

# Membrane humidification—a new method for humidification of respiratory gases in ventilator treatment of neonates

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## Abstract

**A humidifier system for neonatology that functions according to the 'membrane humidification' principle was subjected to a performance test in our laboratory. Humidification and heating of the respiratory gases took place in a module consisting of a net of hollow fibres placed inside the incubator. In 18 measurement combinations flow, respiratory gas temperature, and incubator temperature were varied. At respiratory gas temperatures within the range of 33–37°C the minimum international standard for the absolute air humidity in the respiratory gas was achieved or exceeded in all measurements. No controlled clinical tests regarding the importance and long term effects of different temperatures and different humidity levels in the inspiratory air are yet available for the ventilation treatment of neonates.**

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Humidification of respiratory gases in ventilator treatment of neonates constitutes a problem that has not yet been solved optimally. Studies by Tarnow-Mordi *et al*<sup>1</sup> have shown that in day to day practice minimum standards for humidification of breathing gases<sup>2</sup> during ventilation of neonates are not fulfilled in the majority of the patients.

We have performed laboratory tests on a newly developed humidification system (Aquamod, Dräger), a so called 'membrane humidifier' that could better fulfil the requirements of application in neonates.

## Functional principle of the device

The humidifier module basically consists of a multiple layer of membranes with fine pores of 10 Å size. Here the respiratory gases come into contact with heated water which is continuously pumped through the system. During this process, water molecules diffuse through the membrane leading to a 100% saturation. The module should be installed inside the incubator in order to keep a possible temperature drop along the tubing path to the patient as low as possible and so avoid formation of condensation. In addition, the membrane serves as a bacterial filter. The inspiratory gas temperature is measured near to the patient (20 cm from the Y piece), by means of a sensor, and is adjusted to the set temperature by servocontrol. There is an automatic cut-out mechanism to reduce the

risk of exposure to dangerously high inspiratory gas temperature and an alarm in case of low inspired gas temperature and inadequate function of the pump.

## Methods of measurement

The respiratory gas temperature was measured by means of thermoelements (NiCr-Ni: Impac Tastotherm D 700). We recorded the deviations between set temperature and inspiratory gas temperature near the endotracheal tube (6 cm from the Y piece). In addition, the air temperature drop inside the inspiratory tubing system was measured at two different points (20 and 6 cm from the Y piece). The relative air humidity near the endotracheal tube was measured in the inspiratory circuit at a distance of 3 cm from the Y piece by means of a capacitive measurement technique (Rotronic Hygroskop DT). The thermoelements and the capacitive sensors are not supplied with the commercial humidification system. The absolute air humidity was calculated from the respiratory gas temperatures and the relative humidity. The measurements were carried out at different ambient temperatures inside the incubator (33, 35, 37°C). The set flow of the ventilator was modified: 2, 6, and 16 l/minute. The setpoint temperature of the humidifier was 34 and 37°C. After modification of these parameters and a period of 15 minutes for stabilisation the measurements were carried on for a time of 60 minutes for each combination of temperatures and gas flow. The average of two measurements of inspiratory gas temperatures and relative humidity during this plateau phase were calculated. The ventilator circuit was connected to an artificial lung (volume 50 ml) inside the incubator. The measurements were performed in a single wall incubator at a room temperature of about 26°C. Ventilator parameters (Dräger Babylog 1) were: frequency 45/minute, inspiratory: expiratory ratio 1:2, peak pressure 20 mm Hg, positive and expiratory pressure 4 mm Hg. The results were recorded simultaneously on a recording instrument (BBC Goerz Metrawatt SE 460).

## Results

### RELATIVE AIR HUMIDITY

The measurements of the relative air humidity at the inspiratory tubing system near the endotracheal tube resulted in values in the range of 87.5 and 100% relative humidity (table).

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*Inspiratory gas temperature, relative humidity, and absolute humidity of inspired air with different combinations of flow, incubator temperature, and set temperature of the membrane humidifier system*

Flow (l/min)	Incubator temperature (°C)	Set temperature of Aquamod (°C)	Temperature at Y piece (°C)	Relative humidity (%)	Absolute humidity (mg water/l air)
2	33	34	34.5	100	38
6	33.5	34	33.5	100	36
16	33.8	34	34	100	38
2	34	37	35	100	40
6	34	37	37	99	43.5
16	34	37	36	98	41
2	35	34	34	100	37
6	35	34	33	88	32
16	35	34	33	93.5	33
2	35.5	37	35.5	100	41
6	35.5	37	35.5	99.5	41
16	35.5	37	33.5	99.5	41
2	37	34	35	87.5	34.5
6	37	34	35	88	35
16	37	34	33.5	89	32.5
2	37	37	36.5	91.5	38
6	37	37	36	99	42
16	37	37	36	98	41

At the lower system temperature of 34°C relatively high air humidity values above 95% were only reached at incubator temperatures between 33 and 35°C. At an incubator temperature of 37°C the relative humidity was below 90% regardless of flow.

