ARTIFICIAL VENTILATION WITH CONTINUOUS POSITIVE AIRWAY PRESSURE IN THE MANAGEMENT OF VENTILATORY INSUFFICIENCY OF THE NEWBORN

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SYNOPSIS

Sixty newborn infants were managed for respiratory insufficiency in the newborn period, from 1969 to 1973. Twenty seven (45%) of these were for Tetanus Neonatorum, twenty one (35%) were for Hyaline Membrane disease while the remaining twelve (20%) were for anticipated postoperative respiratory insufficiency. Intermittent positive pressure ventilation (I.P.P.V.) was used exclusively on all 16 infants with respiratory distress syndrome (R.D.S.) up to April 1973 and since then 5 infants with R.D.S. were treated with continuous positive airway pressure (C.P.A.P.). The mortality was high (87·5%) in those treated with IPPV while there was only one death in 5 infants treated with C.P.A.P. Respiratory Distress Syndrome was the second commonest condition in the newborn referred to us for ventilatory management, Tetanus Neonatorum being the commonest one.

The technique and the physiological basis and the criteria for the use of Continuous Positive Airway Pressure Breathing is described in detail.

INTRODUCTION

The adaptation of our intrauterine life to extrauterine is complex and dramatic in which the lung has to undergo transition from a fluid filled dormant organ receiving approximately 10% of foetal cardiac output to an air filled dynamic organ receiving almost the total cardiac output and be responsible for oxygenation and carbon dioxide homeostasis.

Whilst congenital abnormalities of the airway and respiratory tract, (Brechner 1968)[2] cardiovascular system, aspiration of amniotic fluid, blood or gastric contents, pneumonia and pneumothorax may be present, in our experience R.D.S. is the second commonest cause of respiratory insufficiency in the newborn, presenting with generalised persistent miliary atelectasis, insufficient surfactant and inadequate expansion of the lungs producing an increased physiological dead space and intrapulmonary shunting.

Varying degrees of successes have been reported with mechanical assisted ventilation in the management of the syndrome (Reid *et al*,[12] Tunstall *et al*,[14] Cumarasamy *et al*[4]) the mortality generally has been more than 50% when the infants weighed less than 1500 grams at birth or when ventilation was instituted when the infant was less than 24 hours old.

In this series the first 16 infants were treated with intermittent positive pressure ventilation. Fourteen of them died, their mean birth weight was 1680·3 grams, maturity was 35·2 weeks and Apgar score at 1 minute and 5 minutes were 6 and 8·4 respectively. We report our initial experiences in the subsequent ventilatory management of 5 cases of Hyaline Membrane disease in the newborn using Continuous Positive Airway Pressure Ventilation (CPAP).

MATERIALS AND METHODS

Since January 1969, newborn infants who were diagnosed as hyaline membrane disease were referred to us for the management of ventilatory insufficiency. They ranged in weight from 1410 grams to 3110 grams and in gestational age from 29 weeks to 39 weeks. Of the 21 neonates referred for ventilatory management 16 were treated with I.P.P.V. and the rest with C.P.A.P. Table I shows the birth weights, gestational ages and one +5 minute Apgar scores of 16 infants managed with I.P.P.V.

1. Diagnosis

The diagnosis of hyaline membrane disease was based on the history and the presence clinically, of respiratory distress (expiratory grunting; chin, sternal and intercostal retraction; diminished breath sounds, poor peripheral circulation, and

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TABLE I

DETAILS OF 16 NEONATES TREATED WITH I.P.P.V. FOR RESPIRATORY DISTRESS SYNDROME

No.	Gestational Age (Weeks)	Births Weight Grams	Apgar Score at 1 minute	Apgar Score at 5 minutes	Results of Ventilation treatment
1.	40/40	2340	8	10	Died
2.	34/40	2090	5	8	Alive
3.	32/40	1330	7	9	Died
4.	30/40	1750	0	2	Died
5.	36/40	1920	8	8	Died
6.	31/40	1400	6	8	Died
7.	30/40	1700	8	8	Died
8.	40/40	1800	6	8	Died
9.	29/40	1410	2	6	Died
10.	32/40	1400	1	5	Died
11.	36/40	2610	9	10	Died
12.	33/40	2300	7	2	Died
13.	29/40	1950	8	10	Died
14.	39/40	3110	6	10	Alive
15.	34/40	1850	6	8	Died
16.	35/40	1730	5	8	Died
Mean	33·75	1918·13	5·75	5·81	Alive 2 Dead 14

