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Cardiopulmonary Bypass Explained: Nurses' Impact on Perfusion and Patient Care

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Abstract

Background: Perfusion is a critical physiological process that delivers oxygen and nutrients to tissues while removing waste products. In clinical settings, particularly in cardiothoracic surgery, perfusion management is crucial for successful patient outcomes. Registered nurses play a pivotal role in monitoring, managing, and optimizing perfusion intraoperative and postoperative. Aim: This review explores the detailed mechanisms of perfusion and discusses the extensive contributions of RNs in ensuring optimal patient care during cardiothoracic surgeries.

Keywords: Cardiopulmonary Bypass, Nurses' Impact, Patient Care, Perfusion

1. Introduction

Perfusion refers to the delivery of blood through the vascular system to organs and tissues, facilitating oxygen and nutrient supply and removal of waste products. In surgeries such as cardiopulmonary bypass (CPB) and organ transplantation, the management of perfusion becomes especially critical. Registered nurses (RNs) are central to maintaining patient hemodynamic stability, ensuring that proper perfusion is sustained throughout the procedure (Ghosh, Falter & Cook, 2009).

1.1 Perfusion process in cardiothoracic surgeries

During cardiothoracic surgeries, perfusion is essential for the survival and function of tissues. The heart-lung machine (CPB machine) temporarily takes over the roles of the heart and lungs, circulating blood and oxygenating it while the heart is stopped. However, the machine alters the natural physiology of perfusion, introducing both benefits and challenges in tissue oxygenation (Hariri et al., 2023).

1.2 Physiology of perfusion: Perfusion is governed by several critical physiological factors:

- Cardiac output (CO): The volume of blood the heart pumps per minute, determined by heart rate and stroke volume. Cardiac output directly influences tissue perfusion Systemic vascular resistance (SVR): The resistance blood encounters as it flows through the circulatory system. Increased SVR can impair perfusion
- Blood pressure (BP): Adequate perfusion pressure is crucial for ensuring blood reaches tissues, and both hypotension and hypertension can lead to perfusion deficits.
- Blood volume: Sufficient circulating blood volume is required to maintain perfusion. Hypovolemia, caused by blood loss or dehydration, reduces perfusion and can lead to shock (Falter et al., 2022).
- Oxygenation: The gas exchange process in the lungs determines how much oxygen reaches tissues. Impaired oxygenation, as seen in conditions like acute respiratory distress syndrome (ARDS), can significantly affect tissue perfusion (Dai et al., 2022).

1.3 Perfusion monitoring: In clinical settings, the following tools assist in assessing and managing perfusion:

- Invasive monitoring:
    - Arterial lines: Provide continuous BP readings and blood sampling for oxygenation and acid-base balance.
    - Central venous pressure (CVP): Reflects fluid status and venous return, helping assess overall perfusion.
    - Pulmonary artery catheter (Swan-Ganz): Offers detailed information on CO, pulmonary pressures, and SVR
- Non-invasive monitoring:

  - Pulse oximetry: Continuously monitors blood oxygen saturation, reflecting tissue oxygenation levels.
  - Capnography: Measures CO2 levels, which can indicate CO and tissue perfusion.
- Physical assessment techniques:
  - Capillary refill time: Delayed capillary refill (>2 seconds) indicates poor peripheral perfusion.
  - Skin and mucosal membrane assessment: Color and temperature changes signal compromised perfusion.
- Laboratory tests:
  - Lactate levels: Elevated lactate suggests anaerobic metabolism due to inadequate tissue oxygenation.
  - Mixed venous oxygen saturation (SvO2): Low SvO2 indicates that tissues are extracting more oxygen due to reduced perfusion (Falotico et al., 2020).

1.4 Challenges in managing perfusion: Managing perfusion during cardiothoracic surgeries can be challenging due to:

- Fluid imbalances: Excessive fluid administration leads to edema and increased cardiac workload, while dehydration reduces blood volume and perfusion.
- Hemodynamic instability: Rapid changes in BP, common in postoperative cardiac patients, require precise management through fluid therapy and medications.
- Technological dependence: Nurses must be proficient with various monitoring devices and interpret data quickly to adjust interventions for optimal perfusion (Stephens & Whitman, 2015).

