Preface

CO_2-derived variables for hemodynamic management in critically ill patients

CO_2 measurement carries significant physiologic and clinical information when analyzing hemodynamic status and ventilation of patients. While much focus is on O_2 based data, CO_2 derived parameters can provide a wealth of additional information. This is becoming more readily available as technological advances are making headways in CO_2 measurements.

The classic targets clinicians follow in patients in shock have shortcomings. The central venous oxygen saturation ($ScVO_2$) was once hailed as the ideal target to guide resuscitation of patients in shock (1). More recent data challenged its role and reduced its value, although it remains a helpful physiologic parameter to follow (2,3). A normal $ScVO_2$ does not exclude tissue hypoperfusion and could misguide the clinician. Lactic acid is another closely monitored parameter which reflects tissue perfusion. It is also advocated for in multiple guidelines, but also has its own shortcomings: it can be elevated for reasons other than tissue perfusion such as adrenergic stimulation, increased glycolytic activity or reduced clearance from liver dysfunction (4-6). The venous-to-arterial CO_2 partial pressure difference (ΔPCO_2) and tissue CO_2 could help alleviate some of these limitations.

According to the Fick equation, and similar to O_2 metabolism, CO_2 production (VCO_2) is directly proportional to the cardiac output (CO) and the venous-to-arterial CO_2 content difference. The CO_2 content is linearly related to the partial pressure of CO_2 over the general physiological range of CO_2 content (7). Moreover, the mixed venous values correlate with the central venous values (8). Hence the Fick equation can be rewritten as follows: $\Delta PCO_2 = k \times VCO_2/CO$, where the k is a pseudo-linear coefficient supposed to be linear in physiological states.

Based on this modified Fick equation, and for patients in a steady state, ΔPCO_2 is inversely proportional to CO. ΔPCO_2 and its relation to the CO has been studied in a number of situations, including patients in shock on vasopressors, and found to be an appropriate target to titrate such agents (9,10).

ΔPCO_2 has similar value in the operating room, where optimizing tissue perfusion and O_2 delivery is essential to reduce post-operative complications. For high risk non cardiac surgical patients, ΔPCO_2 can be used to reflect CO, identify patients that are not adequately resuscitated and along with $\Delta PCO_2/C(a\text{-}v)O_2$ ratio predict post-operative complications (11). This might not be true with cardiac surgical patients, who have different macro and micro hemodynamic changes (12).

Tissue hypercarbia is a common observation in patients in circulatory failure. Tissue CO_2 values are a reflection of the adequacy of tissue perfusion, as reduced blood flow leads to blood stagnation and failure of CO_2 washout from the tissues. This stagnant hypercapnia phenomenon reflects tissue hypoperfusion, even earlier than systemic parameters (13). This is especially relevant in sepsis where the impaired microcirculation, arteriovenous shunting and reduction in capillary density culminate in heterogeneous tissue perfusion. Direct optical videoscopy permits to assess these microcirculatory changes, but is yet to reach the bedside for mainstream use. Tissue capnometry, on the other hand, might offer similar data and is becoming more readily available.

Gastric, sublingual, bladder and transcutaneous PCO_2 values have been assessed in critically ill patients. The stomach is easy to access, can be used to detect gastric hypoperfusion and splanchnic ischemia. The gastric PCO_2 correlates with outcomes in the critical care and operating room settings (14). The sublingual vasculature has drawn significant interest as it reflects pathologic changes seen during septic shock. Measuring sublingual CO_2 offers a way to assess the microcirculation in such patients (15). Overall, the tissue CO_2 gap seems to perform better than systemic parameters, paving the way to use it as a resuscitation target for septic shock.

Transcutaneous CO_2 ($tcPCO_2$) offers another non-invasive method to estimate $PaCO_2$ with many studies establishing a good correlation between the 2 values (16). Some restrictions persist including the optimal site for $tcPCO_2$ measurement (earlobe with its high vascularity seems to perform better than other sites), technological delays (time is needed to sensor equilibration) and a gap between $PaCO_2$ variations and reflection in the $tcPCO_2$ value. Nonetheless, when the appropriate conditions are met and the skin perfusion is normal, $tcPCO_2$ reflects $PcCO_2$. Similar to other tissues, and as was discussed in the prior section, for patients in shock, the transcutaneous CO_2 gap is a good reflection of tissue perfusion and as such can be used for hemodynamic measurements.

Based on the Fick equation as it applies to O_2 and CO_2, the $\Delta PCO_2/C(a\text{-}v)O_2$ ratio equals VCO_2/VO_2 and hence the respiratory quotient (RQ). While under aerobic conditions, RQ values ranges between 0.6 to less than 1, RQ changes with anaerobic metabolism. This is due to VCO_2 increases to a larger extent than VO_2 under anaerobic conditions. While this is of paramount importance diagnostically, it was also found to be valuable parameter to target during resuscitation (17,18).

The following review articles summarize the available literature on CO_2 physiology and clinical value, as it pertains to the critical care setting as well as the operating room.

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