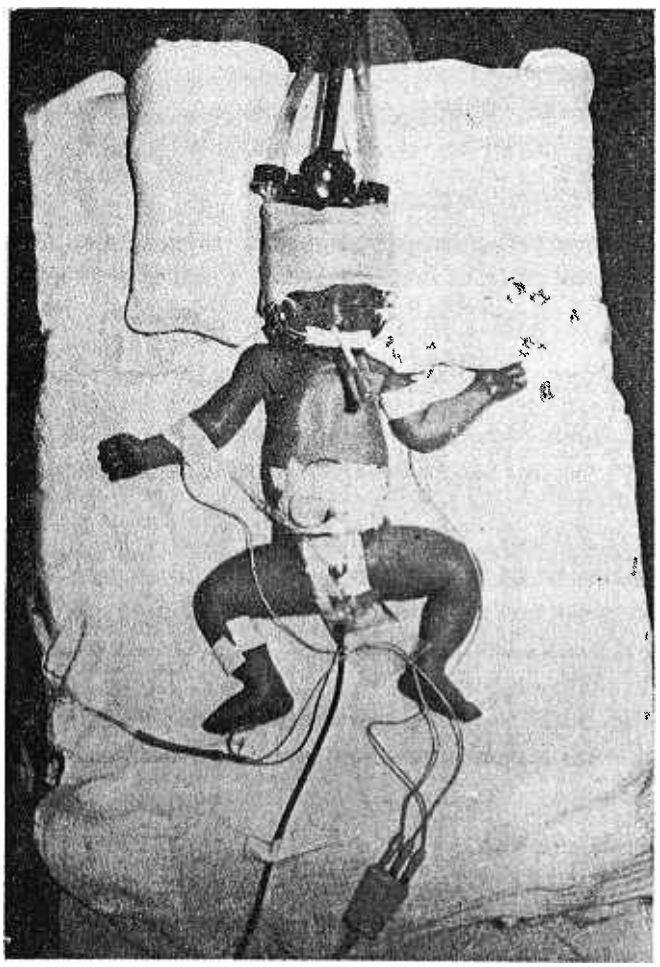


Fig. 1. Infant with RDS showing the Jackson Rees Nasotracheal tube in position, together with ECG electrodes and rectal lead for continuous monitoring.

cyanosis in air and on oxygen of F_iO_2 of 1 (100% oxygen). The arterial blood gases showed a PaO_2 of about 50 torr at F_iO_2 of 1 and there was a combined respiratory and metabolic acidosis with a pH of around 7·1. Chest radiography usually confirms the diagnosis by the presence of finely mottled 'ground glass' appearance and an air bronchogram, and excludes other causes of ventilation insufficiency of the newborn like diaphragmatic hernia or collapse of the lungs.

In all infants, manual artificial ventilation using a red rubber orotracheal tube and a Cardiff Infant Inflating Bag (Penlons) was commenced as part of the resuscitation procedure in the Special Care Nursery or Labour Ward. An I.V. infusion using 10% Dextrose in water was set up, and the calculated dose of Sodium Bicarbonate (7·5% Abbots) to correct the metabolic acidosis was given before transferring to the Intensive Care Unit. On transferring to the I.C.U. the neonate was reintubated using a Jackson Rees Tube (Portex) and following as closely as possible the technique described by him (Jackson-Rees *et al*, 1966)[11] (Fig. 1).

2. Nursing

Nursing care was provided on the basis of one staff nurse per patient per shift, though this was not always achieved particularly during the night shifts.

The infant was nursed either on an Isolette incubator with its lid removed and a flannelette blanket covering both the baby and the port from where the hot air emerged from the incubator. This was necessary to provide heating by convection, as it was essential to keep the body at a rectal temperate of 36°C to 37°C. In other instances the baby was nursed on a standard I.C.U. bed with a water circulated warming blanket. The latter was preferred as it made nursing easier. In order to prevent further heat loss, olive oil was applied twice daily over the infants, and no ceiling fans were turned on as the I.C.U. is not airconditioned.

3. Monitoring

E.C.G. heart rate and rectal temperature were continuously monitored using a 780-7A and 780-3 heart rate (Hewlit Packard) Visoscope and monitor and a 780-8 Sanborn Temperature Monitor (Fig. 1). Urine was collected in little plastic bags and monitored hourly. The F_iO_2 was monitored daily or when changes in the air oxygen mixture were made. Anterial blood gases were monitored at least once a day via a percutaneous femoral artery puncture (on one infant the lower limb went ischaemic due to spasm of the femoral artery after puncture and this technique was therefore abandoned in this baby) or by heel capillary blood. Except in the initial period of resuscitation, I.V. Sodium bicarbonate was avoided for reasons mentioned later, if the infant passed sufficient urine.

The eyes were cared for by cleaning with warm sterile water and Chloramphenicol eye drops were instilled twice daily.

Endotracheal suction was avoided on a routine basis but was done as and when secretions were detected clinically, or when the peak-inflation pressure went higher than that observed during the preceding half hour.

4. Ventilatory Techniques

Various workers have recommended different methods of ventilation, varying from intermittent negative pressure ventilation to positive end expiratory pressure ventilation.

In view of the findings of Harrison and Heese (1968)[6] and of the pathophysiology of the disease (Fig. 2), controlled ventilation with a continuous positive airway pressure seemed to be a logical ventilation technique to keep the alveoli open and ventilated, and thereby to increase alveolar ventilation and improve arterial oxygenation. Total paralysis with controlled ventilation, without end expiratory pressure was used in the first sixteen cases using a volume cycled ventilator (Engstrom Model 150 or 200) using a respiratory frequency of 28/minute. Peak inspiratory pressures of 50 to 60