At higher respiratory gas values of 37°C the relative humidity was below 95% only at an incubator temperature of 37°C and a low gas flow of 2 l/minute. In all remaining combinations of flow and temperature optimum performance with a relative humidity range between 98 and 100% was obtained.

#### TEMPERATURE

At a system temperature setpoint of 34°C the temperature measured near the endotracheal tube varied between 33 and 35°C (table). The temperature was >0.5°C higher than the set value at high incubator temperature (37°C) and low flow (2 l/minute). It was >0.5°C lower than the set value at medium and high flow (6 and 16 l/minute) and at an incubator temperature of 35°C. At a set temperature of 37°C the respiratory gas temperatures near the endotracheal tube were between 35 and 37°C (table). The set temperature of 37°C was actually achieved in only one measurement combination (incubator temperature 34°C, flow 6 l/minute). The highest temperature drop of 2°C was observed with a cool incubator (34°C) and low gas flow (2 l/minute).

#### ABSOLUTE AIR HUMIDITY

The absolute inspired air humidity was, even under unfavourable conditions of cold respiratory gases (33–33.5°C), with 32–33 mg water/l air, above the recommended international standard.<sup>2</sup> At a set air temperature of 37°C the absolute humidity (38–43.5 mg/l) was clearly above this minimum standard (table).

#### CONDENSATION

Significant condensation inside the system was not detected in the parts installed inside the incubator. It was not necessary to install a water trap inside the inspiratory hose. Condensation was produced only in the expiratory hose outside the incubator.

#### FUNCTIONING OF THE MODULES

In some cases, the humidification modules had to be replaced within the first 24 to 48 hours of operating time because of a gradual drop in performance with inadequate relative air humidity. This was not indicated by the alarm system. According to the manufacturers another type of module is now used which has good performance for periods of at least one week. For hygienic safety it is recommended that the humidification modules should be replaced every 48 hours. Movability of the system is slightly restricted by the support inside the incubator.

#### Discussion

Relatively independently of the ambient conditions, air inspired through the nose is heated to body temperature in the lower respiratory tract after having passed the mucous membranes, reaching full water vapour saturation in the alveoli.<sup>3</sup> In artificial ventilation of newborn infants the most common method of humidification of inspiratory gas is vaporisation of water. The performance of the devices used varies considerably according to the functional principle and the type of instrument. In some there is a risk of overheating of the inspired air, especially when a drained nebuliser chamber is refilled with water. If, on the other hand, respiratory gases cannot be sufficiently warmed up the air capacity will not be sufficient to obtain a high absolute humidity in the respiratory tract. If heating filaments are used or in the situation of low flow and high incubator temperature the respiratory gases may actually be heated sufficiently. However, the air humidity might be low as the primary water load in an insufficiently heated nebuliser chamber is too low.<sup>4</sup>

According to our investigations the membrane humidification seems to fulfil the requirements with respect to constantly high respiratory gas temperatures and high air humidity even when the ambient temperature and the ventilator settings are changed. At a low gas temperature setpoint of 34°C the minimum standard<sup>2</sup> for the absolute air humidity in respiratory gases (30 mg water/l air) was reached in all measurement combinations. With high respiratory gas temperatures at a setpoint temperature at 37°C these concentrations were exceeded in all measurements, in some cases considerably. No significant amount of condensation is formed when the module is installed inside the incubator. The function of the hollow fibre net as a bacterial filter offers additional safety in hygiene. At the moment, the humidifier module must be replaced after 48 hours. One of the limitations of this system and of any humidification system that does not monitor inspired gas humidity is the fact that a gradual drop in performance might not be recognised.<sup>4</sup> A breakdown of the device would only be indicated by an alarm if the inspired gas temperature drops or if the pumping system is not working properly.

Inspired gas humidity cannot be predicted reliably from humidifier temperature.<sup>5</sup>

#### CLINICAL RELEVANCY

According to a study by Tarnow-Mordi *et al* a lower pneumothorax rate and less distinct chronic pulmonary changes were observed in ventilated premature babies with birth weights below 1500 g at higher respiratory gas temperatures, and thus probably at higher absolute air humidity, compared with another control group.<sup>6</sup> This seems plausible if results of animal tests and clinical studies are examined; these reveal a series of problems secondary to insufficient humidifier performance. Besides the risk of secretion retention,<sup>7</sup> infection,<sup>8</sup> development of atelectasis and impairment of diffusion<sup>9</sup> especially disturbances of the ciliary activity,<sup>10</sup> morphological changes in the tracheobronchial epithelium<sup>11</sup> were emphasised. By means of the membrane humidification as well as other improved devices, premature infants can now be ventilated with concentrations of absolute air humidity that lie clearly above the minimum international standard.<sup>2</sup> It is conceivable that excessive inspired gas humidification may be detrimental because too much heat and water could be administered to the patient.<sup>8 12</sup> One consequence could be that lower values of absolute humidity may be preferable to the consistently high concentrations we have

documented at an Aquamod temperature setting of 37°C.

By means of controlled prospective studies that deal with the importance of different inspiratory gas temperatures and different inspired air humidity the optimum physical conditions in respiratory care of newborn infants should be investigated.

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