patient care. These activities may include a conscious effort at balancing user preference with patient care issues and cost containment in the selection of perfusion supplies and capital equipment. The perfusionist should be involved in quality management.

Essential XII: The perfusionist must assure that properly maintained equipment is used in the conduct of extracorporeal circulation.

Practice Guidelines

A. The perfusionist should check for the function of all pumps prior to each case. Roller pump occlusions should be verified and adjusted as necessary prior to each case. Blood flow sensor(s) should be checked for proper installation and calibration.

B. Preventive maintenance on perfusion equipment should be performed on a regularly scheduled basis. The interval of such maintenance may be determined any or all of the following:
1. Manufacturer recommendations
2. External accrediting agency guidelines
3. Institutional requirements

SECTION 2: Equipment Selection

Equipment Selection Criteria

General Criteria

- Unless specified otherwise, all equipment is selected on the capacity of any given device to perform safely and effectively according to the published manufacturer specifications with respect to the blood flow rate prescribed for a patient by the following chart.

Patient Kilogram Weight	Blood Flow Rate
0 - 3 kg	200 ml/kg/min
3 - 10 kg	150 ml/kg/min
10 - 15 kg	125 ml/kg/min
15 - 30 kg	100 ml/kg/min
> 30 kg	75 ml/kg/min
>55 kg	65 ml/kg/min

Specific Criteria

Oxygenator

- Do not select an oxygenator whose published manufacturer recommended blood flow rate range is exceeded by the blood flow prescribed for any given patient by the chart above.

Arterial Filter

- It is not recommended to exceed the published manufacturer recommended maximum flow rate of a selected arterial filter.
- Leukocyte depleting arterial line filters are to be used on all heart and/or lung transplants.

Circuit Component Selection Guidelines

Oxygenator Selection Guidelines				
Type	Cobe Micro Reservoir / Lilliput 1	Sorin Infant Masterflow	Sorin Pediatric Masterflow	Avecor Affinity
Criteria	≤ 800 ml/min	> 800 ≤ 2000 ml/min	> 2000 ≤ 3500 ml/min	> 3500 ml/min

Arterial Filter Selection Guidelines For Non-Transplant Cases			
Type	Capiox Infant	Intersect Pediatric	Bard H-675
Criteria	≤ 2500 ml/min	> 2500 ≤ 3000 ml/min	> 3000 ml/min

Arterial Filter Selection Guidelines For Transplant Cases		
Type	Pall Leuco-Guard 3	Pall Leuco-Guard 6
Criteria	≤ 3000 ml/min	> 3000 ≤ 6000 ml/min

Tubing Pack Selection Guidelines For Single Atrial Cannulation					
Type	Neonatal 3/16 - ¼	Infant ¼ - ¼	Pediatric ¼ - 3/8	Small Adult 3/8 - 3/8	Adult 3/8 - 1/2
Criteria	≤ 800 ml/min	> 800 ≤ 1278 ml/min	> 1278 ≤ 2898 ml/min	> 2898 ≤ 3500 ml/min	> 3500 ml/min

Tubing Pack Selection Guidelines For Bicaval Cannulation					
Type	Neonatal 3/16 - ¼	Infant ¼ - ¼	Pediatric ¼ - 3/8	Small Adult 3/8 - 3/8	Adult 3/8 - 1/2
Criteria	≤ 800 ml/min	> 800 ≤ 1566 ml/min	> 1566 ≤ 3000 ml/min	> 3000 ≤ 3500 ml/min	> 3500 ml/min

Pump Boot Selection Guidelines				
Type	3/16"	¼"	3/8"	½"
Criteria	≤ 700 l/min	> 700 ≤ 1300 ml/min	> 1300 ≤ 2700 ml/min	> 2700 ml/min

Cardioplegia Delivery System Selection Guidelines		
Type	Pediatric MUF/ 4:1 CP	Adult 4:1 CP
Criteria	≤ 15 kg*	> 15 kg

*The surgeons may want to MUF selected cases > 15 kg. These selected cases may include those involving Jehovah's Witness patients, those only requiring a short CPB run like ASD repairs, or those which may not require blood product transfusion. It is the perfusionist's responsibility to ascertain the surgeon's wishes on these selected cases.

Equipment Selection Guidelines According to Surgical Procedure & Surgeon

Dr. Edward Bove

Procedure	Small Flexible Sucker	LV Vent	Retro-grade CP	CP Y & Ao root cannula See Note #3	Arterial Cannula See Note #2	Single Atrial Cannula	Bicaval Cannula
Truncus Arteriosus	X	X	possible	X	DLP wire reinforced	X	
PAPVR / TAPVR	X			X	DLP wire reinforced	X	
Arterial Switch	X	See Note #4	possible		DLP wire reinforced	X	
Norwood	X				DLP wire reinforced	X	
BDG / Hemi-Fontan	X			X	THI straight See Note #1	X	
Fontan	X	X		X	THI straight See Note #1	X	
ASD	X			X	See Note #5	See Note #5	See Note #5
VSD	X	X		X	THI angled		X
AVSD	X	X		X	THI angled		X
TOF	X	X		X	THI angled		X
RV-PA Conduit	X	X		X	THI angled	X	
Sub-Aortic Resection	X	X		X	THI angled	X	
AVR/MVR/TVR	X	X	possible	X	THI angled		X
Konno	X	X	possible	X	THI angled		X
Interrupted Aortic Arch	X			X	2 DLP wire reinforced	X	
Ross	X	X	X	X	THI angled		X
Ebstein's Anomaly	X	X		X	THI angled		X

Dr. Bove Table Notes:

1. **Dr. Bove** requests that on post-Norwood BDG/Hemi-Fontan and post-Norwood Fontan procedures use THI straight. All other BDG/Hemi-Fontan and Fontan procedures > 5.0 kg use the THI angled tip.
2. **Dr. Bove** will use a DLP wire reinforced cannula on all cases ≤ 5.0 kg except post-Norwood BDG/Hemi-Fontan and post-Norwood Fontan procedures. On patients > 5 kg, **Dr. Bove** will use and THI angled tip except post-Norwood BDG/Hemi-Fontan and post-Norwood Fontan procedures.
3. CP "Y" adapters and aortic root cannulae are not used if the patient is ≤ 5.0 kg.
4. A wire-malleable vent is used only on arterial switch cases < 2.5 kg unless requested.
5. On ASD's, **Dr. Bove** does not want any cannulae handed up until he asks for them because he may need particular cannulae for a minimally invasive incision case.
6. **Dr. Bove** will construct all bicaval "Y" pieces. Please provide him with the appropriate "Y"connector and 3/8" tubing.
7. Hand held coronary ostial cannulae and retrograde cannulae will be utilized occasionally on an as needed basis per surgeons request.
8. May utilize large flexible suckers for adults and large children or if specifically requested.
9. Myocardial temperature probes should be available in the OR and opened **only** upon the surgeon's request.
10. There will be exceptions to any/all of the above. Consult Dr. Bove when in doubt.

Dr. Ralph Mosca

Procedure	Small Flexible Sucker	LV Vent	Retro-grade CP	CP Y & Ao root cannula See Note #1	Arterial Cannula	Single Atrial Cannula	Bicaval Cannula
Truncus Arteriosus	X	X	possible	X	DLP wire reinforced	X	
PAPVR / TAPVR	X			X	DLP wire reinforced	X	
Arterial Switch	X	See Note #2	possible		DLP wire reinforced	X	
Norwood	X				DLP wire reinforced	X	
BDG / Hemi-Fontan	X			X	DLP wire reinforced	X	
Fontan	X	X		X	DLP wire reinforced	X	
ASD	X			X	DLP wire reinforced		X
VSD	X	X		X	DLP wire reinforced		X
AVSD	X	X		X	DLP wire reinforced		X
TOF	X	X		X	DLP wire reinforced		X
RV-PA Conduit	X	X		X	DLP wire reinforced	X	
Sub-Aortic Resection	X	X		X	DLP wire reinforced	X	
AVR/MVR/TVR	X	X	possible	X	DLP wire reinforced		X
Konno	X	X	possible	X	DLP wire reinforced		X
Interrupted Aortic Arch	X			X	DLP wire reinforced	X	
Ross	X	X	X	X	DLP wire reinforced		X
Ebstein's Anomaly	X	X		X	DLP wire reinforced		X

Dr. Mosca Table Notes:

1. Dr. Mosca will use a DLP wire reinforced cannula on all cases ≤ 15 kg. Consult Dr. Mosca as to what arterial cannula he will use on patients > 15 kg.
2. CP "Y" adapters and aortic root cannulae are not used if the patient is ≤ 5.0 kg.
3. A wire-malleable vent is used only on arterial switch cases < 2.5 kg unless requested.
4. Dr. Mosca will construct all bicaval "Y" pieces. Please provide them with the appropriate "Y"connector and 3/8" tubing.
5. Hand held coronary ostial cannulae and retrograde cannulae will be utilized occasionally on an as needed basis per Dr. Mosca's request.
6. May utilize large flexible suckers for adults and large children or if specifically requested.
7. Myocardial temperature probes should be available in the OR and opened **only** upon Dr. Mosca's request.
8. There will be exceptions to any/all of the above. Consult Dr. Mosca when in doubt.

Arterial Cannula Selection Criteria & Guidelines

Available Arterial Cannula Types

Ascending Aortic Cannulae	
Type	**Sizes**
THI angled	10 12 14 16 18 21 24 - Fr.
THI straight	10 14 18 - Fr.
DLP wire reinforced	8 10 12 16 - Fr.
DLP straight	8 10 12 14 16 18 - Fr.
Sarns	8 mm Kirsch, 8 mm HF aortic

Femoral Arterial Cannulae	
Type	**Sizes**
RMI Fem-Flex II	8 10 16 - Fr.
Bard 1858	10 12 - Fr. smooth tip
Bard 1860	14 16 18 22 24 - Fr. w/suture ring
Bard 1855	10 12 14 16 18 - Fr. (3/8" connector)
Biomedicus	10 12 14 - Fr.

Type Selection Criteria & Guidelines

- **Dr. Bove**
  - The DLP wire-reinforced cannula is to be utilized on all cases $\leq$ 5.0 kg.
  - The THI straight arterial cannula is to be utilized on all post-Norwood BDG/Hemi-Fontan and post Norwood Fontan procedures > 5.0 kg.
  - All other BDG/Hemi-Fontan and Fontan procedures > 5.0 kg use a THI angled tip cannula.
- **Dr. Mosca**
  - The DLP wire-reinforced cannula is to be utilized on all cases $\leq$ 15.0 kg.
  - On patients > 15 kg, consult Dr. Mosca on what type of arterial cannula he wants to use.

Size Selection Criteria & Guidelines

- Maximum flow is estimated by evaluating the flow rate at a pressure drop of approximately **100 mmHg**.
- With interrupted aortic arch procedures, use 2 arterial cannulae of the same type and size to ensure an equal arterial blood flow distribution.

Arterial Cannula Flow Chart

MAXIMUM ARTERIAL CANNULA FLOWS (mL/min) @ 100 mmHg PRESSURE GRADIENT							
Fr	**mm**	**THI angled**	**THI straight**	**DLP wire reinforced**	**Bard whistle tip**	**Bard 16"**	**RMI Fem Flex II**
8	2.7	-----	-----	750	-----	-----	~450
10	3.3	750	750	1300	600 smooth	200	~950
12	4	~ 1300	~ 1300	2200	900 smooth	500	~1400
14	4.7	1800	1800	2900	1400 bump	750	~2300
16	5.3	~ 2500	~ 2500	4000	2600 bump	1500	~3300
18	6	4000	4000	-----	3750 bump	2000	~4300
20	6.3	-----	-----	-----	4700 bump	-----	~5500
21	7	~ 5500	-----	-----	-----	-----	-----
22	7.3	-----	-----	-----	4900 bump	-----	-----
24	8	> 6000	-----	-----	> 4900 bump	-----	-----

Venous Cannulae Selection Criteria & Guidelines

Available Venous Cannulae Types

Atrial, Caval, & Cavo-Atrial Cannulae	
Type	**Sizes**
DLP (Pacifico) Angle Metal Tip	12 14 16 18 20 24 28 31 Fr.
Polystan Straight (basket tip)	18 21 24 28 Fr.
Polystan Angled (basket tip)	18 21 24 28 Fr. (various tip lengths)
USCI straight (lighthouse tip)	12 14 16 18 20 22 24 28 32 34 38 42 -Fr.
Sarns Straight (basket tip)	51 Fr.
Sarns Cavo-Atrial (2-stage)	40/ 32 51/36 -Fr.
DLP Cavo-Atrial (2-stage)	38/34 Fr.

Femoral Venous Cannulae	
Type	**Size**
Argyle Thoracic Catheters	16 20 28 32 -Fr.
DLP	28 Fr.
Biomedicus	10 12 14 -Fr.
RMI Fem Flex II	10 12 14 18 20 24 28 -Fr.

Selection Criteria and Guidelines

- Venous cannulae, singly or in combination, are to be selected on the basis of their capacity to accommodate the maximal expected blood flow rate.
- Unless specifically requested by the surgeon, single atrial cannulation will be used on all DHCA cases.
- **Do not use a 12 Fr DLP as a single atrial cannula unless the patient is ≤ 1 kg.**
- On patients < 5 kg, both Dr. Bove and Dr. Mosca will use DHCA and single atrial cannulation where bicaval cannulation is indicated in "Equipment Selection Guidelines According to Surgical Procedure." On these smaller patients, consult the surgeon before opening any venous cannulae.
- The pressure drop across the venous cannula(e) should not exceed -100 mmHg or -136 cm/H_2O.
- Upon occasion, vessel lumen will not accommodate the prescribed cannula. Under these circumstances, the surgeon should be consulted on additional means to ensure that the heart is effectively unloaded.