2.1 Role of the heart-lung machine in perfusion during cardiothoracic surgeries

In cardiothoracic surgeries, particularly in complex procedures such as coronary artery bypass grafting (CABG) or valve replacement surgeries, the heart is frequently stopped using a method called cardioplegia. This deliberate cessation of heart function creates a still, bloodless surgical field, allowing the surgeon to operate with precision and reduced risk of complications arising from a beating heart. However, while the heart is stopped, the body's tissues still require oxygen and nutrients to function, and metabolic waste products must be removed. To address this, the cardiopulmonary bypass (CPB) machine, also known as the heart-lung machine, is utilized (Zhang et al., 2022).

The CPB machine takes over the essential roles of both the heart and lungs during the surgery. By circulating blood and ensuring it is properly oxygenated, the machine mimics the heart's pumping action and the lungs' gas exchange functions, effectively sustaining the patient's vital organs. This machine works by draining deoxygenated blood from the body, passing it through an oxygenator to remove carbon dioxide and replenish oxygen, and then pumping the oxygen-rich blood back into the body. This artificial circulation ensures that organs like the brain, liver, and kidneys continue to receive adequate blood flow and oxygen throughout the duration of the surgery (Ghosh, Falter & Cook, 2009).

In open-heart surgeries, the CPB machine is indispensable. It allows surgeons to temporarily bypass the heart, giving them the ability to operate on a non-beating heart without compromising systemic circulation. By maintaining oxygenation and blood flow to vital organs, the heart-lung machine ensures that the patient's body continues to function normally during the surgical intervention. This technology has revolutionized cardiac surgery, transforming previously high-risk procedures into safe and routine operations (Zhang et al., 2022).

The machine's importance cannot be overstated. It not only provides a motionless and bloodless field for the surgeon but also enables surgeries that would be impossible without its support. The development of the CPB machine has significantly advanced the field of cardiothoracic surgery, and its continuous refinement has improved surgical outcomes, reduced mortality, and minimized postoperative complications (Smilowitz et al., 2021).

2.2 Components of the cardiopulmonary bypass machine

1. Venous cannula: Large tubes, or cannulas, are inserted into the patient's major veins, typically the superior and inferior vena cava, to drain deoxygenated blood from the body. This blood is directed to the CPB machine, effectively bypassing the heart.
2. Oxygenator: Once the blood enters the machine, it passes through an oxygenator, which is responsible for adding oxygen to the blood while simultaneously removing carbon dioxide, much like the natural function of the lungs. The oxygenator typically contains a semipermeable membrane that allows gas exchange to occur efficiently (Zhang et al., 2022).
3. Pump: After oxygenation, the blood is pumped back into the patient's body through an arterial cannula, usually inserted into the aorta. The pump replaces the heart's role of maintaining blood circulation and is often a roller pump or centrifugal pump. The machine controls the speed and pressure of the blood flow to mimic the natural cardiac output (Ghosh, Falter & Cook, 2009).
4. Heat exchanger: To help protect the patient's organs during surgery, the CPB machine can control the temperature of the blood. Cooling the blood reduces the body's metabolic demands, a process known as hypothermia, which is used to protect organs like the brain and heart during surgery. After the operation, the machine can gradually warm the blood back to normal body temperature (Falotico et al., 2020).
5. Tubing and reservoirs: Blood flows through a closed-loop system of tubing within the CPB machine. The system also contains reservoirs to hold the blood as it is processed, ensuring a continuous flow throughout the procedure.

6. Filters: To prevent air bubbles (air embolisms) or debris from entering the bloodstream, which can lead to severe complications like stroke, the CPB machine has specialized filters. These air embolism filters are placed along the circuit to trap any bubbles before the blood re-enters the patient (Waqanivavalagi et al., 2024).

Weaning of the cardiopulmonary bypass machine: As the surgery ends, nurses assist in weaning the patient off the CPB machine. The surgical team begins the process of weaning the patient off the CPB machine. This involves gradually reintroducing the heart’s normal function and adjusting the machine’s support to reduce its role in pumping blood. Once the heart starts beating and can pump sufficient blood on its own, the CPB machine is turned off, and blood flow is fully restored to the heart and lungs. Close monitoring of hemodynamic stability, ensuring that the heart can sustain adequate perfusion without the machine (Waqanivavalagiet al., 2024).

