Faculty of Medicine - Ain Shams University
Department of Anesthesia,
Intensive Care and Pain Management

Lung Protective Strategies during Cardiopulmonary Bypass

Essay
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By
Mohammad Said Mohammad Radwan Mansour
M.B.B.Ch
Faculty of Medicine- Ain Shams University

Under Supervision of
Prof. Dr. Omar Mohammed Taha Alsafty
Professor of Anesthesia, Intensive Care and Pain Management
Faculty of Medicine- Ain Shams University

Dr. Hanaa Abd Allah El Gendy
Assistant Professor of Anesthesia, Intensive Care and Pain Management
Faculty of Medicine- Ain Shams University

Dr. Mohamed Alaaeldin Alhadidy
Lecturer of Anesthesia, Intensive Care and Pain Management
Faculty of Medicine – Ain Shams University

Faculty of Medicine
Ain Shams University
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Mohammad Said

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List of Abbreviations

Abb.	Full term
ARDS	Acute Respiratory Distress Syndrome
BALF	Bronchoalveolar lavage fluid
BGA	Blood gas analysis
BRMs	Biological response modifiers
cAMP	Cyclic adenosine monophosphate
CCPB	Conventional cardiopulmonary bypass
CPAP	Continuous positive airway pressure
CPB	Cardiopulmonary bypass
ECC	Extracorporeal circulation
ECM	Extracellular matrix
GME	Gaseous microemboli
HLM	Heart lung machine
I/R	Ischemia-reperfusion
IL	Interleukin
IRI	Ischemia reperfusion injury
MCPB	Minimized cardiopulmonary bypass
MECC	Minimal extracorporeal circulation system
MICS	Minimally invasive cardiac surgery
MMP-9	Matrix metalloproteinase-9
mPAP	Mean pulmonary artery pressure
MUF	Modified ultrafiltration

Abb.	Full term
MV	Mechanical ventilation
NO	Nitric oxide
PEEP	Positive end-expiratory pressure
PGI2	Prostacyclin
pHTN	Pulmonary hypertention
PMEA	Poly-2-methoxyethelacrylate
PTX	Pentoxyfylline
ROS	Reactive oxygen species
SIRS	Systemic inflammatory response syndrome
TACO	Transfusion-associated circulatory overload
TNF	Tumor necrosis factor
TRALI	Transfusion-related acute lung injury
TXB2	Thromboxane B2
UTL	Ulinastatin
VCMs	Vital capacity maneuvers

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Introduction

The heart-lung machine enables surgical procedures on the arrested heart by maintaining systemic perfusion and replacing pulmonary function, also. With a standard heart-lung machine circuit, blood is drained from the right atrium or the caval veins with cannulas. With the aid of a pump, it is transported through an oxygenator back into the aorto-arterial tree. An arterial filter lowers the load of systemic emboli (microparticles and air bubbles). Multiple sensors with an online display for line pressures, temperatures, electrolyte concentrations, and blood gases guarantee monitoring of the physiologic milieu and enhance the security of the extracorporeal circulation system **(Ziemer and Leitz, 2017).**

The use of cardiopulmonary bypass (CPB) in cardiac surgeries can lead to a series of pathological changes with varying severities, including ischemia-reperfusion injury (IRI) and systemic inflammatory response syndrome, in vital organs such as heart and lungs. The mechanism for the development of CPB-triggered heart and lung injuries is complex and multifactorial. There have been studies suggesting that the exposure of blood to artificial surfaces of CPB components could activate neutrophils and monocytes through multiple signal cascades, leading to widespread inflammatory response throughout the circulatory system. It is worth noting that these processes are also facilitated by various proinflammatory cytokines. The activated neutrophils then migrate to and are eventually sequestered in the lung, where they can inflict damage to local tissues by secreting various proteases. In addition, there is also evidence that ischemia in the lung could also be a contributing factor to CPB-induced pulmonary injury **(Zhou et al., 2017).**

Various strategies including perioperative management of mechanical ventilation (MV), restrictive transfusion, technical modifications of CPB, and medication administration such as steroids and aprotinin have been developed to reduce impairment of pulmonary function. Ventilation during CPB is an important element of MV management strategies and determined by anesthesiologists in the operation room. Continuous positive airway pressure (CPAP), low-volume ventilation, positive endexpiratory pressure (PEEP), and vital capacity maneuvers (VCMs) are adjustable parameters composing ventilation techniques **(Chi et al., 2017).**

Aim of the Essay

This review essay will give an overview not only on the mechanisms involved in the lung injury in response to cardiopulmonary bypass, but also on the therapeutic interventions, including pharmacologic strategies and modification of techniques or mechanical devices.

Principles of Cardiopulmonary Bypass Equipment

The optimum conditions for cardiothoracic surgery have traditionally been regarded as a “still and bloodless” surgical field. Cardiopulmonary bypass (CPB) or heart lung machine (HLM) provides this by incorporating a pump to substitute for the function of the heart and a gas exchange device, the “oxygenator”, to act as an artificial lung. Cardiopulmonary bypass thus allows the patient’s heart and lungs to be temporarily devoid of circulation, and respiratory and cardiac activity suspended, so that cardiac, vascular or thoracic surgery can be performed in a safe and controlled environment **(Ghosh et al., 2015).**

Generally, CPB circuits consist of several components, of which a few satisfy the most important functions. The essential components of a CPB circuit can be seen in Figure (1) and are blood pumps (artificial hearts), oxygenators (artificial lungs) and the tubing system (artificial vascular system) **(Hessel and Edmunds, 2003).**

