Controlled FiO₂ Therapy to Neonates by Oxygenhood in the Absence of Oxygen Analyzer

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Abstract

Background: A study was conducted to evaluate a system of standardizing the oxygen concentration inside the oxygen hood and to develop guidelines for controlled FiO₂ administration by changing size of the hood, lid position on the hood and the oxygen flow rate, without an oxygen analyzer. The effect of low flow rates on carbon dioxide (CO₂) retention was also studied.

Method: A dummy patient and thirty neonates, requiring oxygen to be delivered through head box, constituted the material for the study group. Oxygen content in the head box was measured using a standard oxygen analyzer while the size of head box, flow rate and lid position were changed independently and in combination. The head boxes were tested on a dummy patient. These results were analyzed, and applied to thirty neonates requiring oxygen therapy using a head box.

Result: Volume of headbox had an inverse relation with the oxygen concentration inside the headbox and smaller sized headbox achieved more predictable oxygen concentration at all flow rates. Maximum difference in oxygen concentration by varying the lid position was seen in the large headbox. Keeping the variables constant, oxygen concentration was significantly lower in babies as compared to dummy. No significant CO₂ retention was found at a flow rate of four litres per minute (lpm) in small and three lpm in a medium and large head box respectively, while lower flow rates were associated with CO₂ retention.

Conclusion: It is possible to predict the oxygen concentration inside the head box without the use of oxygen analyzer. Larger head box and higher lid position, results in lower oxygen concentration, at a given oxygen flow rate. Oxygen concentration achieved in babies is lesser than the concentration achieved in a dummy. Flow rates of less than four lpm in small and three lpm in medium and large sized head boxes are associated with CO₂ retention. These results are not applicable to infants weighing less than 2 kg.

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Key Words: Neonates; Oxygen therapy; Oxygen hood; Oxygen concentration, Oxygen analyzer

Introduction

Oxygen therapy is the most important aspect of supportive care to prevent hypoxia [1]. Oxygen is a drug and should be prescribed in proper dosage with proper mode of delivery and duration [2]. Majority of high risk neonates are being administered uncontrolled oxygen because of lack of oxygen analyzers, which may be toxic. It is associated with free radical diseases like bronchopulmonary dysplasia and retinopathy of prematurity [3,4]. Controlled oxygen therapy is the key preventive factor for these toxic effects.

Oxygen hood is an effective and a widely used device to administer oxygen in neonates with mild to moderate respiratory dysfunction. It is well tolerated, there is no increase in risk of airway obstruction or gastric distension [5]. It allows the oxygen concentration to be determined precisely which depends on the flow rate of oxygen, size, shape, and volume of the hood [6]. The disadvantages are the inability to ascertain the oxygen concentration without the use of oxygen analyzer, inability

to use oxygen flow rates of less than two litres per minute (lpm) and inability to maintain uniform oxygenation while carrying out routine manoeuvres [7]. Different brands are available and there is lack of standardization of the above parameters thus requiring the use of an oxygen analyzer to measure the oxygen concentration [8]. In contemporary literature there is no information available on controlling oxygen concentration in head box without the use of oxygen analyzer. Therefore, this study was undertaken to devise a simple technique to control FiO₂ within the oxygen hood without use of an oxygen analyzer.

Material and Methods

A descriptive and prospective study was conducted in a tertiary care teaching hospital. Thirty neonates born by spontaneous vaginal delivery, requiring oxygen to be delivered through head box and a dummy patient, constituted the material for the study group. Oxygen content in the head box was measured using a standard oxygen analyzer while the size of head box; flow rate and lid position were changed independently and in combination. Oxygen therapy using

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head box was considered when the oxygen saturation of room air was less than 90 % [1], the respiratory rate of neonate more than 60/minute and when $SpO_2 > 90\%$ [5]. The exclusion criteria was preterms neonates, those weighing less than 2 kg, neonates with $SpO_2 < 88\%$ at $FiO_2 > 0.6$ (which is an indication of giving CPAP) [9], severe respiratory distress due to any cause, congenital heart disease and gross congenital anomalies.

Three round oxygen hoods/head boxes (large, medium and small) of sizes 24cm, 21.5cm and 20.5cm internal diameter and a height of 16cm, 18.5cm and 20.5cm respectively were used in the study. Round shape of head box with circular margins was used due to the advantage of easy stacking and cleaning. Silicon lid (Fig. 1), placed at four positions : 1 (fully closed), 2 (partially open), 3 (half open), and 4 (fully open) were used to change the size of the inlet (just above the neck of the baby). Oxygen inlet was provided at the top with a baffle for uniform oxygenation throughout the box. Oxygen was delivered from the source providing 100% oxygen. The head boxes were tested on a dummy patient taking 800 observations of FiO_2 , while the three variables i.e. size of head box, oxygen flow rate and lid position, were varied individually and in combination. FiO_2 was measured close to the nose of the neonate using Miniox oxygen analyzer manufactured by MSA medical products, USA. After changing the oxygen flow rate, an equilibration time of five minutes was given before each new reading. Before every new set of observation, oxygen sensor was calibrated. The results were tabulated, analyzed and a general guideline derived. The results were then applied to thirty neonates requiring oxygen therapy using head box oxygen setup.

