Extracorporeal Carbon Dioxide Removal for Acute Respiratory Failure

Essay

Submitted for Partial Fulfillment for Master Degree of ***Intensive Care***

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مَا الْفَضْلُ إِلا لأَهْلِ الْعِلْـمِ إِنَّـهُـمُ *** عَلَى الْهُدَى لِمَنْ اسْتَهْـدَى أَدِلاَّءُ
وَقَدْرُ كُلِّ امرِئٍ مَا كَـانَ يُحْسِنُـهُ *** والْجَاهِلُونَ لأَهْلِ الْعِلْـمِ أَعْدَاءُ
فَفُـزْ بِعِلْمٍ وَلا تَطْلُبْ بِـهِ بَـدَلاً *** فَالنَّاسُ مَوْتَى وَأَهْلُ الْعِلْمِ أَحْيَـاء

"علي بن أبي طالب -رضي الله عنه-"

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HOSSAM AHMED HAMED

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List of Abbreviations

ABG	Arterial blood gases
AECC	American-European Consensus Conference
ALI	Acute Lung Injury
ARDS	Acute respiratory distress syndrome
$AVCO_2R$	Arterio-Venous Carbon Dioxide Removal
BAL	Bronch-alveolar lavage
CAP	Community acquired pneumonia
CO	Cardiac output
CO_2	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPAP	*Continuous positive airway pressure*
CPB	*Cardiopulmonary bypass*
CPR	Cardiopulmonary Resuscitation
CT	Computed tomography
CVVH	Continuous veno-venous hemodialysis
Csr	Compliance
CXR	Chest x-ray
DAD	Diffuse alveolar damage
DIC	Disseminated Intravascular Coagultion
$ECCO_2R$	Extra-Corporeal Carbon Dioxide Removal
ECG	Electrocardiography
ECLS	Extra-Corporeal Life Support
ECMO	Extra-Corporeal Membrane Oxygenation
E-CPR	Extra-Corporeal Cardiopulmonary Resuscitation

List of Abbreviations (Cont.)

Esr	Elastance
$FecO_2$	Oxygen fraction delivered by the extracorporeal circuit
FIO_2	Inspired oxygen concentration
FRC	Functional Resdial Capacity
HAP	Hospital-acquired pneumonia
HCAP	Health care associated pneumonia
HCO_3^-	Bicarbonate
HIT	Heparin Induced Thrombocytopenia
ICAM	Intercellular adhesion molecule
UCI	Intensive Care Unit
IL	Interleukin
IMV	Invasive Mechanical Ventilation
IVOX	Intravascular Oxygenator
FGK	Keratocyte Growth Factor
LFPPV-$ECCO_2R$	Low Frequency Positive Pressure Ventilation Alongside Extracorporeal Co_2 Removal
LPV	Lung Protective Ventilation
LV	Left Ventricle
LVAD	Left Ventricular Assist Device
MERS-CoV	Middle East Respiratory Syncatial Corona Virus
MLs	Membrane Lungs
MRSA	Methicilin-resistant staph. aures
NIPPV	Non-invasive positive pressure ventillation

List of Abbreviations (Cont.)

NIV	Non-invasive ventillation
O_2	Oxygen
$PaCO_2$	Arteial pressure of Carbon dioxide
PAI-1	Plasminogen activator inhibitor-1
PALP	Pump Assisted Lung Protection
PAOP	Pulmonary artery wedge pressure
PAo_2	Alveolar O_2 Tension
PaO_2	Arterial pressure of Oxygen
Paw	Airway pressure
Pb	Barometric pressure
PE	Pulmonary embolism
PEEP	Positive End Expiratory Pressure
PGF	Primary Graft Failure
PIO_2	Inspired oxygen partial pressure
PP	Prone position
Pplat	Plateau Pressure
PVR	Pulmonary vascular resistance
RF	Respiratory failure
RV	Right ventricle
SOFA	Sepsis Related Failure Assesment
SPO_2	Oxygen saturation level
TNF	Tissue Necrosis Factor
TRALI	Transfusion Acute Lung Injury
Tv	Tidal Volume
UFH	Unfractional Heparin
V/Q	Ventillation/perfusion
V-A ECMO	Veno-Arterial ECMO
VCO_2	Carbon Dioxide Delivery
VILI	Ventillator Induced Lung Injury

List of Abbreviations (Cont.)

