# FORMULAE & CALCULATION PERFUSION HAND BOOK

## Cardiopulmonary Bypass
## Standard Calculations Guide

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## Preface :

Working as a perfusionist is a highly challenging and rewarding career path. The educational standards are high, and the profession appeals to those interested in working on surgical teams and in critical care scenarios.

Cardiac perfusion technology involves the use of medical devices and techniques to ensure that the heart is receiving sufficient blood flow and oxygenation. In emergency situations, errors can occur that can lead to serious complications, including heart failure and even death.This book will help a Perfusionist to calculate standard dosage of drugs, Blood products, Cannula size, Perfusion flows, fluid balance during cardiopulmonary bypass. To minimize the risk of errors and emergencies in cardiac perfusion technology, medical professionals must undergo extensive training in the use of perfusion machines and other equipment. They must also closely monitor patients during surgery and be prepared to intervene quickly in case of an emergency. Additionally, perfusion technology manufacturers must ensure that their machines meet strict safety standards and are regularly maintained to prevent malfunctions or defects. In this book we have explained the possible errors and emergency situations in a life of a Perfusionist. This book is made by the Perfusionist after years of experience and practical knowledge about the Perfusion techniques and skills required to be a quick problem solver and calculate required dosage and sizes for cardiac surgery.

Perfusion technology plays a crucial role in cardiovascular surgery, organ transplantation, and other medical procedures that require maintaining the oxygenation and circulation of vital organs. However, there are several challenges associated with perfusion technology that can impact patient outcomes. Addressing these challenges requires collaboration between healthcare providers, perfusionists, industry, and regulatory bodies to ensure safe, effective, and equitable delivery of perfusion technology to patients in need.

Perfusion technology is a vital component of cardiac surgery, and the role of perfusionists is crucial in ensuring patient safety and successful outcomes. By dedicating yourselves to learning more about perfusion technology, you are making a significant contribution to the field, and are demonstrating your commitment to the well-being of your patients.

I encourage you to continue your pursuit of knowledge and excellence in this field, and to stay engaged with the latest developments and best practices. By remaining curious, open-minded, and willing to learn, you can continue to grow and develop your skills as perfusionists, and make a meaningful impact in the lives of your patients.

Remember that every patient is unique, and every case presents its own challenges and opportunities. By staying focused, collaborative, and compassionate, you can help to ensure that your patients receive the highest quality of care, and achieve the best possible outcomes.

Thank you for your dedication to the field of perfusion technology, and for your commitment to improving patient care. Your efforts are truly appreciated, and I wish you all the best in your future endeavors.

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# 1. Blood Volume Calculations

CPB is a complex procedure that requires careful monitoring and precise calculations to ensure the patient's safety and well-being. During cardiopulmonary bypass (CPB), blood volume calculations are important to ensure that the patient is receiving adequate blood flow and to monitor the degree of hemodilution, which can occur during CPB.

Here are some of the key blood volume calculations that are performed during CPB:

1. Pre-CPB blood volume: The pre-CPB blood volume is the total volume of blood in the patient's body before the start of CPB. This can be estimated based on the patient's weight, height, and body surface area. Knowing the pre-CPB blood volume can help determine the target blood flow rate during CPB.
2. Pump prime volume: The pump prime volume is the total volume of fluid that is used to prime the CPB circuit before the start of CPB. The pump prime volume typically includes crystalloid solution, colloid solution, and blood products. The pump prime volume should be calculated carefully to avoid excessive hemodilution during CPB.
3. Estimated blood volume (EBV): The estimated blood volume is the total volume of blood in the patient's body at any given time during CPB. EBV can be calculated based on the patient's weight, height, and hematocrit value. Hematocrit is the percentage of red blood cells in the blood, and it can be used to estimate the total blood volume. The EBV should be monitored closely during CPB to ensure that the patient is not experiencing excessive hemodilution.
4. Blood flow rate: The blood flow rate is the volume of blood that is pumped through the CPB circuit per unit of time. The blood flow rate should be adjusted based on the patient's EBV to ensure that the patient is receiving adequate blood flow and to avoid excessive hemodilution.

5. Hematocrit (Hct): Hematocrit is the percentage of red blood cells in the blood. During CPB, the hematocrit value can decrease due to hemodilution. The hematocrit should be monitored closely to avoid excessive hemodilution and to ensure that the patient is receiving adequate oxygen-carrying capacity.

These blood volume calculations are typically performed by the perfusionist, who is responsible for managing the CPB circuit and ensuring the patient's safety during cardiac surgery.

Standard blood volume calculations :

T.H Allen published the Allen blood formula in 1956.

- Male = { 0.3669 X (Cm/100 )^3) + 0.03219  X (Kg) + 0.6410
- Female = {0.3561 X (Cm/100)^3)+ 0.03308 X (Kg)} + 0.1833

Given weight Blood Volume is calculated by :

Body weight (Kg) X Volume factor = Blood Volume (ml)

| | Weight ( Kg ) | Volume Factor |
|---|---|---|
| 1 | < 10 | 85 |
| 2 | 10<20 | 80 |
| 3 | 20<30 | 75 |
| 4 | 30<40 | 70 |
| 5 | Above 40 | 65 |

# 2. Blood Flow Calculations

To calculate blood flow during CPB, the following parameters are typically measured:

1. Pump flow rate: The rate at which blood is pumped through the circuit by the heart-lung machine. This is typically measured in liters per minute (L/min).
2. Hematocrit: The percentage of red blood cells in the patient's blood. This can affect the viscosity of the blood and therefore the flow rate.
3. Venous and arterial pressures: The pressures in the venous and arterial lines of the CPB circuit. These pressures can affect the flow rate of blood.

Using these parameters, blood flow can be calculated using the following formula:

Blood flow = Pump flow rate x [(Hematocritv + Hematocrith) / 2] x [(Arterial pressure - Venous pressure) / Mean arterial pressure]
Where:

- Hematocritv is the venous hematocrit
- Hematocrith is the hematocrit measured from the CPB circuit
- Mean arterial pressure is the average of the systolic and diastolic pressures measured in the arterial line

It is important to note that this formula provides an estimation of blood flow, and other factors such as the patient's body temperature and blood pressure can also affect blood flow during CPB. Therefore, clinical judgement and interpretation of multiple parameters are important for the optimal management of CPB.

