ANESTHETIC MANAGEMENT OF ANEMIA

AND

PERIOPERATIVE CEREBRAL OUTCOME

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By

AMR ABDALLAH SAYED SOLIMAN
(M.B., B.CH.)

Supervised
By

Dr. / HODA HASSAN HUSSEIN OKASHA
Professor of Anesthesia
Kasr El Aini Hospital
Cairo University

Dr. / DINA ZAKARIA MOHAMED
Assist. Professor of Anesthesia
Kasr El Aini Hospital
Cairo University

Dr. / EMAN AHMED FOAAD
Lecturer of Anesthesia
Kasr El Aini Hospital
Cairo University

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ABSTRACT

The lack of prospective and randomized clinical trials to assess neurological outcomes at different Hb levels severely restricts the ability to make clinical recommendations on how to manage anemic patients in the perioperative setting. Characterization of complex hypoxic cellular mechanisms, including hypoxia inducible factor (HIF), neuronal nitric oxide synthase (nNOS) and erythropoietin (EPO), which are activated in the brain of anemic animals, may provide valuable preclinical information.

This will help clinicians to develop treatment strategies to minimize cerebral injury associated with anemia in perioperative patients. For example, clinical studies have suggested that erythropoietin (EPO) therapy may reduce cerebral injury and improve survival in stroke and trauma patients.

KEY WORDS:

1- Anemia
2- Cerebral manifestations
3- Hypoxia

النقص فى التجارب العلمية لتحديد الاعراض المخية عندالمستويات المختلفة للهيموجلوبين يقلل القدرة على وضع توجيهات علمية لمعالجة الانيميا عند اجراء العمليات الجراحية. نقص الاكسجين فى الدم يؤدى الى زيادة تكوين الأريثروبويتين،العلاج بالاريثروبويتين يحمى المخ من نقص الاكسجين و يقلل نسبة اصابة المخ أثناء الجلطات.

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List of abbreviations

NO	Nitric oxide
NOS	Nitric oxide synthase
iNOS	Inducible nitric oxide synthase
eNOS	Endothelial nitric oxide synthase
nNOS	Neuronal nitric oxide synthase
HIF	Hypoxia inducible factor
CPB	Cardiopulmonary bypass
CBF	Cerebral blood flow
VSM	Vascular smooth muscle
EPO	erythropoietin
VEGF	Vascular endothelial growth factor
PHDs	Propylhydroxylase enzyme
VO2	Systemic oxygen consumption
DO2	Total oxygen delivery
ATP	Adenosine triphosphate
Hb	Hemoglobin

INTRODUCTION :

DEFINITION:

Anemia is a state of low hemoglobin concentration associated with decreased oxygen carrying capacity.

The adequacy of a hemoglobin concentration in a given clinical situation depends on whether a sufficient amount of oxygen is carried to the tissues to meet metabolic requirements. Therefore, the decision to transfuse a given patient cannot be based only on the hemoglobin level.
Rigid adherence to a predefined transfusion threshold will result in the over transfusion of some patients, but also in the under transfusion of others.
A better knowledge of the physiologic responses developed during acute isovolemic anemia and the clinical factors that can limit the ability of the organism to maintain adequate tissue oxygenation in these situations, will allow the clinician to better define the transfusion trigger for each patient.
An acute decrease in blood oxygen carrying capacity during anemia elicits physiologic adjustments at both the systemic and microcirculatory level, resulting in an increase in both cardiac output and tissue oxygen extraction. In physiologic situations, these are very efficient as they allow maintenance of tissue oxygen delivery up to a systemic hematocrit of 10-15% during resting conditions. In pathophysiologic situations, tolerance to acute anemia depends on the body's ability to recruit each mechanism and the level of tissue oxygen demand. [1]

AIM OF THE WORK:

- To discuss physiologic response of anemia.
- To discuss anesthetic management of anemia.
- To summarize the risk of cerebral injury associated with acute anemia.
- To explore possible physiological and cellular mechanisms which may ameliorate cerebral injury associated with acute anemia

PHYSIOLOGIC RESPONSE TO ACUTE ANEMIA :

The maintenance of tissue oxygen delivery during an acute reduction in red blood cell concentration depends on both an increase in cardiac output and an increase in blood oxygen extraction. [2] These two mechanisms require the preservation of an ample circulating blood volume.