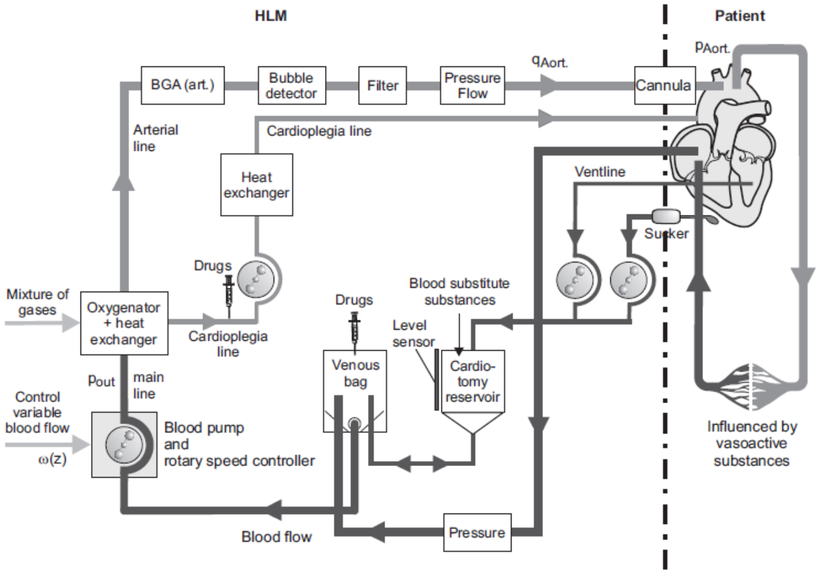

Figure (1): Components of the extracorporeal cardiopulmonary bypass circuit, with the HLM to the left and the patient's vascular system to the right (BGA: blood-gas-analysis (arterial), Ventline: drainage of the ventricle, Cardioplegia line: cooling, suspension of the heart and drug delivery) **(Hessel and Edmunds, 2003).**

The complete heart-lung machine includes many additional components. Most manufacturers consolidate a membrane oxygenator, venous reservoir, and heat exchanger into one unit. A microfilter-bubble trap is added to the arterial line. Depending on the operation, various suction systems are used to return blood from the surgical field, cardiac chambers, and/or the aorta. Aspirated blood passes through a cardiotomy reservoir and microfilter before returning to the venous reservoir. Sites for obtaining blood samples and sensors for monitoring pressures, temperatures, oxygen saturation, blood gases, and pH are included, as are various safety devices **(Lalonde, 2016).**

1. Venous Cannulation and Reservoir:

Venous blood usually enters the circuit via venous cannulae by gravity or siphonage into a venous reservoir placed 40 to 70 cm below the level of the heart. The amount of drainage is determined by central venous pressure, the height differential, resistance in cannulas, tubing and connectors and absence of air within the system **(Hessel and Edmunds, 2003).**

The venous cannulas are designed for either dual caval cannulation or atriocaval cannulation. The cannula used for dual caval cannulation is straight, with a basket tip designed for insertion through a purse string in the right atrium, into the superior vena cava or the inferior vena cava (Figure 2). Alternatively, right-angle plastic cannulas or, occasionally, cannulas with right-angle metal tips are designed for direct insertion into the superior vena cava and inferior vena cava (Figure 2). Generally, about two thirds of the venous return comes back to the inferior vena cava, and one third to the superior vena cava. For this reason, the cannula inserted into the inferior vena cava should generally be slightly larger than the cannula used in the superior vena cava **(Christina et al., 2012).**

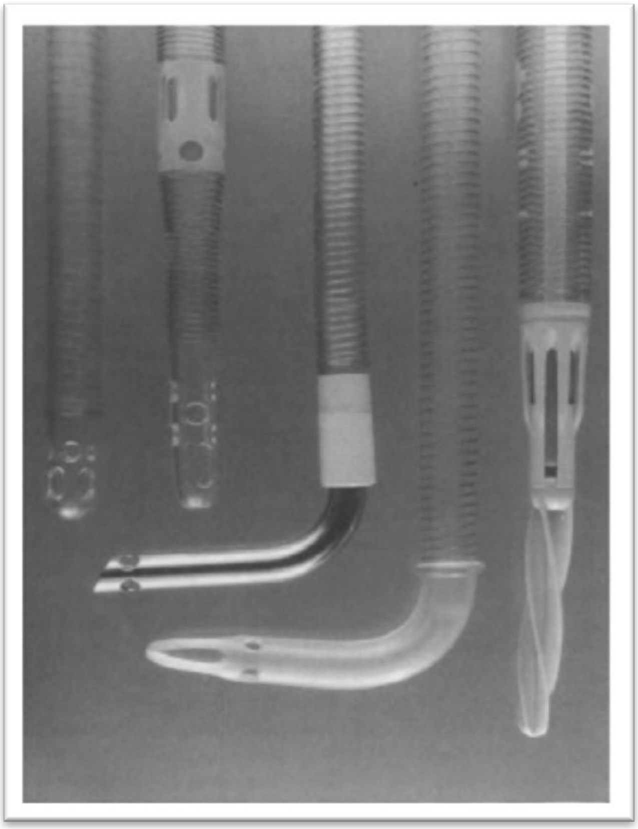

Figure (2): Various types of venous wire-wound cannulas. Left to right: closed-end dual caval (basket type); open-end single arterial cannula (two stage); open-end, right-angle, dual caval; closed-edn, right-angle, dual caval (basket type); and a variation of open-end flexible type **(Christina et al., 2012).**

Complex surgical procedures, including redo sternotomy, aortic dissection repair and minimally invasive cardiac surgery (MICS), have led cardiac surgeons to develop new techniques for cannulation. Peripheral artery access for CPB, including femoral and axillary cannulation,