Single Atrial Cannula Flow Chart for DLP angled metal tip

Cannula	Venous Line Diameter & Venous Reservoir			
Size	**¼"/Cobe Micro mL/min**	**¼"/Sorin Infant mL/min**	**3/8"/ Sorin Infant or Pediatric mL/min**	**½"/Avecor Open mL/min**
12	556*	486	----	----
14	927	817	----	----
16	----	918	----	----
18	----	1197	1636	----
20	----	1278	1737	----
24	----	----	2620	4158
28	----	----	2898	5125
31	----	----	----	5400

*Do not use a 12 Fr DLP venous cannula on patients whose maximum blood flow rate exceeds 200 ml/min. See Selection Criteria and Guidelines on the preceeding page.

Bench Conditions of Bicaval Cannulae Flow Chart for DLP angled metal tip

1. Fluid: H_2O @ 25^{o}C
2. Calculated Gravity Siphon: -30 mmHg
3. 5 Trials

Bicaval Cannulae Flow Chart for DLP angled metal tip

Cannulae	Venous Line Diameter & Venous Reservoir			
Size & Configuration	**¼"/ Cobe Micro mL/min**	**¼"/ Sorin Infant mL/min**	**3/8"/ Sorin Infant or Pediatric mL/min**	**½"/Avecor Open mL/min**
12/12	990	846	----	----
12/14	----	1120	----	----
12/16	----	1197	----	----
14/14	----	1287	1747	----
14/16	----	1332	1848	----
16/16	----	1377	2037	----
16/18	----	1512	2388	----
18/18	----	1566	2699	----
18/20	----	----	2777	----
20/20	----	----	2809	----
20/24 3/8" Y	----	----	3400*	3960
24/24 3/8" Y	----	----	----	5328
24/28	----	----	----	5328
28/28	----	----	----	+6000
28/31	----	----	----	+6000

Bench Conditions of Bicaval Cannulae Flow Chart for DLP angled metal tip

1. Fluid: H_2O @ 25^{o}C
2. Calculated Gravity Siphon: -30 mmHg
3. 5 Trials

RMI Fem Flex II Flow Chart

Cannula Size	ml/min
8 Fr.	~200
10 Fr.	~400
12 Fr.	~800
14 Fr.	~1100
18 Fr.	~1700
20 Fr.	~2200
24 Fr.	~3500
28 Fr.	~5300

Bench Conditions of RMI Fem Flex II Flow Chart

1. Fluid: H_2O @ 25^{o}C
2. Calculated Gravity Siphon: -30 mmHg
3. Based on manufacturer's data.

Cardioplegia Cannula Selection & Guidelines

Aortic Root Cardioplegia Cannula Selection Guidelines

- An aortic root cardioplegia cannula is selected to deliver **antegrade** cardioplegia.
- This type of cardioplegia cannula is used on all procedures for induction, maintenance, and warm reperfusion where the surgical procedure does not physically interfere with the technique.

Aortic Root Cardioplegia Cannula Selection By Kilogram Weight		
Type	**Size**	**Kilogram Weight Range**
angiocath	18 gauge	0 - 5 kg
DLP	16 gauge	5 -20 kg
DLP	14 gauge	20 -35 kg
DLP	12 gauge	> 35 kg

Coronary Ostium Cardioplegia Cannula Selection Guidelines

- A coronary ostium cardioplegia cannula is selected to deliver **antegrade** cardioplegia directly into the coronary ostia.
- This type of cardioplegia cannula is used on procedures for induction where aortic insufficiency precludes the use of an aortic root cardioplegia cannula and where anatomy precludes the use of a retrograde (coronary sinus) cardioplegia cannula.
- This type of cardioplegia cannula is used on procedures for induction, maintenance, and/or warm reperfusion where the surgical procedure physically interferes with the use of an aortic root coronary cannula and where anatomy precludes the use of a retrograde (coronary sinus) cardioplegia cannula.
- The size and type of coronary ostium cardioplegia cannula are selected under direct vision by the surgeon during the surgical procedure.

Available Coronary Ostium Cardioplegia Cannula Types	
Type	**Size**
Hard Tip Coronary Ostium Cardioplegia Cannula	10 12 14 -Fr.
Soft Tip Coronary Ostium Cardioplegia Cannula	universal

Retrograde Cardioplegia Cannula Selection Guidelines

- This type of cardioplegia cannula is used to deliver **retrograde** cardioplegia via the coronary sinus.
- This type of cardioplegia cannula is used for induction, maintenance, and warm reperfusion where aortic insufficiency and/or the surgical procedure preclude the use of an aortic root cardioplegia cannula.
- The size of the retrograde (coronary sinus) cardioplegia cannula is selected under direct vision by the surgeon during the surgical procedure.

Retrograde (Coronary Sinus) Cardioplegia Cannula Types	
Type	**Sizes**
DLP Neonatal	6 Fr.
RMI Pediatric	9 Fr.
DLP Pediatric	10 13 -Fr.
DLP Adult	15 Fr.

Left Ventricular Vent Cannula Selection Guidelines

- A left ventricular vent cannula is used to decompress the left ventricle.
- A left ventricular vent cannula is selected by kilogram weight.

Left Ventricular Vent Cannula Selection By Kilogram Weight		
Type	**Size**	**Kilogram Weight Range**
DLP Malleable Tip[1]	10 Fr.	On surgeon's request
DLP Curved LV Vent	10 Fr.	< 14
DLP Curved LV Vent	13 Fr.	14 - 30
DLP Adult LV Vent	16 Fr.	30 - 50
DLP Adult LV Vent	20 Fr.	> 50

1. On very small patients (< 3 kg), a 10 Fr. DLP malleable tip LV vent is sometimes used.

SECTION 3: Circuit Preparation

Arterial Rollerpump Calibration

Procedure

1) The arterial rollerpump should calibrated prior to the initiation of CPB.
2) Ascertain the prescribed blood flow rate for the patient according to the chart on page 1 of Section 2.
3) Select the appropriate size arterial pump boot according to the **Circuit Component Selection Guidelines** chart on page 3 of Section 2.
4) Refer to the **Sorin-Stokert Rollerpump Calibration** chart below and find the appropriate stroke volume for the prescribed arterial pump boot.
5) Using the supplied screwdriver, adjust the digital readout on the arterial pump console to the calculated flow/rpm.

Sorin-Stokert Rollerpump Calibration Chart

Boot Diameter	Stoke Volume/Revolution
3/16"	7 mL
¼ inch	13 mL
3/8 inch	27 mL
½ inch	45 mL

CPB Circuit Set-Up Standardization Protocol

Purpose

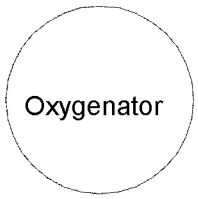
- To establish a consistent circuit set-up facilitating the transfer of case from one perfusionist to another.

Principles

- Always use the manufacturer's specific holders for each component for all systems.
- Avoid wrapping lines around the mast. Tubing length in the revised tubing packs has been altered to make this possible.

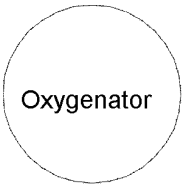
Cobe Micro Cardiotomy/Venous Reservoir with Lillipit I Stand Alone Oxygenator/Neonatal Circuit Configuration

Inside The Mast Configuration



Arterial Pump	Cardioplegia/ MUF Pump	Aortic Needle Vent	LV Vent	Cardiotomy Suckers

All Other Circuit Configurations



Arterial Pump	Cardioplegia/ MUF Pump	Aortic Needle Vent	LV Vent	Cardiotomy Suckers

Pediatric Extracorporeal Circuit Prime Constituents

Normosol R

- The volume of Normosol R contained in the prime will vary with the size of the extracorporeal circuit and the volume of packed red blood cells (PRBC's) added for a Hct on cardiopulmonary bypass (CPB) of 20 - 25%.
- See "Neonatal, Infant, and Pediatric Circuit Prime Protocols" in Section 3.

Albumin

- For all patients < 25 kg, the prime should be 5% albumin unless designated otherwise by Dr. Riegger's prime constituents study.
- See "Neonatal, Infant, and Pediatric Circuit Prime Protocols" in Section 3.

Hespan (6% Hetastarch In 0.9% NaCl)

- All patients weighing 25 - 40 kg will receive 250 mL Hespan instead of 25% albumin.
- All patients > 40 kg will receive 500 mL Hespan instead of 25% albumin.

PRBC's

- A resultant Hct of 20 - 25% on CPB is targeted. If an asanguineous prime would result in excessive hemodilution, then the volume of PRBC's necessary to achieve this target range should be added to the prime or immediately after the initiation of CPB. The resultant Hct on CPB utilizing an asanguineous prime may be calculated using the following formula where IVBV = intravascular blood volume index (the appropriate value may be found in the table below):

CPB Hct = (((IVBV x kg x (patient Hct / 100)) / ((IVBV x kg) + mL prime))) x 100

Patient Kilogram Weight Range	Intravascular Blood Volume Index
$\leq$ 10 kg	85 mL/kg
> 10 kg $\leq$ 20 kg	80 mL/kg
> 20 kg $\leq$ 30 kg	75 mL/kg
> 30 kg $\leq$ 40 kg	70 mL/kg
> 40 kg	65 mL/kg

- For neonates/infants < 5kg, 100 ml PRBC's are added to the prime to avoid a prolonged period a asanguineous perfusion. See "Neonatal, Infant, and Pediatric Circuit Prime Protocols" in Section 3.
- The volume of PRBC's necessary for a given target Hct on CPB may be calculated using the following formula:

? mL PRBC's = (((Target Hct / 100) x ((IVBV x kg) + mL prime)) - (IVBV x kg x (pt Hct / 100))) / 0.6

- Also see "Neonatal, Infant, and Pediatric Circuit Prime Protocols" in Section 3.

Heparin

- 100 units/kg

$NaHCO_3$

- The prime should have a bicarbonate concentration of approximately 24 mEq/L.
- The amount of $NaHCO_3$ necessary for a given amount of asanguineous volume may be calculated where x = mEq $NaHCO_3$ and V = mL asanguineous volume:

$$x = 0.025V$$

- If PRBC's are added to the prime, then a sample should be taken, and $NaHCO_3$ administered according to the following formula:

$$? \text{ mEq } NaHCO_3 = 0.3(\text{kg wt})(\text{BE})$$

Mannitol

- 0.25 g/kg
- An additional 0.25 g/kg is administered on the release of the aortic crossclamp.

$CaCl_2$

- $CaCl_2$ is not routinely added to the prime. However, an ionized Ca^{++} level of the perfusate should be measured shortly after the initiation of CPB and corrected upward to 0.7 - 0.8 mM/L, if necessary.

Phentolamine (Regitine)

- 0.1 mg/kg is added to the pump prime of patients ≤ 10 kg cooled to < 28°C.
- 0.1 mg/kg is administered upon rewarming to patients ≤ 10 kg cooled to < 28°C.
- All circulatory arrest cases are to receive phentolamine; however, if the patient is > 10 kg verify phentolamine administration with the surgeon.
- If during cooling there is > 5 °C between the rectal and nasopharyngeal temperatures and the MAP is > 25 mmHg, then the perfusionist may consult the surgeon as to whether an additional bolus of 0.1 mg/kg phentolamine is appropriate.
- If during rewarming there is > 5 °C between the rectal and nasopharyngeal temperatures and the MAP is > 30 mmHg, then the perfusionist may consult the surgeon as to whether an additional bolus of 0.1 mg/kg phentolamine is appropriate.
- **Note:** Phentolamine is available only in limited quantities at this time due to great demand. In order to maximize the use of available phentolamine, only the amount required for all the cases of the day is reconstituted. Any excess reconstituted phentolamine should be discarded when all the cases of the day are over.

Antibiotics

- Antibiotics are administered as prescribed in the physician's orders.
- Commonly used antibiotics and the usual pediatric dosages are listed in the table below:

Antibiotic	Dosage
Cefazolin (Kefzol, Ancef)	25 mg/kg
Ampicillin	50 mg/kg
Gentamicin	2 mg/kg
Nafcillin	25 mg/kg
Vancomycin	10 -15 mg/kg

Methylprednisolone (Solu-Medrol)

- Pediatric transplant patients receive 30 mg/kg methylprednisolone when the aortic crossclamp is released.
- The anesthesiologist administers 30 mg/kg methylprednisolone to patients undergoing procedures requiring DHCA prior to the initiation of CPB.

Aprotinin

Loading Dose

- Anesthesia personnel administers a 0.01 x 10^6 KIU test dose to ascertain if the patient has an allergy to aprotinin. If the test dose is negative, the patient is loaded with 1.715 x 10^6 KIU/m^2.
    - For patients < 10 kg, the maximum dose is 1.0 x 10^6 KIU.
    - For patients > 10 kg, the maximum dose is 2.0 x 10^6 KIU.

Infusion Dose

- The patient is placed on an infusion at the rate of 0.4 x 10^6 KIU/ m^2 per hour, not to exceed a maximum rate of 0.25 x 10^6 KIU per hour.