# 3. Perfusion Flow Rate

The required perfusion flow on cardiopulmonary bypass (CPB) depends on several factors, including the patient's body surface area, weight, metabolic rate, and cardiac output. The goal of CPB is to provide adequate blood flow and oxygenation to the patient's organs while maintaining stable hemodynamics.

The Perfusion flow is calculated depending upon the patients weight, height, Body surface area and cardiac index.

Where:

- Body surface area is the patient's body surface area, which can be calculated using a formula such as the Dubois formula.
- Cardiac index is the cardiac output per unit of body surface area, which can be measured using a pulmonary artery catheter or estimated using echocardiography or other methods.
- Target perfusion pressure is the desired pressure gradient across the oxygenator or the membrane lung.
- Mean arterial pressure is the average of the systolic and diastolic pressures measured in the arterial line.

The target perfusion pressure can vary depending on the type of oxygenator or membrane lung used and the clinical situation. In general, the goal is to maintain a perfusion pressure gradient of 20-30 mmHg across the oxygenator or membrane lung.

It is important to note that the required perfusion flow may need to be adjusted based on the patient's response to CPB, such as changes in metabolic rate, cardiac output, or vascular resistance. Close monitoring of hemodynamics and other parameters is essential for the optimal management of CPB.

There are other formulas to calculate BSA, such as the Mosteller formula, which is based on the person's height and weight and is simpler to use. However, the Dubois formula is still commonly used in clinical practice and research.

There are several formulas available to calculate BSA, but the most commonly used formula is the Mosteller formula, which is as follows:

BSA ($m^2$) = $\sqrt{}$[(height (cm) x weight (kg)) / 3600]

Where:

- Height is measured in centimeters (cm)
- Weight is measured in kilograms (kg)

For example, if a person is 170 cm tall and weighs 70 kg, the BSA can be calculated as follows:

BSA = $\sqrt{}$[(170 cm x 70 kg) / 3600] BSA = $\sqrt{}$(11900 / 3600) BSA = $\sqrt{}$3.31 BSA = 1.82 $m^2$

Other formulas that can be used to calculate BSA include the DuBois formula, which was previously mentioned, and the Haycock formula, which is similar to the Mosteller formula but uses a different constant:

BSA ($m^2$) = 0.024265 x height (cm)^0.3964 x weight (kg)^0.5378

The Dubois formula is a widely used formula to calculate the body surface area (BSA) of a person, which is an important parameter used in various medical calculations, including drug dosing, nutritional assessment, and cardiac output calculations.

The formula was developed by Eugene Dubois, a Belgian physiologist, in 1916.

The formula is as follows:

BSA ($m^2$) = 0.20247 x height (m)^0.725 x weight (kg)^0.425

Where:

- Height is measured in meters (m)
- Weight is measured in kilograms (kg)

Perfusion flow rate OR Pump flows are calculated with the help of these formulas.

BSA ($m^2$) = $\sqrt{[(\text{height (cm)} \times \text{weight (kg)}) / 3600]}$

Where:
- Height is measured in centimeters (cm)
- Weight is measured in kilograms (kg)

For example, if a person is 170 cm tall and weighs 70 kg, the BSA can be calculated as follows:

BSA = $\sqrt{[(170 \text{ cm} \times 70 \text{ kg}) / 3600]}$ BSA = $\sqrt{(11900 / 3600)}$ BSA = $\sqrt{3.31}$ BSA = 1.82 $m^2$

Now once you get the BSA of the patient, next step is to calculate the Perfusion flow required for the patient by using the following formula :

Pump flows = BSA X Cardiac index

Recommended Cardiac index :
Adult - 2.4$m^2$
Pediatric - 2.8$m^2$

If the patients BSA is 1.8$m^2$

1.8 X 2.4 = 4.32 /L/min

required flows = 4.32/L/min

It is important to note that the pump flow rate may need to be adjusted during cardiopulmonary bypass to maintain appropriate hemodynamics and oxygen delivery. Additionally, other factors such as the patient's blood pressure, oxygen saturation, and temperature should also be monitored closely during the procedure.

Arterial flow rate  Pediatric :

The estimatedArterial flow rate for different age/weight group  are as follows :

0-5kg - upto 6 months  - 200ml/Kg
5-10kg - upto 1 year - 150 - 200ml/kg
10-15Kg - upto 3 years - 150 - 180ml/Kg
15-20kg - upto 6 years - 120 - 150ml/Kg

# 4. Monitoring on CPB

• Mean Arterial pressure :

Paediatric :
Mean arterial pressure vary widely for a given flow to other variables like SVR, viscosity, vascular compliance.

A mean of 30mmHg ( 25-50) is well acceptable for paediatric patients if SVC saturation is >70%, normal ABG, urine output and proper temperature is maintained.

Adult :
In adult patient mean arterial pressure is decided considering the patients Pre-op mean pressure. The possibility of any vascular disease ( Carotid/Renal stenosis ) is checked . Generally a mean pressure of 40-80mmHg is acceptable for adult patients.

• Venous Saturation :

Venous saturation is maintained above 70% ( 55%-85% ). The higher saturation doesn’t ensure the adequacy of cerebral Perfusion because of hypothermia, increased A-V shunting, different drugs, catechalomine levels shock during cardiopulmonary .

• Blood Gases :
The blood gases checked before going on cardiopulmonary bypass should be taken as the referral values. The PaO2 is maintained low (80-100mmHg) in case of cynatotic patients during the initial period of cPB. PaO2 is maintained high (40-50 mmHg) during cooling, which may improve cerebral circulation and helps in uniform cooling. The PaO2 is maintained (>100 mmHg) during rewarming and PaO2 to a lower level (30-40 mmHg) after 32 degree especially in patients with moderate to severe pH level.

• Isoflurane :
Isoflurane is used from the anaesthesia machine the O2 and gas flow should be calculated in (ml) accordingly. For Eg: if required percentage is 50% with flow of 1l/min then 630ml of air and 370ml of O2 through anaesthesia machine will give same composition.

