OXYGEN CONSUMPTION DURING CARDIOPULMONARY BYPASS

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IT is well known that cardiopulmonary bypass (C-P bypass) should be considered as a controlled shock¹ and an impaired peripheral circulation is inevitably provided. Oxygen consumption during C-P bypass has been studied by many investigators for the purpose to evaluate an optimal flow rate and related metabolic state. We attempted elimination of such a circulatory derangement of peripheral vasoconstriction during C-P bypass, with an administration of several vasodilators. The evaluation was made through the measurement of oxygen consumption under the given conditions with several vasodilators.

MATERIALS & METHODS

Oxygen consumption during total C-P bypass was measured in the serial 63 patients, 43 with congenital and 20 with acquired heart diseases, who all received open heart surgery. Age distribution was from 1 year 7 months to 57 years. The cases were divided into following groups: Group I; 30 cases of control, Group II; 10 cases with chlorpromazine (CPZ), Group III; 8 cases with phenoxybenzamine (POB), and Group IV; 15 cases with phentolamine. Doses administered at the commencement of the perfusion were 0.5 mg/kg with CPZ, 1–2 mg/kg with POB, and 10–40 mg with phentolamine. A roller pump and a bubble oxygenator were used in the perfusion.

Key Words:

Oxygen consumption
C-P bypass
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Phenoxybenzamine
Phentolamine

Flow rate of the perfusion ranged from 2.40 to 3.11 L/M²/min with a mean of 2.77 L/M²/min. Blood gas by IL Meter and hemoglobin content by Leitz' Photometer were measured with blood samples obtained in every 15 minutes of total perfusion. Body temperature during perfusion, determined as a mean of esophageal and rectal values, ranged from 24.9 to 37.8°C. Oxygen consumption was calculated by the following formula.

Oxygen Consumption

= Pump Flow × Difference of Arterio-Venous
Oxygen Content

Venous oxygen saturation and peripheral re-

Fig.1. Per cent values of oxygen consumption during perfusion comparing with predicted value in normothermia (35.5–37.0°C) were presented. Apparently a high value of oxygen consumption with POB is seen.

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Fig.2. Correlation between oxygen consumption and body temperature in Group I was presented. Oxygen consumption relates to body temperature significantly.

Fig.3. Correlation between oxygen consumption and body temperature in Group II with CPZ was presented. The regression line reveals a mild slope and crosses with the control line at the point of 32°C of body temperature.

sistance were simultaneously pursued in the selected 20 cases with a total perfusion of over 60 minutes.

RESULTS

The mean value of oxygen consumption in control group (Group I) was 58.3 ± 19.4 S.D. per cent of the predicted value in normothermic perfusion ($35.5\text{--}37.0^\circ\text{C}$), whereas they were 45.0 ± 13.1 S.D., 96.1 ± 28.9 S.D., and $39.8 \pm$

12.4 S.D. per cent in Groups II, III and IV respectively (Fig. 1). In Group III, the oxygen consumption increased significantly. It slightly decreased, however, in Groups II and IV in comparison with control group.

Relationship between body temperature and oxygen consumption during perfusion in every group was presented in Fig. 2, 3, 4, and 5 respectively. The changes in oxygen consumption in control group correlated well to the changes in

Fig.4. Correlation between oxygen consumption and body temperature in Group III with POB was presented. The regression line revealed a parallel change to the control line and oxygen consumption is higher than control in all temperature range.

Fig.5. Correlation between oxygen consumption and body temperature in Group IV with phentolamine was presented. The relation is not statistically significant, however showed a similar inclination to Group II. The regression line crosses with the control line at the same point of 32°C.

body temperature ($P < 0.05$). CPZ revealed a gradual decrease of oxygen consumption with a temperature fall. The regression lines of two groups, control and CPZ, crossed each other at the temperature level of 32°C (Fig. 3). In Group III, the regression line was parallel and was higher than control (Fig. 4). In Group IV, oxygen consumption was not changed significantly with temperature change, revealing a similar pattern

to Group II (Fig. 5).

