EDITORIAL COMMENT

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Carbon dioxide production during cardiopulmonary bypass: continuous measure and clinical relevance

Carbon dioxide production during cardiopulmonary bypass derives from both the aerobic metabolism and the buffering of lactic acid produced by tissues under anaerobic conditions. Therefore, carbon dioxide removal monitoring is an important measure of the adequacy of perfusion and oxygen delivery. However, routine continuous monitoring of carbon dioxide removal is not widely applied.

Carbon dioxide (CO_2) removal monitoring during cardiopulmonary bypass (CPB) is considered a recommended guideline for practice by the American Society of Extracorporeal Technology and a standard of practice by the Australian New Zealand College of Perfusion.[1,2] This monitoring is usually performed through capnometric analysis of gases from the exhaust port of the oxygenator. Despite its relative easiness, this practice is not routinely applied.

CO_2 tension (PCO_2) as measured by capnometry is representative of the complex interaction of CO_2 production (VCO_2) by cells and its elimination by the natural or artificial lung. Therefore, this technique may provide important information, not only on the efficacy of CO_2 removal, but even on the metabolic status of the peripheral organs and on the adequacy of their perfusion with respect to their oxygen (O_2) needs.[3]

The hollow-fibre/membrane oxygenators commonly used on CPB have totally different performance in terms of CO_2 clearance with respect to the natural lung. Actually, the ventilation/perfusion ratio of the natural lung is around 0.8 (higher at the top and lower at the bottom of the lung in the orthostatic position). An increase of this ratio, as happens in the case of low pulmonary blood flow, creates the conditions for a $PvCO_2 - ePCO_2$ gradient (Mixed venous carbon dioxide tension - Exhaled carbon dioxide tension). Conversely, artificial lungs have a much higher efficiency in clearing venous blood from the CO_2, with an optimal ventilation/perfusion ratio of around 0.4-0.5.[4]

This property of the artificial lung offers a great advantage for the measurement of VCO_2 during CPB. The ability of the oxygenator to clear off the CO_2, even at a low ventilation/perfusion ratio, avoids the onset of a $PvCO_2 - ePCO_2$ gradient and the $ePCO_2$ measured at the exhaust port of the oxygenator can be reliably used to assess the VCO_2.

Infra-red spectography is the most popular means currently used to monitor CO_2 and most centres that use oxygenator exhaust capnography routinely use sidestream devices because of their ease of use.

Initially, capnography was mainly used to measure metabolic CO_2 production and to estimate $PaCO_2$. Many studies show a good correlation between ePCO2 and uncorrected $PaCO_2$ during clinical cases,[5-7] making it easier to maintain a specific target $PaCO_2$ during CPB. Although there is a good linear correlation between $ePCO_2$ and uncorrected $PaCO_2$, there is some deviation, especially during the rewarming phase. This deviation is the same for oxygenators of the same type and brand, but can differ between types and brands.

More recent research showed that VCO_2 is a good predictor of anaerobic metabolism[8] and, as such, can help to reduce CPB-related morbidity. Indeed, CO_2-derived parameters are more rapid and sensitive than O2-derived parameters in detecting anaerobic metabolism.[9] A combination of DO_2, VO_2 and VCO_2 parameters was significantly associated with the risk of postoperative renal insufficiency.[10]

The potential clinical relevance of VCO_2 monitoring goes far beyond the safety control of the maintenance of an adequate $PaCO_2$ of the patient throughout the CPB procedure. Certainly, the on-line measurement of $ePCO_2$ at the exhaust port of the oxygenator may prompt sweep gas adjustments to rapidly adjust the systemic $PaCO_2$ during the different phases of CPB. Increased values of $ePCO_2$ as an expression of increased VCO_2 can be found at the release of the cross-clamp, due to the reperfusion of the heart (anaerobic CO_2) or during the rewarming phases after deep hypothermia, as an expression of the increasing VO_2 (aerobic CO_2) and of the decreased solubility of CO_2. This last mechanism should be considered when assessing

VCO_2 during CPB cooling and rewarming phases, where the changes in CO_2 solubility respectively decrease and increase the $ePCO_2$.

Nowadays, the routine use of low temperatures on CPB has been replaced by moderate hypothermia or normothermia in many institutions. However, CPB temperatures <28°C may still be used in congenital heart surgery and for specific interventions of high complexity. Within the setting of profound hypothermia, the changes in CO_2 solubility result in corresponding changes in pH, with a reflection on cerebral blood flow. To compensate for the low values of CO_2 at low temperatures, the pH- stat strategy considers the addition of exogenous CO_2 to the sweep gas.

Another exogenous source of CO_2 may come from the flooding of the surgical field to prevent the formation of large air bubbles inside the heart chambers. The finding of elevated values of $ePCO_2$ is rarely attributable to a failure of the oxygenator.

Apart from this, the measurement of the VCO_2 may offer important information on the adequacy of the perfusion in terms of DO_2 (pump flow x arterial O_2 content). In the pathophysiology of CO_2 production, under conditions of inadequate DO_2, there is an excess CO_2 production as a result of lactic acid buffering. Therefore, VCO_2 may be considered as an indirect marker of lactate increase.

The use of DO_2 and VCO_2 to guide the perfusion management are now included in the concept of the "Goal Directed Perfusion (GDP)".[12-14] The GDP concept considers that the goal of perfusion is to maintain an adequate oxygen supply to all the organs, avoiding the patient entering into the anaerobic zone.

Despite the many possible applications of CO_2-derived parameters during CPB, very few studies have been published in this area. The expanding concept of GDP will probably increase the interest of clinicians and researchers in these measurements. Further studies on the clinical relevance of CO_2 production monitoring are warranted.

The article from Valdir Filho[15] has revived this subject. Shows an available technique to assess carbon dioxide production and removal and the clinically relevant applications of carbon dioxide-related variables as markers of the adequacy of perfusion during cardiopulmonary bypass.

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