• Haematocrit :
The haematocrit is maintained adequately at Pre-determined values. In paediatric patients below 5kg 30-35%, in the patients 6-15kg 25-30% is acceptable.
In adult patients haematocrit of 20-25 is acceptable.
Haemofiltration is used if extra volume is needed to be removed during CPB. It is used in cases of severe PAH patients and if the reservoir volume is to be utilised completely during CPB.

# 5. Temperature Management

During cardiopulmonary bypass (CPB), the blood flow rate is typically adjusted based on the patient's body temperature. Here is a general guideline for blood flow rates based on temperature:

1. Normal body temperature (37°C):
2. At normal body temperature, the blood flow rate is typically around 2.2-2.5 L/min/$m^2$ of body surface area.
3. Mild hypothermia (28-32°C):
4. As the patient's body temperature decreases, their metabolic rate and oxygen consumption may decrease as well. During mild hypothermia, the blood flow rate may be reduced to 1.6-2.0 L/min/$m^2$ of body surface area.
5. Moderate hypothermia (18-28°C):
6. During moderate hypothermia, the blood flow rate may be further reduced to 1.2-1.6 L/min/$m^2$ of body surface area.
7. Deep hypothermia (<18°C):
8. At deep hypothermia, the blood flow rate may be reduced to as low as 0.8-1.2 L/min/$m^2$ of body surface area.

It is important to note that these are general guidelines, and the blood flow rate may need to be adjusted based on the patient's specific clinical condition, metabolic rate, and other factors. Additionally, during CPB, the patient's hemodynamics and perfusion should be carefully monitored, and adjustments should be made as necessary to maintain appropriate oxygen delivery and organ function.

During hypothermia the flow rate can be reduced by 25% as the temperature decreases to 30-32 degree, 50% at 24-26 degree ( Approximately 7% reduction can be done per degree )

Temperature management during cardiopulmonary bypass (CPB) is a critical aspect of patient care during cardiac surgery. The patient's body temperature is typically lowered during CPB to reduce the metabolic demands of the body and protect organs such as the brain and heart.

To prevent hypothermia, the patient is often covered with warming blankets or placed in a warming cabinet to maintain their body temperature. The perfusionist, who is responsible for the heart-lung machine, will monitor the patient's core temperature and adjust the temperature of the circulating blood and oxygenator as needed to maintain the desired temperature range.
During the rewarming phase at the end of CPB, the patient's body temperature is gradually increased to a normal level. This process is monitored closely to avoid rapid changes in temperature, which can lead to complications such as arrhythmias, blood pressure fluctuations, and coagulopathy.

• Cooling Procedure :
Adult patients: A gradient of 10 degree is acceptable for cooling. Gradient should be reduced if patient has AR or any left to right shunt. Adequate amount of vasodilation should be achieved to ensure uniform cooling.

Paediatric patients: High gradient is acceptable in case TCA is anticipated. Set temperature 4 degree is maintained once the nasal and rectal temperature reaches 26 degree . Adequate vasodilation is maintained using Isoflurane , phenoxybenzaine, Nitroprusside is recommended. Once the Nasal/Rectal temperature 16 degree the set temperature is maintained at 16 degree . The nasopharyngeal and rectal temperature is monitored and it should not be more than 2 degree. In case of higher differences adequate flow, vasodilation, selective perfusion is checked. The cooling is continuously maintained till nasal and rectal temperature reaches the target values.

• Rewarming :
Adult patient : Rewarming is done slowly keepinga gradient of 6-8 degree. Vasodialators are use to ensure uniform Rewarming.

Paediatric patient : Rewarming is done keeping a gradient of 4 degree to achieve nasal temperature of 35 degree and rectal above 34 degree.

# 6. Ultrafiltration  Calculations

Ultrafiltration is a technique used during cardiopulmonary bypass (CPB) to remove excess fluid and electrolytes from the patient's blood. This technique helps to prevent complications such as pulmonary edema, cardiac dysfunction, and electrolyte imbalances that can occur after CPB.

During ultrafiltration, a portion of the patient's blood is removed from the circuit and passed through a specialized filter that separates excess fluid and electrolytes from the blood. The filtered blood is then returned to the patient's body, while the excess fluid is discarded. The rate of ultrafiltration is carefully controlled by the perfusionist to avoid excessive fluid removal, which can lead to hypovolemia and other complications.

Ultrafiltration is typically performed during the later stages of CPB, after the patient's body temperature has been gradually increased and the heart has been successfully restarted. It can also be used during CPB in patients with pre-existing fluid overload, such as those with congestive heart failure.

While ultrafiltration can be beneficial in reducing post-CPB complications, it can also lead to a reduction in blood volume and subsequent hypotension. Therefore, careful monitoring of the patient's blood pressure and fluid status is essential during ultrafiltration.

In summary, ultrafiltration is a technique used during CPB to remove excess fluid and electrolytes from the patient's blood. It is a valuable tool in preventing post-CPB complications but requires careful monitoring to avoid hypotension and other adverse events.

Most commonly used unltrafiltrations on CPB are as follows :

- Conventional ultrafiltration (CUF)
- Modified ultrafiltration (MUF)

• conventional ultrafiltration ( CUF ) :
It is done mostly in adult patients if extra volume is present, if haematocrit is below normal value or in patients with renal dysfunction.

• Modified ultrafiltration ( MUF ) :
It gives a extra benefit of untilizing the volume after coming off bypass. The target haematocrit value can be achieved without using additional blood transfusion. Almost all paediatric patients below 10 Kg with severe PAH undergo MUF which effectively remove 200-400ml of fluid making the HCT into 45-50%. Flow rate should be at 40-60 ml and the vacuum at filtration compartment should be 125-300mmHg.

# 7. Cardioplegia dosage

Cardioplegia is a technique used during cardiopulmonary bypass (CPB) to temporarily stop the heart's beating, allowing for a bloodless surgical field and safe surgical access to the heart.
During CPB, the heart is connected to a heart-lung machine that pumps and oxygenates blood for the body while the surgical team performs the necessary repairs or procedures on the heart. Cardioplegia is used to induce a reversible cardiac arrest, which can be achieved by administering a cold potassium-rich solution directly into the coronary arteries or the heart chambers.

