A METHOD OF HUMIDIFICATION IN VENTILATOR TREATMENT OF NEONATES

BY

N. Lomholt, R. Cooke and M. Lunding

SUMMARY

A humidification system is described for use in neonatal ventilator treatment with the child placed in an incubator. By means of a temperature-controlled draw-over humidifier and a thermocouple in the inspiratory tube, it is possible to control the content of water vapour in the inspired gases and to calculate the humidity in percentage of the humidity in the lungs during controlled and spontaneous ventilation. At the same time it has been possible to eliminate the risk of water condensation in the inspiratory tube inside the incubator. During 3 months ventilator treatment of 26 neonates with the respiratory distress syndrome, each being ventilated for more than 24 hours, the humidity was kept consistently above 70 per cent of body humidity for 1,792 hours, in which period three tubes became plugged. During 417 hours ventilation with a humidity below 70 per cent seven tubes became plugged. The impression was gained that most of the tracheal secretions were transported alongside the tube to the pharynx, and in most cases frequent tracheal suction was consequently not necessary.

The successful treatment of neonates with intermittent positive pressure ventilation has been reported from several centres.

One of the most serious complications besetting this difficult procedure is plugging of the endotracheal tube by tracheobronchial secretions, that are dry or of high viscosity. This life-threatening situation can only be managed by immediately changing the tube. It has been suggested that the tube should be changed once or twice daily in order to prevent this complication (Feychting, 1965; Thomas et al., 1965).

It is generally accepted that, in the treatment of both adults and children, plugging of endotracheal tubes can be prevented by proper humidification. Nevertheless it is still claimed to be one of the most common dangers in neonatal ventilator management, which strongly suggests that it remains unsolved in practice (Colgan, Eldrup-Jørgensen and Lawrence, 1960; Smythe, 1963; Delivoria-Papadopoulos, Levison and Swyer, 1965; McDonald and Stocks, 1965; Koller et al., 1966; McCaughey, Kuwabara and Fung, 1966).

A humidification system which has proved effective for neonatal ventilator treatment (Cooke et al., 1967) has been used in the management of the last 41 cases in our hospital. The advantages of the system are that the controlled humidity content of the inspired air is high enough to reduce the frequency of plugging of the tubes, and that condensation of water in the inspiratory tubing inside the incubator no longer occurs. The two main disadvantages with the humidification previously used by the author was the presence of condensed water in the inspiratory tube near the child, and the lack of exact control of humidity in the inspired gases.

METHOD

All children were treated in an Airshields incubator at 31–32°C (88–90°F) and ventilated with a Bird Mark 8 ventilator. The children were intubated with Portex nasotracheal tubes of 3 or 2.5 mm i.d. Care was taken to use a tube small enough to leave some space between the tracheal wall and the tube, thus permitting secretions transported to the tip of the tube by ciliary action to be passed alongside the tube to the pharynx by the force of the ventilator. The tubes were not changed at fixed intervals but were left in place until plugging was suspected or extubation took place. The Micronebulizer of the Bird ventilator, which has not proved to be sufficiently effective, was replaced with a thermostatically controlled...
water bath (Hygrotherm). A thermocouple was placed inside the inspiratory tube immediately before it entered the incubator (fig. 1). In its passage from the humidifier to the incubator the heated humidified gas is cooled by the lower room-temperature and condensation takes place inside the tube. The condensation verifies that the gas is saturated with water vapour as it reaches the incubator. It was planned to regulate the thermostat so that the temperature at the thermocouple is 1–1°C below the temperature of the incubator. In this way the gas is slightly heated inside the incubator and therefore no condensation will take place here. Further, the danger of water inside the tube being “pumped” into the baby should thus be avoided. When the inspiratory air is further heated in the airways of the child, the relative humidity decreases. By knowing the temperature difference between the thermocouple and the body temperature it is possible to calculate the saturation of the inspired air in percentage of humidity in the lungs (body humidity: b.h. table I). The aim has been to keep the calculated humidity of the air delivered to the infants at 70 per cent b.h. or higher, corresponding to a temperature difference of 6.5°C (12°F) or less.