VO_2	Oxygen Delivery
Vt	Tidal volume
V-V ECMO	Veno-Venous ECMO

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Introduction

Respiratory failure is defined as an inadequate oxygen delivery and carbon dioxide (CO_2) elimination at tissue level. At pulmonary level, This represents the inability of the respiratory system to cope with the metabolic needs of the body to oxygenate venous blood and remove CO_2 ***(Grippi, 1998).***

Clinicians use the values of arterial pressure for oxygen (PaO_2) and carbon dioxide ($PaCO_2$) obtained from arterial blood gas analysis (ABG) which evaluate the ability of gas exchange at the pulmonary level. So, Respiratory Failure is defined as a disturbance in gas exchange in the respiratory system which produces values in the arterial ABG of PaO_2 < 60 mmHg (hypoxaemia) and/or a $PaCO_2$ > 50 mmHg (hypercapnoea) ***(Roussos and Koutsoukou, 2003).***

Endotracheal intubation and subsequent mechanical ventilation are often a necessary and life-saving treatment for patients with severe respiratory failure. However, The side effects of intubation, invasive mechanical ventilation itself and the accompanying sedation may trigger a vicious cycle leading to prolonged weaning and may even contribute to mortality ***(Esteban et al, 2002).***

In patients with acute hypercapnic respiratory failure, noninvasive ventilation (NIV) is a well-established means to support the failing ventilatory pump and thus to avoid intubation and invasive mechanical ventilation. However, This approach often fails for a variety of reasons and is therefore followed by intubation and invasive mechanical ventilation ***(Ram et al, 2004).***

Extracorporeal life support (ECLS) is an artificial means of providing oxygenation and CO_2 elimination in patients who have acute respiratory failure. ECLS is not a cure, but can temporarily support heart and lung function, which might provide time for injured lungs to recover and enable treatment of underlying disease. Advances in ECLS technology have reduced its complexity and increased its safety, which has led to a resurgence in its use ***(MacLaren et al, 2012).***

Extracorporeal CO_2 removal devices are type of extracorporeal life support which allow uncoupling of ventilation from oxygenation, thereby removing CO_2 ***(Fitzgerald et al, 2014).***

The use of extracorporeal CO_2 removal allowed avoiding intubation and invasive mechanical ventilation in the majority of patients with acute on chronic respiratory failure not responding to NIV ***(Stefan et al, 2012).***

A solid indication for extracorporeal CO_2 removal devices is hypercapnia due to terminal lung failure during bridging to lung transplantation, pneumonia, and chronic obstructive lung disease or asthma ***(Hermann et al, 2014).***

Aim of the Work

The aim of this essay is to revisit the acute respiratory failure as regard of its causative pathologies, clinical picture and different therapeutic modalities. The novel approach of Extracorporeal Carbon Dioxide removal in such pathology will be discussed heavily, as well as reviewing the recent advances in technology, techniques, indications, limitation, contraindication and complication if any.

Pathophysiology of Acute Respiratory Failure

The respiratory system consists of two parts: the lung and the pump that moves the lung (respiratory centers, spinal cord and respiratory peripheral nerves, respiratory muscles and chest wall). Failure of the lung is primarily manifested as hypoxemia (hypoxemic or type I failure; shunt physiology) and failure of the pump results mainly in hypercapnia (hypercarbic or type II failure; hypoventilation is the principal mechanism) **(Sabin and Jayanta, 2014).**

Alveolar O_2 tension (PAO_2) increases with increase in inspiratory O_2 tension and increase in ventilation. Extraction of O_2 from the alveolus is determined by the saturation, quality and quantity of the haemoglobin of the blood perfusing the alveoli. The O_2 saturation of the haemoglobin in the pulmonary capillary blood is affected by the supply of O_2 to the tissues (cardiac output) and the extraction of the O_2 by the tissues (metabolism) **(Praveen, 2003).**

In general, lower the haemoglobin saturation in the blood perfusing the pulmonary capillaries, a result of low cardiac output (increased tissue extraction) and/or increased tissue metabolism, higher the extraction of O_2 in the alveoli and lower the equilibration partial pressure of O_2. Similarly the absolute quantity of haemoglobin in the circulating pulmonary blood also increases or decreases extraction of O_2, though this particular factor is less important. The partial pressure of O_2 in the alveolus is further affected by the partial pressure of CO_2 in the pulmonary capillary blood. Partial pressure of CO_2 in the alveolus is because of dynamic equilibrium between CO_2 transported to the alveolus and CO_2 removed from the alveolus. The partial pressure of CO_2 in the alveolus increases with the increase in tissue metabolism and in presence of low cardiac output (CO_2 produced in the tissues is transported in less amount of the venous blood) **(Praveen, 2003).**

Definition of respiratory failure:

Respiratory failure (RF) is defined as an inadequate oxygen delivery and carbon dioxide elimination at *tissue level*. At *pulmonary level,* this represents the inability of the respiratory system to cope with the metabolic needs of the organism, oxygenate venous blood and remove CO_2. However, due to the lack of direct measurements for these functions, clinicians use the values of arterial pressure for oxygen (PaO_2) and carbon dioxide ($PaCO_2$) obtained from arterial blood gas analysis (ABG) which evaluate the ability of gas exchange at the pulmonary level. This way, respiratory failure is defined as a disturbance in gas exchange in the respiratory system which produces in ABG a $PaO_2 < 60$ mmHg (hypoxaemia) and/or a $PaCO_2 > 50$mmHg (hypercapnoea) **(Belda *et al.*, 2013**).

It is important whether hypoxemic respiratory failure is acute (over hours to days) or chronic (over weeks to months) as it has implications not just for diagnosis and treatment, but also for the physiologic adaptations to hypoxemia that develop over time. For