The potassium in the cardioplegia solution depolarizes the myocardial cells, which leads to the temporary cessation of the heart's contractions. This allows the surgical team to operate on the heart without the interference of the beating heart and reduces the risk of damage to the heart muscle during the procedure.

The duration of cardiac arrest induced by cardioplegia depends on the type of solution used and the patient's underlying medical conditions. The duration of cardiac arrest is usually limited to 60-90 minutes to minimize the risk of myocardial ischemia.
After the surgical procedure is complete, the cardioplegia is flushed out of the heart, and the heart is gradually restarted by warming and reperfusing the myocardium with oxygenated blood from the heart-lung machine. The patient's vital signs and cardiac function are closely monitored during this process to ensure that the heart is functioning normally.

There are different types of cardioplegia delivery systems and techniques used in cardiopulmonary bypass for better myocardial protection during cardiac surgery. The different techniques and delivery systems have different combinations of drugs used in cardioplegia to arest the arest the for a period. The period of cardioplegia affect on on the heart depends on the cardioplegia solutions, delivery method and the type of cardiac procedures performed for cardiac patients.

Cardioplegia dosage and methods :

• BCD : Blood cardioplegia delivery system
System is primed with plain ringers solution. 20ml of St Thomas solution and 20ml of $NaHCO_3$ is added in 200ml of plain ringer lactate. It is used in paediatric patients.
In adult patients 40ml St Thomas solution and 40ml $NaHCO_3$ is added in 400ml of plain ringer lactate. ( This gives a delivery composition of 20mmol of $K^+$ ).
low dose is used if $K^+$ is >6mmol with 20ml of St Thomas solution in 400ml of ringers lactate. ( delivery composition of 10mmol of $K^+$ ). Cardioplegia time of 25-35 min, repeat the subsequent dosage as requirement. Temperature for delivery is 8-12 degree of better mayocardial protection.

• Koles chamber :
Priming with ringers lactate max upto 25% of total cardioplegia dose istaken in the unit circulated and cooled. 2ml St Thomas solutions with 2ml $NaHCO_3$ per 100ml of cardioplegia dose is added for induction dose as full dose Cardioplegia. This gives a composition of 20mmol of $K^+$ approx . Subsequent dose include 2ml of St Thomas solution and 2ml of $NaHCO_3$ per 200ml of cardioplegia dose. Cardioplegia time of 25-30mins, repeat the subsequent dosage as per requirement of the procedure. Temperature for delivery is 8 degree for proper myocardial protection.

• Delnido cardioplegia:
Solution is prepared in a 50cc syringe with the composition potassium $k^+$, Magnesium, $NaHCO_3$, Manitol and Xylocard.
Potassium $K^+$ - 13ml
$NaHCO_3$ - 16ml
Manitol - 16ml
Magnesium - 2ml
Xylocard 1% - 13ml
This gives a cardioplegia time of 60-90min
Temperature for delivery is 4-8 degree for better mayocardial protection and effective dose.

The delivery pressure of cardioplegia during cardiopulmonary bypass (CPB) is an essential aspect of cardiac surgery, as it affects the efficiency of the cardioplegia solution's delivery to the heart and its subsequent distribution through the coronary arteries.

The delivery pressure of cardioplegia is usually between 100 to 150 mmHg, although this can vary based on the type of cardioplegia solution used, the patient's condition, and the surgeon's preference. The pressure is typically controlled by adjusting the flow rate and the pressure of the cardioplegia pump.

If the delivery pressure is too high, it can lead to an increased risk of myocardial damage, as it can cause overdistension of the coronary arteries and lead to reduced coronary blood flow. On the other hand, if the delivery pressure is too low, it may result in inadequate distribution of cardioplegia to the heart, leading to incomplete cardiac arrest and possible damage to the myocardium during surgery.

To ensure the safe and effective delivery of cardioplegia during CPB, the perfusionist closely monitors the delivery pressure and adjusts it as necessary to maintain the appropriate pressure range. In addition, other factors, such as the temperature of the cardioplegia solution and the duration of cardiac arrest, are also closely monitored to ensure the successful completion of the procedure.

The cardioplegia dosage is calculated according to the weight of the patient.

Adult : 15-20ml/kg
Paediatric : 30/Kg

# 8. Priming volume on CPB

- Prime Composition:

- Ringers Lactate
- Haes-sterile 6% - 20ml/Kg or 500ml
- Manitol 20% - 0.4gm/Kg - 1gm/kg
- $NaHCO_3$ 7.5% - 25ml/litre - 50ml/litre
- Heparin 50mg/litre
- Blood products as per requirement

Note: In cynotic patient 50ml $NaHCO_3$ is added.
In neonatal case Tri hydroxy methyl amino methane ( THAM ) is preferred.

Priming calculations:

Adult: 1200ml to 1500ml of total prime volume of various composition and drugs.

Paediatric : 500ml to 100ml of total prime volume including composition of drugs. Avoid Normal Saline.

# 9. Calculation of circulating haematocrit

The circulating Haematocrit is calculated according to the following equations :

$$C2 = \frac{P1 \times C1}{P2}$$

P1 is patients blood volume
C1 is patients haematocrit
P2 is patients blood volume + prime volume
C2 is haematocrit during CPB

# 10. Calculations of additional blood products

Requirement of blood products can be calculated by the following equation :

$$\text{Volume of blood required} = \frac{\{ (P2XC2) - (P1XC1) \}}{35 \text{ OR } 70}$$

$$CHct = \frac{BV \text{ X } Hct}{BV \text{ X } PV}$$

CHct is Circulating haematocrit
BV is the blood volume
PV is Prime volume
Hct is the patients haematocrit

In adult patients CHct should be > 20% if it is less than 20% blood products should be added.
In paediatric patients CHct should be > 30% if it is less than 30% blood products should be added.

$$Breq = \frac{( BV+PV)\ RCHct-BVxHct}{30 \text{ OR } 70}$$

Breq is blood/pack cell required
PV is prime volume
Hct is patients haematocrit
35 is whole blood used
70 is pack cell used
PCHct is required CHct

other equation as follows:

$$Breq = BV - \frac{\{ Req\ Hct\ ( BV+PV ) \}}{Hct}$$

In paediatric patients fresh whole blood is preferred. In all blood primes the pH & electrolytes are checked and corrected.

