Bull. Mater. Sci., Vol. 5, No.2, June 1983, pp.91-96. © Printed in India.

A blood oxygenator from indigenous materials: Functional evaluation using sheep lung as deoxygenator

V S VENKATESAN, G ARTHUR VIJAYAN LAL and M S VALIATHAN

Sree Chitra Tirunal Institute for Medical Sciences and Technology, Trivandrum 695 012, India

MS received 31 December 1981

Abstract. *In vitro* evaluation of an oxygenator is an integral part of its development. In order to obtain meaningful data the test conditions must be standardised. The natural lung offers a large surface area for gas exchange and provides excellent oxygenation over wide range of blood flows. Consequently it should act as a good deoxygenator too. Our experience in using a sheep lung for deoxygenation is described.

Keywords. Oxygenator; *In vitro* evaluation; deoxygenation; sheep lung; gas exchange.

1. Introduction

An oxygenator is an integral part of an extra corporeal circuit. Different versions employing the principles of filming, foaming and gas transfer across a membrane are currently in use world over, the most popular ones being bubble oxygenators. Despite the advantages of membrane oxygenators, a recent innovation, bubble oxygenators have been found to be absolutely safe for routine open heart surgery (Bjork *et al* 1977) in terms of gas exchange performance and blood trauma.

Different versions of bubble oxygenator are used for open-heart surgery. Notwithstanding the good performance of the existing models, newer versions are being evolved continuously. Establishment of techniques to study the parameters such as gas transfer, blood trauma, protein denaturation,etc is an integral part of these developments. Various *in vitro* and *ex vivo* techniques have been developed in the past to study the functional parameters of oxygenator (Galletti and Brecher 1962). Because of the drawbacks of each technique, new methods are still being sought to evaluate oxygenator performance. Earlier, our laboratory had reported a simplified *in vitro* technique for evaluating the gas transfer characteristics of a bubble oxygenator (Venkatesan *et al* 1981). The merits and demerits of other techniques have been discussed elsewhere (Galletti *et al* 1972). The following report discusses our experience in the experimental use of an isolated sheep lung for deoxygenation.

Meaningful evaluation of an oxygenator is possible only if the conditions of blood at the inlet of the oxygenator are specified. Different input conditions have been proposed by various groups (Nose 1975). Deoxygenation, especially at high blood flows, is a major difficulty which makes the *in vitro* circuits more complex and

elaborate. Since natural lung is the best oxygenator and provides a surface area of approximately 200 m^2 for gas exchange, its use as a deoxygenator for short term evaluation of oxygenators was studied in our laboratory.

2. Description

Nontoxicity and inertness of the materials, easy processability, strength and cost are the main criteria used in the selection of materials. A variety of polymeric materials are used in the fabrication of the oxygenator. The outer shell is made up of soft, plasticized PVC.

A nylon-knitted fabric acts as a coarse filter. The defoaming section consists of high density polyethylene substrate coated with dimethyl polysiloxane. This silicone coating reduces the surface tension of the bubbles and effectively defoams the frothy mixture of blood and oxygen. Polypropylene, polycarbonate and polyvinyl chloride are other plastic materials which are used to fabricate various minor components of the oxygenator. All the materials have been tested for toxicity according to techniques specified in US Pharmacopia and they satisfy the criteria for class VI materials coming into contact with blood. Further the leaching of plasticizers from the PVC has been studied and the plasticizer levels have been found to be within acceptable limits. The techniques used and the results obtained are the subject of discussion elsewhere.

3. Materials and Methods

In all our experiments a sheep lung was used for deoxygenation. The appropriate body weight (about 20–25 kg) of sheep which required an average flow rate of 1.5–2 lpm and our experience in handling sheep made it the species of choice over mongrel dogs which are too small and lack adequate lung capacity. In this series of 8 experiments the weight of the sheep was in the range of 18–25 kg. The animals were premedicated with Siquil (10 mg) and anaesthesia was induced using Thiopentone Sodium. After incubation the animal was ventilated using 100% oxygen. The chest was entered through sternotomy and pulmonary artery, left atrium and left ventricle were cannulated. This double cannulation of left atrium and left ventricle using wire reinforced cannulae ensured adequate drainage of blood from the left side of the heart.