In dummy patient, FiO_2 at flow rates starting at two lpm with increments of one lpm every five minutes were taken. On neonates oxygen was started at a flow rate of five lpm and increments of one lpm were made every five minutes till a FiO_2 of 0.99 or a flow rate of 10 lpm was reached. Flow rates higher than 10 lpm were not used due to the cooling effect on the baby and higher noise levels[10]. Using Futura capnograph, simultaneous measurement of end tidal CO_2 ($EtCO_2$) was done. The $EtCO_2$ was noted at five lpm and the flow of oxygen decreased in decrements of one lpm till there was an increase in $EtCO_2$ of 10 % of the reading obtained at

five lpm. Data collected was tabulated and statistically analyzed.

Result

A total of 30 neonates requiring oxygen therapy by head box were studied. The observations taken on a dummy patient served as baseline and the results obtained on babies were compared with these. There was male preponderance (57 %) with male: female ratio of 2.6:2. 77% newborns had birth weight of more than 2.5kgs. 7% babies were small for gestational age. Majority (73%) were of mild to moderate birth asphyxia. There were no cases of severe asphyxia. Transient tachypnoea of newborn (TTNB) constituted the rest.

There was no statistical difference in oxygen concentration between babies weighing > 2.5 kg and those between 2 and 2.5 kg ($p < 0.29$, CI 0.31-1.01). Babies weighing less than 2 kg were not included in the study to avoid the variable of low birth weight babies.

By changing flow rates of oxygen and keeping lid position constant at a particular station (1-4), values of concentration of oxygen inside the head box and its relationship between sizes of the head box were recorded (Table 1). There was a significant difference between small and medium sized head box ($p < 0.0027$, CI 0.184- 0.615) at even low flow rate of two lpm. This difference is more significant between small and large head box at all lid positions ($p < 0.0001$ CI 4.16- 5.31) with standard error of difference of 0.249.

Table 2 shows the oxygen concentration achieved inside the head box when two variables, head size and lid position, are changed independently and in combination in babies. There is a significant difference between small and medium sized head box ($p < 0.0001$, standard error of difference of 0.399) at even low flows. This difference was even more significant between small and large head box ($p < 0.0001$ CI 8.87 to 10.52).

Comparing the concentration of oxygen between dummy and babies at different flow rates when the lid position is kept constant at position-1, in a small head box, at the maximum oxygen concentration achieved at three lpm in dummy, babies had 17% less concentration. With medium sized head box, when maximum concentration was achieved at five lpm in dummy, babies had 8 % less concentration, while in the large head box; difference was 13 % at a flow rate of seven lpm. This difference is statistically significant at all flow rates ($p < 0.0001$ CI 16.37 - 18.72). Similarly in other lid positions from 2-4, babies had a lesser concentration than dummy at all flow rates, which was statistically significant.

Table 3 depicts changes in the $EtCO_2$ concentration with varying flow rates from six lpm to two lpm. In a small headbox with lid at position 1, significant increase (13% from baseline) in $EtCO_2$ was observed at three lpm. From a baseline value of 24.32 mmHg it increased to 27.47 at 3 lpm. With lid at position 2, 3 and 4 significant increase was observed at two lpm. In the medium and large sized head boxes the retention occurred at a flow rate of two lpm in lid positions 1, 2 and 3, while there was no retention at lid position 4. An increase in the $EtCO_2$

Fig. 1 : Oxygen hood with lid at position 1

Table 1**Relationship of oxygen concentration with size and lid position of head box (Dummy)**

Size	Lid position	2	3	4	5	6	7	8	9	10
Small	Lid -1	93.2	99.8							
	Lid -2	91.8	95.7	99.8						
	Lid -3	89.7	94.7	97.4	99.8					
	Lid -4	89.4	92.5	96.3	99.5	99.9				
Medium	Lid -1	92.8	95.7	97.6	99.9					
	Lid -2	90.7	94.3	95.8	97.9	99.9				
	Lid -3	83.1	91.8	94.7	97.6	98.6	99.8			
	Lid -4	69.7	74.7	88.5	91.9	96.7	98.8	99.9		
Large	Lid -1	88.4	90.6	93.5	96.8	98.7	99.9			
	Lid -2	62.5	64.5	67.4	68.6	72.5	75.4	79.3	82.9	85.7
	Lid -3	54.7	58.5	61.6	63.4	66.7	67.3	70.5	74.5	76.6
	Lid -4	51.4	53.6	55.6	57.4	59.5	61.7	62.6	65.7	67.3

(Figures in the table indicate mean percentage of O₂ concentration achieved inside the box)

This table shows the concentration achieved inside the head box when two variables (size and lid position) are changed independently and in combination inside different sizes of oxygen hood in a dummy.