Three precautions were taken with this system. (1) The incubator temperature was kept strictly constant. If allowed to cool, as for example when the incubator was opened, condensed water might have been transferred to the endotracheal tube. (2) The ventilator was stopped when the child was disconnected from it, for instance during endotracheal suction, since the gas flow and con-

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**Fig. 1**

Equipment used in neonatal respirator treatment.

1. Temperature-controlled draw-over humidifier (Hygrotherm).
2. Inspiratory tube with downward slope.
3. Electrical thermometer (El-lab).
4. Thermocouple in inspiratory tube.
sequently the temperature of the gas could have risen. (3) The temperature of the thermocouple was checked every 15-30 min.

Table I

Relative humidity (±1 per cent accuracy) of air 100 per cent saturated with water vapour after being heated 1-10°C to a temperature of 30-40°C (1.8-18°F to 86-104°F).

<table>
<thead>
<tr>
<th>Temperature difference between thermocouple and body temperature</th>
<th>Per cent body humidity</th>
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<tbody>
<tr>
<td>C°</td>
<td>F°</td>
</tr>
<tr>
<td>1</td>
<td>1.8</td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>4</td>
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<td>5</td>
<td>9.0</td>
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<td>10.8</td>
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<td>9</td>
<td>16.2</td>
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<td>10</td>
<td>18.0</td>
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</table>

This method of humidifying inspired gases can only be used when it is possible to keep the incubator temperature not more than 6°C (11°F) below the body temperature of the child. If this is not possible, adequate humidification with water vapour cannot be achieved without some condensation of water in the inspiratory tube inside the incubator.

RESULTS

Forty-one neonates with the respiratory distress syndrome were treated using the humidification system described. In all cases the problem of condensation of water in the inspiratory tube inside the incubator was eliminated. Fifteen neonates who were ventilated for periods of less than 24 hours (mean 8.7 hours) are excluded from consideration. Plugging of the tubes did not occur in any of these 15 cases.

The birthweight of the remaining 26 neonates was 1,410-3,400 g (mean 2,300 g). They were intubated and ventilated immediately after birth or after observation for periods of up to 121 hours (mean 32 hours). The children were intubated on average for 101 hours (max 337 hours). The mean time of intubation with each tube was 60 hours (3-236 hours). Sixteen of the 26 babies survived. The 26 children were ventilated for a total time of 2,209 hours. During 417 hours the temperature difference was more than 6.5°C (12°F) corresponding to a calculated b.h. of less than 70 per cent. During 1,792 hours the temperature difference was less than 6.5°C (12°F) and the humidity of the inspired air was consequently above 70 per cent. These figures are based on mean temperature differences for 3-hour periods. The importance of ventilating with gas of a sufficient high humidity was not realized to its full extent in the beginning. Lack of knowledge, not technical difficulties, was the only reason for the periods of low humidity. Plugging of the endotracheal tubes occurred in 7 instances during the 417 hours of ventilation when humidity was below 70 per cent and only 3 instances of plugging occurred during the 1,792 hours of ventilation when humidity was above 70 per cent. Plugging of the endotracheal tubes was not the immediate cause of death in any of the neonates because of the constant careful supervision of the babies.

The thermostat of the Hygrotherm regulates the temperature of the water within ±0.6°C (±1°F).

The first five patients were treated under close supervision by one of the authors and tracheal suction was only carried out when needed as judged from auscultation of the lungs at half-hour intervals. The mean interval between tracheal suction was 7 hours (1-30 hours). In the later cases tracheal suction has been carried out either as a routine, with an interval of 1-2 hours, or when needed.

