CIRCULATION II

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

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INTRODUCTION: The rates of CO₂ elimination (VCO₂) and oxygen uptake (VO₂) from the oxygenator during total cardiopulmonary bypass (CPB) reflect aerobic metabolic activity, tissue perfusion, and oxygenator function. We used multiplexed mass spectrometry (MS) to perform routine monitoring of VCO₂ and VO₂ during CPB in infants and children.

METHODS: With Clinical Investigation Committee approval, we studied 25 pediatric patients, age 30±5.4 mo (2d–8.9 y), weighing 11.7±0.4 kg (2.3–29 kg). Anesthesiologists during CPB included only fenotanil and pancuronium. Cooling to 19.4±1.5 °C (vemous temperature, Tᵥ) was achieved with integral heat exchangers of American Bontley BEN 5 or BÖI 2 bubble oxygenators. All patients received phen tolamine 0.75 mg·kg⁻¹. Circulatory arrest patients (n=10, 34±4 min), also received surface cooling.

Techniques: We modified and simplified the method of Abbott et al.¹ (gas phase Fick principle²) to measure VCO₂ and VO₂ 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 O₂ (F₆O₂=0.1%; F₆N₂=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) CO₂, O₂, and N₂ fractional concentrations (F). VCO₂ (in mℓ·min⁻¹·kg⁻¹) was calculated as [F₆CO₂] × [gas flow]·kg⁻¹. VO₂ was computed from: [F₆O₂]−[F₆N₂] × [gas flow]·kg⁻¹ (n=83). Respiratory quotient (RQ), and Q₁₀ (the increase in metabolic activity produced by a 10 °C rise), were determined from the regression slopes of VCO₂ vs. VO₂ and VCO₂ vs. Tᵥ, respectively. If F₆N₂>5% (room air contamination), data were not analyzed. After a log transform produced homoscedasticity, ANOVA determined significance (p<0.05). Values are mean±SEM, and the graph shows the regression line and 95% prediction interval.

RESULTS: (Figure) CO₂ elimination correlated highly with Tᵥ (r=0.88, P<0.001, n=199; VCO₂=0.30Tᵥ−4.5) over a Tᵥ range of 16.8–39.5 °C. Similarly, oxygen uptake was correlated with Tᵥ (r=0.79, P<0.001, n=83; regression equation log₁₀VO₂=0.030Tᵥ−0.13). VCO₂ correlated better with venous temperature than with the other temperature monitoring sites.

VCO₂ also correlated well with VO₂ (r=0.94, P<0.0001, VCO₂=0.60VO₂−0.31) indicating a mean RQ of 0.60. The RQ tended to decrease with lower temperatures. The VCO₂ vs. Tᵥ regression indicated a mean Q₁₀ of 3.0. The use of circulatory arrest did not affect either the Tᵥ–VCO₂ (P=55), or the Tᵥ–VO₂ (P=28) relationships.

DISCUSSION: We demonstrated that the rates of CO₂ elimination and O₂ uptake are easily measured in the gas phase during CPB, are more informative than measuring P₆CO₂ alone, and may be valuable as a routine clinical tool. Because VCO₂ and VO₂ are highly correlated, we recommend CO₂ elimination as the better test for routine monitoring.

VCO₂ during CPB has been measured previously in only 4 patients, and without real-time results.¹ The rise in VCO₂ seen with increasing Tᵥ may be due to greater metabolic CO₂ generation, mobilization of CO₂ tissue stores, and reduced gas solubility in blood. These factors all tend to increase blood CO₂ delivery to the oxygenator. Decreased RQ with hypothermia may reflect preferential sequestration of CO₂ in blood and tissues at low Tᵥ. A Q₁₀ of 3.0 is consistent with most biological systems.

VCO₂ values above normal for a given Tᵥ may indicate hyperactive metabolism; this technique may be valuable for detecting malignant hyperthermia crisis during rewarming on CPB, when temperature normally rises quickly. Also, subclavian shivering may elevate VCO₂, helping to guide muscle relaxant administration. VO₂ values below normal for a given Tᵥ may indicate: 1) nonuniform regional blood flow, which may benefit from vasodilator therapy; 2) impaired O₂ delivery to tissues; and 3) oxygenator malfunction. Also, high F₆CO₂ with normal VCO₂ may signify inadequate gas inflow. Real-time determination CO₂ elimination may be a useful continuous monitor of metabolic, circulatory, and oxygenator function during CPB, and may help guide drug therapy.

REFERENCES