Table 2**Relationship of oxygen concentration with size and lid position of head box (Babies)**

Size	Lid position	2	3	4	5	6	7	8	9	10
Small	Lid -1	81.1	82.2	84.6	95.7	99.1				
	Lid -2	76.1	78.1	79.5	82.3	98.8	99.7			
	Lid -3	74.1	76.4	77.2	80.1	91.5	96.1	99.4		
	Lid -4	68.7	74.1	74.8	77.9	90.3	93.8	97.1	99.1	
Medium	Lid -1	77.1	81.6	86.1	91.4	94.3	96	99.1		
	Lid -2	74.7	78.3	85.7	88.5	91.3	93.9	96.5	98.8	
	Lid -3	64.7	69.3	76.5	79.7	84.5	89.3	91.2	94.4	98.7
	Lid -4	51.1	58.1	66.9	72.3	77.4	82.6	86.5	90.7	92.7
Large	Lid -1	71.3	73.9	77.3	81.4	84.3	86.1	90.9	92.3	94.8
	Lid -2	43.5	48.7	53.3	55.4	59.8	64.2	67.1	70.4	73.6
	Lid -3	38.3	43.6	46.1	49.3	52.1	56.1	60.1	63.6	67.1
	Lid -4	35.6	39.1	42.1	45.7	49.5	52.4	59.1	60.2	63.3

(Figures in the table indicate mean percentage of O₂ concentration achieved inside the box),

This table shows the concentration achieved inside the head box when two variables (size and lid position) are changed independently and in combination inside different sizes of oxygen hood in babies.

Table 3**Relationship of EtCO₂ (mmHg) with change in flow rate of oxygen**

Size	Lid position	2	3	4	5	6
Small	Lid -1	28.14	27.47	25.84	24.32	24.21
	Lid -2	27.03	26.02	24.89	24.15	24.04
	Lid -3	26.64	25.95	24.51	24.05	23.44
	Lid -4	26.28	25.63	24.19	23.85	23.56
Medium	Lid -1	26.88	25.71	24.83	23.97	23.51
	Lid -2	26.67	25.58	24.34	23.81	23.24
	Lid -3	26.66	24.15	23.54	23.72	23.11
	Lid -4	25.84	24.58	23.46	23.41	23.27
Large	Lid -1	25.86	23.41	23.08	22.56	22.84
	Lid -2	24.12	23.55	23.14	22.13	21.89
	Lid -3	24.93	23.17	22.85	21.46	22.58
	Lid -4	22.41	22.18	21.43	21.09	21.82

(Figures indicate mean EtCO₂ in mmHg achieved inside the box).

Table shows the concentration achieved inside the head box when two variables (size and lid position) are changed independently and in combination with different sizes of oxygen hood.

concentration was observed when the flow was decreased. This increase was significant when oxygen flow was reduced to three lpm in a small head box with lid at position 1 ($p < 0.0001$ CI 4.4 - 3.2), while a decrease in flow to two lpm led to significant retention in the other lid positions ($p < 0.0001$). At an oxygen flow of two lpm in medium sized head box there was significant rise in EtCO₂ ($p < 0.001$ CI 3.5- 2.26), at all lid positions. Large headbox did not have any retention of carbon dioxide even at a flow of two lpm in lid positions 2, 3 and 4 ($p < 0.078$).