# 11. Calculations for collection of Autologous Blood

Autologous blood prime refers to the use of a patient's own blood to prime the cardiopulmonary bypass (CPB) circuit during cardiac surgery. This technique is used to reduce the amount of foreign material introduced into the patient's bloodstream and minimize the risk of transfusion-related complications.

The process of autologous blood prime involves collecting and processing the patient's blood prior to the surgery. The collected blood is then filtered, centrifuged, and added back into the CPB circuit to replace the traditional priming solution. This technique has been shown to reduce the need for allogeneic (donor) blood transfusions during and after cardiac surgery.

Autologous blood prime is typically used in patients undergoing elective cardiac surgery, and it is not suitable for emergency situations or patients who are unable to donate their own blood. Additionally, this technique may not be appropriate for patients with certain medical conditions, such as anemia or coagulation disorders.

Overall, autologous blood prime is a safe and effective method of reducing the need for allogeneic blood transfusions during cardiac surgery. However, it requires careful planning and coordination between the surgical team and blood bank to ensure that the patient's own blood is collected and processed in a timely and efficient manner.

It is important to note that the calculation of autologous blood prime requires careful monitoring and adjustment during surgery to ensure that the patient's hemodynamics and oxygen delivery are maintained within appropriate limits.

• Equations for collection of autologous blood :
In cyanotic patients with high haematocrit if the circulating haematocrit is above 25% the amount of blood to be collected is calculated according to the following equation.

$$Bcol = BV - \frac{\{ Req\ Hct\ (BV + PV) \}}{Hct}$$

Bcol = Amount of blood to be collected

Equal amount of plasma or colloid ( or albumin ) is given to the patient to avoid hypertension.

However, a general formula for calculating the required volume of autologous blood is:

Autologous blood volume (mL) = Patient's body weight (kg) x (desired hematocrit - patient's preoperative hematocrit) x 0.5
For example, if a patient weighs 70 kg and has a preoperative hematocrit level of 40% and a desired hematocrit level of 30%, the calculation would be:

Autologous blood (mL) = 70 kg x (30% - 40%) x 0.5 = -350 mL

This means that the patient would need to donate 350 mL of their own blood prior to surgery, which would then be used to prime the cardiopulmonary bypass circuit during the procedure. It's important to note that the formula may need to be adjusted based on individual patient factors, and should only be used under the guidance of a qualified medical professional.

# 12.Calculation of circulating Oncotic pressure

.To calculate circulating oncotic pressure, you can use the following formula:

Circulating oncotic pressure (mmHg) = 2.8 x plasma albumin concentration (g/dL)

For example, if a patient has a plasma albumin concentration of 3.5 g/dL, the circulating oncotic pressure can be calculated as:
Circulating oncotic pressure = 2.8 x 3.5 = 9.8 mmHg

It's important to note that this formula assumes that albumin is the only significant plasma protein contributing to the oncotic pressure. In reality, other proteins such as globulins and fibrinogen may also contribute to the total oncotic pressure, so this formula provides an estimation rather than an exact calculation. Additionally, factors such as fluid shifts and changes in vascular permeability can affect circulating oncotic pressure, so it should be interpreted in the context of the patient's clinical condition.

Other equation is as follows:
The amount of plasma protein to be given or to be added to the priming fluid is calculated according to the following equation.

$$PLvol = \frac{BV(100-Hct)}{100}$$

PLvol = Plasma volume of patient
BV = Blood volume
Hct = Hct of the patient

PLvol X Novp = (PLvol + PV) Cocp

Cocp = circulating oncotic pressure
Nocp = Normal oncotic pressure

$$Cocp = \frac{PLvol \times Nocp}{PLvol + PV}$$

# 13.Calculation for addition of Plasma

The addition of plasma during cardiopulmonary bypass (CPB) can be necessary to maintain appropriate levels of circulating blood volume and coagulation factors. The amount of plasma to be added is calculated based on the patient's weight, hematocrit level, and desired plasma volume expansion.

Here is a general formula for calculating the amount of plasma to add during CPB:

Plasma volume to add (mL) = (patient weight in kg) x [(desired hematocrit - actual hematocrit)/desired hematocrit] x (estimated blood volume in L/kg) x (plasma volume as a fraction of blood volume)

The estimated blood volume in L/kg varies depending on the patient's age, sex, and body habitus. A commonly used value for adults is 70 mL/kg. The plasma volume as a fraction of blood volume is typically around 0.25, although this can also vary based on individual patient factors.

For example, if a patient weighs 70 kg, has an actual hematocrit of 30%, and a desired hematocrit of 35%, the calculation would be:
Plasma volume to add = 70 kg x [(35% - 30%)/35%] x 70 mL/kg x 0.25 = 367.5 mL

This means that 367.5 mL of plasma would need to be added to the CPB circuit to achieve the desired plasma volume expansion. It's important to note that the formula may need to be adjusted based on individual patient factors and should only be used under the guidance of a qualified medical professional.

It's important to note that adding plasma to the CPB circuit can also increase the risk of transfusion-related reactions and infections. Therefore, the decision to add plasma should be made based on the patient's clinical condition and the judgment of the surgical team, and the process should be closely monitored to ensure patient safety.

Other equation for addition of plasma:

If the Cocp is >15 addition of plasma is required

$$PLadd = \frac{Plvol - \{ Req\ Ocp\ (Plvol + PV) \}}{Nocp}$$

PLadd = Plasma to be added

The acceptable crystalloid addition can be calculated according to the following equation :

$$ADL = \frac{BLOOD\ VOLUME. \quad \dfrac{100 - REQ\ Hct \times 100}{Hct}}{100}$$

The priming volume is taken into account considering the following variables.

- The volume transfused Pre-bypass period
- The urine output Pre-bypass period
- The cardioplegia solutions

# 14. Calculation for Anticoagulation

During cardiopulmonary bypass (CPB), anticoagulation is necessary to prevent blood clotting in the circuit and the formation of blood clots, which can cause serious complications. The anticoagulation is typically achieved by administering heparin, a medication that inhibits blood clotting.