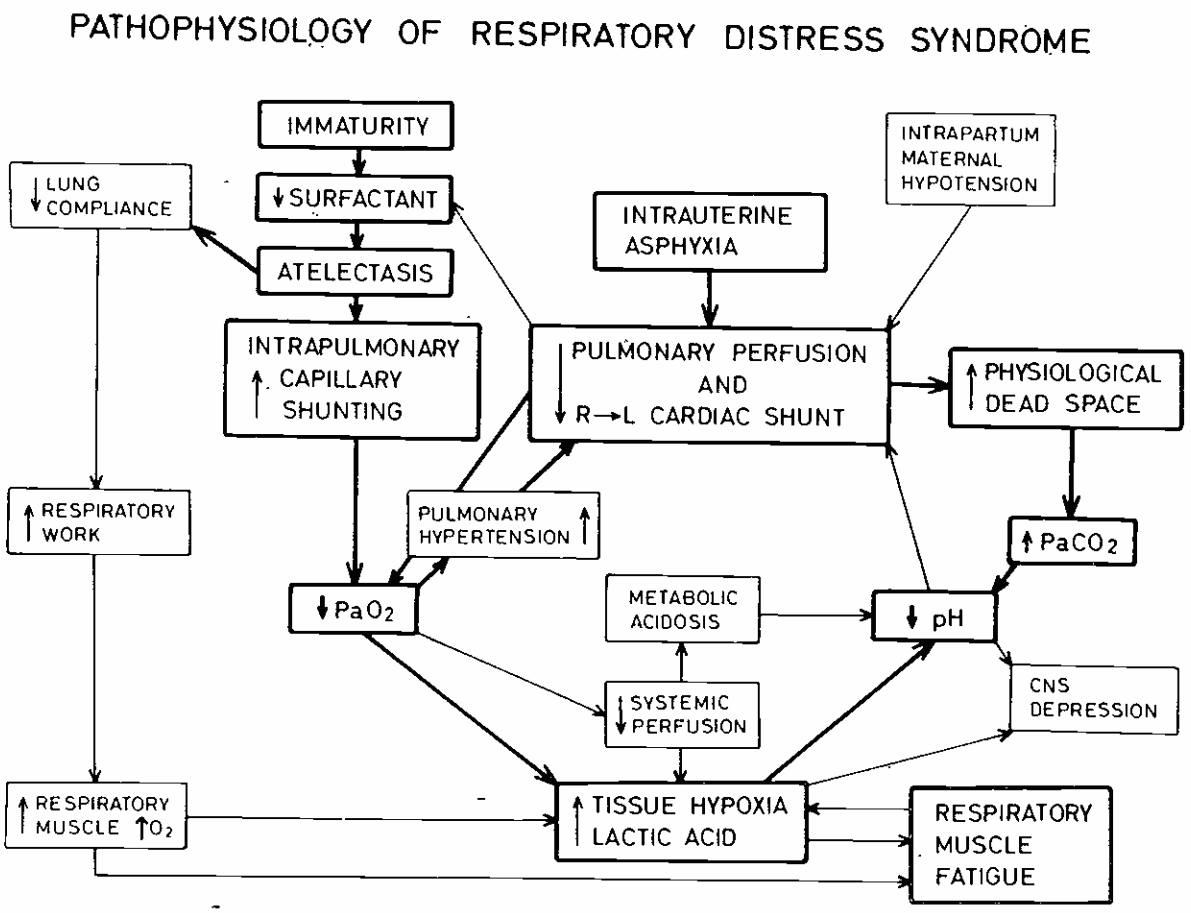


Fig. 2. Pathophysiology of respiratory Distress Syndrome.

cm. of water were reached to maintain a $PaCO_2$ of about 50 torr. This was not achieved in 14 of the infants and the severe respiratory acidosis, low arterial oxygenation and peripheral cyanosis progressed to cardiac arrest and death. In the last five cases the ventilatory technique was as follows:—

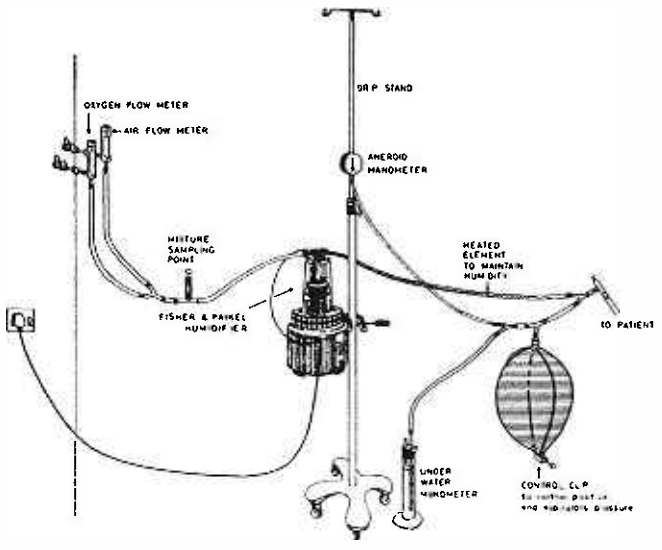
(i) Controlled ventilation using a volume cycled ventilator (Engstrom Model 150 or 200) was used with continuous positive airway pressure. The F_iO_2 was adjusted to keep the PaO_2 from 70 to 130 torr, and the minute volume was adjusted to bring the $PaCO_2$ to 40-50 torr. This was not always possible as very high peak inspiratory airway pressures were obtained sometimes. Therefore a $PaCO_2$ of 50 to 60 torr was acceptable at a peak inspiratory airway pressure of not more than 50 cm. H_2O.

(ii) All inspired gases were humidified and CPAP was instituted by using the spring valve provided for this purpose in the Engstrom Ventilator and the application of positive and expiratory pressure does not alter the ventilation characteristic of this ventilator.

(iii) Total paralysis was maintained with tubocurarine chloride until the peak inspiratory airway pressure dropped to 25 to 30 cm. of H_2O and this usually took 36 to 140 hours.

(iv) The infant was then allowed to breathe spontaneously and CPAP was maintained using the apparatus shown (Fig. 3) with controlled $F_i O_2$ to give $Pa O_2$ of 70 torr to 90 torr.

(v) About 24 hours after the infant was transferred to an incubator, oxygen was added to the incubator to give an F_iO_2 of 0·4 and extubated.



SYSTEM FOR APPLYING CONTINUOUS POSITIVE AIRWAY PRESSURE USING AN ENDOTRACHEAL TUBE AND HUMIDIFIED GASES

Fig. 3. System for applying continuous positive airway pressure using an endotracheal tube and humidified gases.