Pump Prime Dose

- Designated patients undergoing cardiac surgery have 1.715 x 10^6 KIU/m^2.added to the pump prime.
    - For patients < 10 kg, the maximum dose is 1.0 x 10^6 KIU.
    - For patients > 10 kg, the maximum dose is 2.0 x 10^6 KIU.
- Be certain to verify that the test dose is negative for anaphylaxis prior to adding aprotinin to the pump prime.

Circuit Prime Protocols

Cobe Micro Reservoir, Lilliput 1 Oxygenator, & Neonatal Tubing Pack

All cases done with PRBC's
Prime volume = 380 mL when venous reservoir level = 100 ml
Weight range = up to 5.3 kg

Prime constituent	No Colloid	5% Albumin
Normosol w/25meq NaHCO3/Liter	280 mL *level = 0	280 mL *level = 0
PRBC's	100 mL	100 mL (pull off 76 mL Normosol R)
25% Albumin		76 mL
Heparin (See page 5 of Section 3)	*	*
Antibiotic (See page 6 of Section 3)	*	*
Mannitol (See page 5 of Section 3	*	*
$NaHCO_3$ (See page 5 of Section 3)	*	*
Venous Reservoir Level	100 mL*	100 mL*
Total Prime Volume	380 mL	380 mL

* denotes minuscule variable volumes

Notes for the set-up procedure

No Colloid

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 0.
- Drop 100 mL. of PRBC's and add drugs.
- This results in a reservoir level of 100+ mL.

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 0.
- Drop 100 mL of PRBC's while pulling off 76 mL of Normosol R. Add 76 mL of 25 % albumin and drugs. You could also drop the albumin with the PRBC's then **SLOWLY** pull off the 76 mL of Normosol R.
- This results in a reservoir level of 100+ mL.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin as we do in our current protocols, i.e. aprotinin 40 mL/ albumin (25%) 10 mL.

Implemented: September 25, 1997 Revised: November 30, 1998

Sorin Infant Masterflow Oxygenator & Infant Tubing Pack With PRBC's

Prime volume = 600 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 5.3 -8.5 kg
Weight range with bicaval cannulation = 5.3 - 12.5 kg

Prime constituent	No Colloid	5% Albumin
Normosol R w/25meq NaHCO3/Liter	500 mL *level = 100 mL	500 mL *level = 100 mL
PRBC's	100 mL	100 mL (pull off 120 mL Normosol R)
25% Albumin		120 mL
Heparin (See page 5 of Section 3)	*	*
Antibiotic (See page 6 of Section 3)	*	*
Mannitol (See page 5 of Section 3)	*	*
$NaHCO_3$ (Seepage 5 of Section 3)	*	*
Venous Reservoir Level	200 mL*	200 mL*
Total Prime Volume	600 mL	600 mL

* denotes minuscule variable volumes

Notes for the set-up procedure

No Colloid

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 100 mL.
- Drop 100 mL of PRBC's and add drugs.
- This results in a reservoir level of 200+ mL.

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 100 mL.
- Drop 100 mL of PRBC's while pulling off 120 mL of Normosol R.
- Add 120 mL of 25 % albumin and drugs.
- You could also drop the albumin and PRBC's and **SLOWLY** pull off the 120 mL Normosol R.
- This results in a reservoir level of 200+ mL.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin as we do in our current protocols, i.e. aprotinin 40 mL/ albumin (25%) 10 mL

Implemented: September 25, 1997 Revised: November 30, 1998

Sorin Infant Masterflow Oxygenator & Infant Tubing Pack With No PRBC's

Prime volume = 600 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 5.3 -8.5 kg
Weight range with bicaval cannulation = 5.3 - 12.5 kg

Prime constituent	No Colloid	5% Albumin
Normosol R w/25meq NaHCO3/Liter	600 mL *level = 200 mL	480 mL *level = 80 mL
25% Albumin	0 ml	120 mL
Heparin (See page 5 of Section 3)	*	*
Antibiotic (See page 6 of Section 3)	*	*
Mannitol (See page 5 of Section 3)	*	*
$NaHCO_3$ (See page 5 of Section 3)	*	*
Venous Reservoir Level	200 mL*	200 mL*
Total Prime Volume	600 mL	600 mL

- denotes minuscule variable volumes

Notes for the set-up procedure:

No Colloid

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 200 mL.
- Add drugs.
- This results in a reservoir level of 200+ mL.

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 80 mL.
- Add 120 mL 25 % albumin and drugs.
- This results in a reservoir level of 200+ mL.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin according to the current protocol, i.e. aprotinin 40 mL/ albumin (25%) 10mL.

Sorin Infant Masterflow Oxygenator & Pediatric Tubing Pack With PRBC's

Prime volume = 650 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 8.5 - 20 kg
Weight range with bicaval cannulation = 12.5 - 20 kg

Prime constituent	No Colloid	5% Albumin
Normosol R w/25meq NaHCO3/Liter	550 mL *level = 100 mL	450 mL *level = 0 ml
PRBC's	100 mL	100 mL (pull off 30 mL Normosol R)
25% Albumin		130 mL
Heparin (See page 5 of Section 3)	*	*
Antibiotic (See page 6 of Section 3)	*	*
Mannitol (See page 5 of Section 3)	*	*
$NaHCO_3$ (See page 5 of Section 3)	*	*
Venous Reservoir Level	200 mL*	200 mL*
Total Prime Volume	650 mL	650 mL

* denotes minuscule variable volumes

Notes for the set-up procedure

No Colloid

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 100 mL.
- Drop 100 mL of PRBC's and add drugs.
- This results in a reservoir level of 200+ mL.

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 100 mL.
- Drop 100 mL of PRBC's while pulling off 130 mL of Normosol R.
- Add 130 mL of 25 % albumin and drugs.
- You could also drop the albumin and PRBC's and **SLOWLY** pull off the 10 mL Normosol R.
- This results in a reservoir level of 200+ mL.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin as we do in our current protocols, i.e. aprotinin 40 mL/ albumin (25%) 10 mL

Sorin Infant Masterflow Oxygenator & Pediatric Tubing Pack With No PRBC's

Prime volume = 650 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 8.5 - 20 kg
Weight range with bicaval cannulation = 12.5 - 20 kg

Prime constituent	No Colloid	5% Albumin
Normosol R w/25meq NaHCO3/Liter	650 mL *level = 200 mL	520 mL *level = 70 mL
25% Albumin	0 ml	130 mL
Heparin (See page 5 of Section 3)	*	*
Antibiotic (See page 6 of Section 3)	*	*
Mannitol (See page 5 of Section 3)	*	*
$NaHCO_3$ (See page 5 of Section 3)	*	*
Venous Reservoir Level	200 mL*	200 mL*
Total Prime Volume	650 mL	650 mL

- denotes minuscule variable volumes

Notes for the set-up procedure:

No Colloid

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 200 mL.
- Add drugs.
- This results in a reservoir level of 200+ mL.

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 70 mL.
- Add 130 mL 25 % albumin and drugs.
- This results in a reservoir level of 200+ mL.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin according to the current protocol, i.e. aprotinin 40 mL / albumin (25%) 10mL.

Capiox Infant Arterial Filter, Sorin Pediatric Masterflow Oxygenator & Pediatric Tubing Pack With PRBC's

Prime volume = 700 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 20 - 25 kg
Weight range with bicaval cannulation = 20 - 25 kg

Prime constituent	5% Albumin
Normosol R w/25meq NaHCO3/Liter	500 mL *level = 0 ml
PRBC's	100 mL (pull off 40 mL Normosol R)
25% Albumin	140 mL
Heparin (See page 5 of Section 3)	*
Antibiotic (See page 6 of Section 3)	*
Mannitol (See page 5 of Section 3)	*
Venous Reservoir Level	200 mL*
Total Prime Volume	700 mL

- denotes minuscule variable volumes

Notes for the set-up procedure

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 0 mL.
- Drop 100 mL of PRBC's while pulling of 40 mL of Normosol R.
- Add 140 mL of 25 % albumin and drugs.
- You could also drop the albumin and PRBC's and **SLOWLY** pull off the 40 mL Normosol R.
- This results in a reservoir level of 200+ mL.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin as we do in our current protocols, i.e. aprotinin 40 mL/ albumin (25%) 10 mL

Capiox Infant Arterial Filter, Sorin Pediatric Masterflow Oxygenator & Pediatric Tubing Pack With No PRBC's

Prime volume = 700 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 20 - 25 kg
Weight range with bicaval cannulation = 20 - 25 kg

Prime constituent	5% Albumin
Normosol R w/25meq NaHCO3/Liter	560 ml *level = 60 ml
25% Albumin	140 ml
6% Hetastarch	
Heparin (See page 5 of Section 3)	*
Antibiotic (See page 6 of Section 3)	*
Mannitol (See page 5 of Section 3)	*
$NaHCO_3$ (See page 5 of Section 3)	*
Venous Reservoir Level	200 ml
Total Prime Volume	700 ml

- denotes minuscule variable volumes

Notes for the set-up procedure:

5% Albumin

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 60 ml.
- Add 140 ml 25 % albumin and drugs.
- This results in a reservoir level of 200+ ml.

Aprotinin

- Due to the timing of the aprotinin dosing, it is feasible to add the dosage of aprotinin even at the last minute, as long as the albumin concentration is compensated for at that time.
- Add the appropriate dosage of aprotinin, then add albumin according to the current protocol, i.e. aprotinin 40 mL / albumin (25%) 10mL.

Intercept Pediatric Arterial Filter, Sorin Pediatric Masterflow Oxygenator & Pediatric Tubing Pack With No PRBC's

Prime volume = 775 mL when venous reservoir level = 200 ml
Weight range with single atrial cannulation = 25 - 38 kg
Weight range with bicaval cannulation = 25 - 40 kg

Prime constituent	6% Hetastarch
Normosol R w/25meq NaHCO3/Liter	575 ml *level = 0
25% Albumin	0 ml
6% Hetastarch	250 ml (Pull off 50 ml Normosol R.)
Heparin (See page 5 of Section 3)	*
Antibiotic (See page 6 of Section 3)	*
Mannitol (See page 5 of Section 3)	*
$NaHCO_3$ (See page 5 of Section 3)	*
Venous Reservoir Level	200 ml
Total Prime Volume	775 ml

- denotes minuscule variable volumes

Notes for the set-up procedure:

6% Hetastarch

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 0 ml.
- Add 250 ml 6% Hetastarch and drugs.
- Pull off 50 ml Normosol R.
- This results in a reservoir level of 200+ ml.

Bard H-675 Arterial Filter, Sorin Pediatric Masterflow Oxygenator & Small Adult Tubing Pack With No PRBC's

Prime volume = 1250 mL when venous reservoir level = 200 ml
Weight range with cavo-atrial cannulation (not single atrial) = 28 - 46 kg
Weight range with bicaval cannulation = 40 - 46 kg

Prime constituent	6% Hetastarch
Normosol R w/25meq NaHCO3/Liter	750 ml *level = 0
25% Albumin	0 ml
6% Hetastarch	500 ml
Heparin (See page 5 of Section 3)	*
Antibiotic (See page 6 of Section 3)	*
Mannitol (See page 5 of Section 3)	*
$NaHCO_3$ (See page 5 of Section 3)	*
Venous Reservoir Level	200 ml
Total Prime Volume	1250 ml

* denotes minuscule variable volumes

Notes for the set-up procedure:

6% Hetastarch

- Prime the entire circuit and cardioplegia tubing with crystalloid.
- Pull off volume from the venous line until your reservoir = 0 ml.
- Add 500 ml 6% Hetastarch and drugs.
- Pull off 300 ml Normosol R.
- This results in a reservoir level of 200+ ml.

Bard H-675 Arterial Filter, Avecor Affinity Oxygenator & Adult Tubing Pack With No PRBC's

Prime volume = 1750 mL when venous reservoir level = 500 ml
Weight range for single atrial cannulation = > 28 kg
Weight range for cavo-atrial or bicaval cannulation = > 46 kg

Prime constituent	6% Hetastarch
Normosol R w/25meq NaHCO3/Liter	1250 ml
25% Albumin	0 ml
6% Hetastarch	500 ml
Heparin (See page 5 of Section 3)	*
Antibiotic (See page 6 of Section 3)	*
Mannitol (See page 5 of Section 3)	*
$NaHCO_3$ (See page 5 of Section 3)	*
Venous Reservoir Level	500 ml
Total Prime Volume	1750ml

* denotes minuscule variable volumes

SECTION 4: Patient Management & Perfusion Technique

General Patient Management Guidelines

Anticoagulation

Hemochron Anticoagulation Management System

- **Indication:**
  - The Hemochron Anticoagulation Management System is used on all cases requiring systemic heparinization unless stated otherwise by the staff surgeon and/or anesthesiologist.
- **Patient Heparinizing Dose:** 300 units/kg
- **Pump Heparinizing Dose:** 100 units/kg
- **ACT Criteria For CPB Initiation:**
  - **Patients On Aprotinin:** A kaolin ACT $\geq$ 480 seconds is considered adequate for the initiation and maintenance of safe CPB.
  - **Patients Not On Aprotinin:** A celite ACT $\geq$ 480 seconds is considered adequate for the initiation and maintenance of safe CPB.
- **Heparin Maintenance:**
  - **Patients On Aprotinin:** Maintain a kaolin ACT $\geq$ 480 seconds by administering boluses of 500 - 5000 units depending on the ACT and the size and age of the patient.
  - **Patients Not On Aprotinin:** Maintain a celite ACT $\geq$ 480 seconds by administering boluses of 500 - 5000 units depending on the ACT and the size and age of the patient.

