HUMIDIFICATION AND LOSS OF BODY HEAT DURING ANAESTHESIA
I: QUANTIFICATION AND CORRELATION IN THE DOG

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SUMMARY
Nine of ten anaesthetized dogs were ventilated with dry gases and lost heat, at an average rate of 15.7 kilo-calories per hour. A heated humidifier was adjusted to deliver saturated gases above body temperature, and during its use the average hourly heat loss was 1.5 kilocalories. Temperature and humidity were measured in the endotracheal tube and the effect of the changeover was calculated to be 14.5 kcal per hour. It is suggested that heated humidification of dry gases is a simple addition to the other methods used to limit hypothermia during surgery, and has especial value when hyperventilation is part of the anaesthetic technique.

Rashad and Benson (1967) reported that heated humidification could limit or prevent hypothermia in infants and children anaesthetized using a dry non-rebreathing apparatus. After studying respiratory humidity in adults, Sato (1961) concluded that this heat loss was not a dominant factor in heat regulation in patients during anaesthesia and surgery.

When normal subjects at rest breathed dry gases, the evaporative heat losses averaged 0.0905 kcal/min/m² (Caldwell, Gomez and Fritts, 1969). These subjects, and those with respiratory disease, showed an hourly total of heat loss from the airway which was approximately 1 kilocalorie for each litre of the respiratory minute volume. This is in agreement with the figure calculated from data obtained during anaesthesia with a non-rebreathing system by Sato (1961) and Shanks (1974) but less than that suggested by Clark, Orkin and Rovenstine (1954).

Caldwell and his colleagues showed that the total respiratory heat loss was equivalent to 12% of the total body heat production at rest. When the latter is diminished by general anaesthesia, hyperventilation with dry gases could become an important factor in the production of inadvertent hypothermia during prolonged surgery. Conversely, delivery of saturated gases at temperatures above that of the body can produce heat gain via the respiratory tract (Wessel, James and Paul, 1966; Kirch and DeKornfeld, 1967).

It is proposed that heated humidification might limit reductions in body temperature during adult anaesthesia, particularly if hyperventilation is part of the technique. These studies were performed to examine the differences in total body heat which might be related to humidification of dry gases in a non-rebreathing system.

METHOD
Studies were made with 10 large dogs, 8 Greyhounds and 2 German Shepherds. One dog was premedicated (dog 8), using chlorpromazine. Anaesthesia was induced with thiopentone or pentobarbitone, and muscular relaxation was maintained with pancuronium. After endotracheal intubation, the dogs were ventilated with 75% nitrous oxide in oxygen (10 litre/min, room temperature and pressure). A preheated humidifier could be inserted into the delivery line, so that saturated gases at a temperature in excess of 40°C reached the animal (figure 1).

Thermocouples were used for thermometry. Deep body temperatures were measured in the upper and lower oesophagus, rectum and, sometimes, the iliac artery. Mean skin temperatures were derived from an unweighted average of 12 sites: the pinna of the ear, muzzle, neck, foreleg, forefoot, shoulder, chest, abdomen, rump, hindfoot, medial and lateral aspects of the hind leg.

The end-inspired and end-expired temperatures were measured after the method of Ingelstedt (1956). These were recorded from a pair of thermocouples placed axially in the endotracheal tube at lip level. The system has been described previously (Shanks and Sara, 1973); it involves TRA-1
Airway probes, at lip level

Fig. 1. The laboratory investigations during use of the heated water-bath humidifier. Deep body temperatures were measured in the upper and lower oesophagus, and in the rectum. The numbered sites were for measurement of skin temperatures. The airway probes gave end-inspired and end-expired temperature and humidity within the endotracheal tube.

probes, the second of the pair modified to provide "wet bulb" readings, from which the humidities were derived by psychrometry.

Not less than 40 min after induction of anaesthesia, the first of the contiguous 2-hour study periods was begun. On six occasions dry gases were delivered during the first test period, to be followed immediately by 2 hours with humidification. In several dogs confirmation was sought with a third period, in which the initial test conditions in the airway were repeated.

Calculations.

The measurements were made every 15 min: the end-tidal values for each dog were averaged and the respiratory heat exchange calculated. Heat in the gases was taken as the product of the difference between the inspired and expired temperatures \( (t_i - t_e) \), the specific heat of the gas mixture, and the volume of expired gas at STP. The specific heat of the mixture was taken at 0.409 calories per litre. Evaporative heat loss was obtained from multiplying the difference between the end-inspired and end-expired absolute humidities \( (h_i - h_e) \) by the expired volumes and the heat of vaporization of water. This was taken as 0.580 kcal per gram of water during ventilation with "dry" gases, and 0.574 during humidification.

Changes in stored body heat \( (Q_s) \) were calculated from the mean body temperature \( (\overline{T_b}) \) the body mass \( (m_b) \), and the specific heat of the body (taken as 0.83): 

\[
Q_s = \overline{T_b} \times m_b \times 0.83
\]

The mean body temperature was derived from the lower oesophageal temperature \( (T_o) \) and the mean skin temperature \( (\overline{T_s}) \), where the latter was the unweighted average of 12 sites:

\[
\overline{T_b} = 0.8T_o + 0.2 \overline{T_s} \quad \text{(Hardy, 1961)}
\]

RESULTS

The respiratory heat exchange shown in table I are the mean and standard deviations of results from all 10 dogs. These decreased within a narrow range, and reflect the standardized conditions. The dry gases reached lip level with end-inspired temperatures in the range 24.6 to 28.0°C, with relative humidities of 47 to 60%; the saturated end-expired gases were at 31.9 to 36.3°C, tending to decrease in parallel with core temperature reductions. It was calculated that the average loss from the respiratory tract during the supply of dry gases was 10.4 kcal per hour.

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Weight (kg)</th>
<th>Dry gases (kcal/hr)</th>
<th>Humidified (kcal/hr)</th>
<th>Difference (kcal/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>-4.6</td>
<td>+11.2</td>
<td>15.8</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>-11.8</td>
<td>+7.4</td>
<td>19.2</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>+0.9</td>
<td>+12.6</td>
<td>11.7</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>-10.3</td>
<td>+1.7</td>
<td>12.0</td>
</tr>
<tr>
<td>5</td>
<td>31</td>
<td>-21.6</td>
<td>-7.5</td>
<td>14.1</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>-24.9</td>
<td>-6.2</td>
<td>18.7</td>
</tr>
<tr>
<td>7*</td>
<td>33</td>
<td>-25.6</td>
<td>-10.4</td>
<td>15.2</td>
</tr>
<tr>
<td>8*</td>
<td>21.5</td>
<td>-7.3</td>
<td>+1.6</td>
<td>8.9</td>
</tr>
<tr>
<td>9</td>
<td>25</td>
<td>-30.1</td>
<td>-12.8</td>
<td>17.3</td>
</tr>
<tr>
<td>10</td>
<td>22.5</td>
<td>-21.3</td>
<td>-12.9</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Mean heat change (SD) -15.7 ± 1.5 14.1 3.8

Mean respiratory exchange (SD) -10.4 ± 4.0 14.5 1.0

*German shepherds.

With humidification the saturated gases showed end-inspired temperatures of 40.0 to 43.6°C, though they were slightly higher immediately after the insertion of the humidifier. With end-expired temperatures of 35.8 to 41.0°C, the respiratory tract gained 4 kcal per hour; a net effect with the changeover in excess of 14 kcal per hour.

Table I shows the hourly changes in body heat which were calculated for each dog. These varied considerably between animals, with the greatest losses occurring when the room air (20.1 to 23.2°C) was blown across the dog by the air conditioner. In the dry gas period, all dogs but one...
showed a reduction in the (lower) oesophageal temperature. During humidification this increased in 6 of the 10 dogs. The mean skin temperature always decreased with the dry gases; with humidification it decreased less rapidly, and there was a net increase in 4 dogs. It appeared to make no difference whether dry or humidified gases were used in the initial study period. The least satisfactory agreement in the third 2-hour study was shown by dog 8 (fig. 2). Here, the greater heat gain in the second humidified period may have been related to the decreased vasodilator effect of chlorpromazine, as $T_{sk}$ decreased.

Each animal was used as its own control, and the hourly changes in body heat shown in the initial dry gas and humidified periods were subtracted from each other. This difference between the pairs averaged 14.1 kcal, and varies significantly from zero at the 99% confidence level.

**DISCUSSION**

The humidifier was able to reverse the respiratory heat exchange, by an amount which was reflected in the change in stored body heat. During open-circuit ventilation with dry gases, all dogs but one showed a loss in total body heat. The major part of the respiratory tract losses results from the transfer of mucosal water into the expired gas (Burch, 1945). Conversely, condensation from hot gases releases more than half a kilocalorie from each gram of water, and the body gains heat. Delivery of gases saturated at body temperature results in a balance for respiratory exchange of heat and moisture (Dery, 1973).

The calculations of respiratory heat exchange used end-inspired and end-expired temperatures, and these gave agreement with the detailed studies of Caldwell, Gomez and Fritts (1969). In estimating the convective component of the gas heat, they derived the mean inspiratory and expiratory temperatures; the evaporative component was obtained from collection of the expired gas and moisture. They also showed that the heat lost by the decomposition of carbonic acid (Burch, 1945) was approximately equalled by the exothermic reaction between blood and oxygen. In the construction of table I, it would appear that the errors and omissions in method have cancelled each other.

In using each dog as its own control, it was assumed that each maintained a constant metabolic heat production proportional to its elimination of heat; all other confirmatory runs were better than that depicted in figure 2. This dog showed a poorer heat gain in the first period than in the third, and this might be related to the higher skin temperatures at that time. It demonstrates that the cold patient whose periphery is poorly perfused will retain more heat than one who is vasodilated; when this heat is supplied to the body “core” from the humidifier, there will be a more rapid rewarming. This is of importance in the management of accidental hypothermia.

Figure 2 also illustrates the findings of Whitby and Dunkin (1969), who reported that temperatures in the upper oesophagus were affected by ventilation with dry gases. The pulmonary circulation also participates in heat exchange. Wessel, James and Paul (1966) found that the changeover from dry to humidified gases reversed the gradient between the aortic and pulmonary artery temperatures.

At normal body temperatures, the major benefit from heated humidification related to cancellation of losses which had been caused by ventilation with dry gases. During thoracotomy, Lunn (1969) and Dyde and Lunn (1970) reported hourly body heat losses of about 21 kcal. Half the number of dogs in table I had losses of this order and humidification reduced this hypothermic tendency. When heat production was almost able to keep pace with heat elimination, humidification of the dry gases converted the respiratory tract losses from their negative figure to produce a net gain in total body heat.

If inadvertent hypothermia is likely to become a problem during prolonged surgery, then heated humidification provides a simple addition to the other preventative measures.
ACKNOWLEDGEMENTS

I am most grateful to the Department of Surgery, University of Sydney, for allowing me to study their animals and use their laboratories.

REFERENCES