The complete test circuit is shown in figure 1. In addition to the lung, the circuit consisted of the test oxygenator*, a reservoir**, a heat exchanger and two roller pumps. Blood was drained by gravity, through the cannulae in the LA and LV into the cardiotomy reservoir. A calibrated pump, interposed between the reservoir and oxygenator, provided controlled flow into the oxygenator. From the outlet of the oxygenator blood was pumped back into the lungs through a heat exchanger.

Fresh blood for the experiment was collected from a slaughter house under clean, but not sterile conditions. Blood was collected in 3.25% acid citrate dextrose solution and filtered using a 25 μ filter. The haemoglobin was adjusted to 12 ± 0.5 g%

---

* Chitra oxygenator

** Chitra cardiotomy reservoir

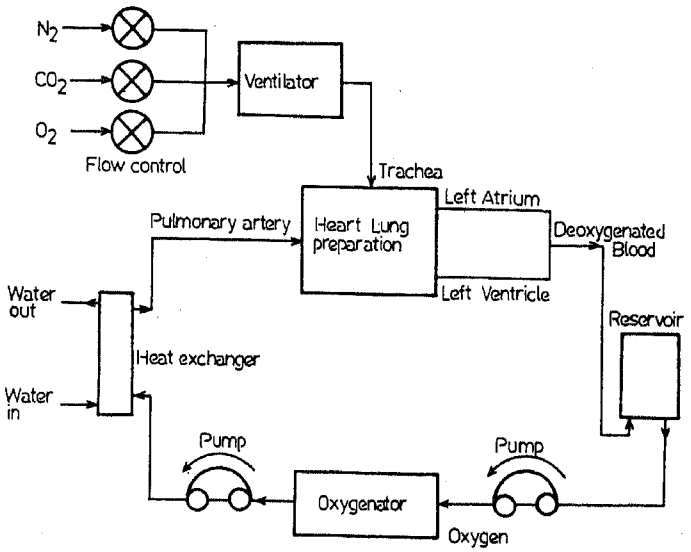

Figure 1. Schematic diagram of the test circuit.

by adding packed cells, and the pH was adjusted to 7.375–7.400 using sodium bicarbonate. The external circuit was primed with 3.5 litres of this blood. Blood temperature was brought up to 37°C and maintained at 37 ± 0.5°C throughout the experiment.

Before starting the test the superior vena cava, inferior vena cava and the aorta were cross-clamped and the arterial blood pump slowly started. The ventilation was switched over to a gas mixture of N_2 + CO_2, with the % CO_2 depending upon the PCO_2 values. Deoxygenated blood coming out of the lungs was analysed for PCO_2 and percent oxygen saturation. By varying the ventilation parameters and % CO_2, the O_2 saturation was adjusted to 60% and the PCO_2 to 40 torr. The flow of blood into the oxygenator and the O_2 flow were set at required values and the arterial pump was adjusted to keep a constant level in the oxygenator. Minor variations in the set flows of the two pumps were compensated by the blood in the reservoir. Initially the blood flow was set at 1 LPM and after 30 min of observation, blood flow was readjusted to a new setting. This process was continued until the maximum flow rates of the oxygenator were reached or until the performance of the lung deteriorated. Throughout the experiment venous and arterial blood gases and oxygen satuaration were checked every 5 min using a blood gas analyser* and oximeter**

4. Results

In this series of 8 experiments the weight of the sheep ranged from 18–25 kg with an average weight of 20 kg. The rated flow for all the animals was calculated at 70 ml/kg body weight. All the experiments were conducted at different flow rates (1,2 and 3 LPM) with each setting lasting for 30–35 minutes under stable conditions.

---

* Radiometer BGA 3 blood gas analyser system.
* American optical reflection micro-oximeter

Table 1. Range of venous parameters obtained using sheep lung as deoxygenator

Haemoglobin	12 ± 0.5 mg%
Temperature	37 ± 1°C
pH	7.350-7.430
PCO_2	40-46
Oxygen saturation	58-64%

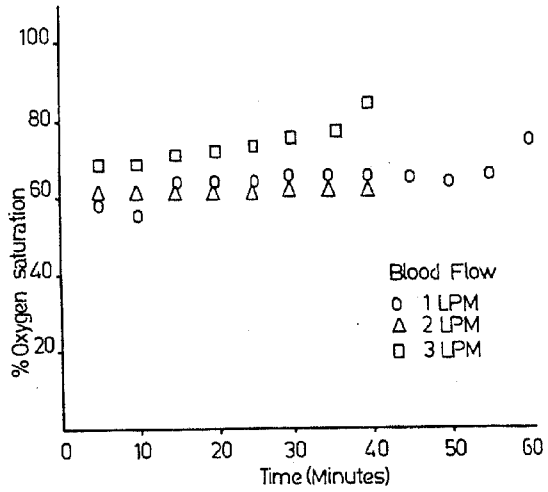

Figure 2. % oxygen saturation of the venous blood vs time at different blood flows.

Table 1 gives the range of parameters obtained during these experiments. The oxygenator also performed well with blood to O_2 ratios varying from 1:1 to 1:1.2 giving a PO_2 of 250 from an inlet saturation of 58–64%. The duration of the experiments varied from 35 min to 2 hr. All the experiments were selectively terminated when pulmonary edema set in. In all the cases, the onset of pulmonary edema was preceded by deteriorating deoxygenation. The oxygen saturation of the deoxygenated blood went up from 60% to 75–83% (figures 2, 3, 4). Similarly there was a marked decrease in CO_2 transfer in spite of very high percentage (up to 15%) of CO_2 in the N_2 + CO_2 gas mixture.

Microscopic examination of the lung sections showed severe congestion of capillaries (see figure 5). Many specimens showed over distension of the alveoli and septal capillary rupture. A moderately severe degree of pulmonary edema with intra-alveolar and peribronchial fresh hemorrages in the lungs characterized the specimens.

5. Discussion

Perfusion results on isolated lungs are widely reported (Yong *et al* 1965; Veith *et al* 1966). Other groups have used isolated lung preparations to evaluate membrane

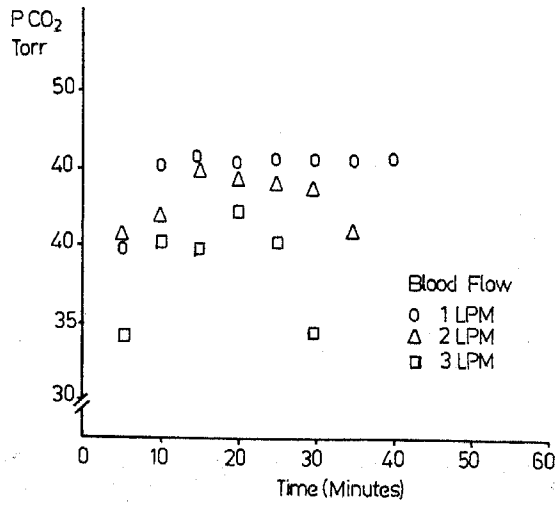

Figure 3. Steady state PCO_2 values indicating poor CO_2 transfer across the alveolar membrane at high blood flows.

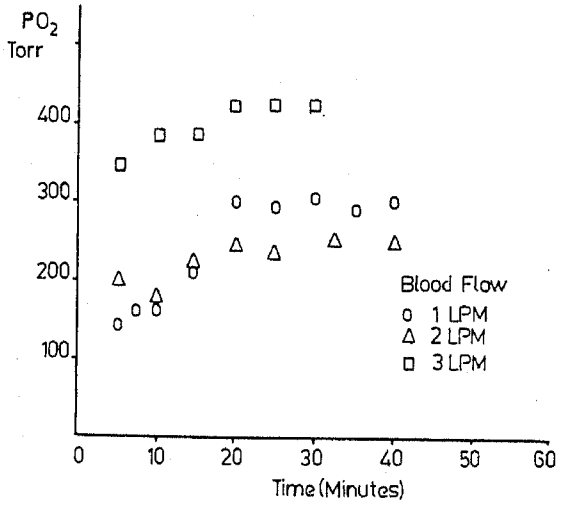

Figure 4. Gas transfer performance of the oxygenator. Increase in PO_2 at higher blood flows is due to increased venous saturation.

oxygenators at lower rates of blood flow (Peierce *et al* 1969). Our results conform to the experience of the others. In our experience the lungs provide excellent deoxygenation at low flow rates (1.0 lpm). More elaborate circuits involving partial by pass on sheep have been reported. Our experience shows that good evaluation of the gas transfer characteristics at low flows can be obtained using sheep lung. However the performance of the lungs deteriorate fast at flow rates approaching 70 ml/kg body weight and higher. The rapid development of edema suggests that the damage is more due to excessive blood flows rather than deterioration of lung tissue.

6. Conclusion

Our experience in the use of isolated lung for deoxygenation indicates that the lung performs well as a deoxygenator up to 2 hr under low flow conditions (40 ml/kg body wt). Blood flows higher than the rated flow (70 ml/kg) result in rapid

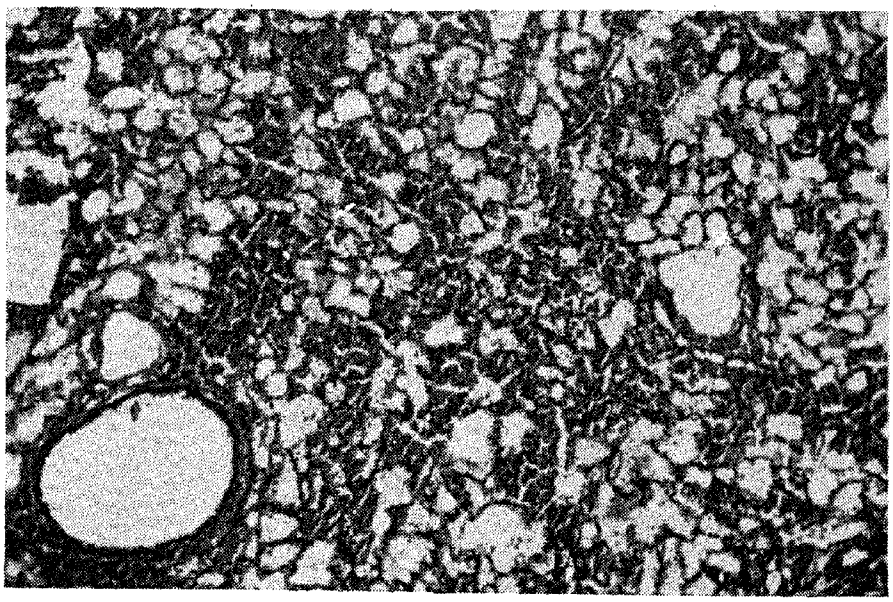

Figure 5. Photomicrograph of the lung section indicating severe pulmonary edema.

Table 2. Experimental animal data

Weight of sheep	18–25 kg (av. 20 kg)
Computed blood flow	1.2–2 LPM
Duration of evaluation	35 min – 120 min (average 60 min)

development of pulmonary edema. Theoretically it should be possible to use the lung of cattle weighing 70 kg to get adequate deoxygenation at flows of 4 litres. However the time limitation of 2 hrs imposes a severe restriction on the experiment. Efforts are in progress to modify the system to get good deoxygenation at higher blood flows and for longer periods.

Acknowledgement

The authors thank Dr Kartha for studying the histopathology of the lung specimens.

References

Bjork V-O, Bergdahl L and Wussow C 1977 *Scand. J. Thorac. Cardiovasc. Surg.* **11** 81

Galletti P M and Brecher G A 1962 Heart lung bypass: Principles and techniques of extracorporeal circulation 1962

Galletti P M, Richardson P D, Snider M T and Friedman L T 1972 *Trans ASAIO* **18** 359

Nose Y 1975 *Ann. Report, Dept. Art. Org, Cleveland clinic*

Peirce E C II, Corrigan J J and Kent B B 1969 *Trans ASAIO* **15** 33

Veith F J, Deysine M, Neblsen S L and Carl R C 1966 *J. Thorac. Cardiovasc. Surg.* **52** 437

Venkatesan V S, Arthur Vijayan Lal G, Bhuvaneshwar G S and Valiathan M S 1981 *J. Extra. Corporeal technology* **13** 3

Yong N K, Eiseman B, Spencer F C and Rossi N 1965 *J. Thorac. Cardiovasc. Surg.* **49** 581