Hepcon Anticoagulation Management System

- **Indication:**
  - The Hepcon Anticoagulation Management System is used only in the following circumstances.
    - Research requiring heparin assays.

    - Post-protamine heparin assays.
- **Patient Heparinizing Dose:** amount designated by heparin dose response for a ACT of 480 seconds.
- **Pump Heparinizing Dose:** Administer a heparin dose in the prime to create a heparin concentration (units/mL) corresponding to heparin concentration designated by the heparin dose response for an ACT of 480 seconds.
- **ACT criteria for CPB initiation:** Please note that Hepcon ACT cartridges utilize kaolin as an activator; therefore, an ACT $\geq$ 480 seconds is considered adequate for the initiation and maintenance of safe CPB for all patients.
- **Heparin Maintenance:** Administer the amount of heparin indicated by a heparin assay to maintain the heparin concentration designated by the heparin dose response for an ACT of 480 seconds.

Heparin Resistance

- If the heparin loading dose results in an ACT < 480 seconds, then the anesthesiologist and the surgeon should be consulted, and an additional bolus of heparin should be administered.
- If the resulting ACT is still < 480 seconds, then the surgeon and anesthesiologist should again be consulted on the possible diagnosis of AT3 deficiency.
- If a diagnosis of AT3 deficiency is reached, then the appropriate amount of plasma should be ordered, and either administered before CPB by the anesthesiologist or added to the pump prime by the perfusionist.
- Additional heparin in the prime should be considered.

Blood Flow Rate (BFR)

- Most current literature addressing management of neonatal, infant, and pediatric patients on CPB concurs that BFR is more important than MAP because of the general absence of occlusive vascular disease. A lower MAP than commonly observed during adult CPB is usually tolerated without complication.
- BFR is calculated by patient kilogram weight according to the following chart.

Patient Kilogram Weight	Blood Flow Rate
0 - 3 kg	200 mL/kg/min
3 - 10 kg	150 mL/kg/min
10 - 15 kg	125 mL/kg/min
15 - 30 kg	100 mL/kg/min
> 30 kg	75 mL/kg/min
> 55 kg	65 ml/kg/min

Mean Arterial Pressure (MAP)

MAP Range During Cooling: 20 - 70 mmHg

MAP Range During Rewarming: 30 - 70 mmHg

Low MAP Intervention Checklist

1. Verify closure of membrane recirculation line.
2. Compensate for blood steal whenever the arterial purge line is open and during cardioplegia delivery, hemofiltration, and aortic needle vent usage.
3. Lower isofluorane delivery if depth of anesthesia is adequate. Consult anesthesiologist.
4. Ascertain presence of A-V shunts. Consult surgeon.
5. Increase BFR until either adequate MAP or the upper limit of BFR range is reached.
6. Administer phenylephrine in boluses of 10 - 50 mcg until an adequate MAP is obtained. Administer phenylephrine only after consultation with the surgeon.

High MAP Intervention Checklist

1. Administer isofluorane at 0.1 - 2.0%. Administration of isofluorane at > 2.0% has been linked to the uncoupling of cerebral autoregulation and should, therefore, probably be avoided.
2. Consult the anesthesiologist as to whether opioid or muscle relaxer agents should be administered.
3. Lower BFR if SvO_2 > 65%.

Central Venous Pressure (CVP)

- During CPB, the CVP should be < 5 mmHg.
- An elevated CVP can result in hypoperfusion, hypervolemia, and edema, particularly when the MAP is low.

Elevated CVP Intervention Checklist

1. Verify that the venous line is not occluded.
2. Ask the anesthesiologist to check the patient for evidence of facial edema, the patency of the CVP monitoring line, and the zero and calibration of CVP transducer.
3. Ask the surgeon to check the position of the venous cannulae.

Alpha Stat pH Management Strategy

pH Range measured at 37°C: 7.35 - 7.45
$PaCO_2$ Range measured at 37°C: 35 - 45 mmHg

Blood Gas Management

PaO_2

PaO_2 Range measured at 37°C: 90 - 150 mmHg

- It is particularly important to keep the PaO_2 in the low end of the range during the initiation of CPB (especially for cyanotic patients), during myocardial reperfusion, and during re-initiation of CPB following deep hypothermic circulatory arrest (DHCA).

$PaCO_2$

$PaCO_2$ Range measured at 37°C: 35 - 45 mmHg

- Avoid extended excessively low $PaCO_2$ values in order to ensure uniform cerebral perfusion.

SvO_2

SvO_2 Range: ≥ 65%

- Avoid excessive transfusion of PRBC's and donor exposure during rewarming and following aortic crossclamp release when drops in SvO_2 are transitory.

Low SvO_2 Intervention Checklist:

1. Increase BFR.
2. Increase isofluorane delivery.
3. Consult anesthesiologist as to whether the patient opioid or muscle relaxer agents should be administered.
4. Add PRBC's.

Low SvO_2 Management @ Low BFR

- If maintaining 1/2 or 1/4 BFR at the surgeon's behest, consider deepening hypothermia and/or adding PRBC's.
- Consult the surgeon.

Electrolyte Management

Ca^{++}

- Maintain an ionized Ca^{++} level of approximately 0.8 mmol/L until 15 - 20 mins after myocardial reperfusion.
- Correct the ionized Ca^{++} level to approximately 1.2 mmol/L 15 - 20 mins after myocardial reperfusion.

K^+

Normal K^+ Range: 3.5 - 5.5 mEq/L

- Hyperkalemia is corrected by conducting hemofiltration replacement therapy with buffered 0.9% saline or Normosol R.

Glucose Management

Normal Glucose Range: 72 - 137 mg/dL

Causes of Progressive Hyperglycemia During CPB

- surgical stress
- CPB
- hypothermia
- cardioplegia solution
- IV solutions containing glucose

Clinical Treatment of Hyperglycemia During CPB

- Glucose levels during CPB should be kept < 300 mg/dL by conducting hemofiltration replacement therapy with either buffered Normosol R or buffered 0.9% saline.
- Upon consultation with the surgeon and the anesthesiologist, insulin administration could be considered on cases where hyperglycemia persists.

Standard Cooling Technique

Hemodilution

- Patients cooled from 32 - 20^{o}C are hemodiluted to 20% or higher upon initiation of CPB.
- Prior to rewarming, PRBC's are added according oxygen demand as measured by the SvO_2 (see above).

Perfusate Temperature and Temperature Gradient

- During cooling, do not exceed an 8 - 12^{o}C temperature gradient between the perfusate and rectal or nasopharyngeal temperature whichever is highest.
- The perfusate temperature should not fall below the target temperature designated by the surgeon.
- Should a temperature gradient in excess of 5^{o}C arise between the rectal and nasopharyngeal temperatures titrate the patient with 0.5 - 2.0% isofluorane. If the cooling gradient persists, consult the anesthesiologist for methods of therapeutic

vasodilation.

Topical Cooling
- Set the water blanket temperature to the target temperature designated by the surgeon.

Temperature Maintenance
- The target cooling temperature is obtained and maintained by keeping the perfusate at the target temperature.

DHCA Cooling Technique

Hemodilution
- Patients requiring DHCA are hemodiluted to a Hct of 20 - 25% upon initiation of CPB.
- Prior to rewarming, PRBC's are added according oxygen demand as measured by the SvO_2 (see above).

Perfusate Temperature and Temperature Gradient
- During cooling, do not exceed an 8 - 12^{o}C temperature gradient between the perfusate and rectal or nasopharyngeal temperature whichever is highest.
- The minimum perfusate temperature is 13^{o}C.
- Once a perfusate temperature of 15 ^{o}C is safely reached, do not allow the perfusate temperature rise above 15 ^{o}C prior to circulatory arrest.
- Should a temperature gradient in excess of 5^{o}C arise between the rectal and nasopharyngeal temperatures titrate the patient with 0.5 - 2.0% isofluorane. If the cooling gradient persists, consult the anesthesiologist for methods of therapeutic vasodilation.

Topical Cooling
- Set the water blanket temperature to ~18^{o}C.
- Have anesthesia pack the patient's head with ice bags.

Rewarming

- Rewarming is initiated at the request of the surgeon.
- The ice bags are removed from the patient's head by anesthesia.
- The patient is rewarmed to a nasopharyngeal and/or rectal temperature of 37^{o}C.

Pharmacology During Rewarming

Mannitol

- 0.25 g/kg mannitol is administered when the aortic crossclamp is released.

$NaHCO_3$

- Do not treat metabolic acidosis unless the Base Excess is less than -4.0 mmol/L.
- When the patient reaches 32^{o}C, $NaHCO_3$ is administered to resolve metabolic acidosis according to the following formula: (0.3 x BE x kg wt)/2.
- When transfusing PRBC's, 5 - 10 mEq $NaHCO_3$/RBC unit may have to be added to correct the acidosis of the donor unit.

$CaCl_2$

- Maintain an ionized Ca^{++} level of approximately 0.8 mmol/L until 15 - 20 mins after myocardial reperfusion.
- Correct the ionized Ca^{++} level to approximately 1.2 mmol/L 15 - 20 mins after myocardial reperfusion.
- Transfusion of PRBC's can significantly lower the perfusate ionized Ca^{++} of patients < 10 kg. Administration of $CaCl_2$ may be necessary.

Perfusate Temperature and Temperature Gradients

- During rewarming, maintain a 8 - 12^{o} C gradient between the water bath of the heater/cooler unit and the nasopharyngeal or rectal whichever is lowest.
- Do not allow the perfusate temperature to exceed 38^{o}C.
- Do not allow the water bath temperature of the heater/cooler unit to exceed 42^{o}C.
- When the nasopharyngeal temperature reaches 37^{o}C, lower the perfusate to 37^{o}C to avoid overheating the brain.

Topical Rewarming

- The water blanket is set to 38^{o} C.
- Set the Bare-Hugger to 38^{o}C.

Rewarming Rate

- The rewarming rate should probably be limited to a 1^{o}C increase every 3 - 5 mins.

Hematocrit

- During rewarming, the Hct is increased to the level designated by the surgeon before the patient is weaned from CPB.
- The addition of PRBC's is avoided, if possible, to reduce donor exposure.
- Generally, patients ($\leq$ 15 kg) who will remain hypoxemic following the surgical repair should have their Hct increased to ~30 - 35% during rewarming to ensure that their Hct will be $\geq$ 40% following Modified Ultrafiltration.

Blood Transfusion Guidelines

- PRBC units are to be given in the following order of preference:
    1. Autologous
    2. Donor Directed Non-Blood Relative
    3. Donor Directed Blood Relative
    4. Homologous

Cardioplegia Protocols

Solutions

Description

- At Mott, 4 types of cardioplegia solution are used. They include Cold Induction Solution (high K^+), Maintenance Solution (low K^+), Warm Reperfusion Solution (low K^+), and Warm Induction Solution (high K^+). All cardioplegia solutions are mixed and delivered by a customized 4:1 blood-to-crystalloid cardioplegia system manufactured by Sarns, Inc.

Crystalloid Component

- The crystalloid component of all four cardioplegia solutions is modified from a common 200 mL base solution. Modification instructions for each solution are located on the label of the base solution bag. Check boxes are provided to indicate which solution has been prepared. Blanks are also provided for the initials of the preparer as well as the time and date of preparation. A copy of the label is reproduced on the following page.

Home Med UMMC Home Infusion Pharmacy
2850 S. Industrial Hwy., Ann Arbor, MI 48104
1-800-862-2731

UMMC CARDIOPLEGIA SOLUTION: MOTT BASE SOLUTION #1

Base Solution Ingredients

Dextrose 5% + 0.225% Sodium Chloride	140 mL
Tromethamine solution (THAM) 1/3 M	56 mL
Citrate Phosphate Dextrose Solution	4 mL
Total Base Volume	200 mL

Prepare the desired final cardioplegia solution option as directed and indicate which final solution option is prepared by placing an "X" in the appropriate box.

( ) Cold Induction Solution (high K^+):
Aseptically add 8 mL KCl (2 mEq/mL) for a final volume of 208 mL.
( ) Maintenance Solution (low K^+):
Aseptically add 4 mL KCl (2 mEq/mL) for a final volume of 204 mL.
( ) Warm Reperfusion Solution (low K^+):
Aseptically add 4 mL KCl (2 mEq/mL) and 70 mL Aspartate/Glutamate 0.46 M for a final volume of 274 mL.
( ) Warm Induction Solution (high K^+):
Aseptically add 8 mL Potassium Chloride (2 mEq/mL) and 70 mL Aspartate/Glutamate 0.46 M for a final volume of 278 mL.

Final solution prepared by: _____ Date:_____
Time: _____

REFRIGERATE
MUST PREPARE FINAL CARDIOPLEGIA SOLUTION JUST PRIOR TO USE
WITHIN 24 HOURS AFTER PREPARING THE FINAL SOLUTION

Expiration date: _____ Control #: _____
RPhkm_____

Base Solution Storage

- All base solution bags are to be stored under refrigeration. Solutions with the nearest outdate will be stored in the refrigerator between rooms 7 and 8. Solutions with furthest outdate will be stored in the refrigerator by the Mott OR desk.

Outdated Base Solution Handling

- All outdated bags of base solution are to be removed from either storage refrigerator, placed in a ziplock bag clearly marked as outdated, and stored on the counter in the Mott pump room. The perfusionist in charge of ordering should alerted in a timely manner.

Approximate Final Composition of 4:1 Cardioplegia Solutions

	Cold Induction Solution	Warm Induction Solution	Maintenance Solution	Warm Reperfusion Solution
pH	7.5 - 7.6	7.5 - 7.6	7.5 - 7.6	7.5 - 7.6
Ca^{++}	0.4 - 0.6 mmol/L	0.4 - 0.6 mmol/L	0.4 - 0.6 mmol/L	0.4 - 0.6 mmol/L
K^{+}	20 24 mEq/L	20 - 24 mEq/L	8 - 10 mEq/L	8 - 10 mEq
Glutamate	- - - - - - - - - -	13 mmol	- - - - - - - - - - -	13 mmol
Aspartate	- - - - - - - - - -	13 mmol	- - - - - - - - - - -	13 mmol
Osmolarity	380 - 400 mOsm	380 - 400 mOsm	340 -360 mOsm	380 - 400 mOsm
Hematocrit	80% perfusate Hct	80% perfusate Hct	80% perfusate Hct	80% perfusate Hct

Delivery Systems

Type	Selection Criteria
Sarns Pediatric 4:1 CP System	$\leq$ 15 kg
Sarns Adult 4:1 CP Systems	> 15 kg

Set-Up

Pump Calibration

- The conversion factor for the 4:1 pump stroke volume on a Sorin/Stockert roller pump is 16.7 mL or 17 mL/min for practical purposes (13.7 mL for the blood line and 3.0 mL for the crystalloid line). Prior to loading the tubing into the raceway, calibrate the digital readout to read 0.17 L/min at 10 rpm.

Blood Line Connection

- **Cobe Micro, Sorin Infant Masterflow, and Sorin Pediatric Masterflow**
    - The blood line is connected to the luer-lock on the 1/4"/1/4" straight through connector in the arterial line just distal to the arterial output of the oxygenator.
- **Avecor Affinity**
    - The blood line may be connected to a luer-lock on the 1/4"/1/4" straight through connector cut into the membrane recirculation line or to the luer-lock port on the arterial outlet.

Cardioplegia Temperature Control

- Cardioplegia solution temperature is controlled with a Cincinnati Sub-Zero Hemotherm dual cooler/heater unit. The cooler portion of the unit is set at 4^{o}C for cold cardioplegia delivery. The heater portion of the unit is set at 39^{o}C for warm induction and warm reperfusate cardioplegia delivery.

Cardioplegia Delivery Technique

Ionized Ca^{++}

- Following the initiation of CPB, the ionized Ca^{++} levels of patients < 10 kg are often significantly diluted by the essentially Ca^{++} free pump prime. Consequently, an ionized Ca^{++} level of the perfusate should be measured shortly after the initiation of CPB and corrected upward to 0.7 - 0.8 mmol/L, if necessary. A minimal perfusate ionized Ca^{++} level of 0.7 - 0.8 mmol/L is necessary to ensure that the ionized Ca^{++} level of the cardioplegia falls between 0.4 - 0.6 mmol/L.

Cardioplegia Line Flushing

1. De- Airing
    - Make certain that as much cardioplegia as possible is returned to the pump once it is mixed with perfusate. Avoid excessive amounts of high K^+ flush being returned to the pump.
2. Flushing After Induction
    - **Remember** that given the small amount of cardioplegia solution delivered to neonates and infants, it is necessary to flush the delivery line in order to ensure that the cardioplegia solution is cold or warm.
    - Flushing the delivery line is also necessary to change the composition of the solution delivered.

Cold Induction

- Cold induction cardioplegia is usually initiated after the aorta is crossclamped.
- Upon the surgeon's request, Cold Induction Solution is "dribbled" and then delivered at a pressure never to exceed 300 mmHg measured at the pump. If the delivery pressure seems excessive, i.e. 150 - 200 mmHg, the perfusionist should ask the surgeon to palpate the aorta to determine if the pressure in the aorta is dangerously high.
- A total dose of 20 - 30 mL/kg is ideally delivered over a 2 - 4 minute period. At 10 mL/kg intervals, the amount of cardioplegia solution delivered is announced as well as the myocardial temperature provided it is being monitored.
- The target myocardial temperature range is 10 - 15^{o}C. The perfusionist should be prepared to continue cardioplegia solution delivery if the target myocardial temperature is not obtained.

Warm Induction

- Both Warm Induction Solution and Maintenance Solution are prepared and spiked.
- The Cincinnati Sub-Zero dual heater-cooler is set at 37^{o}C and circulating. The patient should not be actively cooled until after warm induction cardioplegia has been delivered.
- Warm induction cardioplegia is usually initiated after the aorta is crossclamped. Upon the surgeon's request, the cardioplegia solution is "dribbled" and then delivered at a pressure never to exceed 300 mmHg measured at the pump. If the delivery pressure seems excessive, i.e. 150 - 200 mmHg, the perfusionist should ask the surgeon to palpate the aorta to determine if the pressure in the aorta is dangerously high.

- A total dose of 30 mL/kg is ideally delivered over a 2 - 4 minute period.
- When the dose is completed, the crystalloid component is switched from Warm Induction Solution to Maintenance Solution. Simultaneously, the Cincinnati Sub-Zero dual heater-cooler is set to cooling mode. Cold Maintenance Solution is delivered until the myocardial temperature reaches 10 - 15^{o}C.

Maintenance

- The perfusionist will notify the surgeon when 20 minutes has elapsed since the last dose of cardioplegia solution or when the myocardial temperature (if measured) exceeds 15^{o}C. Regardless, maintenance cardioplegia is delivered at the surgeon's discretion.
- Routinely, after the delivery line is flushed, a dose of 15 mL/kg of Maintenance Solution is delivered over a 1 - 2 minute period.
- The target myocardial temperature range is 10 - 15^{o}C. Occasionally, additional cardioplegia solution is required to reach the target temperature range. If myocardial electrical activity persists, the surgeon and perfusionist should consult and consider delivering a dose of Cold Induction Solution.

Warm Reperfusion

- The surgeon should give ample warning to the perfusionist that he wants to deliver a dose of Warm Reperfusion Solution. If the perfusionist believes that warm reperfusion is indicated, he may suggest it to the surgeon.
- A bag of Warm Reperfusion is prepared and spiked.
- Please note that KCl is added to Warm Reperfusion Solution at the surgeon's discretion.
- The Cincinnati Sub-Zero dual heater-cooler is set at 37^{o}C and circulating.
- Typically, after the delivery line is flushed, a 15 - 20 mL/kg dose of Warm Reperfusion Solution is delivered just prior to the release of the aortic crossclamp over a 2 - 3 minute period at a pressure of 100 - 200 mmHg measured at the pump.

Deep Hypothermic Circulatory Arrest Technique

Cooling

1. Procedures requiring circulatory arrest typically utilize single venous cannulation.
2. The perfusionist initiates topical cooling by setting the water bath of the warming blanket to 20^{o}C once the patient is **stable** and prepped and draped. Otherwise, topical cooling is not initiated until CPB is established.
3. Prior to the dividing of the A-V loop, the pump prime is recirculated at 30^{o}C. This is the lowest controllable setting on the Sarns Heater/Cooler Unit and assures that an 8 - 12^{o}C temperature gradient between the perfusate and body temperature is not violated during the initiation of cardiopulmonary bypass (CPB).
4. Upon initiation of CPB, the perfusionist cools the patient maintaining an 8 - 12^{o}C temperature gradient between the perfusate and rectal and/or nasopharyngeal temperature whichever is highest. This technique avoids the generation of gaseous emboli when the solubility in the blood of atmospheric gases is lowered by excessive rewarming of the perfusate in the tissue. When a perfusate temperature of 15 ^{o}C is safely reached, do not allow the perfusate temperature to rise above 15 ^{o}C prior to circulatory arrest. At no point should the perfusate temperature be allowed to fall below 13^{o}C.
5. When CPB is established, the anesthesiologist should pack the patient's head in ice in order to facilitate cerebral preservation.
6. If a significant temperature differential (> 5^{o}C) arises between the nasopharyngeal and rectal temperatures during cooling, the perfusionist should administer 0.1 - 2.0% isofluorane to facilitate uniform cooling. If the temperature gradient resists isofluorane administration, then consult the staff anesthesiologist.
7. Fifteen minutes after the initiation of CPB, the perfusionist should administer a dose of muscle relaxant prescribed by the anesthesiologist.
8. Twenty minutes is the minimal amount time allowed to cool the patient to 18 -20^{o}C at which point the surgeon requests the perfusionist to take the patient off CPB. The perfusionist sequentially turns off the gas flow and purge line of the arterial line filter (ALF), slows down the arterial pumphead, simultaneously clamps the arterial line and unclamps the membrane recirculation line, stops the CPB clock, and declares "off bypass." The venous line is not clamped until cardioplegia has been delivered and venous drainage has ceased.

Recirculation

1. Upon the surgeon's request, the cardioplegia solution (CPS) delivery line is first flushed, then "dribbled," and finally delivered at a pressure not to exceed 300 mmHg measured at the pump. If the delivery pressure seems excessive, i.e. greater than 200 mmHg, the perfusionist should ask the surgeon to palpate the aorta to determine if the pressure in the aorta is dangerously high. A total dose of 30 mL/kg is ideally delivered over a 3 minute period. At 10 mL/kg intervals, the amount of CPS delivered is announced as well as the myocardial temperature provided it is being monitored.
2. When the CPS has ceased to drain into the venous reservoir, the perfusionist informs the surgeon of the fact whereupon the venous line is clamped proximal to the reentry point of the ALF purge line. This allows the perfusate on the machine side of the CPB circuit to be recirculated without inadvertently pressurizing the venous line.
3. During circulatory arrest, the perfusate should be recirculated at 28^{o}C unless a second period of circulatory arrest is anticipated by the surgeon. It is **the perfusionist's responsibility** to make certain the surgeon will want to rewarm upon the re-initiation of CPB.
4. A perfusate sample should be taken for blood gas and electrolyte analysis. Enough PRBC's should be added to raise the hematocrit (Hct) to 25% or higher. Samples should be taken to assess the effect of PRBC transfusion on pH, glucose, and electrolytes. Ultrafiltration can be used to correct hyperglycemia (> 300 mg/dL) and potassium (> 5.5 mEq) levels. If hyperglycemia resists ultrafiltration, the perfusionist should consult the anesthesiologist concerning possible insulin administration.
5. The $PaCO_2$ should be kept between 32 - 38 mmHg. The PaO_2 should be kept at the lower end of the range guideline: 90 - 150 mmHg. Negative base excess resulting from PRBC transfusion should be corrected . Again, hypocalcemia should be treated only when levels fall below 0.8 mmol/L. At this time, calcium chloride administration should probably not exceed 10 mg/kg. Before CPB is re-initiated, the perfusate should be diluted to a Hct of ~25% with buffered Normosol R.
6. If the heart is reperfused when CPB is re-initiated, as in the Norwood procedure, then administer 0.25 g/kg mannitol to the recirculating perfusate. Otherwise, administer 0.25 g/kg mannitol when the aortic crossclamp is released.

Re-initiation and Rewarming

1. Just prior to re-iniation of CPB, the surgeon will request that the ice be removed from the patient's head.
2. CPB is re-instituted at the surgeon's request. The flow rate should be increased gradually to refill the patient. When the surgeon is satisfied with arterial and venous pressures, he will request that the tubing clamp on the venous line be removed by saying "drain the venous line."
3. When CPB is fully re-established, the untoward effects of global tissue acidosis should be monitored carefully. Sodium bicarbonate should be administered in a timely manner according to the following formula: (0.3 x base deficit x kg weight)/2.
4. When rewarming is initiated, the perfusionist should also begin to hemoconcentrate the perfusate to the target Hct. PRBC's should be added if necessary.
5. During rewarming, a 10^{o}C temperature gradient between the water bath of the Sarns Heater/Cooler Unit and the venous perfusate should not be exceeded for the reasons given in #4.
6. From this point onward, the conduct of perfusion during procedures utilizing circulatory arrest does not differ remarkably from other CPB procedures.

Modified Ultrafiltration

Overview

- Despite advances in pediatric cardiopulmonary bypass (CPB) circuits and perfusion technique over the last decade, elevated capillary permeability and increased water weight gain continue to complicate post-operative recovery following open heart surgery. Increased water weight gain can lead to tissue edema and organ dysfunction. Several modalities are utilized to counter the accumulation of excess extravascular water. These include smaller CPB circuits and ultrafiltration. Conventional ultrafiltration, however, has limitations especially in smaller patient populations (< 10 kg) due to volume constraints peculiar to pediatric CPB. Conventional ultrafiltration hemoconcentrates the perfusate of the extracorporeal circuit during and after CPB. This technique is also used to treat post-operative edema and renal failure. Modified Ultrafiltration (MUF) is a modification of conventional ultrafiltration developed at the Hospital for Sick Children in London where the patient undergoes ultrafiltration immediately after the termination of CPB allowing the red blood cells and plasma proteins remaining in the extracorporeal circuit to be returned to the patient while simultaneously removing excess extravascular water. Several investigators report that MUF decreased post-operative water weight gain and lowered donor exposure. Evidence has also been presented suggesting that MUF may reduce the inflammatory response secondary to CPB by removing vasoactive materials and mediators of inflammation.