5. Physiotherapy

This was limited to gentle vibration to mobilise secretions. Infants on CPAP appear to be 'dry'. Passive movement of all limbs was however done as frequently as possible.

6. Blood Gas Analysis

Arterial blood was obtained by femoral artery puncture. PO_2 was measured by Radiometer Type E 5047 electrode, while PCO_2 pH and Acid Base state was done by the Astrup interpolation technique using PHM 72 digital readout pH meter and Microtonometer AMT (Radiometer).

RESULTS

Fig. 4 shows a clinical course of an infant which had a spontaneous vaginal delivery, gestational age of 36 weeks and Apgar score of 7 at 1 minute and 9 at 5 minutes, birth weight 1960 gm., deteriorated and 18 hours later had a PaO_2 68 torr and $PaCO_2$ of 41 torr. IPPV was commenced after nasotracheal intubation, using an East Radcliffe ventilator with the Tunstall paediatric attachment. There was no improvement despite an F_iO_2 of ·95 and 36 hours later, an Engstrom Model 150 was used and ventilation with CPAP of 3 to 5 cm. H_2O was instituted, at peak inspiratory pressure of 40 cm. H_2O. Within 12 hours it was found possible to lower the F_iO_2 to ·60 and later to ·55 and to have a paO_2 of 60 torr and $paCO_2$ of 65 torr. Ventilation was continued up to the 6th day when on the same minute volume, the peak inflation pressure suddenly dropped to 35 cm.H_2O and within the next 48 hours to 30 cm.H_2O. The improvement in compliance, with the concomitant improvement in blood gases was an indication to switch over to spontaneous ventilation with CPAP.

DISCUSSION

Reid *et al* (1967)[12] showed that there was a significant decrease in mortality rate in ten ventilated infants as against 10 infants as control who were not ventilated, and the difference in mortality rate was highly significant amongst infants of birth weight of 1000 grams to 1999 grams, but not significant for those of 2000 grams to 2·99 grams. All the infants referred to us for ventilatory manage-

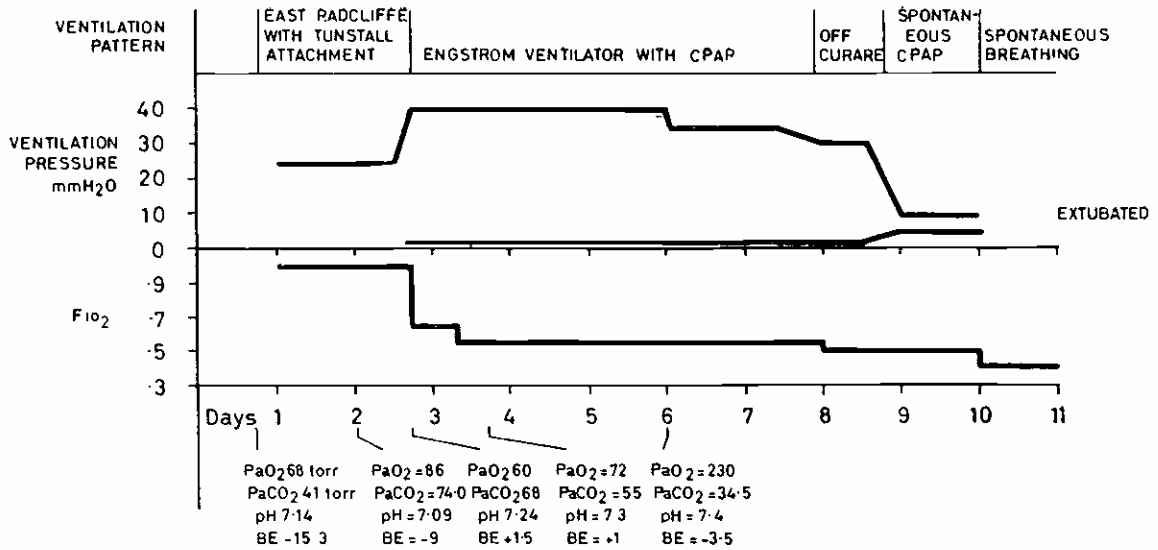


Fig. 4. Chart showing the clinical course of an infant who was treated with mechanical artificial ventilation with CPAP, and subsequently weaned off with spontaneous ventilation with CPAP using the apparatus described in Fig. 3 (see text).

ment fall into the former group. In our first sixteen infants intermittent positive pressure ventilation using a volume cycled ventilator produced unsatisfactory results. High peak inspiratory airway pressures were used, > 50 cm. H_2O as the maximum rate that could be used in those machines (Engstrom 150 and 200) were 30 and therefore most of them developed pneumothoracis and died. Infants with RDS who require as much as 50 cm. H_2O pressure for more than a few hours to maintain an improved but not to correct the blood gas picture, usually die, Tunstall *et al* (1968)[14].