2.3 Impact of the Heart-Lung Machine on Perfusion

While the heart-lung machine effectively maintains circulation and oxygenation during surgery, it introduces certain changes and potential complications in the perfusion process:

- Hemodynamic changes: One significant difference between natural heart function and the CPB machine is that the latter delivers blood in a continuous, non-pulsatile flow, whereas the heart naturally pumps blood in a pulsatile manner. Although non-pulsatile flow is generally well-tolerated, it can alter the dynamics of blood circulation in the microvascular systems, especially during prolonged surgeries.
- Hemodilution: During CPB, the blood is often diluted with crystalloid or colloid solutions to maintain an adequate blood volume in the circuit. This hemodilution helps prevent clotting in the machine but also reduces the oxygen-carrying capacity of the blood, which can pose risks during prolonged surgeries.
- Hypothermia: To reduce the metabolic demands of the body during surgery, the heart-lung machine often cools the blood (inducing hypothermia). While this is protective, prolonged hypothermia can cause vasoconstriction and delay postoperative recovery (Falter, 2022).
- Coagulation management: Because blood contacts foreign surfaces in the CPB machine, it can trigger the body’s clotting mechanisms. To prevent clotting, anticoagulants (like heparin) are administered throughout the procedure. However, this requires careful monitoring to avoid excessive bleeding during or after surgery (Gilbey, 2023).
- Air embolism prevention: One of the greatest risks during CPB is air embolism, where air bubbles enter the bloodstream and obstruct blood flow, potentially causing severe complications such as stroke. Air filters and bubble detectors are incorporated in the CPB machine to mitigate this risk (Falter, 2022).

- Inflammatory response: The exposure of blood to the non-physiological surfaces of the CPB machine can provoke a systemic inflammatory response. This response, known as systemic inflammatory response syndrome (SIRS), can cause complications such as organ dysfunction, particularly in the lungs, kidneys, and gastrointestinal tract (Gilbey et al., 2023).

3.1 Patient complications associated with cardiopulmonary bypass

In cardiothoracic surgeries, such as coronary artery bypass grafting (CABG) or valve replacement surgeries, the use of the cardiopulmonary bypass (CPB) machine is indispensable, but it is not without complications. These potential issues can impact patient outcomes and the overall success of the procedure. Understanding these complications and their statistical occurrence is essential for managing risks and improving care (Grant et al., 2023).

- Postoperative bleeding: Postoperative bleeding is a frequent complication in cardiothoracic surgery, occurring in approximately 2-5% of patients. The use of anticoagulants, such as heparin, during surgery to prevent clot formation can increase the risk of excessive bleeding once the procedure is complete. This often requires blood transfusions, and in 1-3% of cases, a return to surgery is needed to manage uncontrollable bleeding (Lwin et al., 2024).

- Renal impairment (acute kidney injury, AKI): Acute kidney injury occurs in up to 30% of patients who undergo CPB, with severe forms requiring dialysis in 1-5% of cases. AKI is one of the most common and serious complications, significantly increasing postoperative mortality. Prolonged CPB time, low blood pressure during surgery and hemolysis (destruction of red blood cells) contribute to reduced renal perfusion and function (Gilbey, 2023).
- Neurological complications (Stroke, Cognitive Dysfunction): The risk of stroke during or after cardiac surgery with CPB is reported to be around 1-3%. Cognitive dysfunction, which can manifest as memory loss, difficulty concentrating, or confusion, is more common, affecting up to 50-70% of patients shortly after surgery. This is often referred to as "pump head. The presence of micro-emboli (small blood clots or air bubbles) can obstruct blood flow to the brain, leading to ischemic events or subtle cognitive deficits (Lwin et al., 2024).
- Pulmonary complications: Pulmonary complications, such as atelectasis (partial lung collapse) and pleural effusion (fluid buildup around the lungs), affect approximately 10-15% of patients. Prolonged mechanical ventilation, poor oxygenation during surgery, and the inflammatory response induced by the CPB machine contribute to these issues. Respiratory therapy and early mobilization are keys to mitigating these risks, and in severe cases, prolonged ventilation or re-intubation may be required (Nteliopoulos et al., 2022).