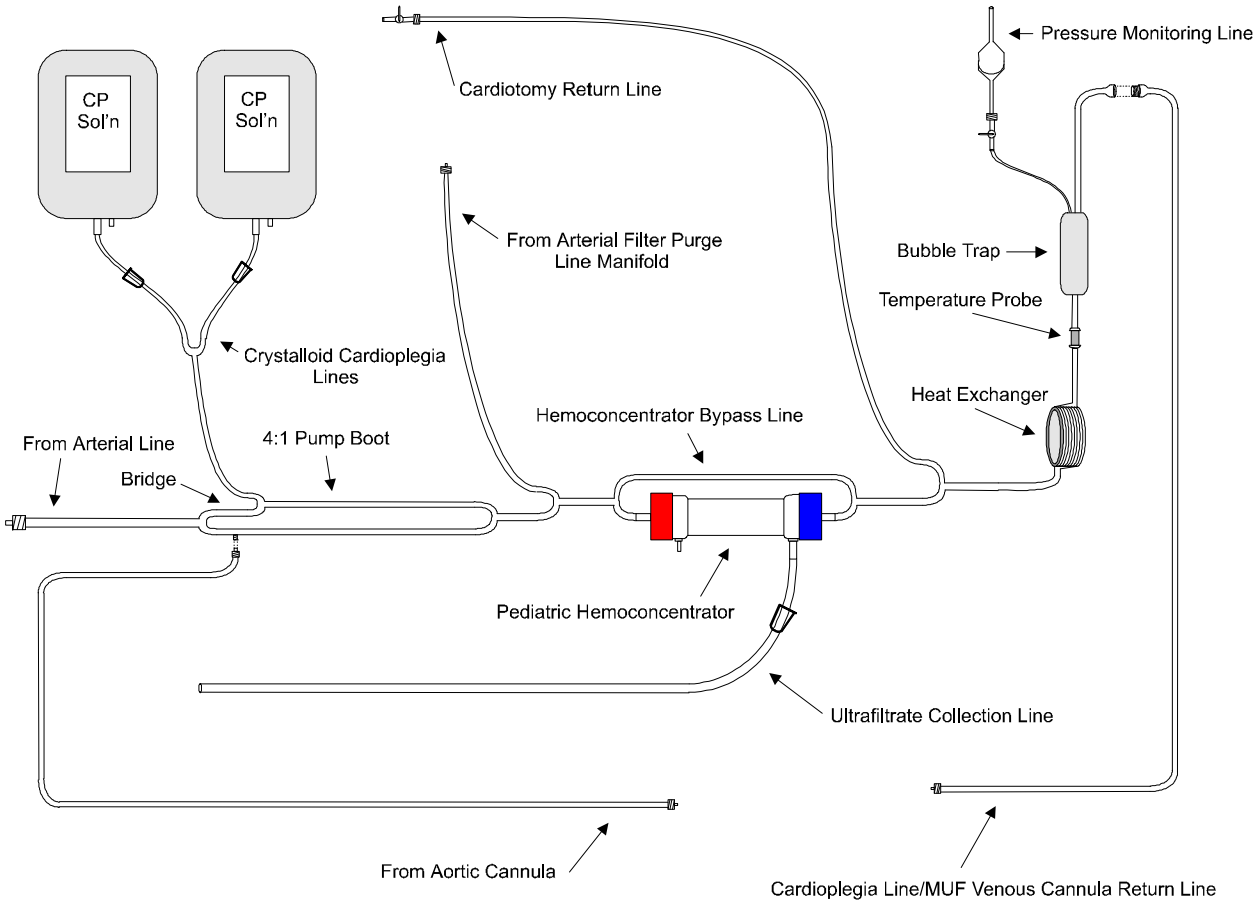
Indication

- The perfusionist should be prepared to conduct MUF on all patients $\leq$ 15 kg undergoing open heart surgery at Mott Children's Hospital. Otherwise, MUF will be utilized at the surgeon's discretion.

Special Note On Integrated Cardioplegia/MUF System

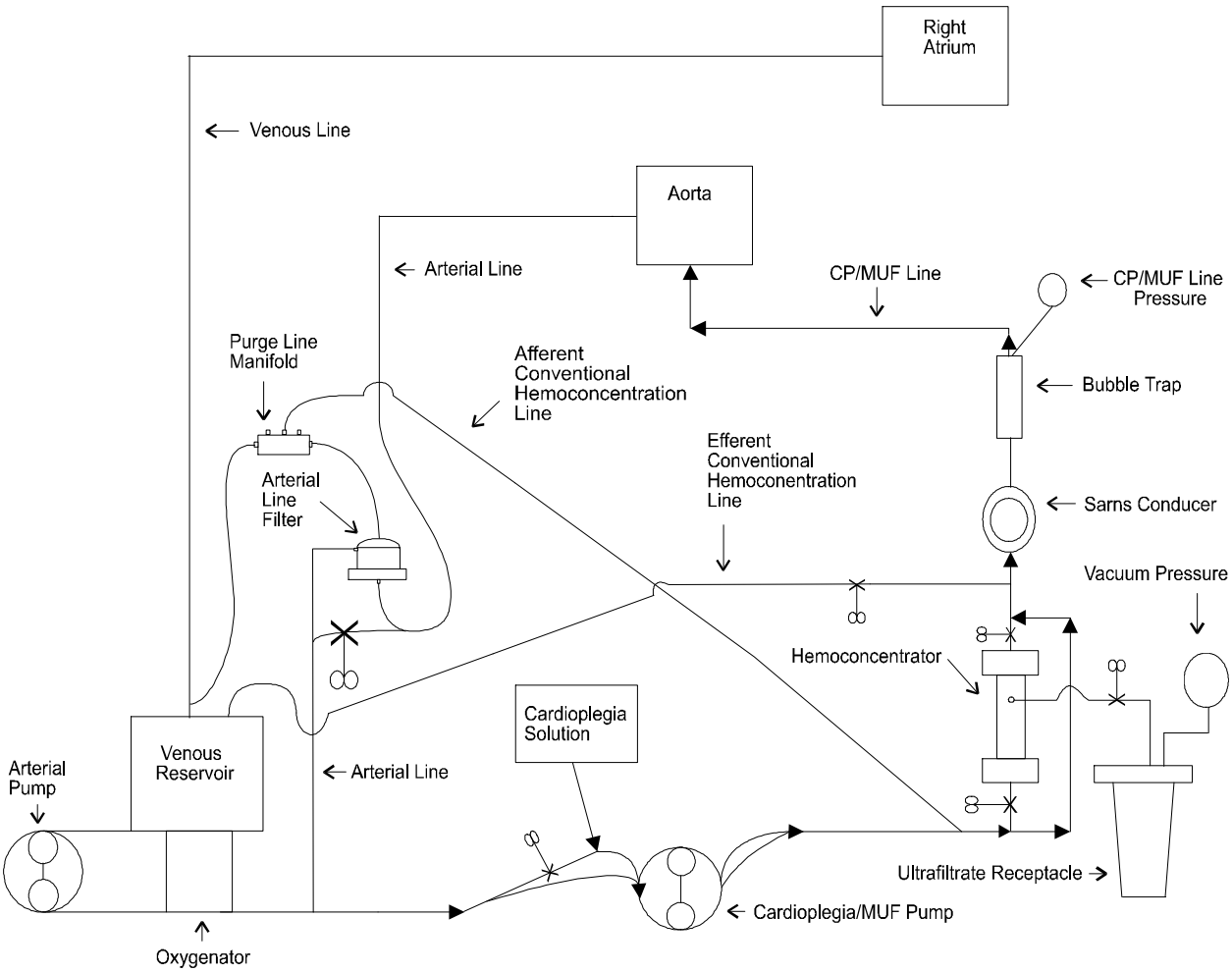
- The integrated cardioplegia/MUF system is capable of being configured for cardioplegia delivery, conventional hemoconcentration, MUF, and circuit volume salvage following MUF. Refer to the following diagrams for appropriate tubing clamp orientation during a given function.

University of Michigan Integrated Cardioplegia/MUF Circuit



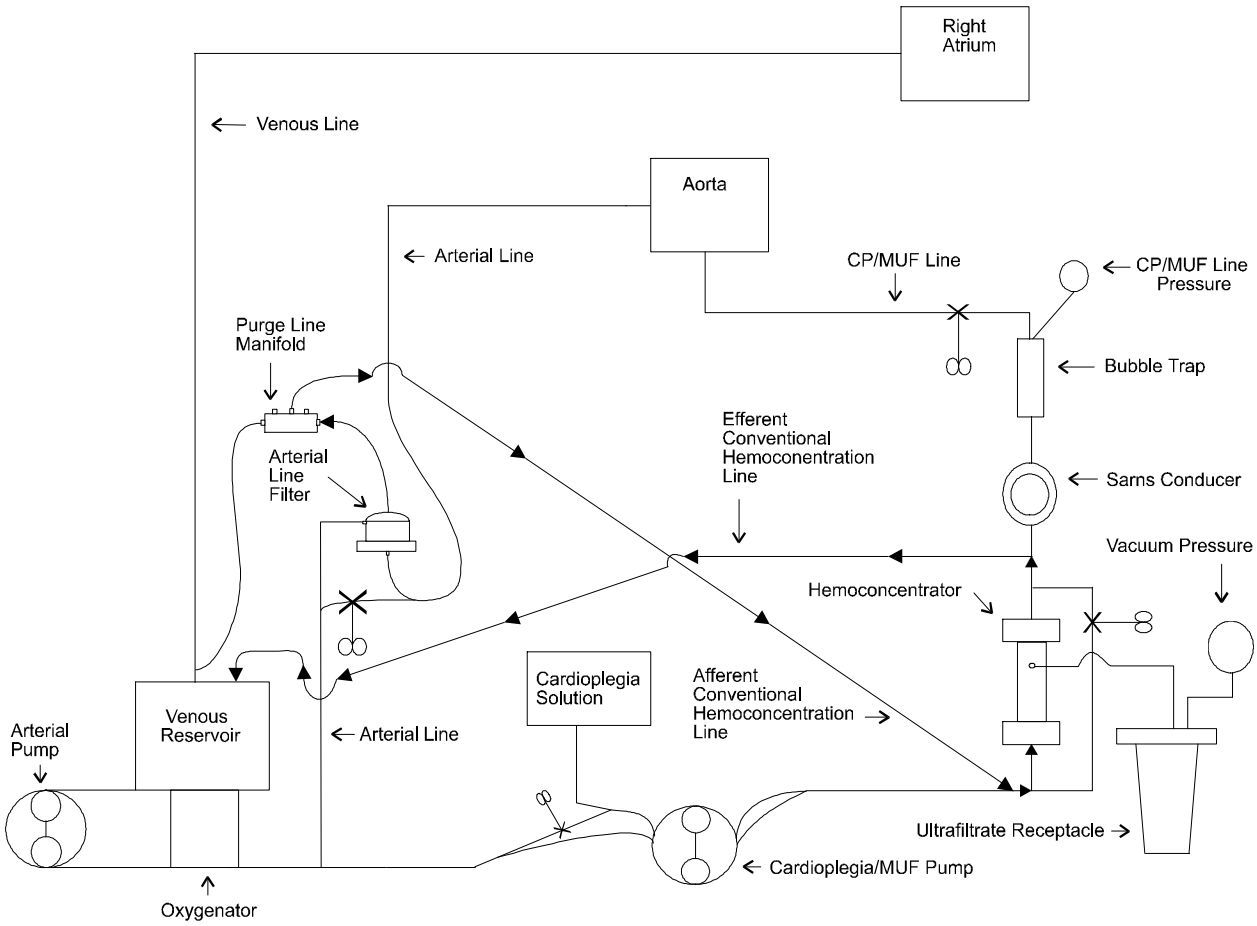
Cardiolpegia / Modified Ultrafiltration Circuit