DISCUSSION

The reason why endotracheal tubes are plugged by dry or viscid secretions is that inspired air with low humidity causes excessive evaporation from the mucus in the trachea. When about 50 per cent of the water content in the mucus is evaporated viscosity begins to rise steeply (Cragg and Smith, 1961). The point of maximum drying in the trachea, when ventilating with insufficiently humidified gases, is at the tip of the tube and just below it, the secretions deposited inside the tube forming crusts. Plugging probably starts because a small lump of mucus sticks to the inside of the tube. If this lump adheres too strongly to be removed by a suction catheter it will slowly grow drier, while more mucus sticks to the viscid lump until the tube is completely blocked. Long before
there is any risk of plugging, however, the ciliary function is influenced by the changes in viscosity of the mucus (Burton, 1962). As stressed by Proetz (1933), “The only natural enemy known to the cilia in their line of functioning is excessive drying.” The signs indicative of impaired ciliary function are not as dramatic as those of plugging but they are easy to detect. The coarse rales heard on auscultation are a sign of an accumulation of secretions in the bronchi indicating that the “ciliary escalator” is not working efficiently. Secretions of high viscosity are not readily blown through the leak between the tube and the tracheal wall to the pharynx, and make quick and effective tracheal suction impossible.

The airways below the carina are known to be sterile under normal conditions despite the amount of airborne bacteria deposited on the bronchial mucosa (Laurenzi, Potter and Kass, 1961). This defence mechanism is thought to be due in large part to the continuous secretion transport system and as this transport becomes slower the resistance against infection is lowered.

With the humidification system described it has been possible to keep a continuous check on the humidity of the gases delivered to the children’s lungs. At body temperature within the range of 30–40°C (86–104°F) there is a simple correlation (with an accuracy of ±1 per cent) between the rise in temperature from the thermocouple to the body temperature and the fall in saturation of the gas in per cent b.h. (table I). Thus all calculations of the water content of the gas at different temperatures can be omitted.

The normal temperature and humidity of inspired air in the trachea is 32°C (90°F) and 75 per cent b.h. (Ingelstedt, 1956), and normal ciliary function is preserved if the humidity of the inspired air is 70 per cent b.h. or higher (Toremalm, 1961).

Complete security against plugging of tubes by dried secretions can only be obtained when ventilating with gas fully saturated with water vapour at body temperature. Due to the necessity of ensuring the dryness of the inspiratory tube near the baby, 100 per cent b.h. cannot be used. Ventilation with gas of a lower humidity content inevitably causes some degree of evaporation from the tracheal secretions. Yet the water loss when ventilating with, for instance, gas of 75 per cent b.h. is not equal to 25 per cent drying, due to the fact that endotracheal tubes as shown by Déry et al. (1967) have a considerable capacity for heat and moisture exchange. The actual amount of water evaporated is expressed by the difference in water-content between inspired and expired gases, measured at the Y-piece, multiplied by the minute volume. These data have not been measured but we consider that the percentage b.h. of the inspired gas is the most important factor determining the water loss.

The selection of 70 per cent b.h. as the dividing line between sufficient and insufficient humidification has been made on the basis of the data referred to concerning normal physiological conditions in the lower airways. The clinical results support this choice. On average, plugging of the tube occurred once in 60 hours of IPPV when body humidity was below 70 per cent, whereas it occurred, on average, once in 600 hours of IPPV when the body humidity was 70 per cent or more. The conditions which led to the seven instances of plugging of the tube due to insufficient humidification are summarized in table II.

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Relative body humidity (%)</th>
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<tr>
<td>1</td>
<td>19</td>
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<td>2</td>
<td>18</td>
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<td>6</td>
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<td>7</td>
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</table>

* Manual ventilation. † Without tube.

For comparison, the longest periods of ventilation with insufficient humidification without plugging were 34 hours with 65 per cent b.h. (62-67 per cent) and 25 hours with 67 per cent (66-69 per cent). After these periods the children were either extubated or the humidity was raised above 70 per cent.

The conditions leading to plugging of three tubes during sufficient humidification were as
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follows: The first block occurred after 144 hours ventilation with the same nasotracheal tube, humidity being 80 per cent. The second block occurred in a baby suffering from pneumonia caused by *Pseudomonas aeruginosa*, viscid tenacious tracheal secretions being present from the start of treatment; the tube blocked after 54 hours ventilation with 75 per cent b.h. (67–80 per cent). The third block occurred after 73 hours ventilation with 74 per cent b.h. (68–80 per cent); during the last 10 hours before the tube blocked the baby had been breathing without the ventilator for a total of 5½ hours, and the humidity during spontaneous respiration was not controlled.

