

Original Article

Residual Blood in Neonatal Oxygenators After Drainage

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ABSTRACT

The objective of this investigation was to measure the quantity of residual blood remaining in neonatal cardiopulmonary bypass (CPB) circuits after they had been drained and to assess the overall significance with regards to total patient blood volume.

The residual blood volume left in three infant/neonatal CPB circuits—Medtronic Minimax 3381 (Group MM; n=5), Polystan Safe Micro (Group SM; n=6), and Terumo Capiiox 308 (Group CX; n=3)—after they had been drained was determined. This was done by using an electronic scale to weigh the circuit before setup and after CPB when all possible blood was recovered from it. Total priming volume, estimated patient blood volume, residual blood volume, surgical blood loss in theater, and autogeneic blood usage were recorded in each case.

Mean residual blood volumes measured were MM=161ml (SD 27ml), SM=103ml (SD 19ml), and CX=133ml (SD 15ml). These volumes were significant, because calculations show that the volume of red cells lost in the circuit is equivalent to fourteen percent of the total patient blood volume.

In view of this, neonatal oxygenator design should be minimized to reduce the priming volume and more consideration should be given to ease of residual blood recovery.

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INTRODUCTION

It is generally accepted that a reduction in the priming volume of neonatal and infant extracorporeal circuits is beneficial to the patient (1,2). Minimising the cardiopulmonary bypass (CPB) circuit can mean the avoidance of excessive hemodilution and use of autogeneic blood (3).

In order to reduce autogeneic blood usage, several techniques are employed to conserve the patient's blood. After discontinuation of bypass, the residual volume of perfusate in the oxygenator and circuit is either directly infused after aortic decannulation (4), concentrated using ultrafiltration techniques, or centrifuged and washed (5). In the majority of cases, the patient's red cells are returned to them in some manner. However, not all of the perfusate can be recovered and some residual blood remains in the circuit.

Although the reduction in a patient's hematocrit due to hemodilution is largely reversible (6), the residual blood left in the oxygenator and circuit after draining is lost altogether and therefore contributes to the overall blood loss. Our investigation attempted to measure this residual blood and to assess whether or not this residual volume was of any significance.

MATERIALS AND METHODS

The residual blood volume left in three infant/neonatal cardiopulmonary bypass circuits was determined after the circuit contents had been drained. The three circuits were a Medtronic^a Minimax 3381 oxygenator, hard-shell reservoir with integrated cardiomy filter and custom tubing (Group MM; n=5), a Polystan^b Safe Micro oxygenator, hard-shell venous reservoir with integrated cardiomy filter and custom tubing (Group SM; n=6), and a Terumo^c Capiiox 308 oxygenator, hard-shell cardiomy reservoir CX*CR10, soft-shell venous reservoir CX*VRA and custom tubing (Group CX; n=3).

Circuit tubing was of 1/4 inch diameter throughout with 3/8 inch tubing in the pump raceway. An arterial line filter was not used. The circuit did not include any ultrafiltration or blood cardioplegia systems.

An electronic scale (Mettler PE6 Electronic^d) was calibrated using known volumes of water from zero to 2000 ml. The lower end of the range was calibrated using 1 ml aliquots to verify the readings, confirming an accuracy of ± 0.5 ml. Known volumes of blood from 50 ml to 180 ml with hematocrits in the working range were weighed and compared with identical volumes of water. Since the maximum difference between the weights of blood and water was less than 1%, it was accepted, then, for the purpose of this investigation, that equal amounts of this blood

and water weighed the same.

The scale was then used to weigh the entire circuit (oxygenator, reservoirs and tubing) before setup. After CPB, the circuit was drained of as much perfusate as possible, high-pressure suction was applied to the heat exchanger to remove any remaining water, and the entire circuit was weighed again taking care to include only components that were also weighed preoperatively. The difference in weights yielded a value for residual blood volume.

Residual blood volume (RES), total priming volume (TPV), estimated preoperative patient blood volume (EBV), preoperative patient hematocrit (HCT), surgical blood loss in theater, and autogeneic red cell usage were recorded in each case.

Having determined the residual blood volume being discarded, it was then necessary to assess the overall significance with regards to total patient blood volume. This was done by calculating patient blood loss (PBL), defined as the volume of blood that the patient would have to lose preoperatively in order to lose the same red cell volume discarded in the circuit.

First, the total circulating volume (TCV) on was calculated as follows:

$$TCV = (EBV + TPV + \text{additions during CPB})$$

Anesthesia volume minus the volume of urine output, in most cases, was negligible compared to the above factors and so was not considered in the calculation.

The packed red cells that were used have a mean hematocrit of 0.65, so we can calculate the total red cell volume (RCV) at the end of CPB as:

$$RCV = (EBV \times HCT) + (\text{blood volume added} \times 0.65)$$

The red cell volume lost in the circuit is then:

$$\text{Residual volume} \times RCV/TCV$$

We can then write:

$$PBL = \text{Residual volume} \times HCT \times \{[(EBV \times HCT)/RCV]/HCT\}$$

This expression can be simplified to:

$$PBL = (EBV/TCV) \times \text{Residual volume}$$

This value was calculated for each case and a mean value for each group was determined. Data is expressed as means with standard deviations in parenthesis. Statistical significance was determined using Student's t-test with significance considered a p value of less than 0.05.