The amount of heparin needed for anticoagulation during CPB is calculated based on the patient's weight and activated clotting time (ACT). The ACT measures the time it takes for a clot to form in a sample of the patient's blood, and is used to monitor the level of anticoagulation during CPB.

The usual target ACT during CPB is around 400-480 seconds. The amount of heparin needed to achieve this target varies depending on the patient's weight and other factors, but a commonly used formula for calculating the initial dose of heparin is:

Heparin dose (units) = patient weight (kg) x 400

For example, if a patient weighs 70 kg, the initial dose of heparin would be:

Heparin dose = 70 kg x 400 = 28,000 units

The heparin is typically administered as a bolus dose, followed by additional doses as needed to maintain the target ACT. The actual dose of heparin used during CPB may need to be adjusted based on individual patient factors and the judgment of the surgical team. It's important to note that heparin can also increase the risk of bleeding, so the anticoagulation process should be closely monitored during CPB to ensure patient safety.

The standard dose of heparin is 3-4mg/Kg ( Full does which is given by the anaesthetist before going on bypass )

Subsequent does depends on the type of surgery and the time required for the procedure.

# 15. Calculation for Total circulatory arest ( TCA )

Total circulatory arrest (TCA) is a technique used during complex cardiovascular surgeries to achieve a bloodless surgical field. During TCA, the circulation is stopped completely, and the body is cooled to decrease the metabolic rate and protect vital organs. The amount of time that TCA can be safely performed is limited, and depends on factors such as the patient's age, underlying health conditions, and the temperature at which the body is cooled.

The calculation for TCA time during CPB depends on the patient's body surface area (BSA) and the target temperature for cooling.
A commonly used formula for calculating the TCA time is:

TCA time (minutes) = 5 x BSA x [(normal body temperature - target temperature) / cooling rate]

The cooling rate can vary depending on the cooling method used, but a commonly used value is 0.25°C/min. The normal body temperature is 37°C, and the target temperature for cooling during TCA is typically between 18-22°C.

For example, if a patient has a BSA of 1.8 $m^2$ and a target temperature of 20°C, the calculation for TCA time would be:
TCA time = 5 x 1.8 $m^2$ x [(37°C - 20°C) / 0.25°C/min] = 648 minutes, or 10.8 hours

It's important to note that the TCA time calculation is only an estimate, and the actual TCA time may need to be adjusted based on individual patient factors and the judgment of the surgical team. TCA is a complex and potentially high-risk technique, and should only be performed by qualified medical professionals in a carefully monitored setting.

# 16. Correction for blood gases on cardiopulmonary bypass

During cardiopulmonary bypass (CPB), blood gases are frequently monitored to ensure adequate oxygenation and ventilation. The most commonly measured blood gases are arterial oxygen tension ($PaO_2$), arterial carbon dioxide tension ($PaCO_2$), and arterial pH.

The calculations for these parameters depend on the specific monitoring equipment being used, but in general, the following formulas are used:

Arterial oxygen tension ($PaO_2$): $PaO_2 = FiO_2 \times (PB - PH_2O) - (PaCO_2 / R) - (1.25 \times Hb)$

where: $FiO_2$ = Fraction of inspired oxygen PB = Barometric pressure $PH_2O$ = Water vapor pressure $PaCO_2$ = Arterial carbon dioxide tension R = Respiratory quotient (usually assumed to be 0.8) Hb = Hemoglobin concentration

Arterial carbon dioxide tension ($PaCO_2$): $PaCO_2 = VCO_2 / (K \times Vd \times PB)$

where: $VCO_2$ = Carbon dioxide production K = Solubility of carbon dioxide in blood (usually assumed to be 0.03) Vd = Dead space ventilation PB = Barometric pressure

Arterial pH: $pH = 6.1 + \log_{10} (HCO_3^- / 0.03 \times PaCO_2)$
where: $HCO_3^-$ = Bicarbonate concentration $PaCO_2$ = Arterial carbon dioxide tension

It's important to note that these calculations are only an estimate, and the actual values may be affected by a variety of factors such as changes in temperature, pressure, and oxygen delivery during CPB. Additionally, the interpretation of blood gas values should be done in the context of the patient's overall clinical condition and other laboratory values.

During cardiopulmonary bypass (CPB), blood gas values are monitored to ensure adequate oxygenation and ventilation. The normal values for arterial blood gases (ABG) during CPB can vary depending on the specific patient, their underlying health conditions, and the type of surgery being performed. However, some general guidelines for normal ABG values during CPB are as follows:

• Arterial oxygen tension ($PaO_2$): Normal values during CPB are typically between 100 and 150 mmHg. Higher values may be needed in certain cases, such as surgeries involving the brain or the heart, while lower values may be acceptable for surgeries in other areas of the body.

• Arterial carbon dioxide tension ($PaCO_2$): Normal values during CPB are typically between 35 and 45 mmHg. Values that are too high or too low can indicate issues with ventilation or perfusion, and may require adjustments in the patient's ventilator settings or other interventions.

• Arterial pH: Normal values during CPB are typically between 7.35 and 7.45. Values outside of this range can indicate acidosis or alkalosis, which can have significant effects on the patient's overall health and require prompt intervention.

Normal oxygen saturation levels during CPB can vary depending on the specific patient and their underlying health conditions, but in general, oxygen saturation levels should be maintained above 90% during CPB to ensure adequate oxygen delivery.
However, there are certain situations where higher oxygen saturation levels may be necessary, such as surgeries involving the brain or the heart. In these cases, oxygen saturation levels may need to be maintained above 95% to prevent injury to these organs.