The pathophysiology of Respiratory Distress Syndrome (Fig. 2) as it was understood, points to immaturity, intrauterine asphyxia and low birth weights as the main trigger for a series of chain reactions, which produce persistent miliary ateletasis in the lungs, intrapulmonary capillary shunting and increase in physiological dead space. The end result of all these would be a decrease in lung compliance, with an increase in respiratory work, and increase in oxygen demand; low cardiac output, severe respiratory and metabolic acidosis which potentiates and is potentiated by systemic hypoperfusion resulting in cellular hypofunction and death. This chain of events can be reversed provided that adequate cardiac output and its subsequent cellular metabolism be restored to normal by, vigorous and early correction of hypoxia, respiratory and metabolic acidosis.

The physiological significance of grunting had been unnoticed until Harrison *et al* (1968)[6] showed that it was a physiological val salva manoeuvre to improve oxygenation by keeping alveoli open, which had collapsed by the lack of pulmonary surfactant. (A lipoprotein consisting of dipalmityl-lecithin). Endotracheal intubation which overcame this grunting allowed the alveoli to collapse and decreased the PaO_2 and increased $paCO_2$ while removal of the E.E.T.T. restored the grunting and raised the PaO_2 Gregory *et al* (1971)[5], applied CPAP, which produced the same effect of grunting on arterial oxygenation, on 20 infants 18 of them via an endotracheal tube breathing spontaneously and two via a pressure chamber around the infant's head. He had sixteen survivors including seven out of 10 weighing less than 1500 grams at birth. Several workers have reported varying degrees of success with different techniques of ventilation, Tunstall *et al* (1967)[14], Linsao *et al* (1970)[9], Murdock *et al* (1970)[10] and Cumarasamy *et al* (1973)[4].

We report our experience with five infants all below 2000 grams birth weight and who developed R.D.S., (Table II) on whom we have used CPAP ventilation. Though the number is very small, our previous experience with 16 infants where mechanical ventilation was used without CPAP and where mortality was high prompts us to suggest that CPAP has a definite place in the management of R.D.S. as follows:—

i. Mechanical Ventilation

The infants should have a nasotracheal tube and humidified air enriched with oxygen should be used for CPAP ventilation, with total paralysis, using the minimum concentration of oxygen to maintain arterial oxygenation of 70 torr to 90 torr. Without the latter the work of breathing could increase the oxygen requirement as much as 200-600%[15] particularly that the infant albeit a premature, would be expiring against a constant continuous positive pressure. Fatigue and metabolic derangement resulting in metabolic acidosis would

TABLE II

DETAILS OF 5 NEONATES MANAGED WITH CONTROLLED AND SPONTANEOUS VENTILATION USING C.P.A.P.

No.	Gestational Age (Weeks)	Birth Weight (grams)	Apgar 1 Minute	Apgar 5 Minute	Mechanical Ventilation with CPAP (hours)	Spontaneous Ventilation with CPAP (hours)	Result
1.	36/40	1770	6	8	48 hours	24 hours	Alive
2.	34/40	1420	6	6	24 hours	48 hours	Died
3.	36/40	1560	5	8	48 hours	72 hours	Alive
4.	36/40	1960	7	9	184 hours	36 hours	Alive
5.	32/40 (APH)	1920	3	4	60 hours	108 hours	Alive
Mean	34·8 wks.	1726 gm.	5·4	7	72·8 hours	57·6 hours	Alive 4 Dead 1

occur. The latter combined with the respiratory acidosis secondary to the increased physiological dead space would perpetuate the low cardiac output and decrease tissue perfusion. Total paralysis, with CPAP ventilation of 3-5 cm. H_2O, would provide conditions with minimum oxygen demand, with the maximum opportunity to lower the raised $PaCO_2$ to provide maximum oxygenation (up to safe limits) by minimising intrapulmonary capillary shunting. We have found the clinical condition to improve dramatically as the blood gases and acid base status returns to normal.