Cardioplegia Delivery Configuration



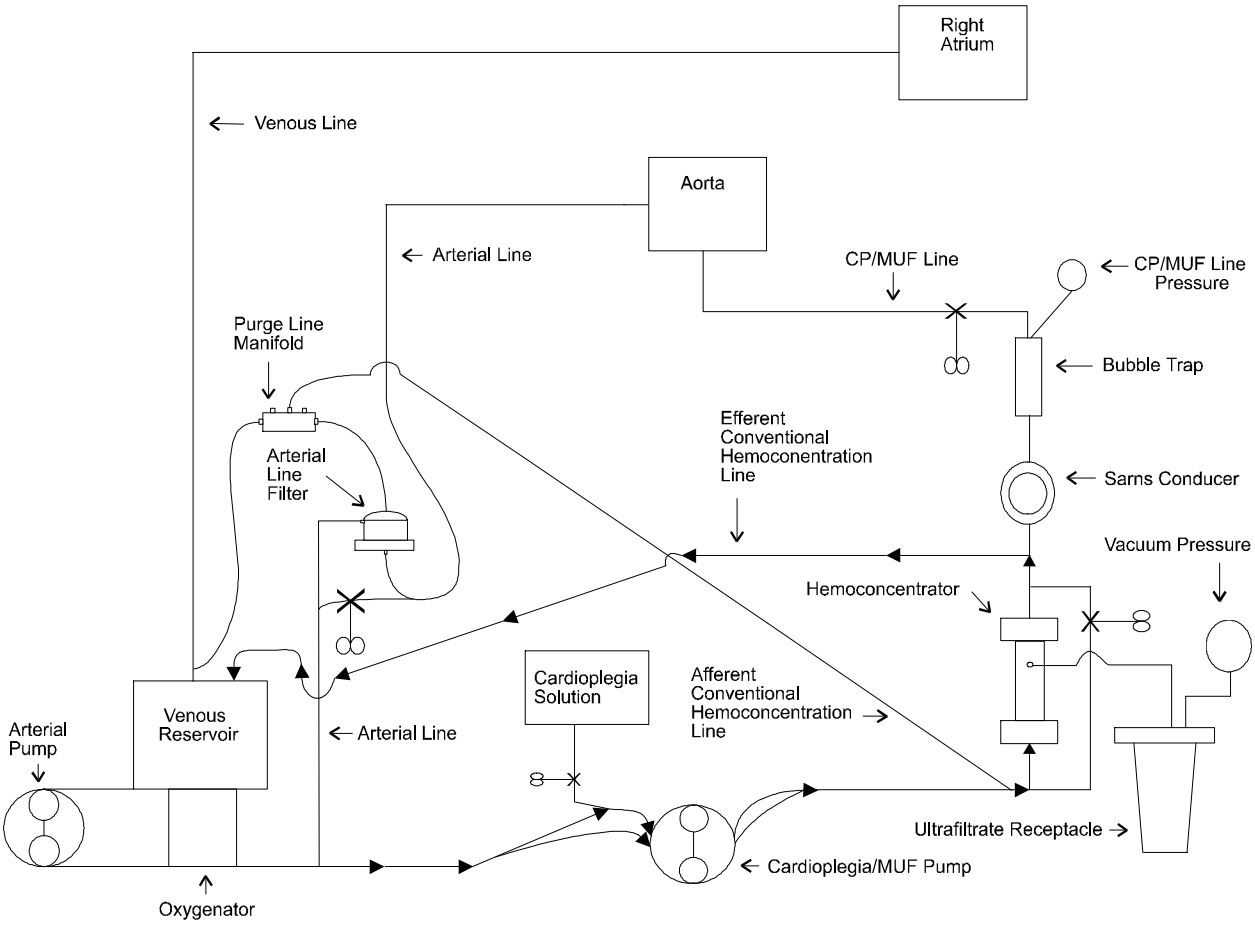
Cardiolpegia / Modified Ultrafiltration Circuit

Conventional Hemoconcentration Configuration



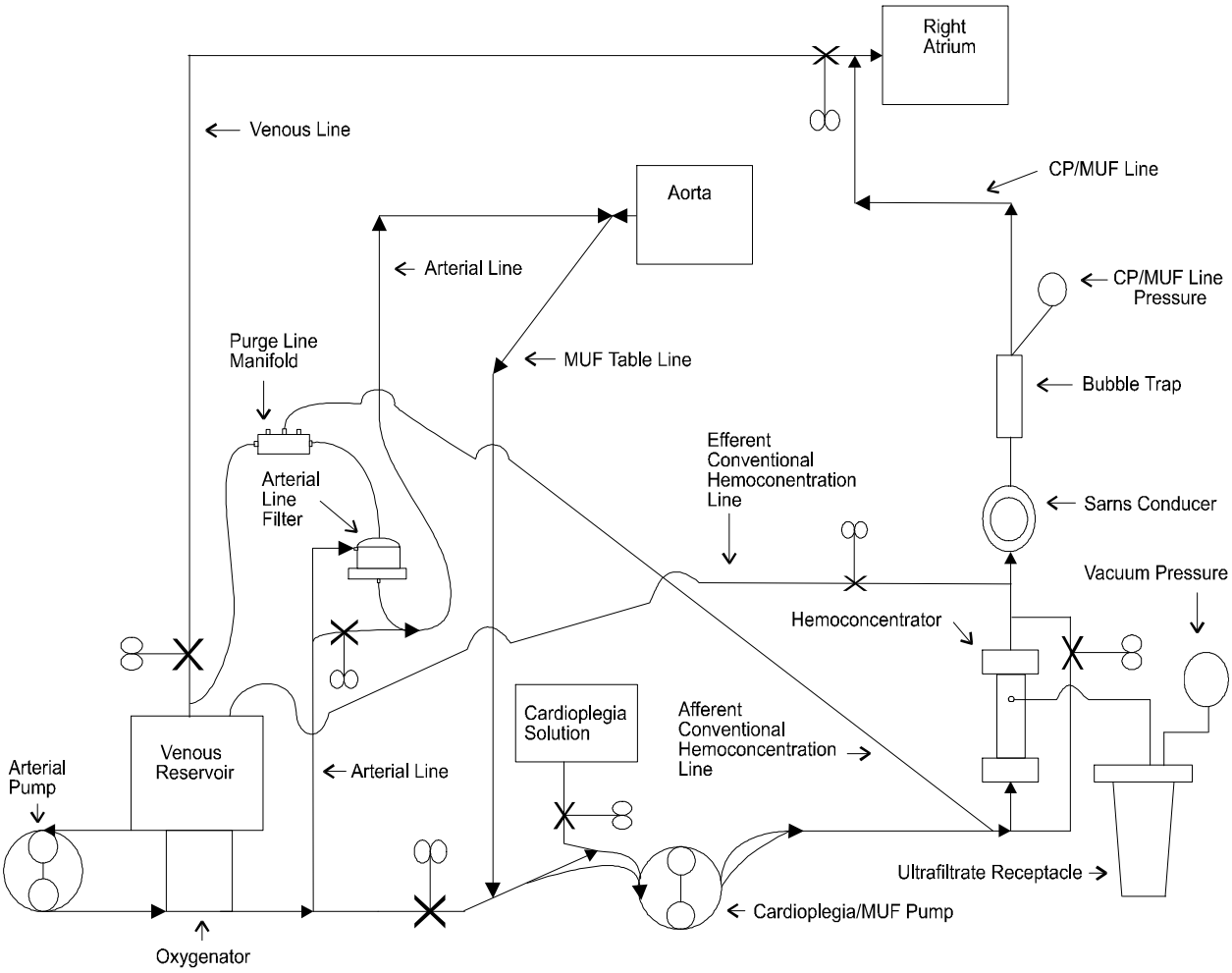
Cardiolpegia / Modified Ultrafiltration Circuit

Conventional Hemoconcentration Configuration



Cardiolpegia / Modified Ultrafiltration Circuit

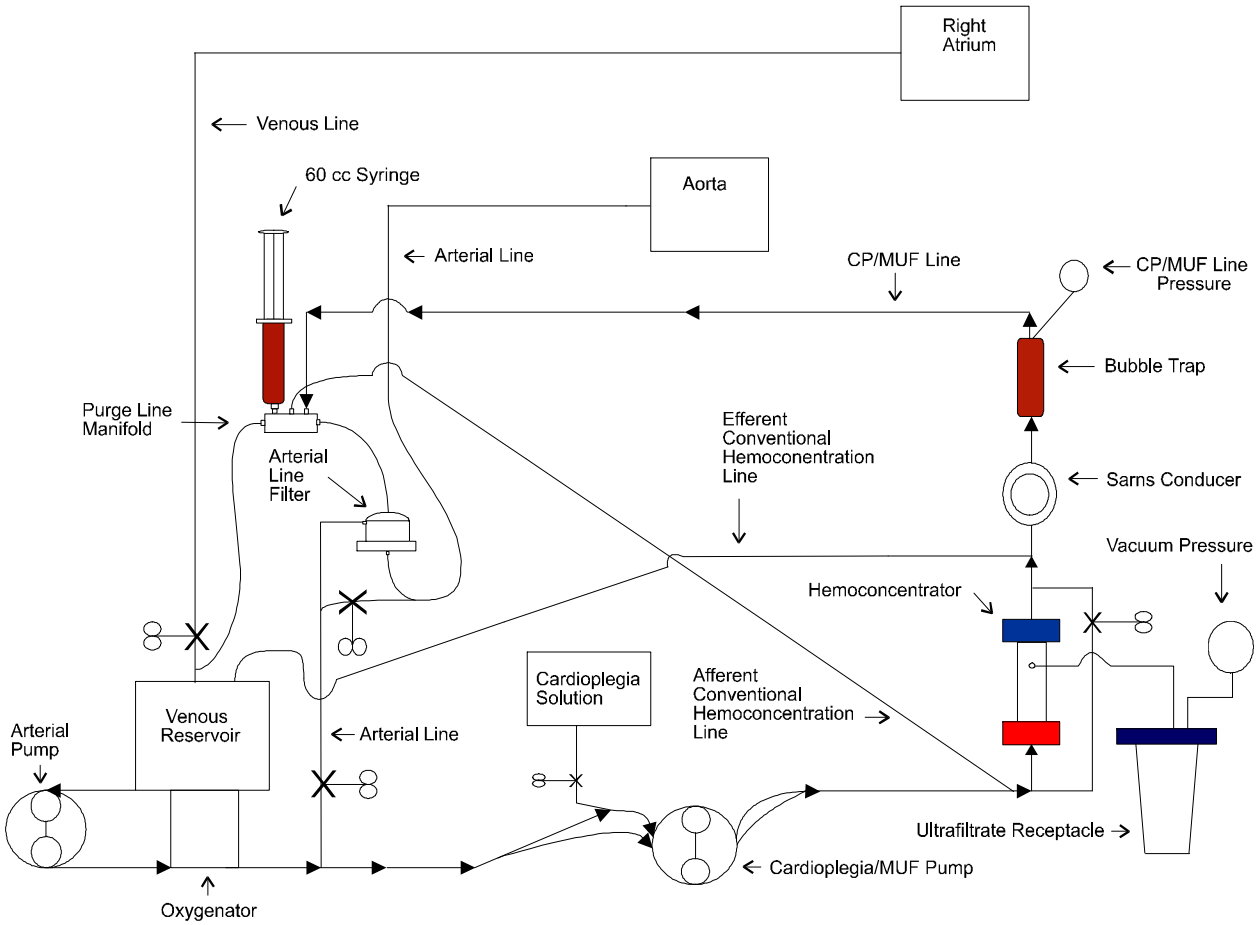
Modified Ultrafitration Configuration



Implemented: March 23, 1995 Revised: July 1, 1998

Cardiolpegia / Modified Ultrafiltration Circuit

Post-MUF Circuit Volume Salvage Configuration



Set-Up

1. Open the Cardioplegia/MUF Pack and insert the Minntech HP400 hemoconcentrator.
2. The hemoconcentrator is primed at the same time as the cardioplegia system. It is recommended that the ultrafiltrate line be attached to the hemoconcentrator and clamped before priming.
3. **Make certain that the CP/MUF pump is totally occlusive.**
4. The scrub nurse will need the following supplies:
    - 1 venous connector with a luer lock. This connector should be placed on the IVC cannula if bicaval cannulation is going to be utilized. Otherwise, it can be placed on the venous cannula used for SAC.
    - An arterial connector with a luer lock unless a DLP wire wound arterial cannula is used since it already has a luer lock connector.
    - A MUF table line. A separately packaged MUF table line is contained in the Cardioplegia/MUF Pack. Spares are located on the bottom shelf of the cabinet labeled Avox Oximeter if the original is contaminated.
5. A suction canister with regulated suction is required.
6. After the last dose of cold cardioplegia is administered, switch the dual heater-cooler to warm mode. Make sure the temperature setting is at 42^{o}C.
7. Sometime after delivery of the last cardioplegia dose, the cardioplegia system must be flushed of high K^{+} solution before MUF can commence in order to prevent transient hyperkalemia from possibly inducing cardiac arrest. This can be accomplished by doing the following procedure:
    - Clamp the crystalloid line proximal to the bridge between the crystalloid line and the blood line.
    - Remove the clamp from the bridge between the crystalloid line and the blood line.
    - Transfuse, via the cardioplegia system, approximately 80 mL (roughly equal to 5 or more complete rotations of the pump head) into a basin on the field. Have the volume returned to the pump via the sucker/cardiotomy system. Clamp the cardioplegia line.
    - In order to facilitate the connection between the cardioplegia line and luer lock connector on the IVC or single atrial cannula, pressurize the cardioplegia system until the cardioplegia aneroid reads approximately 150 mmHg.

- *Note: This procedure ought to be done prior to CPB termination should hemodynamic problems occur post-CPB.

8. After the cardioplegia line has been flushed and the patient is still on CPB, the MUF table line is set-up as follows:
   a. The cardioplegia blood line is clamped between the arterial line and the luer lock connector proximal to the cardioplegia pumphead inlet.
   b. The MUF line is passed from the table to the perfusionist and connected to the luer lock connector proximal to the cardioplegia pumphead inlet.
   c. The MUF table line is then flushed by slowly opening the clamp between the arterial line and the luer lock connector proximal to the cardioplegia pumphead inlet. Have the volume returned to the pump via the sucker/cardiotomy system. When the line air free, clamp the MUF table line.
   d. Do not clamp the cardioplegia blood line between the arterial line and the luer lock connector proximal to the cardioplegia pumphead inlet at this time.

