The Use of the Classical Shunt Equation in the Evaluation of Coronary Artery Hypoxemia During Cardiopulmonary Bypass

Charles F. Jerabek, BS, CCP, Howard G. Walton, BA, CCP, Sally Doerfler, BA

Providence Medical Center
Portland, OR

Key words: Oxygenator, ventilation, pulmonary circulation

ABSTRACT

With the decreasing usage of left heart venting in routine cardiac surgery, there is a possibility of coronary artery hypoxemia impairing myocardial recovery after the removal of the aortic cross clamp. This study was undertaken to determine whether coronary artery hypoxemia was present in the period following clamp removal and if the degree of hypoxemia could be predicted. Fifteen patients were studied with blood gas samples being drawn from the aortic root (as near to the coronary ostia as possible), oxygenator inflow line, radial artery line and oxygenator venous return line at a rewarming temperature of at least 34°C. Relative coronary artery hypoxemia was present in nine patients. No pre-operative tests predicted the patients at risk for developing this condition. A modification of the classical shunt equation proved to be the most accurate test (R=.86) to predict coronary artery pO_2 levels. Proposed solutions to the problem of coronary artery hypoxemia include left heart venting when the shunt is >5% (a value of 10% is projected to be acceptable when oxygenator pO_2 exceeds 250), leaving the patient hooked to the anesthesia machine with a sweep gas FIO_2 of >80% and the use of PEEP or low frequency ventilation during the rewarming period.

INTRODUCTION

With the increasing incidence of cardiopulmonary bypass being conducted using a two stage venous cannula, without the use of left ventricular or pulmonary artery venting,[1] there may be a variable amount of blood being shunted around the cardiopulmonary bypass circuit and through the patient's normal pulmonary circulation after aortic cross clamp removal. This study was designed to evaluate three questions. First, whether the blood flow through the pulmonary system during bypass could be recognized and quantified using currently available laboratory tests in conjunction with normal patient assessment. Next, what effect the blood contributed by the native pulmonary circulation had on the oxygen availability in the coronary arteries and whether there was a significant difference in the pO_2 valves between the oxygentor and the aortic root. Finally, whether there was a specific patient group at risk for experiencing deleterious effects and what contribution these effects had on patient morbidity.

MATERIALS AND METHODS

A patient sample size of fifteen was used. These patients were selected at random and the operation type along with other patient data is listed in **Table 1.** Blood samples were drawn during the rewarming phase of bypass after the cross clamp was removed and a normal sinus rhythm had resumed. The blood gases were obtained using an in room Radiometer[a] ABL3 blood gas machine and were not temperature corrected. Patient venous return temperature was at least 34°C. Sample sites included the radial arterial line, oxygenator arterial port, venous return line sample port and the aortic root as proximal as possible to the coronary ostia. At the time of the sampling, anesthesia gas FIO_2 and ventilator settings were recorded along with the patient's mean arterial pressure, central venous pressure, pulse pressure and cardiopulmonary bypass pump speed. All values were sampled and recorded using the Providence Perfusion Software Package 2. Pressure values were obtained from a Sorenson[b] strain gauge transducer coupled to a Siemens[c] pressure monitor. Statistical evaluations were performed using the Kwikstat Statistical Program supplied by Alan C. Elliot.

RESULTS

Tables 2-5 list the results of the sampling. All values were within acceptable range as defined by the Providence Medical Center Perfusion Protocol. **Table 6** lists the results of independent group t test for selected variables.

DISCUSSION

During cardiopulmonary bypass blood can enter the left ventricle from the thebesian vessels, bronchial collateral branches, coronary sinus and venae cavae with only the blood from the venae cavae being partially oxygenated by the lungs.[5] Assuming a competent aortic valve and no venting arrangement, this blood is inconsistently ejected[4] having little systemic effect,[4] but sometimes providing the coronary arteries oxygen poor blood, the amount of which depends upon the flow dynamics of the inflow cannula and aortic root response. This study showed

Address correspondence to: Charles F. Jerabek, Department of Surgery, Providence Medical Center, 4805 N. E. Glisan, Portland, OR 97213

a. Radiometer, Copenhagen, Denmark
b. Sorensen
c. Siemens, Iselin, NJ

that in 60% of the patients sampled there was an aortic root PO_2 value less than the oxygenator's PO_2 (**Table 2**). This group was therefore at risk for developing some degree of coronary artery hypoxemia along with myocardial hypoxia if there was a drop in the oxygenator PO_2 level to the systemically acceptable range of 90 to 120 mmHg. Fortunately, this drop was not recorded with any of the patients studied.