- Systemic inflammatory response syndrome (SIRS): SIRS, which is triggered by the exposure of blood to the non-physiological surfaces of the CPB machine, affects the vast majority of patients to some degree, though it manifests in severe forms in 5-10% of cases. The body's immune response is activated as blood interacts with the artificial surfaces of the CPB circuit, leading to widespread inflammation that can affect multiple organs. This inflammatory response can contribute to organ dysfunction, including renal failure, respiratory issues, and cardiac instability (Nteliopoulos et al., 2022).
- Vasoplegic syndrome: It is characterized by severe hypotension despite adequate cardiac output, occurs in 5-10% of patients undergoing cardiothoracic surgery. It is more common in patients undergoing longer surgeries or those with preexisting conditions. The combination of inflammatory mediators and prolonged use of anesthetic agents during surgery leads to the dilation of blood vessels, causing systemic vascular resistance to drop. The condition is treated with vasopressors like norepinephrine, which constrict blood vessels and raise blood pressure (Waqanivavalagiet al., 2024).
- Mortality rate: The in-hospital mortality rate for patients undergoing CABG with CPB is approximately 2-3% for isolated procedures, rising to 5-6% for more complex surgeries such as combined CABG and valve replacements Grant, M. C., et al. (2023).
- Reoperations: About 20% of cardiac surgeries are reoperations, which carry increased risks due to complications like scar tissue from previous surgeries (Oh et al., 2022).

3.2 Nurses' role and patient care

Registered nurses play a critical role throughout cardiothoracic surgeries. Their responsibilities encompass intraoperative and postoperative care to ensure the patient's hemodynamic stability and optimal perfusion (Wang et al., 2023).

Intraoperative Monitoring: Nurses also work closely with perfusionist to monitor the heart-lung machine during surgery. They assist in managing complications related to the machine, such as air embolism or coagulation disorders, ensuring the safe operation of the CPB machine (Ismail et al., 2024).

- Hemodynamic monitoring: Monitoring for early signs; nurses continuously monitor vital signs and hemodynamic parameters such as BP, heart rate, and oxygen saturation and laboratory values such as lactate levels, oxygenation, and urine output to detect early signs of complications like bleeding, AKI, or respiratory issues. They communicate with the surgical team to adjust CPB machine settings based on the patient's physiological needs (Amer, 2020).
- Administering medications: Nurses are responsible for administering vasoactive medications like vasopressors or inotropes to maintain BP and cardiac output, ensuring tissues receive adequate blood supply, ensuring that the patient's blood pressure remains stable and that clotting times are within a safe range (Ismail et al., 2024).

- Fluid management: Maintaining an optimal fluid balance is crucial to preventing both dehydration which can reduce perfusion, and fluid overload which can cause pulmonary complications. Nurses monitor fluid balance and manage intravenous fluids to maintain adequate blood volume during surgery. Nurses also carefully monitor input and output, adjusting fluids as necessary. This helps prevent hypovolemia or fluid overload, both of which can compromise perfusion (Badwy Rateb, 2022).
- Postoperative Care: Post-surgery, nurses focus on pain management, respiratory support (such as incentive spirometry to prevent atelectasis), and early mobilization to reduce the risk of complications like pneumonia or deep vein thrombosis (Ismail et al., 2024).
- Early Detection of Complications: Nurses play a key role in detecting early signs of complications, such as bleeding, hypotension, or arrhythmias that could impair perfusion. They monitor for symptoms like reduced urine output, cold extremities, or changes in mental status, which may indicate poor perfusion (Lwin et al., 2024).
- Pain Management: Proper pain management is essential to reduce stress and ensure stable hemodynamics, which supports better perfusion outcomes (Amer, 2020).
- Postoperative Monitoring: Nurses continue to monitor hemodynamic parameters and oxygenation levels post-surgery to detect any deterioration in perfusion status (Smilowitz et al., 2021).
- Patient Education: Nurses educate patients on postoperative care, emphasizing mobility and deep breathing exercises to improve circulation and prevent complications like deep vein thrombosis (DVT) and pulmonary embolism (Wang et al., 2023).

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الملخص العربي

مقدمة: يعتبر الإرواء عملية فسيولوجية حيوية تقوم بمد الأنسجة بالأكسجين والمغذيات مع إزالة الفضلات. في بيئة الرعاية الصحية، وخاصة جراحة القلب والصدر، يعد إدارة الإرواء أمرًا بالغ الأهمية لتحقيق نتائج ناجحة للمرضى. ويلعب الممرضون دورًا محوريًا في مراقبة الإرواء وإدارته وتحسينه أثناء هذه العمليات الجراحية وما بعدها.

الهدف : يهدف هذا المقال تقديم الآليات التفصيلية لعملية الإرواء وتناقش الدور الحيوي للممرضين في تقديم رعاية مثلى للمرضى خلال جراحات القلب والصدر