

Original Article

Correlation of Whole-Body Oxygen Consumption with Mixed Venous Blood Temperature During Hypothermic Cardiopulmonary Bypass in Man

Anis Baraka, MD¹, Sahar Siddik, MD², Samar Taha, MD², Abla Sibai, MS³ and Rania El-Khatib, MD²
1-Professor and Chairman, 2-Clinical Fellow, Cardiovascular Anesthesiology, 3-Instructor,
Biostatistics and Epidemiology Department of Anesthesiology and Department of
Biostatistics and Epidemiology, American University of Beirut, Beirut, Lebanon

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Abstract

The correlation between whole-body oxygen consumption and mixed venous blood temperature was investigated in ten adult patients during hypothermic cardiopulmonary bypass. The perfusion flow was maintained constant at 2.4 L/min/m² during cooling and rewarming. Mixed venous blood temperature was continuously monitored during bypass at the venous inlet of the oxygenator. The mixed venous blood temperature was decreased to 25-28°C. During rewarming, at every two-degree increase in temperature, blood samples were withdrawn simultaneously from the arterial and venous

ports of the oxygenator for blood gas analysis. Whole-body oxygen consumption (arterial-venous oxygen content difference multiplied by the perfusion index) was calculated at the different mixed venous blood temperatures. The whole-body oxygen consumption showed a linear correlation with the venous blood temperature on a semi-logarithmic scale. The Q10 (the ratio of oxygen consumption at two temperatures separated by 10°C) was approximately 2.0, which is in agreement with Van't Hoff's rule describing the effect of temperature on the equilibrium constant of a chemical reaction.

Introduction

The effect of hypothermia on whole-body oxygen consumption (VO₂) has been previously investigated in experimental animals using surface cooling¹⁻³, perfusion cooling⁴, or both⁵. Also, the effect of hypothermia on VO₂ has been investigated in man during cardiopulmonary bypass (CPB)⁶⁻⁹. However, the correlation of VO₂ with body temperature showed wide variations according to the site of body temperature monitoring⁵, and the perfusion flow used^{6,8}.

The present report correlated VO₂ during CPB in man with the mixed venous blood temperatures ranging from 25°C to 37°C, while perfusion flow was maintained constant at 2.4 L/min/m² during hypothermia and rewarming.

Methods

The investigation was performed in 10 patients aged 35-70 yrs and weighing 60-90 kgs who underwent coronary artery bypass grafting or valve replacement during CPB. The investigation was approved by the Institution Research Committee, and informed consent was obtained. Patients were premedicated with 0.1 mg/kg morphine, scopolamine 0.3 mg and promethazine 25 mg intramuscularly. Anesthesia was induced with midazolam 0.1-0.2 mg/kg, fentanyl 40 ug/kg and alcuronium 0.5 mg/kg. Following complete neuromuscular blockade, the trachea was intubated and ventilation was

Address correspondence to:
Anis Baraka, MD
Professor & Chairman
Department of Anesthesiology
American University of Beirut
Beirut, Lebanon

controlled with 100% oxygen without inhalational anesthetic supplementation. Patients were monitored with an electrocardiogram (V5), a radial artery catheter and a pulmonary artery catheter. Ringer's lactate solution of 1500 ml was used to prime the Bentley bubble oxygenator^a. During CPB, patients were perfused by a roller pump^b at a perfusion index of 2.4 L/min/m², and the flow was monitored by a flow rate computer^b. The perfusion flow was kept constant during cooling and rewarming. The oxygenator was ventilated throughout CPB with an equal flow of 100% oxygen. The central venous body temperature was continuously monitored during CPB by a thermometer probe attached to the venous inlet of the pump oxygenator.

After institution of CPB, the aorta was cross-clamped, the heart was arrested with a cardioplegic solution, and the mixed venous blood temperature was decreased to 25-28°C. The mean hemoglobin concentration during CPB was 8.8 ± 0.7 gm/dl. After 30-50 minutes, rewarming was started. A mixed venous blood temperature of 37°C was reached after 20-30 minutes. During rewarming and at every two degree increase in mixed venous blood temperature, blood samples were withdrawn simultaneously from the arterial and venous ports of the pump oxygenator for gas analysis. A Radiometer^c (thermostated at 37°C) was used to measure the arterial and mixed venous blood gases, as well as the oxyhemoglobin saturation.

Individual VO₂ at the different mixed venous blood tem-

peratures was calculated as the product of the arterial-venous oxygen content difference multiplied by the perfusion flow as follows:

$$VO_2 \text{ (ml/min/m}^2\text{)} = \left([(SaO_2\% - SvO_2\%) \times Hb \times 1.36] + [(paO_2 - pvO_2) \times 0.003] \right) \times PI$$

PI = Perfusion flow index (ml/min/m²)
 SaO₂% = arterial O₂ saturation
 SvO₂% = mixed venous O₂ saturation
 Hb = hemoglobin concentration (g/dl)
 1.36 = Huffer factor (ml/g)
 paO₂ = arterial O₂ tension (mmHg) measured at 37°C
 pvO₂ = venous O₂ tension (mmHg) measured at 37°C
 0.003 = solubility coefficient of O₂ at 37°C (ml/dl/mmHg)

The individual VO₂ values were correlated with mixed venous blood temperatures ranging from 25-37°C on a semi-logarithmic scale. Regression analysis was conducted, and the mean VO₂ at the different mixed venous blood temperatures was estimated from the regression line using the formula Y = 0.73 + 0.035X. Q10, which is the ratio of oxygen consumption at two temperatures separated by 10°C, was estimated.

Results

The mean paO₂, SaO₂%, pvO₂ and SvO₂% at the different mixed venous blood temperatures are shown in Table 1. The arterial hemoglobin was fully saturated at all temperatures, whereas the SvO₂ was 94.8 ± 2.2% at 27°C and was signifi-

Temp (°C)	paO ₂ (mmHg)	SaO ₂ (%)	pvO ₂ (mmHg)	SvO ₂ (%)
25	606.3 ± 47.7	99.9 ± 6.7 x 10 ⁻⁷	175.3 ± 36.6	96.7 ± 1.5
27	610.4 ± 83.06	99.9 ± 1.5 x 10 ⁻⁶	103.6 ± 24.2	94.8 ± 2.2
29	575.0 ± 62.26	99.9 ± 1.6 x 10 ⁻⁶	82.7 ± 14.4	93.3 ± 2.1
31	475.9 ± 121.50	99.9 ± 1.4 x 10 ⁻⁶	66.8 ± 13.3	88.8 ± 4.5
33	440.8 ± 83.75	99.9 ± 0.07	52.0 ± 6.0	81.2 ± 4.0
35	346.7 ± 111.93	99.8 ± 1.9	43.3 ± 3.8	75.0 ± 3.9
37	280.9 ± 126.47	99.1 ± 1.57	36.8 ± 3.2	68.6 ± 6.2

Table 1
 The mean (± SD) paO₂, SaO₂, pvO₂ and SvO₂% at the mixed venous blood temperatures ranging from 25°C to 37°C.

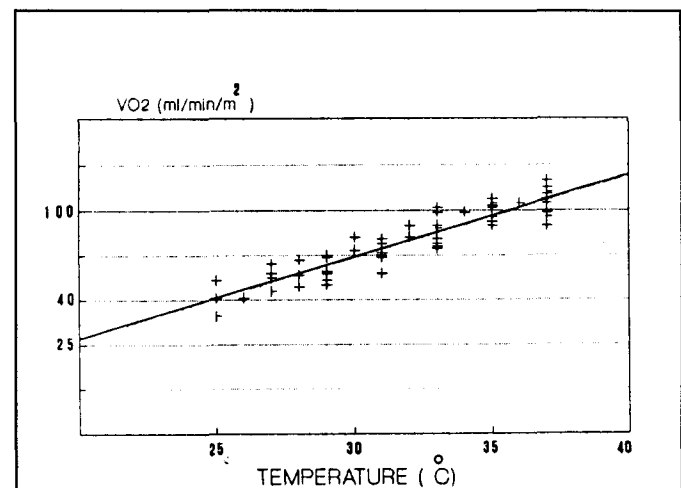


Figure 1
 Individual VO₂ values correlated with the different mixed venous blood temperatures on a semi-logarithmic scale, showing a linear correlation (r = 0.89, a = 0.73, b = 0.035, P < 0.001).

a Bentley 10, Bentley Laboratories, Inc., Irvine, CA
 b Sarns 5000, Sarns, 3M Health Care, Ann Arbor, MI
 c Radiometer, Copenhagen, Denmark

cantly decreased to 68.6 + 6.2% following rewarming to 37°C.

Correlation between the calculated individual VO_2 (ml/min/m²) and the different mixed venous blood temperatures shows a linear relationship, as plotted on a semi-logarithmic scale (Figure 1).

The mean VO_2 at the different mixed venous blood temperatures as derived from the regression line is shown in Table 2. The Q10 estimated from the mean VO_2 values at 37°C versus 27°C was 2.2.

Discussion

It is well established that tissue oxygen consumption decreases progressively with decreasing temperature¹¹ in an exponential relationship¹²⁻¹⁴. The magnitude of this relationship is expressed by the Q10, which is the ratio of oxygen consumption at two temperatures separated by 10°C. Van't Hoff's rule describes the effect of temperature on the equilibrium constant of a chemical reaction and states that a rise in temperature of 10°C increases the equilibrium constant two to three times^{3,6}.

It has been reported that the Q10 shows wide variations depending on the reference body temperature^{4,6}. Even in a stable environment, quite different temperatures exist throughout the "shell" as compared to the "core." When the body temperature is changing rapidly by perfusion cooling or rewarming, large thermal differences occur between different organs of the core¹⁰. Moreover, marked temperature disparity exists within the same organ¹⁵. During CPB, temperature measurement of the mixed venous blood at its entrance to the pump oxygenator most closely represents the mean temperature of all tissues of the patient¹⁰. In the present report, VO_2 was correlated with mixed venous blood temperatures ranging from 25°C up to 37°C.

VO_2 may also be affected by changing the perfusion flow. Decreasing the perfusion flow can decrease oxygen transport and VO_2 ^{6,8}. Our report calculated the VO_2 at the different mixed venous blood temperatures, while the perfusion flow was maintained constant at 2.4 L/min/m² during cooling and rewarming.

The results of the investigation demonstrate a linear correlation between VO_2 and mixed venous blood temperature ranging from 25°C to 37°C, as plotted on a semi-logarithmic scale. The Q10, as estimated from the ratio of VO_2 at 37°C to VO_2 at 27°C, is approximately 2.0. This is in agreement with Van't Hoff's rule describing the effect of temperature on the equilibrium constant of a chemical reaction^{3,6}.

T °C	VO_2 (ml/min/m ²)	% VO_2
25	40.6 ± 1.2	38.0
26	43.9	41.1
27	47.6	44.6
28	51.6	48.4
29	56.0	52.5
30	60.7	56.9
31	65.8	61.7
32	71.3	66.8
33	77.3	72.5
34	83.7	78.5
35	90.8	85.1
36	98.4	92.3
37	106.6	100.0

Table 2
Mean VO_2 at the different mixed venous blood temperatures, as estimated from the regression line depicted in Figure 1. The % VO_2 is the VO_2 at the different temperatures as a percentage of the 37°C value.

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