In respiratory physiology, the classical shunt equation:

Oxygen Content of Pulmonary Capillary Blood -
Oxygen Content of Mixed Venous Blood
Oxygen Content of Arterial Blood - Oxygen Content of
Mixed Venous Blood

is used to estimate the percentage of blood in the pulmonary circulation not coming in contact with the alveoli.[3] This equation was used as a starting point to try to predict coronary blood oxygen supply. By substituting the oxygenator's arterial sample port for the pulmonary capillary value and using the bypass venous line sample port as the mixed venous site, the perfusion shunt value equation was derived (**Figure 5**).

Oxygen Content of Oxygenator Art. Blood - Oxygen Content of Mixed Venous Blood
Oxygen Content of Radial Art. Blood - Oxygen Content of Mixed Venous Blood

When this value was compared to the oxygenator PO_2 minus the aortic root PO_2 gradient a R value of .86 was obtained (**Figure 1**) when the following linear regression formula was used:

Shunt = .11 + (.04 * (Aortic Root PO_2 - Oxygenator Art. PO_2))

This correlation was superior to comparing oxygenator PO_2 minus radial arterial PO_2 values. R equals .79 (**Figure 2**). The shunt correlation was also more accurate than using the shunt equation compensated for cardiac output as a ratio of predicted flow. R=.85 (**Figure 3**). Finally, measuring oxygen content differences between the oxygenator minus radial arterial sites versus the oxygenator minus aortic root sites produced an R value of only .84 (**Figure 4**).

The next step was to see whether there were factors in addition to the blood gas results which could alert the perfusionist that a deleterious shunt might be occurring. When the data from tables one and four was evaluated against the oxygenator PO_2 minus aortic root PO_2 gradient, no statistical difference was found in any of the preoperative or intraoperative categories selected (**Table 6**). Statistical analysis was conducted using the independent group t test with a p-value less than .05 being significant.

All attempts to quantify the shunt value with an actual pulmonary vascular blood flow proved unsuccessful . The reason proposed is that the lung oxygenation efficiency along with the non-pulmonary blood return to the left ventricle during bypass was unpredictable and these values must be known in order to get an accurate flow prediction.[3]

Post operatively there was no correlation between the oxygenator PO_2 minus aortic root PO_2 gradient simplified to either positive (an aortic value less than the oxygenator value) or negative (an aortic value greater than that of the oxygenator) and morbidity in the areas of total hospital stay, ventilatory support in hours or CPK-MB levels obtained one day after surgery (table six). We hope that this was due to the acceptable PO_2 levels in the aortic root even with patients with high gradients. However, a critical area of difference was encountered when the pulmonary morbidity was compared. Patients who had a negative gradient (a shunt < 0 percent) experienced more pulmonary complications then those with a positive gradient (p=.015). The complications were minor, two incidence of pleural effusion and one case of pulmonary edema, yet their negative correlation with the expected hypothesis was troubling. A larger study is underway to determine if this was just an aberration from our small sample size or that somehow, by having the lungs oxygenate the blood during bypass and improving the oxygen content in the coronary circulation, there is a concomitant detrimental effect on post bypass pulmonary function. It should be also noted that 67% of the patients experiencing these pulmonary complications had a shunt value more negative than -1 percent perhaps implicating a high residual pulmonary blood flow with these complications.

In conclusion, we have found that by sampling the radial line as well as the oxygenator arterial port for blood gas analysis after cross clamp removal, we have been able to prevent inadvertent myocardial hypoxemia during the reperfusion and rewarming period of cardiopulmonary bypass. When the shunt value is obtained the predicted root PO_2 value can be calculated using the equation:

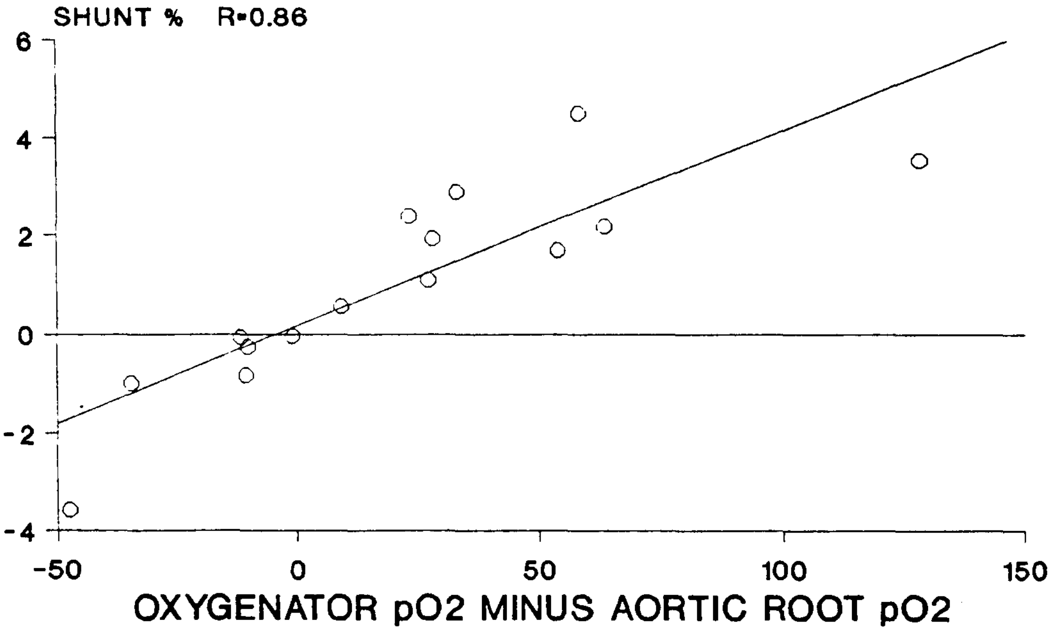
ROOT PO_2 = ((SHUNT - .11) * 25) + OXYGENATOR ART. PO_2

The perfusion department at Providence Medical Center has set our recommendations for shunt limits from five percent down to -1 percent as a safe range assuming the oxygenator pO^2 is kept between 150 and 200 mm Hg. Ideally, this shunt should occur with a low but greater than zero central venous pressure to dilute the deoxygenated blood in the left ventricle with a small amount of pulmonary oxygenated blood. The in room computer displays these calculated values as well as the aortic root pO^2 predictions (table seven shows sample case data). For cardiac surgery programs that do not have the use of in-room computers, simply measuring the pO^2 difference between the oxygenator arterial value and the radial artery value gives almost as reliable a prediction of aortic root pO^2 as the shunt equation.

The pulse pressure was not a reliable indicator of whether there would be a positive or negative shunt, although we did not experience any pulse pressures greater than 20 during the experiment and should this value be exceeded a high shunt (and low coronary artery pO^2) should be expected[4] if no active ventilation is being performed by the anesthesiologist. Should a high shunt be encountered, it is recommended that a left ventricular venting be initiated or the anesthesiologist start