Venous oxygen saturation and peripheral resistance pursued in selected 20 cases (every 5 cases in each group) were shown in Fig. 6. Venous oxygen saturation in control group slightly increased with a prolongation of the perfusion time. Similar changes were observed in Groups II and IV. Group III revealed a transient elevation with a terminal decrease. Peripheral

Fig. 6. Venous oxygen saturation and peripheral resistance pursued in selected cases of over 60 minutes' perfusion were presented. Venous oxygen saturation and peripheral resistance are well maintained by administration of the drugs.

resistance in control group represented an apparent increment, whereas the changes in Groups II, III, and IV remained minimum.

DISCUSSION

Decreased oxygen consumption during C-P bypass was suggested by Moffitt, since the oxygen saturation of the venous blood during bypass was higher than the preoperative despite the reduction in blood flow.² In our series, it was rarely seen that the venous oxygen saturation was lower than 60 per cent during C-P bypass. Insuring an adequate perfusion, the flow rate should be kept with an indication of venous oxygen saturation to be maintained at 70 per cent or above.³ Shackman et al. noted that about a 15 per cent fall in the oxygen consumption had been recognized by anesthesia alone.⁴ Additional depression of oxygen consumption would be produced by an induction of total body perfusion. In the experimental studies of Paneth, Anderson and Clowes, the oxygen consumption during perfusion ranged from 50 to 85–100 per cent of preperfusion level, corresponded with the changing flow rate from low to high.^{5–7} Clinical studies of Starr, Underwood, and Harris, demon-

strated an identical conclusion.^{8–10} With a relative high flow of 2.77 L/M²/min, oxygen consumption in our control group remained at 58.3 per cent of the predicted value. As body temperature decreases, oxygen consumption falls correlatively. This phenomenon is of importance when one attempts an adequate perfusion in any selected temperature level. In addition, to recognize the effect of vasoactive substances in all temperature range is necessary for an adequate perfusion.

Chlorpromazine is available for a better maintenance of extracorporeal circulation. It beneficially decreases the oxygen consumption of the total body, depresses peripheral resistance, and sustains venous oxygen saturation to a favorable level during C-P bypass.¹¹ Fujikura et al. exhibited an enhancement of peripheral flow with a favorable clinical appearance by prebypass administration of CPZ.¹² From another point of view, Furuse et al. demonstrated that CPZ increased tissue oxygen tension during bypass.¹³ Oxygen consumption with CPZ showed relatively decreased value in normothermia and increased in hypothermia.

Phenoxybenzamine, alpha adrenergic blocking agent, has been used in shock therapy.^{14–16} Efficiencies of POB on C-P bypass which is considered as "controlled shock", have been reported with a reasonable support, preventing deleterious effects of catecholamine and other vasoactive substances (histamine, serotonin) released in prolonged C-P bypass.^{17–19} POB not only depresses catecholamine's effect, but also counteracts histamine and serotonin, and increases pulmonary flow in patients with pulmonary hypertension in consequence of a reduction of pulmonary resistance.^{15,20,21} Reasonable result of increased oxygen consumption was obtained in Group III with POB and an increment of peripheral blood flow was suggested.

Investigation of the effect of phentolamine, also an alpha adrenergic blocking agent, on the oxygen consumption are controversial. There are both descriptions referred with a little increase of oxygen consumption despite narrowing of A-V oxygen content difference and with decreased oxygen consumption.^{22–24} However, the former concept will be acceptable generally at present. Phentolamine depressed oxygen consumption in normothermia and increased it in hypothermia below 32°C. This is a similar inclination seen in the group with CPZ.

CONCLUSIONS

The mean oxygen consumption during total perfusion compared with the predicted value obtained under the condition without C-P bypass, was 58.3 per cent in control, 45.0 per cent in CPZ, 96.1 per cent in POB, and 39.8 per cent in phentolamine groups respectively.

POB increased oxygen consumption during perfusion in all temperature range. Thus an increment of peripheral blood flow was suggested. CPZ and phentolamine revealed an increasing effect of oxygen consumption particularly in hypothermia below 32°C.

All drugs used in this study, effectively prevented the elevation of the venous oxygen saturation level owing to decreased peripheral resistance in prolonged perfusion.

It was concluded as follows. POB was effective to maintain an adequate circulation during C-P bypass under both hypothermia and normothermia. CPZ and phentolamine were also effective particularly in the instances of C-P bypass with hypothermia.

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