# 17. Correction of electrolytes imbalance

Electrolyte imbalances can occur during cardiopulmonary bypass (CPB) due to a variety of factors such as changes in fluid balance, acid-base disturbances, and altered metabolism. These imbalances can have significant effects on the patient's overall health and require prompt correction. The following are general guidelines for electrolyte correction during CPB:

1. Sodium (Na+): If the patient's sodium levels are too high (hypernatremia), this can be corrected by administering hypotonic solutions or adjusting the dialysis or ultrafiltration rate. If the patient's sodium levels are too low (hyponatremia), this can be corrected by administering hypertonic solutions or adding sodium to the CPB circuit.
2. Potassium (K+): If the patient's potassium levels are too high (hyperkalemia), this can be corrected by administering insulin and glucose, administering bicarbonate, or administering medications that promote potassium elimination such as furosemide or sodium polystyrene sulfonate. If the patient's potassium levels are too low (hypokalemia), this can be corrected by administering potassium supplements or adding potassium to the CPB circuit.
3. Calcium (Ca2+): If the patient's calcium levels are too high (hypercalcemia), this can be corrected by administering medications such as calcitonin or bisphosphonates, or by performing dialysis or ultrafiltration. If the patient's calcium levels are too low (hypocalcemia), this can be corrected by administering calcium supplements or adding calcium to the CPB circuit.

It's important to note that electrolyte correction during CPB requires careful monitoring of the patient's electrolyte levels and other laboratory values, as well as consideration of the patient's overall clinical condition and medical history. Additionally, any interventions for electrolyte imbalances should be carefully titrated to avoid overcorrection or other complications.

The normal electrolyte values during cardiopulmonary bypass (CPB) can vary depending on the specific patient and their underlying health conditions, as well as the monitoring equipment being used.

However, in general, the following are the normal ranges for some of the commonly measured electrolytes during CPB:

1. Sodium (Na+): Normal range is between 135-145 mEq/L
2. Potassium (K+): Normal range is between 3.5-5.0 mEq/L
3. Calcium (Ca2+): Normal range is between 8.5-10.5 mg/dL

It's important to note that the normal values for electrolytes may vary depending on the specific laboratory reference range used by the monitoring equipment being used. Additionally, any deviations from normal electrolyte values during CPB should be promptly addressed by adjusting the patient's fluids and electrolyte balance as necessary to maintain the patient's overall health and prevent complications.

• (hypernatremia) or too low (hyponatremia). The following are general guidelines for correcting sodium levels during CPB:

1. Hypernatremia: If the patient's sodium levels are too high, this can be corrected by administering hypotonic solutions, such as 5% dextrose in water or half-normal saline (0.45% NaCl), to dilute the sodium concentration in the bloodstream. It's important to monitor the patient's sodium levels closely during this process to avoid overcorrection or complications such as cerebral edema or seizures.
2. Hyponatremia: If the patient's sodium levels are too low, this can be corrected by administering hypertonic solutions, such as 3% or 5% saline, to increase the sodium concentration in the bloodstream. Alternatively, sodium can be added to the CPB circuit to increase the sodium concentration in the perfusate. Again, careful monitoring of the patient's sodium levels is necessary to avoid overcorrection or complications such as osmotic demyelination syndrome.

• (hyperkalemia) or too low (hypokalemia).

The following are general guidelines for correcting potassium levels during CPB:

1. Hyperkalemia: If the patient's potassium levels are too high, this can be corrected by administering insulin and glucose, which helps to shift potassium from the extracellular space into the intracellular space. Additionally, potassium can be removed from the bloodstream using a cation exchange resin, such as sodium polystyrene sulfonate (Kayexalate), which exchanges sodium ions for potassium ions in the gastrointestinal tract. Potassium can also be removed using hemodialysis or other extracorporeal methods.
2. Hypokalemia: If the patient's potassium levels are too low, this can be corrected by administering potassium chloride (KCl) intravenously or adding KCl to the CPB circuit. However, caution should be taken when administering potassium, as rapid correction of hypokalemia can lead to cardiac arrhythmias.

• (hypercalcemia) or too low (hypocalcemia).

The following are general guidelines for correcting calcium levels during CPB:

1. Hypercalcemia: If the patient's calcium levels are too high, this can be corrected by administering fluids such as lactated Ringer's solution or normal saline to dilute the calcium concentration in the bloodstream. Additionally, diuretics such as furosemide can be given to promote calcium excretion. In severe cases, hemodialysis may be necessary.
2. Hypocalcemia: If the patient's calcium levels are too low, this can be corrected by administering calcium gluconate or calcium chloride intravenously. Calcium can also be added to the CPB circuit to increase the calcium concentration in the perfusate.

# 18. Correction of base excess on cardiopulmonary bypass

Base excess (BE) is a measure of the amount of excess or deficit of base in the blood, and is used to assess the metabolic component of acid-base balance.
During cardiopulmonary bypass (CPB), the patient's BE may become abnormal due to various factors, including changes in blood flow, oxygenation, and metabolic rate.

Correction of BE on CPB involves identifying and addressing the underlying cause of the imbalance, as well as careful monitoring of the patient's acid-base balance and electrolyte status.

If the patient's BE is too high (indicating a metabolic alkalosis), this can be corrected by increasing the partial pressure of carbon dioxide ($pCO_2$) in the blood. This can be achieved by decreasing the respiratory rate, increasing the tidal volume, or adding carbon dioxide to the CPB circuit. In some cases, intravenous administration of a weak acid such as acetic acid or hydrochloric acid may be necessary to correct the alkalosis.

If the patient's BE is too low (indicating a metabolic acidosis), this can be corrected by increasing the bicarbonate concentration in the blood. This can be achieved by adding sodium bicarbonate to the CPB circuit or administering bicarbonate intravenously. In some cases, hyperventilation or administration of a weak base such as sodium lactate or sodium acetate may be necessary to correct the acidosis.

# 19. Calculations for administering diuretic drugs on CPB

Diuretics are sometimes used during cardiopulmonary bypass (CPB) to help maintain urine output and prevent fluid overload. The following are general guidelines for calculating diuretic dosages during CPB:

• Loop diuretic:
Loop diuretics, such as furosemide, are the most commonly used diuretics during CPB. A typical starting dose of furosemide is 0.5-1.0 mg/kg given intravenously. The dose may be repeated every 6-8 hours as needed, based on the patient's urine output and fluid balance.