FIGURE 1

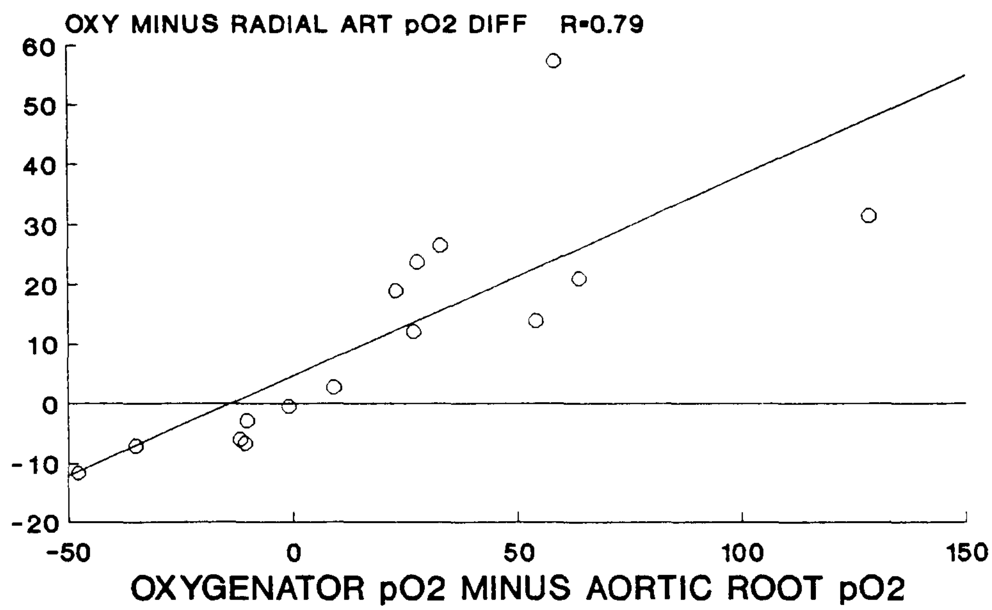
SHUNT % VS OXY-AO ROOT pO2 DIFF



Y= .11 + .04 X

FIGURE 2

OXY-RAD VS OXY-ROOT pO2 DIFF