Recently the writers have started to control humidification during spontaneous respiration in the same way as during IPPV. A flow of gas with the oxygen percentage needed by the baby is blown through the humidifier and the inspiratory tube with the thermocouple in place, whilst the baby breathes through the suction port in the Y-piece. The temperature maintained during ventilation in the humidifier and at the thermocouple is kept unchanged by regulating the flow of gas. This amounts to 5–10 l./min and should not exceed the limits 4–15 l./min. With a constant flow of 15 l./min the Bird Y-piece of the Infant-Q-Circle offers the baby an expiratory resistance of 0.5 cm/H2O, which is considered safe. In this way it is easy to change between IPPV and spontaneous respiration whilst maintaining the humidity control.

In practice it is the authors’ impression that most of the secretions in the trachea have been transported alongside the tube to the pharynx as is shown by the fact that tracheal suction during the first 5 cases was only necessary every 7th hour (mean value), with a maximum of 30 hours between suctions, while suction in the pharynx was required every half hour. This suggests that ciliary function was at least partially intact.

On the basis of the data from 26 neonates with the respiratory distress syndrome, each ventilated for more than 24 hours for a total of 2,209 hours it is concluded that the risk of plugging of nasotracheal tubes of 2.5–3 mm i.d. is about 10 times higher when ventilating with gas of 60–70 per cent body humidity compared with ventilation with gas of 70–80 per cent body humidity.

In most cases the humidification was effective in keeping the secretions thin. When tracheal suction was performed only when needed, frequent suction was not necessary. This fact suggests that ciliary function has at least partially been preserved.

It is important to check the humidity content of inspired gases continuously when bypassing the upper airways with an endotracheal tube. This applies to IPPV as well as to spontaneous ventilation.

REFERENCES


UNE METHODE D'HUMIDIFICATION DANS LE TRAITEMENT PAR LE VENTILATEUR CHEZ LES NOUVEAU-NES

SOMMAIRE

Un système d'humidification est décrit pour servir au traitement des nouveau-nés par ventilateur avec l'enfant placé dans un incubateur. Au moyen d'un humidificateur aspirant à thermostat et d'un thermocouple dans le tube inspiratoire, il est possible de contrôler le contenu de la vapeur d'eau dans les gaz inspirés et de calculer l'humidité par rapport au pourcentage d'humidité dans les poumons pendant la ventilation contrôlée et spontanée. En même temps, il a été possible d'éliminer le risque de condensation de l'eau dans le tube inspiratoire, à l'intérieur de l'incubateur. Pendant 3 mois le traitement par ventilateur de 26 nouveau-nés présentant le syndrome de détresse respiratoire, chacun étant ventilé pour plus de 24 heures, l'humidité fut prise de façon méthodique aux environs de 70 pour cent de l'humidité du corps pour une durée de 2 mois ; pendant cette période trois tubes se sont bouchés. Pendant 2 semaines ½ de ventilation avec une humidité inférieure à 70%, sept tubes se sont bouchés. On avait acquis l'impression que la plus grande partie des sécrétions trachéennes étaient transportées le long du tube jusqu'au pharynx, et dans la plupart des cas, une succion trachéale fréquente ne fut, par conséquent, pas nécessaire.

REGISTRARS' PRIZE (ANAESTHETICS)

Applications are invited by the Royal Society of Medicine, Section of Anaesthetics, for a prize of £50 provided by Messrs. May & Baker Ltd., for a paper written by a medical practitioner of Senior Registrar or Registrar status holding an appointment in anaesthesia in a department or hospital, or in the armed forces of the Commonwealth or of the Republics of South Africa or Eire. Fellowship of the Royal Society of Medicine is not necessary for entry. The subject will be of the author's choice, but must be connected with anaesthesia. All papers for the 1969 award must be submitted in triplicate by January 1, 1969.

Further details and rules of the prize can be obtained from the Assistant Secretary, Royal Society of Medicine, 1 Wimpole Street, London, W.1.

A further prize of £25 may be awarded on the recommendation of the judges.