1- The cardiac output response:

Cardiac output increases during isovolemic anemia and the extent of this response appears to be closely related to the decrease in hematocrit. The cardiac output response is usually due to an increase in stroke volume and to some extent, an increase in heart rate. [2]

The decrease in blood viscosity plays a fundamental role in the rise in stroke volume by increasing venous return and decreasing total peripheral vascular resistance. These changes in cardiac loading conditions lead to improved myocardial functioning and a direct enhancement of myocardial contractility has also been described. [3]

The decrease in total peripheral vascular resistance results, essentially, from reduced blood viscosity, but may also be related to the decreased scavenging capacity of blood to inactivate nitric oxide. [4] The adequate cardiac output response to isovolemic anemia also appears to be dependent on the presence of an intact autonomic nervous system and alpha-adrenergic tone. [2]

2-The oxygen extraction response :

The aim of the second compensatory mechanism is to better match oxygen delivery to oxygen demand at the tissue level. This mechanism, which

permits the extraction of blood oxygen to increase, involves physiologic alterations at both the systemic and the microcirculatory level.

A-At the systemic level:

Matching oxygen delivery to tissue oxygen demand requires the redistribution of blood flow to areas of high demand (e.g. the brain and heart) in order to more effectively utilize oxygen held in venous blood. [5]

Several experimental studies have demonstrated that cerebral and coronary vasodilatation occurs during acute anemia; as a result, blood flow in these areas increases out of proportion to the rise in cardiac output.

This exceptional increase in blood flow to the brain and heart occurs because these organs are "flow-dependent" tissues, in contrast to other organs (e.g. the splanchnic area, kidneys, and skin) that are "flow independent" tissues. Flow-dependent organs extract most of the oxygen available, even under basal conditions, and are unable to increase oxygen extraction further to meet their metabolic requirements.

Coronary blood flow increases even more than cerebral blood flow as myocardial oxygen demand increases during anemia. When the hematocrit is reduced to 10-12%, myocardial oxygen consumption more than doubles. [6] Under these conditions, coronary vasodilatation is nearly maximal.

When the hematocrit is below 10%, coronary blood flow can no longer match the increased myocardial oxygen demand and ischemia develops, resulting in cardiac failure. This has been demonstrated in experimental data showing a decrease in systemic oxygen uptake when hematocrit values are close to 10%. [7]

Excess perfusion to the brain and heart occurs at the expense of "flow-independent" organs. Relative vasoconstriction occurs in some tissues so

that renal, mesenteric, and hepatic blood flows are proportionately less than the total cardiac output response. This regional blood flow redistribution among organs is partly due to alpha-adrenergic stimulation, but is unaltered in the presence of β-adrenergic blockade. [8]

B-At the microcirculatory level:

Several physiological adjustments contribute markedly to providing a more efficient utilization of the remaining oxygen in the blood. [9] The main effect of hemodilution on the microcirculation is an increase in red blood cell velocity that allows red blood cell flux in the capillaries to be maintained up to a systemic hematocrit of 20%. This increased flow velocity stimulates arterial vasomotor and provides a more homogeneous distribution of red cells in the capillary network. [9]

By shortening the transit time, the increase in red blood cell velocity may also reduce the loss of oxygen before it reaches the capillaries and, thereby, improve oxygen transfer to the tissues. An increase in the ratio of microcirculatory to systemic hematocrit has also been demonstrated. [10]

This phenomenon is related to complex interactions between axially migrating red blood cells and the heterogeneous nature of the microcirculatory network. Finally, changes in the dynamics of the hemoglobin molecule can result in more efficient tissue oxygen delivery in anemia. Indeed, a right shift of the oxyhemoglobin dissociation curve which enhances oxygen release at a constant oxygen tension begins at a hemoglobin level of 9 g dL^{-1} and becomes more prominent when levels are <6.5 g dL^{-1} [11] .This phenomenon results from increased synthesis of 2, 3 diphosphoglycerate and appears with declining hemoglobin after 12 to 36 hours.