Y = 44.64 + .33 X

FIGURE 3

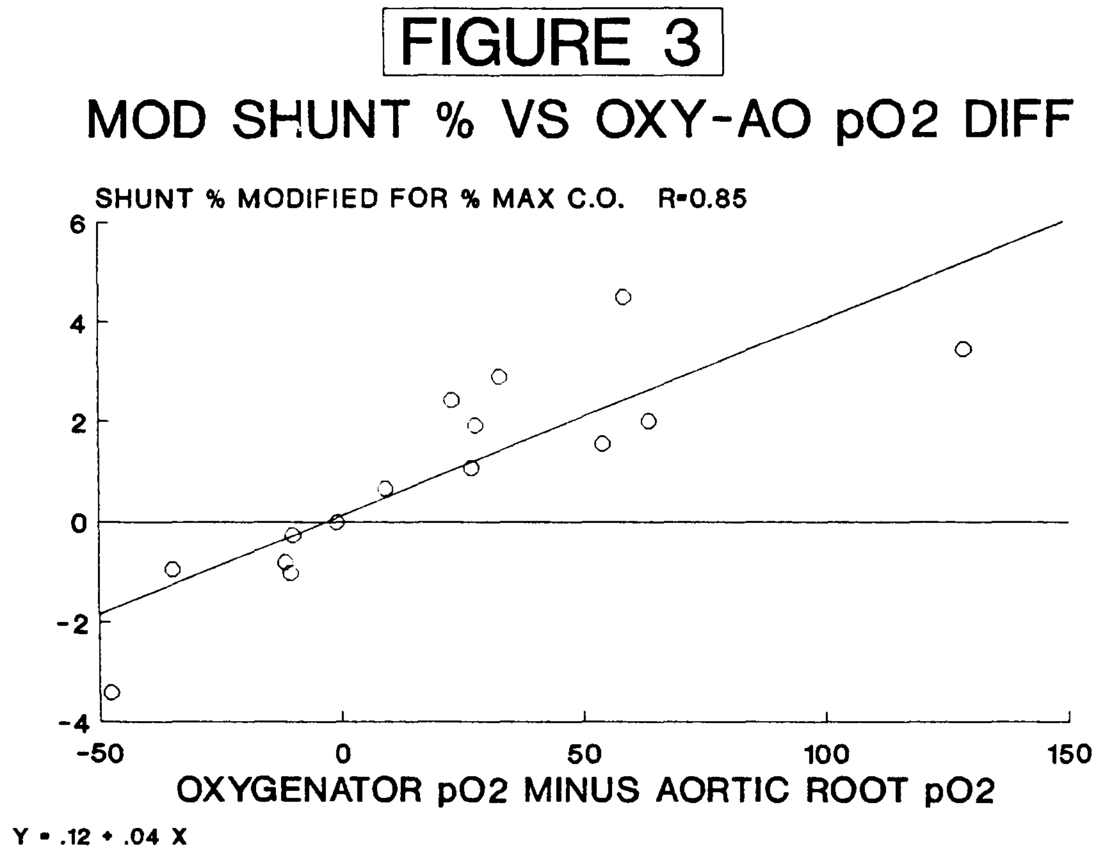
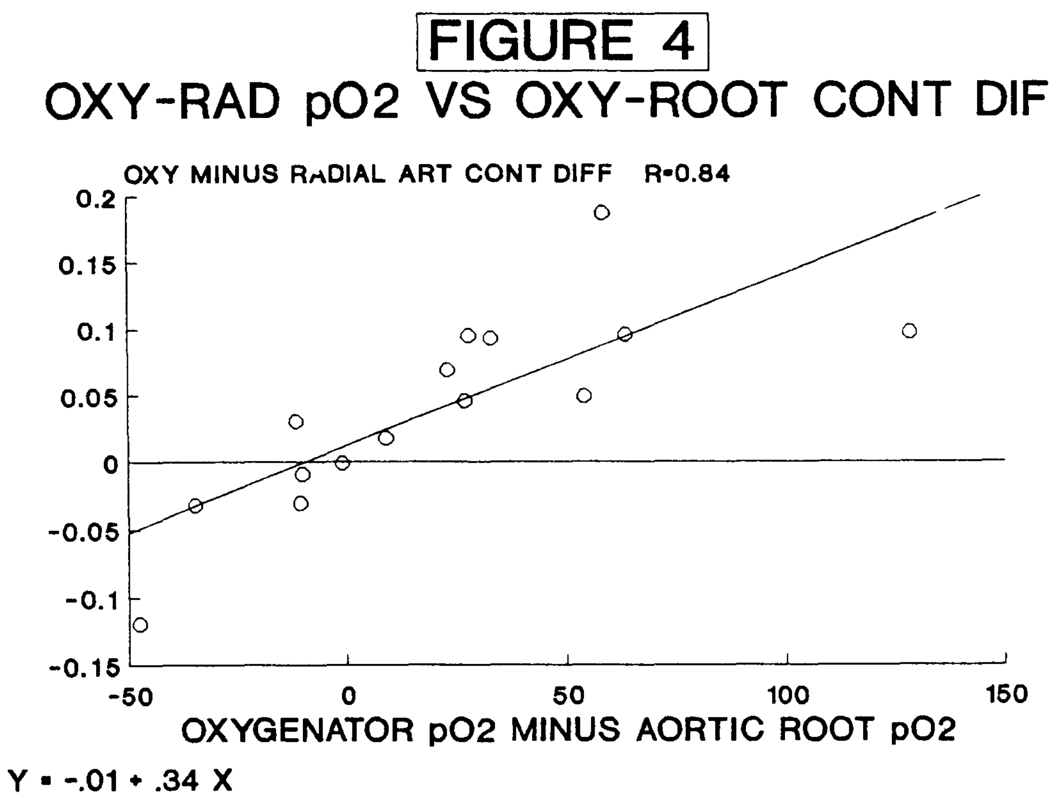
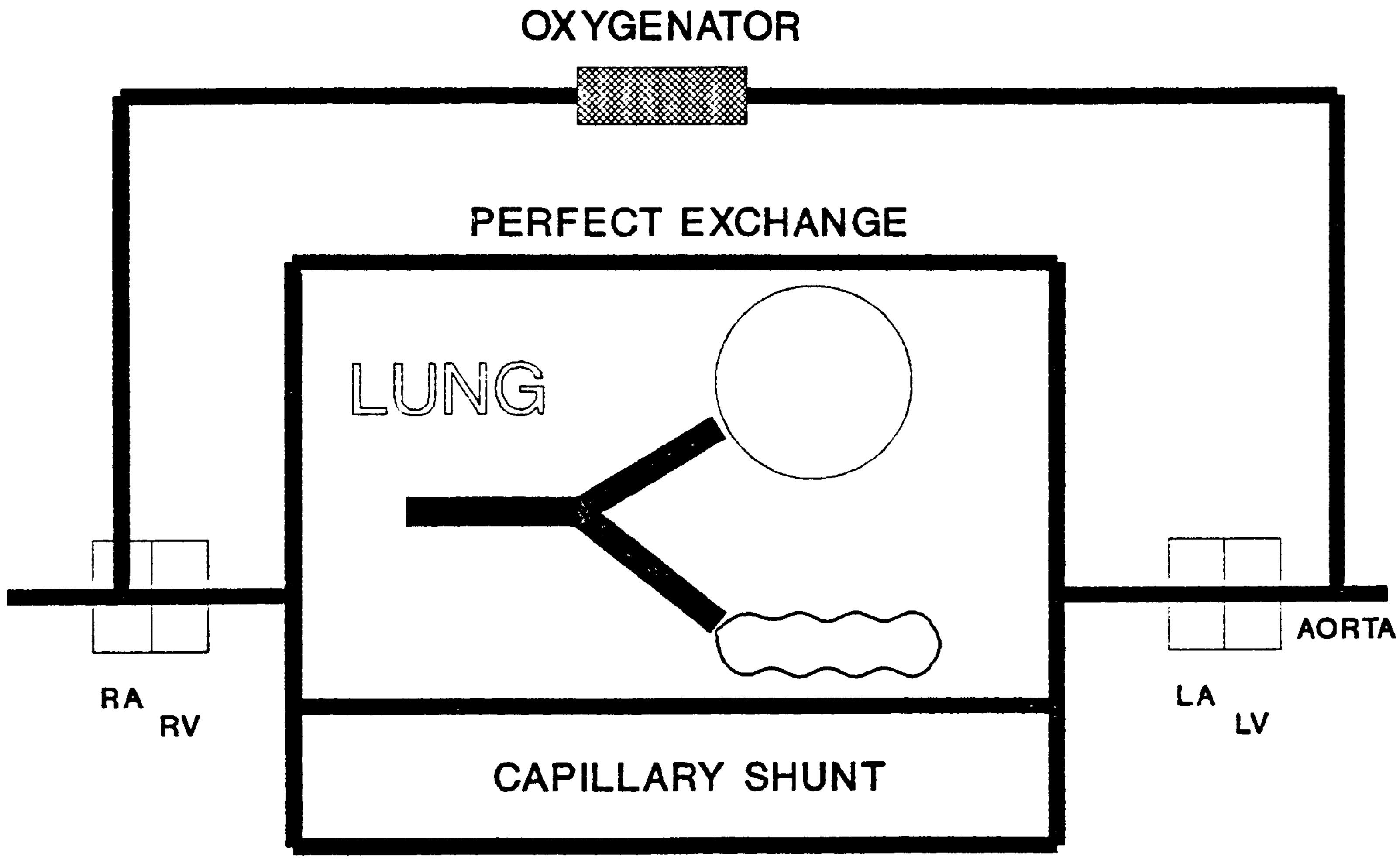


FIGURE 4





ANATOMIC SHUNT

FIGURE 5

ventilating the patient both of which, along with improving venous return to the oxygenator, have improved the shunt values in cases conducted after this experiment (**Table 7**). Routine lung ventilation during bypass, however, has proved to be of little value and may lead to lowering systemic pCO^2 levels leading to increased peripheral vascular resistance.[4,6] The use of FIO^2 values less than 90% in the anesthesia circuit or the disconnection of the patient from the anesthesia machine during cardiopulmonary bypass is not recommended in the literature.[7]

The use of PEEP and CPAP in the anesthesia circuit has decreased our shunt values on several cases but its broad application is still questionable.[7] More research needs to be done in this field particularly in animal studies. The reason for this is that the authors' believe the area of respiratory physiology during cardiopulmonary bypass needs further exploration, since most of the research reviewed was over ten years old and the ability to quantify pulmonary and left ventricular blood flow during cardiopulmonary bypass is possible and should be made available to the surgical team.

REFERENCES

1. Breyer RH et al.: Is a left ventricular vent necessary for coronary artery bypass operations performed with cardioplegic arrest? *Journal of Thoracic and Cardiovascular Surgery*. 86:338. 1983.

2. Jerabek CF, Walton HG, Sugden EH.: An inexpensive real-time computer system for cardiac surgery. *AmSECT 26th International Conference Proceedings*. 23-27, 1988.

3. Shapiro BA.: Clinical Application of Blood Gases. Chicago, Year Book Medical Publishers Inc., 1977, p. 219-225.

4. Moore et al.: The effect of ventilation on systemic blood gases in the presence of left ventricular ejection during cardiopulmonary bypass. *The Journal of Thoracic and Cardiovascular Surgery*. 90:287-290, 1985.

5. Cartwright RS. et al.: Pathophysiological changes in the lungs during extra-corporeal circulation. *Circ Res*. 10:131-141,1967.

6. Cullen DJ, Eger EI.: Cardiovascular effects of carbon dioxide in man. *Anesthesiology*. 41:354-349, 1974.

7. Stanley EH et al.: The influence of IPPB, CPAP, and IPPB with CPAP during cardiopulmonary bypass on post-bypass and post-operative pulmonary function. *Annals of Thoracic Surgery*. 22:182- 187, 1976.