The ventilation should continue until the compliance improves and this usually occurs between 48 hours and 150 hours and signifies the adequate production of surfactant, by the Type II alveolar cells, which would now keep alveoli open. This is signified by the rapid improvement of blood gases and acid base status to normal, and the clinical evidence that there is adequate cardiac output and tissue perfusion.

ii. **Spontaneous ventilation**

This should be allowed to commence only when the above has been achieved and should be maintained with CPAP (3-5 cm. H_2O) as rapid removal of the latter could collapse some alveoli. We have used a locally 'put together' apparatus, which works in principal to that described by Gregory *et al* (1971) Fig. 3. Oxygen and Compressed Air are channelled from wall outlets through flowmeters to a Fisher and Paykel humidifyer, and the humidified gases are delivered close to a 'Y' tube which is attached to the endotracheal tube. The delivery tube from the humidifyer has a heating element which maintains the temperature of inspired gases at 34°C. The limb of the 'Y' piece carrying expired gases is connected to a double-ended reservoir bag which has a screw clip at one end. It is also connected to an aneroid manometer to indicate the pressure in the system as well as to an underwater seal—which is adjusted to blow off at 5 cm. H_2O so that the pressure in the system should not exceed that during expiratory pauses. A sampling point is inserted near the input limb of the humidifyer and samples are analysed by a Beckman D_2 paramagnetic oxygen analyser and hence accurate F_iO_2 can be administered. By judiciously adjusting the flow rates in both the flowmeter and the screw clip in the double ended rebreathing bag the required CPAP could be achieved with the minimum of rebreathing and accurate F_iO_2.

iii. **Metabolic Considerations**

The metabolic acidosis should be corrected with Sodium bicarbonate calculated as the 1/3 × base deficit × the body weight. Sodium bicarbonate should be used cautiously as the intravenous administration of the alkali improves the arterial blood acidosis with the concomitant C.S.F. acidosis and rise in $paCO_2$ Cotev *et al* (1969)[10]. The latter would be reflected by the blood gas analysis and the minute volume should be adjusted to compensate for this. A rise in CSF acidosis would either depress an immature respiratory centre or stimulate it, both of them having disastrous consequences in an immature infant breathing spontaneously. We prefer to allow slow but spontaneous total renal correction of the metabolic acidosis and this would happen once a sufficient cardiac output is achieved, and good urinary output is obtained. A pH of $> 7{\cdot}3$ is necessary to improve pulmonary blood flow to decrease intrapulmonary capillary shunting and hasten surfactant production. Fluids 65-80 mls./Kg./day of 10% hypertonic glucose in water may be used and after the first day of life Na^+, K^+ and Cl^- may be added with the establishment of good renal function.

iv. **Physiotherapy**

Chest physiotherapy should be limited to postural drainage and gentle tapping before endotracheal suction. Bimanual squeezing of the chest or vibration must be avoided at all costs as it is easy to produce a pneumothorax particularly if the infant is being mechanical ventilated, as the set tidal volume would need very high pressures to be delivered to the lungs when there is chest compression. Passive movements of all limbs is also essential as it will provide venous return and prevent contractures.

CONCLUSION

Respiratory distress syndrome does not present as a condition of uniform severity requiring a single standardised method of treatment. Those with mild disease would respond with just extra oxygen, while those with moderate severity may benefit from metabolic correction with hypertonic glucose and alkali therapy in addition to oxygen. Such vigorous therapy has not influenced the outcome in small premature infants (Usher 1963[15], Iverson and Christenson[7] Tock 1965[13]) nor does it reduce the severity of the primary condition. We feel that in premature infants, of birth weight 1000-1999 gram with respiratory distress syndrome and Hyaline Membrane Disease controlled artificial ventilation with CPAP followed by C.P.A.P. with spontaneous ventilation during the weaning period offers the best change of survival. This would, of course, be in addition to specialised Nursing care, metabolic considerations and physiotherapy.

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