Discussion

Although oxygen therapy by head box is regularly used in clinical practice, there is paucity of data in infants [8]. General guidelines are available, but there are few studies on the effect of various variables like oxygen flow rate, size of head box and lid position, on the oxygen concentration inside head box [6,7]. The present study was conducted to obviate the need for an oxygen analyzer by standardizing the variables in the head box

Table 4**Relationship of oxygen concentration with size and lid position of head box (Babies)**

Size	Lid position	2	3	4	5	6	7	8	9	10
Small	Lid -1	81	82	85	96	99				
	Lid -2	76	78	80	82	99				
	Lid -3	74	76	77	80	92	96	99		
	Lid -4	69	74	75	78	90	94	97	99	
Medium	Lid -1	77	82	86	91	94	96	99		
	Lid -2	75	78	85	88	91	94	96	99	
	Lid -3	65	69	76	80	84	89	91	94	99
	Lid -4	51	58	67	72	77	82	86	91	93
Large	Lid -1	71	74	77	81	84	86	91	92	95
	Lid -2	43	49	53	55	60	64	67	70	74
	Lid -3	38	44	46	49	52	56	60	64	67
	Lid -4	36	39	42	46	49	52	59	60	63

(Figures in the table indicate percentage of O₂ concentration achieved inside the box)

Table shows the concentration achieved inside the head box when two variables (size and lid position) are changed independently and in combination inside different sizes of oxygen hood.

in order to achieve predictable oxygen concentration inside the head box.

Size and Oxygen Concentration

Volume of the headbox had an inverse relation with the oxygen concentration inside the headbox. A smaller sized headbox therefore achieves better and more predictable oxygen concentration at all flow rates. However, selection of size depends on the baby's weight and size. Neck irritation and pressure sores may occur if the size of the headbox is too small. A loss in oxygen concentration of approximately 4 % between small and medium and 9 % between small and large at a given flow rate was attributed to increase in size. This difference is statistically significant.

Varying the lid position from 1 to 4 in the dummy and in babies, led to a significant difference in oxygen concentration. An inverse relation at all flow rates and in all the 3 different sized head boxes was found. Maximum difference in oxygen concentration by varying the lid position was observed in the large headbox. Therefore, to achieve a desired concentration in a larger head box with a high lid position, higher oxygen flow rate is required. This is clinically relevant in weaning a baby from a high concentration of oxygen. The size of head box or/and lid position can be altered without lowering the flow rate of oxygen (associated with risk of CO₂ retention) to reach lower concentration inside the head box [8]. Jain S et al [6], concluded that the concentration of oxygen was markedly affected by the capacity of the box, window size and oxygen flow rate. The significant findings of their study were an increase in oxygen concentration on increasing the oxygen inflow and by decreasing the window size. The above findings are similar to our study.

Dummy versus Babies

Keeping the variables constant, oxygen concentration was lower in babies as compared to dummy, which is statistically significant. However, it is difficult to explain the variability across flow rates, lid positions and headbox sizes. In the present study, patient factors affecting oxygen concentration were not studied. There is no study available in the literature, in which variables present in the baby affecting oxygen concentration inside headbox are described. It is assumed that patient factors like tidal volume, respiratory rate, underlying morbidity condition and basal metabolic rate may have contributed to the variability in oxygen concentration between dummy and babies.

EtCO₂ and Flow Rate

Head box is a high flow oxygen delivery device and flow rate of less than five lpm is not advised due to the fear of CO₂ retention inside the closed system, which may lead to CO₂ rebreathing [11]. In the present study oxygen to babies was started at five lpm and decrements of one lpm were made while simultaneous measurements of EtCO₂ and oxygen concentration inside the headbox were taken. It was found that at lid position 1, no significant CO₂ retention was found at flow rate of four lpm in a small and three lpm in a medium and large head box. Flow rates below this were associated with significant CO₂ retention. In a study by Jain MM et al [7], EtCO₂ was recorded in a newly designed headbox. Our findings are in discordance with these findings. However, as the study population in their study had only four babies, the statistical strength of their observation is questionable. No other studies correlating the effect of low flows rates with CO₂ retention are available.

To conclude, factors affecting concentration of oxygen inside the head box and the effect of low flow rate on CO₂ retention were studied in babies. Based on the findings of the study the following recommendations are made (not applicable to infants weighing less than 2 kg) :-

1. Smallest appropriate size of the head box should be used.
2. In order to avoid excessive noise and cooling of the baby, flows greater than 10 lpm should not be used.
3. Standard size of head boxes should be used. Rounded head box used in this study was effective in delivering oxygen.
4. FiO₂ to be delivered should be decided and then flow rate of oxygen and lid position adjusted to deliver for the required oxygen concentration.
5. In the absence of oxygen analyzer, values given in Table 4 can be used effectively to achieve the desired oxygen concentration in the head box by altering various variables. These recommendations apply only for standardized head boxes used in this study (20.5 cms, 21.5 cms and 23 cms internal diameter) with a 100 % oxygen source.
6. In order to prevent CO₂ retention and risk of rebreathing of CO₂ inside the head box, flow rates of less than four lpm in a small and three litres in medium and large head box should not be used.

This method of control of FiO₂ is to be used only when oxygen analyzer is not available. Perhaps larger and multicentric studies would help in further

understanding of the subject.

Conflicts of Interest

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