• Osmotic diuretic:
Mannitol is a commonly used osmotic diuretic during cardiopulmonary bypass (CPB) to help manage brain swelling and to promote diuresis.
The following are general guidelines for calculating mannitol dosages during CPB:

1. The typical starting dose of mannitol is 0.25-0.5 g/kg given intravenously over 15-30 minutes.
2. The dose may be repeated every 2-4 hours as needed based on the patient's urine output, serum osmolality, and electrolyte status.
3. The maximum total dose of mannitol during CPB is typically 2 g/kg.
4. Mannitol should be used with caution in patients with renal impairment, as it can exacerbate pre-existing renal dysfunction.

It's important to note that the use of diuretics during CPB requires careful monitoring of the patient's fluid and electrolyte balance, as well as renal function.

# 20. Tubing Size and selection

During cardiopulmonary bypass (CPB), several tubing sizes and tubing flow rates are used to facilitate the flow of blood through the extracorporeal circuit.
The following are general guidelines for tubing sizes and tubing flow rates during CPB:

1. Arterial tubing: The arterial tubing carries oxygenated blood from the heart-lung machine to the patient. The typical size of the arterial tubing is 3/8 inch (9.5 mm) in diameter, and the flow rate is usually set between 2.0-2.4 L/min/m2 of body surface area.
2. Venous tubing: The venous tubing carries deoxygenated blood from the patient to the heart-lung machine. The typical size of the venous tubing is 1/2 inch (12.7 mm) in diameter, and the flow rate is usually set between 2.4-3.0 L/min/m2 of body surface area.
3. Cardioplegia tubing: The cardioplegia tubing carries cardioplegia solution to the heart to induce cardiac arrest during the surgical procedure. The typical size of the cardioplegia tubing is 1/4 inch (6.4 mm) in diameter, and the flow rate is usually set between 100-250 mL/min.
4. Ultrafiltration tubing: The ultrafiltration tubing is used to remove excess fluid from the patient during CPB. The typical size of the ultrafiltration tubing is 1/4 inch (6.4 mm) in diameter, and the flow rate is usually set between 0-100 mL/min.

• Approximate volume delivery per rotation of the pump :
1/2 inch = 45ml, 3/8 inch = 26ml, 1/4inch = 12ml

Volume delivered is calculated accordingly:
1. Feed required tubesize in pump head, set occlusion.
2. keep inlet into a bucket.
3. Keep outlet into measuring vessel.
4. Run the pump for 10min 50 or 100 RPM
5. Measure the volume for one rotation

# 21. Cannula Size & flow chart

The selection of cannula size for cardiopulmonary bypass (CPB) depends on several factors, including the patient's body size, the type of surgery being performed, the surgeon's preference, and the available equipment.
The following are general guidelines for selecting cannula sizes for CPB:

1. Arterial cannula: The arterial cannula is inserted into the ascending aorta to provide oxygenated blood from the heart-lung machine to the patient. The size of the arterial cannula is typically determined by the patient's body surface area (BSA) and ranges from 14 Fr to 28 Fr. A common guideline is to use a cannula size that is approximately 1/3 to 1/2 of the patient's BSA in square meters.
2. Venous cannula: The venous cannula is inserted into the right atrium or the superior vena cava to collect deoxygenated blood from the patient and return it to the heart-lung machine. The size of the venous cannula is typically determined by the arterial cannula size, with a general guideline of using a cannula that is 2-4 Fr smaller than the arterial cannula.
3. Cardioplegia cannula: The cardioplegia cannula is inserted into the aortic root to deliver cardioplegia solution to the heart. The size of the cardioplegia cannula is typically 16 Fr or larger, depending on the surgeon's preference and the available equipment.

It's important to note that these are general guidelines, and cannula sizes may vary depending on the patient's clinical condition, the type of surgery being performed, and other factors. The selection of appropriate cannula sizes for CPB should be guided by the patient's clinical condition and managed in consultation with the healthcare team.
The maximum flow possible varies depending on the ID/OD ratio, site of Cannulation, viscosity of the blood. Accurate size selection should be done considering the patients age, weight and type of surgery.

- **Arterial cannula maximum flow rate**

08Fr = 500ml < 3kg

10FR = 1000ml < 6kg

12FR = 1600ml < 11kg

14Fr = 2400ml < 15kg

16Fr = 2800ml < 25kg

18Fr = 3300ml < 35kg

20 Fr = 4300ml < 45Kg

22 Fr = 5000ml < 60kg

24 Fr = 7000ml > 60kg

- **Venous cannula selection**

| Weight | Drain | bend tip | | Straight tip | |
|---|---|---|---|---|---|
| | | SVC | IVC | SVC | IVC |
| <5kg | 1.0lt | 08/10 | 10/12 | 18/20 | 20/22 |
| 5-10kg | 1.6lt | 10/12 | 12/14 | 18/20 | 20/22 |
| 10-15Kg | 2.5lt | 12/14 | 14/16 | 20/22 | 22/24 |
| 15-20kg | 3.0lt | 14/16 | 16/18 | 22/24 | 24/28 |
| 20-30kg | 3.5lt | 16/18 | 18/20 | 24/26 | 24/28 |
| 30-40Kg | 4.0lt | 18/20 | 20/22 | 26/28 | 28/30 |
| 40-50kg | 4.5lt | 20/22 | 22/24 | 28/30 | 30/32 |
| 50-60kg | 5.0lt | 22/24 | 24/28 | 28/30 | 30/32 |
| 60-70kg | 5.5lt | 22/24 | 24/28 | 28/30 | 32/32 |

Dear readers,

I want to express my heartfelt gratitude for your interest and support of the perfusion technology book that I have written. I am truly honored to have had the opportunity to share my knowledge and experience with you.
It is my sincere hope that the information presented in the book has been helpful in advancing your understanding of perfusion technology, and has provided practical guidance on the use of cardiopulmonary bypass and other essential techniques in cardiac surgery. I have worked hard to ensure that the book is comprehensive, up-to-date, and accessible to a wide range of healthcare professionals involved in perfusion technology.
Your feedback and engagement is crucial to the success of this book, and I am grateful for your support. I hope that it will continue to serve as a valuable resource for you, and that it will contribute to improving patient outcomes and advancing the field of cardiac surgery.

Once again, thank you for your interest in this book, and for your dedication to improving healthcare through the use of perfusion technology.

Sincerely,

Vivek .V. Paul
( Cardiac Perfusionist )