CPB Termination, MUF Initiation, & MUF Technique

1. **The patient must remain heparinized while MUF is taking place.**
2. CPB is terminated in the usual manner with clamps placed on both the venous and arterial lines.
3. If the patient had bicaval cannulation, the SVC cannula is removed and placed in a basin of normal saline. If single atrial cannulation was used, the "bunny ear" on the venous line is placed in a basin of normal saline. The venous line is then chased from the field with normal saline. When the venous line is clear, clamp the venous line just proximal to the venous inlet.
4. After the venous line is chased, the surgeon connects the cardioplegia line to either the single atrial or IVC venous cannula. To facilitate this connection, the surgeon will request that perfusionist "bump up the cardioplegia line." This is accomplished by slowly releasing the pressure on the cardioplegia line by carefully opening the clamp on the cardioplegia line. Once an air free connection is made, clamp the cardioplegia line.
5. After the CP line is connected to the venous line, the surgeon connects the MUF table line to the arterial cannula. To facilitate this connection, the surgeon will request that perfusionist "bump up to the arterial line." This is accomplished as follows. First, remember that the arterial line is and should remain clamped during this connection. Under no circumstances open the recirculation line during this connection because it will de-prime the MUF table line. Second, remove the clamp from the MUF table line. Third, slowly turn on the arterial pump until the surgeon

has made an air free connection. Fourth, clamp the CP blood line between the arterial line and the bridge between the CP blood line and the crystalloid line. This ensures that the perfusate in the arterial line and arterial line filter will enter the MUF circuit at the arterial cannula during MUF.

6. The surgeon will now tell the perfusionist to initiate MUF. However, the perfusionist should take a few seconds to check over the MUF circuit. Refer to "Cardioplegia/Modified Ultrafiltration Circuit: Modified Ultrafiltration Configuration" on page 47 for tubing clamp orientation during MUF. Remove the clamp on the arterial line and the CP line. Verify that there are no clamps on the arterial line except for the arterial filter bypass line. Make sure that the CP blood line between the arterial line and the MUF line connection is clamped. Trace the MUF circuit from the arterial line to the venous line. There should only be a clamp between the 2 luer lock connectors distal to the CP pump. This clamp ensures that the perfusate flows through the hemoconcentrator. Use the diagram provided below to verify clamp placement for MUF initiation.
7. The perfusionist must consult with the surgeon and anesthesiologist to determine the target filling pressure necessary to achieve hemodynamic stability.
8. To initiate MUF, the cardioplegia pump is turned on and eased up to 10 mL/kg. Once flow is established and the patient is stable, start the arterial head slowly. The arterial pump should run slower than the CP pump. Provided the patient remains stable, the flow can be increased up to 15 - 20 mL/kg, not exceeding 200 mL/min. **The absolute maximum flow rate during MUF is 200 mL/min.**
9. **The flow rate of the arterial pump should never exceed the flow rate of the CP pump.** Remember that the actual flow of the CP pump is 20% less than the digital display when the crystalloid line is clamped or taken out of the raceway.
10. **Be vigilant for air in the MUF line. During MUF, manipulation of the aorta or heart can cause the arterial cannula to become inadvertently stuck against the aortic wall causing cavitation. Cavitation is particularly dangerous at higher flow rates. If air is spotted, immediately discontinue MUF and inform the surgeon.**
11. Connect the suction line and ensure the suction is initially set at -150mmHg. Provided the patient is stable, the suction can be gradually increased to facilitate more rapid ultrafiltration. However, suction in excess of -200 mmHg is not recommended. **Under no circumstances set the vacuum regulator to "line" during MUF.**

12. **If for some reason MUF must be emergently discontinued, be sure to release the vacuum. If the vacuum is left on and the CP/MUF pumphead is not occlusive, air could be pulled across the oxygenator membrane de-priming the extracorporeal circuit.**
13. Continuously monitor the hemodynamic status of the patient. In the event that the filling pressure drops below the target value, the arterial head output can be increased and/or the cardioplegia/MUF head output can be decreased. In the event that the filling pressure increases above the target value, the arterial head output can be decreased and/or the cardioplegia/MUF head output increased.
14. Make certain the arterial line pressure remains positive at all times because air could be drawn into the arterial line.
15. MUF should continue for approximately 10 minutes or terminated because . . .
    a. There are no red cells left in the extracorporeal circuit to be salvaged.
    b. The target Hct has been achieved.
    c. The patient becomes unstable.
    d. Air is spotted in the MUF table line or CP line.

Termination of MUF

1. Stop the CPS and the arterial pump heads.
2. Make sure all the pertinent data was recorded on the MUF Data Sheet.
3. The surgeon can decannulate, removing the CP line and MUF table line and placing caps on the luer ports in case there is a need to re-initiate CPB.
4. A Hepcon heparin assay may be performed to determine the appropriate protamine dose. The sieving coefficient of heparin is 0.2. Consequently, MUF may increase patient heparin concentration, and the appropriate protamine dose may be higher than expected.
5. Give anesthesia a couple of 60 cc syringes of concentrated blood from the MUF circuit so they can transfuse volume if needed after MUF.

SECTION 5: Special Procedures

Left Heart Bypass

Overview

- Minimal heparinization: 50 - 100 units/kg. Carmeda coated components should be used if available. ACT's are not routinely monitored. With this technique, the patient is the reservoir. Of critical importance is the ability of the anesthesiologist to maintain patient volume load Accordingly, adequate venous access to allow large amounts of volume to be transfused is necessary.
- If the patient is large enough, a dual lumen endotracheal tube is utilized to selectively ventilate right lung, while the left is collapsed during exposure and repair. If the patient cannot be adequately ventilated on the right lung, then full CPB or "clamp and sew" must be considered.

Required Arterial Monitoring Lines

- A femoral arterial line is necessary to monitor perfusion pressure distal to the clamped aorta.
- A right radial arterial line is necessary to monitor perfusion pressure proximal clamped aorta.

Cannulation

- Left atrium to femoral artery or left atrium to descending aorta.
    - **Left Atrium:** Usually a DLP angled metal tip (Carmeda coated if available).
    - **Femoral Artery:** Usually a DLP wire reinforced, Bard whistle tip, Biomedicus wire reinforced (Carmeda coated if available).
    - **Descending Thoracic Aorta:** Usually a DLP wire reinforced or a angled or straight THI (Carmeda coated if available).

Equipment

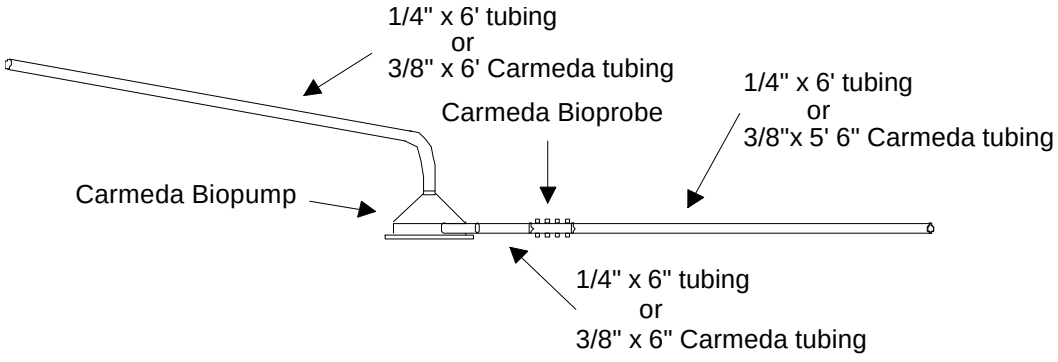
1. Biomedicus console with flow probe transducer
2. Biomedicus disposable blood pump (Carmeda coated if available).
    - For flows < 3 L/min, use the pediatric Biomedicus pump.
    - For flows > 3 L/min, use the adult Biomedicus pump.

3. Biomedicus disposable flow probe (Carmeda coated if available). Available in 1/4" and 3/8" sizes.
4. Tubing (Carmeda coated if available).
    - For flows < 3 L/min: two 6 ft. 1/4" diameter sterile PVC tubing
    - For flows > 3 L/min: two 6 ft. 3/8" diameter sterile PVC tubing.
5. 1 sterile blade
6. 1 large sterile basin (obtained from circulating RN or sterile supply)
7. 2 sterile tubing clamps
8. Approximately 5 liters of warm normal saline solution (located in the sterile room warmer)
9. Sterile gown, sterile gloves, and a sterile table cover.
10. Small table for sterile assembly and placement of the pump during the procedure.
11. Sterile towels (at least 2)
12. Cannulae (Carmeda coated if available) per surgeon's request

Setup

1. In the OR, cover a table with a sterile drape to create a sterile field on which the circuit can be assembled.
2. Place all the sterile, disposable supplies on the sterile field. Pour the priming solution into the basin and discard the bottles.
3. Scrub, gown and glove.
4. Get the tubing clamps from the scrub nurse.
5. Construct and prime the circuit by submersion using the "Pediatric Left Heart Bypass Circuit Diagram" below as a guide.

Pediatric Left Heart Bypass Circuit Diagram



6. Dry the circuit off with sterile towels and hand it to the scrub nurse.
7. When the aortic lesion and cannulation sites are exposed, the Biopump portion of the circuit will be handed off the field to the perfusionist for attachment to the Biomedicus console.

Balance and zero the Bioprobe transducer.

Initiation

- Initiation of left heart bypass is made at the surgeons request, and accomplished by unclamping the Biopump inlet and then the Biopump outlet.

Perfusion Parameters

- **Distal Perfusion:** Maintain a minimum flow according the chart below at a mean arterial pressure of 20 - 60 mmHg.

Patient Kilogram Weight	Blood Flow Rate
0 - 3 kg	100 ml/kg/min
3 - 10 kg	75 ml/kg/min
10 - 15 kg	63 ml/kg/min
15 - 30 kg	50 ml/kg/min
> 30 kg	38 ml/kg/min
>55 kg	33 ml/kg/min

- **Proximal Perfusion:** After placement of the aortic clamps, adjust the blood flow rate or have the anesthesiologist transfuse volume to maintain a proximal pressure of **80 -120 mmHg systolic.**

Termination

- Termination of left heart bypass is made at the surgeon's request, and accomplished by clamping the Biopump outlet and then the Biopump inlet.

Interrupted Aortic Arch Arterial Cannulation

Initial Arterial Cannulation

- Patients with interrupted aortic arch require arterial cannulation both proximal and distal to the point of interruption to ensure adequate perfusion. To this end, the surgeon will construct a bifurcated arterial line at the table.
- The two arterial cannulae must be equal in size to ensure that blood flow to the upper and lower body is equally distributed. Accordingly, the perfusionist will determine what size arterial cannulae would safely accommodate the maximal blood flow rate required for adequate perfusion. Typically, the proximal arterial cannulation site is the aortic root. The distal arterial cannulation site is just distal to the interruption.

Post-Repair Arterial Cannulation

- The repair of interrupted aortic arch usually requires DHCA (see DHCA protocol above) during which one or both arterial cannulae are removed.
- After the repair has been effected, adequate perfusion necessitates only aortic root cannulation. The perfusionist must make certain that the arterial cannula used is large enough to accommodate the maximal blood flow rate.

SECTION 6: Transplant Protocols

Heart Transplant

Equipment Selection

Arterial Filter Selection Guidelines For Transplant Cases		
Type	Pall Leuco-Guard 3	Pall Leuco-Guard 6
Criteria	$\leq$ 3000 ml/min	> 3000 $\leq$ 6000 ml/min

Cooling

- Patient is cooled to a bladder temperature of 28^{o}C by maintaining a perfusate temperature of approximately 28^{o}C unless requested otherwise by the attending surgeon..

Cardioplegia

- At the surgeon's discretion, 15 ml/kg cold maintenance cardioplegia is delivered antegrade to the donor heart.

Post-Aortic Crossclamp Pharmacology

- **Drug Regimen**
  - 30 mg/kg methylprednisolone (Solu-Medrol)
  - 250 mg/kg Mannitol

- **Delivery Time**
  - Administer the regimen when the aortic crossclamp is released

Implemented: December 8, 1997

Heart & Lung Transplantation

Perfusionist Responsibilities

Steroid Administration

- The perfusionist is responsible for steroid administration.

Pneumoplegia

- The perfusionist is responsible for the delivery of pneumoplegia.

CPB

- The perfusionist is responsible for the assembly and operation of the appropriate extracorporeal circuit.

Intraoperative Pneumoplegia Delivery for Heart & Lung Transplantation

Equipment

1. IV pole
2. ice bucket

Supplies

- All of the supplies listed below are located in the organ transplant supply room next to OR #15 except the TUR Y-Set, which is located in the Cores.

1. 1000 ml bag of ViaSpan
2. Penicillin G
3. Regular Insulin
4. Dexamethasone
5. in-line Pall Blood Transfusion Filter (No. SQ4OS)
6. non-sterile ice
7. TUR Y-Set

Pre-Administration Instructions

1. Obtain a 1000 ml bag of ViaSpan from the refrigerator in the organ transplant supply room.
2. Inject the ViaSpan with the following drugs located in a drawer across from the refrigerator:
    - 40 units Regular Insulin
    - 16 mg Dexamethasone
    - 200,000 units Penicillin G

    Do not inject the Penicillin G if the organ recipient has an allergy to penicillin.

Implemented: December 8, 1997

3. Ice down the ViaSpan in the bucket.

Administration Instructions

1. Hand the TUR Y-Set sterilely to the sterile field.
2. When the scrub nurse passes off the TUR Y-Set, attach the Pall Blood Transfusion Filter and spike the ViaSpan.
3. Hang on IV pole and gravity prime the line to the field.
4. Wait for instructions to begin pneumoplegia delivery.
5. Guidelines for delivery of pneumoplegia
    a) Heart & Lung Transplantation
        - The first pneumoplegia dose is generally given when the lung comes out of cold storage.
        - ~30 ml/kg is given at this time.
        - Rarely, a second pneumoplegia dose is given just prior to reperfusion of the donor lung.

CPB

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