TOLERANCE AND CLINICAL LIMITS OF ANEMIA:

Maintenance of adequate tissue oxygenation during acute isovolemic anemia depends on the physiologic adjustments that occur at the systemic and microcirculatory levels and result in increased blood flow and oxygen extraction. The relative contribution of these 2 mechanisms depends on the ability of the patient to recruit each of them. Several studies have demonstrated that both are already involved in the early stages of isovolemic anemia. [12]

They allow the maintenance of tissue oxygen balance until the hematocrit falls to about 10-12%. Below this "critical" value, oxygen delivery can no longer match tissue oxygen demand and cellular hypoxia develops. The critical hemoglobin value could, therefore, be defined as "the value of hemoglobin below which oxygen uptake becomes delivery-dependent".

experimental studies have demonstrated the critical hemoglobin value to be approximately 4.0 g dL^{-1} [13].

Corresponding values are obviously difficult to obtain in man. In a study in healthy conscious volunteers, Weiskopf et al demonstrated that tissue oxygenation remains adequate during severe isovolemic hemodilution up to a hemoglobin value of 5 g dL^{-1} [14].

Van Woerkens et al studied a Jehovah's Witness patient who died from extreme hemodilution and observed a critical hemoglobin value of 4 g dL^{-1} [15]

Tolerance to severe acute isovolemic hemodilution not only depends on the integrity of compensatory mechanisms, but also on the level of tissue oxygen demand. For a given cardiac output and oxygen extraction response,

any increase in tissue oxygen demand requires a higher hemoglobin level and, therefore, will reduce the patient's tolerance to hemodilution.

Factors altering either the cardiac output response and/or the oxygen extraction response will reduce the patient's tolerance to acute anemia

1-Factors altering the physiologic response to isovolemic anemia

2-Factors associated with decreased cardiac output response:

- Hypovolemia
- Cardiac failure, negative inotropic agents (E.g. β-blocking agents)
- Coronary artery disease(CAD)
- Valvular disease

3-Factors associated with decreased O_2 extraction response:

- Acute respiratory distress syndrome (ARDS)
- Sepsis
- Systemic inflammatory response syndrome (SIRS)
- Traumatic injury
- Ischemia reperfusion syndrome
- Vasodilating drugs

4-Factors associated with altered gas exchange:

- ARDS
- Chronic pulmonary obstructive disease

5-Factors associated with increased O_2 consumption:

- Fever
- Pain, stress, anxiety
- Sepsis, SIRS
- Hyperventilation syndromes

Maintenance of adequate volume replacement is of paramount importance. The cardiac output response to hemodilution may be reduced in the presence of altered myocardial contractility. Acute administration of negative inotropic agents (e.g. β-blocking agents) results in a decreased cardiac output response during hemodilution. [16]

Coronary artery disease (CAD) will obviously limit the tolerance of the heart to isovolemic hemodilution. As myocardial oxygen extraction is already nearing maximal during resting conditions, the maintenance of myocardial oxygen consumption depends essentially on the increase in coronary blood flow.

Therefore, the coronary reserve (the ratio between maximal coronary blood flow and resting coronary blood flow) is significantly reduced during hemodilution, especially in CAD patients who already have decreased maximal coronary blood flow. The lowest tolerable hematocrit in CAD patients is not known, but experimental data on animals with extrinsically applied coronary stenosis has demonstrated a significant increase in the critical hematocrit level to 17-18%. [17]

Even if CAD patients can tolerate some degree of hemodilution intraoperatively, they will require a higher hematocrit in the early postoperative period to meet increased tissue, and especially cardiac,

oxygen demand. Cardiovascular disease patients with a lower preoperative hematocrit have an increased risk of death when compared to no cardiovascular disease patients with the same preoperative hematocrit. [18]

In patients with no evidence of cardiovascular disease, age alone does not seem to be a major factor in determining tolerance to anemia, although compensatory mechanisms to an acute reduction in blood oxygen content may be less efficient. [19]

