Title: CARBON DIOXIDE ELIMINATION DURING TOTAL CARDIOPULMONARY BYPASS IN INFANTS AND CHILDREN

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INTRODUCTION: The rates of CO_2 elimination ($\dot{V}CO_2$) and oxygen uptake ($\dot{V}O_2$) from the oxygenator during total cardiopulmonary bypass (CPB) reflect aerobic metabolic activity, tissue perfusion, and oxygenator function. We used multiplexed mass spectroscopy (MS) to perform routine monitoring of $\dot{V}CO_2$ and $\dot{V}O_2$ during CPB in infants and children.

METHODS: With Clinical Investigation Committee approval, we studied 25 pediatric patients, age 30.1±5.4 mo (2d–9.2y), weighing 11.7±0.4 kg (2.3–29 kg). Anesthetics during CPB included only fentanyl and pancuronium. Cooling to 19.4±0.5°C (venous temperature, T_v) was achieved with integral heat exchangers of American Bentley BEN 5 or BIO 2 bubble oxygenators. All patients received phentolamine 0.75 mg·kg^{-1}. Circulatory arrest patients (n=10, 34±4 min), also received surface cooling. Technique: We modified and simplified the method of Abbott *et al.*[1] (gas phase Fick principle[2]) to measure $\dot{V}CO_2$ and $\dot{V}O_2$ in real-time. A multiplexed MS (Perkin-Elmer Advantage) analyzed gas from the oxygenator exhaust port during total CPB. Inflow gas to the oxygenator was primarily O_2 (F_iCO_2<0.1%; F_iN_2<4.5%). At 5-15 min intervals (except during circulatory arrest or partial CPB), we recorded venous, nasopharyngeal, and rectal temperatures, gas flow, and inlet (i) and exhaust (e) CO_2, O_2, and N_2 fractional concentrations (F). $\dot{V}CO_2$ (in ml·min^{-1}·kg^{-1}) was calculated as $\{F_eCO_2\}$ × {gas flow}÷kg. $\dot{V}O_2$ was computed from: $\{F_iO_2-F_eO_2\}$ × {gas flow}÷kg (n=83). Respiratory quotient (RQ), and Q_{10} (the increase in metabolic activity produced by a 10°C rise), were determined from the regression slopes of $\dot{V}CO_2$ *vs.* $\dot{V}O_2$ and $\dot{V}CO_2$ *vs.* T_v, respectively. If F_eN_2 >5% (room air contamination), data were not analyzed . After a log transform produced homoscedastity, ANOVA determined significance (α=.05). Values are mean±SEM, and the graph shows the regression line and 95% prediction interval.

RESULTS (Figure) CO_2 elimination correlated highly with T_v (r=0.88, P<.0001, n=199; $\dot{V}CO_2$=0.30×T_v−4.5) over a T_v range of 16.8–39.5°C. Similarly, oxygen uptake was correlated with T_v (r=0.79, P<.0001, n=83; regression equation $\log_{10}\dot{V}O_2$=0.030×T_v−0.13). $\dot{V}CO_2$ correlated better with venous temperature than with the other temperature monitoring sites.

$\dot{V}CO_2$ also correlated well with $\dot{V}O_2$ (r=0.94, P<.0001, $\dot{V}CO_2$=0.60×$\dot{V}O_2$+0.31) indicating a mean RQ of 0.60. The RQ tended to decrease with lower temperatures. The $\dot{V}CO_2$ *vs.* T_v regression indicated a mean Q_{10} of 3.0. The use of circulatory arrest did not affect either the T_v–$\dot{V}CO_2$ (P=.55), or the T_v–$\dot{V}O_2$ (P=.26) relationships.

DISCUSSION: We demonstrated that the rates of CO_2 elimination and O_2 uptake are easily measured in the gas phase during CPB, are more informative than measuring P_eCO_2 alone[3], and may be valuable as a routine clinical tool. Because $\dot{V}CO_2$ and $\dot{V}O_2$ are highly correlated, we recommend CO_2 elimination as the better test for routine monitoring.

$\dot{V}CO_2$ during CPB has been measured previously in only 4 patients, and without real-time results[1]. The rise in $\dot{V}CO_2$ seen with increasing T_v may be due to greater metabolic CO_2 generation, mobilization of CO_2 tissue stores, and reduced gas solubility in blood. These factors all tend to increase blood CO_2 delivery to the oxygenator. Decreased RQ with hypothermia may reflect preferential sequestration of CO_2 in blood and tissues at low T_v. A Q_{10} of 3.0 is consistent with most biological systems.

$\dot{V}CO_2$ values above normal for a given T_v may indicate hyperactive metabolism; this technique may be valuable for detecting malignant hyperthermia crisis during rewarming on CPB, when temperature normally rises quickly. Also, subclinical shivering may elevate $\dot{V}CO_2$, helping to guide muscle relaxant administration. VCO2 values below normal for a given T_v may indicate: 1)nonuniform regional blood flow, which may benefit from vasodilator therapy; 2)impaired O_2 delivery to tissues; and 3)oxygenator malfunction. Also, high F_eCO_2 with normal $\dot{V}CO_2$ may signify inadequate gas inflow. Real-time determination CO_2 elimination may be a useful continuous monitor of metabolic, circulatory, and oxygenator function during CPB, and may help guide drug therapy.

REFERENCES
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