RESULTS

Although the priming volumes of the circuits and the blood

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 b Polystan, Nottingham, England
 c Terumo UK, Knowsley, Merseyside, England
 d Mettler Instrumente AG, Zurich, Switzerland

Table 1. Measured and calculated results for the three groups

	MM (n=5)	SM (n=6)	CX (n=3)
Total priming volume	434(25)	289(23)	380(14)
Estimated preoperative patient blood volume	563	352	354
Residual blood volume	162(27)	103(19)	133(15)
Surgical blood loss	27(17)	42(71)	63(24)
Packed cells used	64(39)	134(82)	173(31)
Patient blood loss(PBL)	78(17)	45(8)	56(13)
PBL as % EBV	14%	13%	16%
"Ease of drainage"	37%	36%	35%

All values (other than percentages) are in milliliters and are means with standard deviations in parenthesis. Packed cells used refers to autogeneic blood used in the priming of the bypass circuit and added during bypass. "Ease of drainage" = Residual blood volume expressed as a percentage of the total priming volume. PBL = Patient blood loss, or the volume of patients' blood that, pre-bypass, is equivalent to the red cell volume lost in the circuit.

volumes of patients in each group are different, it should be noted that there is a consistency in the calculated results. The apparent difference in surgical blood loss between the three groups (Table 1) is not statistically significant ($p>0.05$) and could be attributed to the variation in patient size and the degree of difficulty of the respective operations. The percentage of the patients' blood volume lost in the residual volume (PBL as % EBV, in Table 1), is similar in each group at 14%, 13%, and 16% respectively. No single oxygenator is superior to the others in this respect.

The mean volumes of autogeneic blood that were lost in the residual volume were calculated for group MM, 11 ml (standard deviation 3 ml), group SM, 18 ml (10 ml) and group CX, 27 ml (7 ml).

The mean percentage of the total circulating volume at the end of CPB that is residual blood volume, (RES/TCV), was calculated to be 14% in group MM, 13% in group SM and 16% in group CX.

DISCUSSION

The objective here was to measure the amount of blood that was not recoverable from the circuits after bypass and to assess its significance. In an attempt to determine the significance of the residual volumes and subsequent results, several approaches were taken.

The perfusate just at termination of CPB is identical to the blood in the patients' circulatory system. However, it should be remembered that the perfusate, although containing the preoperative patient blood volume, is, at this point, hemodilute. Rather than considering residual blood discarded as blood loss, we should determine how much of the patients pre-bypass hemoglobin is contained therein. This yielded the results for PBL, (the volume of patients' blood that is equivalent to the red cell volume lost in the circuit). It can be seen from Table 1, that the calculated means for PBL are 78 ml, 45 ml, and 56 ml, respec-

tively. These volumes are considerable. As a percentage of the mean estimated patient blood volume there is no difference between the three groups with around fourteen percent of the patient blood volume being lost. In comparison, a typical result for an adult patient with an adult oxygenator is two percent.

The result that we termed the "ease of drainage," that is, the percentage of the total priming volume that, once introduced to the circuit, cannot be drained out, is the same in each of the groups, at around thirty six percent.

Autogeneic blood was used in each of the fourteen cases, being either used in the prime pre-bypass, or added during bypass to maintain the appropriate

haematocrit at each stage of the operation. However, after having added autogeneic blood to the circuit, a proportion of it is discarded after bypass in the residual volume. It may be possible to minimize or reduce the transfusion of red cells in neonates, if we could reduce the amount of red cells lost, which is often a key indicator for autogeneic blood transfusion.

It should be noted that some, or all, of the blood recovered from the oxygenators and circuits was used for transfusion in 12 of the 14 cases.

In conclusion, we feel it is important that the users of neonatal oxygenators be aware of the significant volume of blood left in the oxygenator after drainage. Precisely where this blood lies needs to be determined. Only then can we consider options to minimize this volume.

REFERENCES

1. Elliot MJ, Hamilton JRL, Clark I. Perfusion for paediatric open-heart surgery. *Perfusion*. 1990; 5: 1-8.
2. De Somer F, Foubert L, Poelaert J, Dujardin D, Van Nooten G, Francois K. Low extracorporeal priming volumes for infants: a benefit? *Perfusion*. 1996; 11: 455-460.
3. Elliot M. Minimising the bypass circuit: a rational step in the development of paediatric perfusion. *Perfusion*. 1993; 8: 81-86.
4. Lodge FA, Lamberti JJ, Winkler MH, et al. Blood conservation during open-heart surgery in infants and children. *J Extra-Corp Tech*. 1984; 16: 121-124.
5. Groom RC, Hill AG, Kurusz M, et al. Paediatric perfusion practice in North America: an update. *Perfusion*. 1995; 10: 393-401.
6. Naik SK, Elliot MJ. Ultrafiltration and paediatric cardiopulmonary bypass. *Perfusion*. 1993; 8: 101-112.