Controlled hypotension is frequently used during surgical procedures to decrease peroperative blood loss. However, the use of vasodilating agents and, in particular, alpha-blocking agents, may interfere with the normal regional redistribution of blood flow during hemodilution. Experimental studies have demonstrated impaired renal and splanchnic tissue oxygenation when controlled hypotension is superimposed on isovolemic hemodilution. [20]

Respiratory insufficiency also limits the physiologic adjustment to acute anemia. On the one hand, altered arterial oxygenation contributes to the decrease in oxygen-carrying capacities of the blood. On the other hand, hemodilution could have a deleterious effect on pulmonary gas exchange, possibly through attenuation of hypoxic pulmonary vasoconstriction. [21]Although the optimal hematocrit during respiratory insufficiency is not known, patients with chronic respiratory failure develop polycythemia in an attempt to maintain adequate tissue oxygen delivery.

During a critical illness, most of the compensatory mechanisms for anemia are reduced by the presence of hypovolemia, hypoxemia, depressed myocardial function, and/or altered tissue oxygen extraction capabilities. In addition, tissue oxygen demand is often increased in these situations due to fever, pain, stress, and increased respiratory effort. Therefore, it is not surprising that anemia is associated with an increased risk of morbidity and mortality in critically ill patients, especially in those with cardiovascular disease. However, there is no evidence in the literature that the use of a more liberal transfusion strategy in this “at risk” population is associated with better outcomes. [22]

THERAPEUTIC OPTIONS DURING CRITICAL HEMODILUTION:

1- Maximizing cardiac output

The efficacy of mechanisms to preserve tissue oxygen delivery when the oxygen- carrying capacity of the blood is reduced depends primarily on maintenance of an adequate blood volume. This is especially true for the cardiac output response to hemodilution. Indeed, hypovolemia will blunt the effects of decreased blood viscosity on venous return. [23]

Crystalloid solutions alone may be insufficient because of rapid extra vascular redistribution. Synthetic colloids may thus be required. Depending on the size and structure of the macromolecules and their actual concentration in the blood, any solution containing artificial colloids may increase plasma viscosity. An increase in plasma viscosity elicited by exchange of whole blood for colloid solutions may jeopardize micro vascular perfusion and tissue oxygenation. However, the impact of plasma viscosity on the rheological properties of whole blood is completely offset by the concomitant reduction in hematocrit. [24]

The critical hemoglobin level does not appear to be influenced by the type of synthetic colloid (e.g. 6% Hydroxyethyl starch 200/05 or 3% modified fluid gelatin). [13]

2-Increasing oxygen content:

The inspired fraction of oxygen (FiO2) may also influence the critical hemoglobin level since dissolved oxygen in plasma increases markedly during hemodilution. [24]

However, hyperoxemia reduces the cardiac output response occurring during isovolemic anemia and partially reverses the decrease in systemic vascular

resistance. Nevertheless, tissue oxygenation appears to be improved under these conditions, as the microcirculatory changes induced by hyperoxemia (arteriolar vasoconstriction mediated locally by the arachidonic acid metabolic pathway) may be at least partially blunted by hemodilution induced vasodilatation**.** [6] A recent experimental study demonstrated that hyperoxic ventilation increases short-term survival in anesthetized pigs undergoing critical hemodilution. [26]

However, high FiO2 (50%-100%) can be administered only for short periods of time. Indeed, increased FiO2 for long periods of time induces ongoing free radical formation in the lungs, with subsequent lung tissue damage. [27]

3-Decreasing metabolic rate:

Moderate hypothermia:

Deliberate mild hypothermia has been used in the peri- and postoperative management of severe anemic patients. [28]

Moderate hypothermia decreases tissue oxygen demand, but also increases the amount of oxygen dissolved in plasma and improves tissue affinity for oxygen.

HYPOTHERMIC EFFECTS:

1-Effects on the cardiac output response:

- Alteration in cardiac loading conditions
- Negative inotropic properties

2- Depressed autonomic nervous system activity

3-Vasodilatation

4-Decreased functional residual capacity

5-Effects on tissue oxygen demand: