OPTIMUM HUMIDIFICATION OF AIR ADMINISTERED TO A TRACHEOSTOMY IN DOGS

Scanning electron microscopy and surfactant studies

T. Tsuda, H. Noguchi, Y. Takumi and O. Aochi

SUMMARY

The effect of the inhalation of dried (less than 40% water-saturation) or humidified air (100% water-saturation at 25, 30, 35 and 40 °C) was studied in dogs in which a tracheostomy had been performed to determine the optimal humidity. After inhalation for various periods, the dogs were killed and pieces of lung tissue were excised for analysis of surfactant. Sections of the trachea and the primary to tertiary bronchi were taken for scanning electron microscopic examination. Structural changes were observed in the trachea of dogs inhaling dried air and in the tertiary bronchi of dogs inhaling 100% water-saturated air at 35 °C. No change was observed after 24 h in dogs which had inhaled 100% water-saturated air at 25 °C under anaesthesia or at 30 °C without anaesthesia. Consequently, the optimal range of humidity was determined to be 100% water-saturation between 25 and 30 °C.

When the upper respiratory tract is bypassed following endotracheal intubation or tracheotomy, the normal function of the mucosa of the nasal passages and upper airways, as a heat and moisture exchanger (Ingelstedt, 1956; Andersen, Lundqvist and Proctor, 1972), is disturbed and the inhalation of dry gas directly into the lungs may be inevitable unless proper means of humidification are available.

The inhalation of dry gas through a tracheal, or tracheostomy, tube causes ciliary paralysis (Dalhamn, 1956; Forbes, 1973) resulting in the inspissation of mucus and encrustation of the trachea. Further complications may include damage (Chalon, Loew and Malebranche, 1972) and inflammation of the mucosal epithelium, decreased pulmonary compliance (Rashad et al., 1967; Noguchi, Takumi and Aochi, 1973), microatelectasis (Nunn, 1966; Boys and Howells, 1972) and a decrease in functional residual capacity (FRC) (Noguchi, Takumi and Aochi, 1973). Therefore the inspiration of warm and humid gas is an essential procedure in the long-term care of patients whose lungs are ventilated through an endotracheal or tracheostomy tube.

On the other hand, the hazardous effects of over-humidification following prolonged exposure to ultrasonic aerosols have been demonstrated by Modell, Giammona and Davis (1967). If the patient inhales air preheated above body temperature and saturated with water vapour, the air will be cooled in the airway and the water vapour will condense (Graff, 1975). This water may obstruct small airways mechanically and dilute the surface-active substance in them.

Furthermore, there are several other dangers of humidification or over-humidified gas therapy such as bacterial infection (Reinarz et al., 1965), increase in airway resistance (Cheney and Butler, 1968) or water and electrolyte imbalance (Graff, 1975). These complications seem to result from mismanagement rather than from humidification itself, but the optimal humidity of inspired air has yet to be determined. There are few descriptions in the literature of safe and reliable criteria of humidification (Loew, Klein and Chalon, 1972; Forbes, 1973; Noguchi, Takumi and Aochi, 1973).

Pulmonary surfactant is a lipoprotein consisting mainly of α, β-dipalmitoyl lecithin (Brown, 1964) which covers the alveolar surface (alveolar lining layer) (Gil and Weibel, 1969–70), lowers the surface tension and maintains alveolar stability (Clements, Brown and Johnson, 1957; Clements, 1962). Recent investigations of the biochemical, physiological and morphological properties of pulmonary surfactant have included several which have studied the effects of the humidity of inhaled gas on pulmonary surface activity (Toung et al., 1970; Fonkalsrud et al., 1975).

The following studies on the effects of humidity in inspired air on airway mucosa and on pulmonary surface...
activity were performed to determine the optimum humidity of inspired air in tracheostomized dogs.

**METHODS**

Thirty-two adult mongrel dogs of both sexes, weighing 7–18 kg, were anaesthetized by the i.v. injection of sodium pentobarbitone 20 mg kg⁻¹ body weight. Except for two of the dogs which served as controls, all the dogs were placed in the supine position and the femoral artery and vein were cannulated to allow the withdrawal of blood and the administration of lactated Ringer's solution (100 ml kg⁻¹ day⁻¹). A tracheotomy was performed and a cuffed tracheostomy tube inserted. The balloon was inflated tightly. All 32 dogs were used for the study of surfactant activity. In eight, an examination of the airway mucosa by scanning electron microscopy was undertaken.

**Surfactant study**

The dogs were allowed to breathe spontaneously, through the tracheostomy tube, either air dried by calcium chloride (CaCl₂) or air humidified by a heated Bennet Cascade humidifier in which the water temperature was controlled between 25 and 40 °C.

The air, delivered from an air-compressor, was blown into a canister filled with CaCl₂ or into the humidifier at a rate of 15 litre min⁻¹. A small glass bottle was inserted between the humidifier and the T-piece connected to the tracheostomy tube as a trap for surplus water. The dial for controlling the water temperature in the humidifier was set in such a way that the air temperature at the port to the dog could be maintained at approximately 25, 30, 35 or 40 °C and the humidity of the inspired air changed from less than 40% to 100% water-saturation at the given temperatures (fig. 1).

The dogs were divided into six groups depending on the condition of the inspired air (table I).

**Group I (2 dogs):** No treatment (control group).

**Group II (6 dogs):** Three pairs of dogs inhaled dried air under anaesthesia for (a) 3, (b) 6, or (c) 16 h, respectively. The humidity in this dried air was less than 40% water-saturated at 15 °C.

**Group III (8 dogs):** Two pairs of dogs inhaled 100% water-saturated air at 25 °C under anaesthesia for (a) 3, or (b) 6 h respectively, and the remaining four dogs inhaled the same type of air for 24 h, (c) two under anaesthesia (maintained by slow infusion of pentobarbitone) and (d) two without anaesthesia.

**Group IV (6 dogs):** 100% water-saturated air at 30 °C (a) for 6 h under anaesthesia (two dogs); for 24 h, (b) under anaesthesia (two dogs) and (c) without anaesthesia (two dogs).

**Group V (6 dogs):** Pairs of dogs inhaled 100% water-saturated air at 35 °C for (a) 3 h under anaesthesia, (b) 6 h under anaesthesia or (c) 24 h without anaesthesia.

**Group VI (4 dogs):** Two pairs of animals inhaled 100% water-saturated air at 40 °C for (a) 3 h or (b) 24 h.

**Fig. 1.** Method of humidification. The air from the air-compressor was reduced to 15 litre min⁻¹ with a flowmeter placed just downstream from the compressor. After passing through the humidifier, surplus water in the air was trapped into a small glass bottle placed about 20 cm downstream from the outlet of the humidifier. The tracheostomy tube was connected to a T-piece placed about 20 cm downstream from the water trap. The temperature in the inspired air was controlled with the thermostat built into the humidifier, and 100% saturated air at the prescribed temperatures were obtained at the port to the dog.
**TABLE I. Experimental design and results**

<table>
<thead>
<tr>
<th>Group no.</th>
<th>No. of dogs</th>
<th>Humidity</th>
<th>Inhalation time (h)</th>
<th>Anaesthetized</th>
<th>Surface tension $\gamma$ (dyne cm$^{-1}$)</th>
<th>$\bar{S}$</th>
<th>Mean $\gamma$ (dyne cm$^{-1}$)</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>2</td>
<td>Control</td>
<td>—</td>
<td>—</td>
<td>9.4 25.2 0.91 10.2 28.8 0.95</td>
<td>9.8</td>
<td>27.0</td>
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<tr>
<td>II</td>
<td>a 2</td>
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<td>30.0</td>
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<td>b 2</td>
<td>Dry*</td>
<td>6</td>
<td>Yes</td>
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<td></td>
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<td>16</td>
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<tr>
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<td>3</td>
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<td>18.6 44.4 0.82 16.8 44.4 0.90</td>
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$\gamma$ = surface tension (dyne cm$^{-1}$).

$\bar{S}$ = extract activity index = \( \frac{2(\gamma_{\text{max}} - \gamma_{\text{min}})}{\gamma_{\text{max}} + \gamma_{\text{min}}} \).

* Less than 40% at 15 °C.

Scanning electron microscopy was performed in groups I, IIc, IIIc, and Vc.

At the end of the inhalation all the dogs were sacrificed by exsanguination. The thorax was opened and 5 g of lung tissue was excised from the right diaphragmatic lobe. Tissue samples were minced into small pieces with scissors, stirred in 50 ml of saline for 30 min and then filtered through four layers of gauze into a Teflon trough.

Measurement of the surface activity of the lung extract was made with a modified Wilhelmy surface balance by the method of Clements (1962) at 24 °C and the surface tension was recorded using a transducer and an X–Y recorder.

**Scanning electron microscopic study**

Two dogs from each of groups I, IIc, IIIc and Vc were used to study the mucosal surface of the airway. Immediately after cardiac arrest, the trachea just beneath the tip of the tracheostomy tube, the left primary bronchus 1 cm distal to carina, secondary and tertiary bronchi of the left cardiac lobe and the left...
diaphragmatic lobe were taken for examination. The specimens were fixed, either after washing with isotonic saline to remove blood and debris on the ciliated mucosa, or without washing. The specimens were fixed in 2.5% glutaraldehyde buffered with cacodylate 0.05 mol. litre$^{-1}$ for 2 h at 4 °C, rinsed in a 0.05-mol. litre$^{-1}$ cacodylate buffer at pH 7.4 and postfixed in 1% osmium tetroxide solution for 30 min at 4 °C. After each specimen had been dehydrated through a graded series of ethanol solutions and transferred to n-amyl acetate for 30 min, critical point drying was performed. The specimens were coated with thin gold and examined with a scanning electron microscope (Hitachi type HHS-2R) at an accelerating voltage of 15–20 kV.

RESULTS

Surfactant study

The minimum and maximum surface tension and extract activity index are shown in table I. The average minimum surface tension of two control samples was 9.8 dyne . cm$^{-1}$ on compression of the surface to 20% of its original area.

After inhalation of dried or humidified gas for 3 h, the average minimum surface tension of groups IIa, IIIa, Va and VIa was 10.5, 9.6, 8.0 and 21.3 dyne . cm$^{-1}$, respectively (fig. 2).

After inhalation of dried or humidified gas for 6 h, the average minimum surface tension of groups IIb, IIIb, IVa and Vb was 15.9, 11.7, 11.1 and 13.4 dyne . cm$^{-1}$, respectively (fig. 2).

The mean minimum surface tension in those dogs which inhaled dried air (group II) increased with time from 10.5 dyne . cm$^{-1}$ after 3 h to 15.9 after 6 h and 16.9 after 16 h (figs 2 and 3).

In the group of dogs that inhaled 100% water-saturated air at 25 °C (group III) the average minimum surface tension obtained after 3 and 6 h of inhalation was 9.6 and 11.7 dyne . cm$^{-1}$, respectively (figs 2 and 4).

After inhalation of humidified air for 24 h, the average minimum surface tension in group III was 11.4 dyne . cm$^{-1}$ when the dogs were anaesthetized,

![Fig. 2. Effects of the inhalation of dried and humidified air on pulmonary surface tension. Values represent the means of minimum surface tension of two specimens. Values less than 12 dyne . cm$^{-1}$ indicate the presence of normal surface activity. Control; $\bullet$ inhalation for 3 h under anaesthesia; $\bullet$ 6 h under anaesthesia; $\bullet$ 16 h under anaesthesia; $\bullet$ 24 h under anaesthesia; $\bullet$ 24 h without anaesthesia.](image)
Fig. 3. Surface tension–area diagrams of saline extracts of lungs after inhaling dried air. These diagrams were obtained from the groups breathing dried air (less than 40% saturated at 15 °C). After inhalation for 3 h under anaesthesia (——), minimum surface tension was less than 12 dyne cm⁻¹ as seen in the control (—–), suggesting the presence of normal surface activity. But, after 6 (——) and 16 h (——) inhalation under anaesthesia, the decrease or loss of surface activity was demonstrated (upward deviation). Saline control curve at 72 dyne cm⁻¹ is shown at the top.

but the value was 19.5 dyne cm⁻¹ if the dogs remained awake (figs 2 and 4).

After 24 h, the average minimum surface tension in group IV was 15.2 dyne cm⁻¹ under anaesthesia, in contrast with 9.4 dyne cm⁻¹ in unanaesthetized dogs (figs 2 and 5).

In the group inhaling 100% water-saturated air at 35 °C (group V), the mean minimum surface tension was 8.0 dyne cm⁻¹ after 3 h and 13.4 dyne cm⁻¹ after 6 h of inhalation (figs 2 and 6).

In groups in which overhumidified air was inhaled (Vc and VIb) the mean minimum surface tension was 20.4 dyne cm⁻¹ and 17.7 dyne cm⁻¹ (figs 2, 6 and 7), respectively.

Scanning electron microscopic study

Group I (control). Most of the surface of the trachea and of the primary to tertiary bronchi was covered with a regular array of cilia projecting from the apical border into the lumen (fig. 8). Spherical mucus droplets of almost uniform size were found scattered on the tips of the cilia. The surface of the mucus droplets was nearly smooth but had very fine shallow ridges.

Group IIc (dried air). In the trachea and primary bronchus, mucus droplets showed marked variation in size and shape (fig. 9). Some were broken into pieces and others were adherent to degenerated cilia or were fused together. When these mucus droplets were removed by washing with saline, significant injury of the cilia was observed. They had lost their regular array, were matted down, tangled and twisted, and appeared to fuse and stick together. In secondary and tertiary bronchi, no abnormality in mucus droplets or cilia was observed (fig. 10).

Group IIIc (100% water-saturated at 25 °C). The cilia showed only slight irregularity of array in the trachea (fig. 11), but no other abnormalities were detected.

Group Vc (100% water-saturated at 35 °C). In the trachea and primary bronchus, ciliary array was regular and mucus was spherical, similar to group I
FIG. 4. Surface tension–area diagrams of saline extracts of lungs after inhaling 100% saturated air at 25 °C. These diagrams were obtained from the groups inhaling 100% saturated air at 25 °C. Only the extract from the lung excised after inhalation for 24 h without anaesthesia (---) showed decreased surface activity and absence of significant hysteresis. Control; --- inhalation for 3 h under anaesthesia; --- 6 h under anaesthesia; --- 24 h under anaesthesia. Saline control curve at 72 dyne cm⁻¹ is shown at the top.

FIG. 5. Surface tension–area diagrams of saline extracts of lungs after inhaling 100% saturated air at 30 °C. These diagrams were obtained from groups inhaling 100% saturated air at 30 °C. Only the extract from the lung excised after inhalation for 24 h under anaesthesia (---) showed decreased surface activity. Control; --- inhalation for 6 h under anaesthesia; --- 24 h without anaesthesia. Saline control curve at 72 dyne cm⁻¹ is shown at the top.
HUMIDIFICATION OF TRACHEOSTOMY IN DOGS

FIG. 6. Surface tension–area diagrams of saline extracts of lungs after inhaling 100% saturated air at 35 °C. These diagrams were obtained from groups inhaling 100% saturated air at 35 °C. Only the extract from the lung taken after inhalation under anaesthesia for 3 h (——) showed the presence of normal surface activity. The decrease of surface activity observed in the groups which had been breathing the air for 6 h under anaesthesia (——) and 24 h without anaesthesia (————) appears to be a result of dilution of surfactant by condensed water from over-humidification. — Control. Saline control curve at 72 dyne . cm⁻¹ is shown at the top.

DISCUSSION

In the estimation of pulmonary surface activity it is necessary to determine a threshold value. At values greater than this threshold value normal surface activity would be considered lost. Although several investigators have reported various values for this threshold, it has not yet been determined decisively because surface activity cannot be evaluated by using the Wilhelmy surface balance. In this investigation, the threshold value was assumed to be 12 dyne . cm⁻¹ of minimum surface tension (Drews, Tierney and Benfield, 1974). The results in this study were evaluated accordingly.

In the dogs that were breathing dried air (at relative humidity less than 40% at 15 °C) for 3 h (group IIa), minimum surface tension was 9.6 and 11.4 dyne . cm⁻¹. Both values were less than the threshold mentioned above (fig. 2). The surface tension–area diagrams of the saline extracts from the lungs of these dogs showed wide hysteresis (Sutnick and Soloff, 1963) similar to the diagrams from control dogs (fig. 3). It appears that the inhalation of dried air for 3 h is not deleterious to the pulmonary surfactant. However, when dogs inhaled dried air for 6 h (group IIb), the minimum surface tension of the lung extracts increased remarkably and exceeded the threshold (fig. 2). An absence of significant hysteresis (Sutnick and Soloff, 1963) was noted also (fig. 3). These findings indicate that the surface activity is impaired after the dried air has been inhaled for 6 h.

Using scanning electron microscopy, marked injury of cilia and degeneration of mucus droplets in both trachea and primary bronchi were observed in specimens obtained from dogs receiving dried air for 16 h (group IIc) (fig. 9). It appears that ventilation with dried air leads to excessive cooling and drying of cilia and mucus droplets (Forbes, 1973), resulting in tangling and twisting of cilia and inspissation of (fig. 12). In secondary and tertiary bronchi the regular array of cilia was destroyed completely with degeneration of cilia as indicated by twisting, adhesion and matting (fig. 13). The surface of mucus droplets was rough with many ridges. These injuries appeared to be more severe in the more peripheral bronchi.
secreted mucus. Consequently, the normal function of cilia as transporters of mucus, cell debris or foreign bodies would be significantly disturbed (Dalhamn, 1956; Burton, 1962; Forbes, 1973). In contrast to these findings, cilia and mucus droplets in secondary bronchi showed little degenerative change (fig. 10). This suggests that the harmful effect of dried air does not spread to secondary bronchi or more peripherally.

The mechanism by which inhalation of dry gas induces the lung lesions is understood poorly. Decreased transport of mucus resulted from degeneration of cilia and mucus droplets within the proximal airway of dogs receiving dried air. If the inhalation of dried air continued, retention and drying of mucus droplets intensified and bacterial contamination of retained mucus would be likely. Once mucus was retained on the wall of the proximal airway, its capacity to humidify the inhaled air would be diminished, causing inhaled air to absorb heat and water directly from the mucosal surface of the more distal airways. Thus the lesions would extend distally, and the retained mucus in the proximal airway would become encrusted. These changes in the airway might be expected to increase the localized resistance to air flow to an extent depending on the degree of mucus retention. Further, the altered flow rate of inspired air would result in ventilation/perfusion abnormalities in the lung (Takumi and Aochi, 1970) such that in areas of the lung where ventilation was decreased, circulation would be suppressed with a consequent reduction in the synthesis of surfactant (Finley et al., 1960). Such a sequence of events is supported by our results demonstrating that the minimum surface tension of group IIc exceeded the threshold (18.1 and 15.6 dyne cm⁻¹) and the absence of significant hysteresis in the tension–area diagram (figs 2 and 3).

Similarly in the rat, movement of cilia of the mucus epithelium of the trachea was reported to be greatly disturbed when exposed to dry gas (Dalhamn, 1956). Fonkalsrud and associates (1975) reported also that surface activity in the dog lung decreased significantly after ventilation with dry gas, often after only 2 h, whereas the same change occurred only after 6 h in our experiments. This increased time might be a
FIG. 8. Scanning electron micrograph of normal epithelial surface of the trachea of a control dog (group I). Regular array of cilia and spherical mucus droplets are shown. Magnification bar represents 5 μm. Inset: Cilia with regular array in tertiary bronchus, from the same dog. Magnification bar represents 1 μm.

FIG. 9. After inhalation of dried air (less than 40% saturated at 15 °C for 16 h under anaesthesia (group IIc), cilia in the trachea have lost their regular array and show marked degeneration if mucus droplets are removed by saline before fixation. Magnification bar represents 1 μm. Inset: Degenerated mucus droplets adhere to cilia in the trachea. Magnification bar represents 1 μm.

FIG. 10. Surface of secondary bronchus after inhalation of dried air for 16 h (group IIc). Mucus droplets and cilia show little degenerative change. Magnification bar represents 5 μm.
FIG. 11. After inhalation of 100% saturated air at 25 °C for 24 h under anaesthesia (group IIIc), most of the cilia in the trachea show very slight irregularity of the array. Magnification bar represents 1 μm.

FIG. 12. After inhalation of 100% saturated air at 35 °C for 24 h without anaesthesia (group Vc), cilia in the trachea show a regular array and mucus droplets are spherical (see fig. 8). Magnification bar represents 5 μm. Inset: Same specimen at higher magnification. Magnification bar represents 0.5 μm.

FIG. 13. In the tertiary bronchus of the dog described in figure 12, the regular ciliary array is lost and bundles of cilia are matted. Surface structure of the mucus droplets is rough with “raspberry” appearance. Magnification bar represents 5 μm.
result of differences in the composition of ventilating gas and the method of ventilation (McClenahan, 1971). Knudsen, Lomholt and Wisborg (1973), however, observed that the frequency of pulmonary complications in patients undergoing anaesthesia was not significantly different between groups inhaling either dry or humidified gas for an average of 5 h. This was possibly a result of the humidifying effect of the non-rebreathing valve and tube (Déry et al., 1967) utilized in their study so that the patients were not actually inhaling "dry" gas. Also, since it is absolutely necessary to give physiologically conditioned humid gas to a patient who needs long-term respiratory care via an endotracheal, nasotracheal or tracheostomy tube, this transitional moisture exchanger (Déry et al., 1967) would not be useful as it does not function over a long period.

In addition to demonstrating the hazards of the inhalation of dry gas, hazardous effects from overhumidified gas inhalation were demonstrated clearly in our experiment (groups Vb, Vc, Vla and Vlb). In the group treated with 100% water-saturated air at 40 °C for only 3 h (group Vla), a rapid decrease in surface activity (16.2 and 26.4 dyne cm⁻¹ of minimum surface tension) was noted. This may be a result of: (1) atelectasis caused by obstruction of the peripheral airway with the condensed and retained water inhibiting the production or release of surfactant; (2) inactivation or displacement of surfactant by intra-alveolar fluid (Johnson et al., 1963); (3) dilution of surfactant by the condensed water. In the groups inhaling 100% humidified air at 35 °C, surface activity remained normal only when the inhalation period was 3 h (group Va). Since the humidified gas depresses evaporation from secretions (Knudsen, Lomholt and Wisborg, 1973), the latter become more fluid and copious, exceeding the capacity of ciliary transport. Obvious injury of the cilia was demonstrated by scanning electron microscopy in the trachea and primary bronchus (figs 12 and 13).

The different degrees of ciliary injury in the different airways may be a result of either differences in the capacity of ciliary transport according to the depth of the airway or different susceptibilities to the abnormal conditions. Whatever the reason, the unfavourable effects of the inhalation of over-humidified air as well as that of dry air was demonstrated clearly in our experiment.

Thus it is necessary to determine the optimal humidity of the inspired gas. Noguchi, Takumi and Aochi (1973) concluded, from a study on alveolar ventilation, functional residual capacity and lung compliance, that the optimal humidity was 100% water-saturation between 20 and 30 °C. By histological examination of the desquamated ciliary epithelium, Loew, Klein and Chalon (1972) reported that the relative humidity of 60%, at room temperature (22-26 °C) was a standard for minimal supplementary humidification in fresh gas. Forbes (1973), observing mucus flow rate, suggested that gas introduced at the port of an endotracheal tube at 37 °C should have a relative humidity greater than 50%, preferably 75%, to maintain tracheal mucus flow.

In the present study, minimum surface tension of the lung extracts was below the threshold of 12 dyne cm⁻¹ only in the groups inhaling 100% humidified air at 25 °C under anaesthesia (group IIIc) and at 30 °C without anaesthesia (group IVc) for 24 h. In these two groups, the surface activity of lung extracts from unanaesthetized dogs differed from that of anaesthetized dogs. As scanning electron microscopy revealed that the airway surface in dogs inhaling 100% humidified air at 25 °C remained intact, this degree of humidity seems to meet the physiological requirements of the dog with a tracheostomy.

Airway lesions induced by insufficient humidification seem to depend to some extent on the amount of ventilation, since the hazardous effect of poor humidification may be masked by a small ventilation volume. When the ventilation volume is large, complications may be exaggerated. The i.v. barbiturate anaesthesia does not influence mucus flow rates (Marin and Morrow, 1969). Thus, the differences in the minimum surface tension between anaesthetized and unanaesthetized dogs inhaling 100% water-saturated air at both 25 and 30 °C for 24 h, may be a result of altered ventilation volume and loss of vital reflexes such as postural movement, cough and sigh reflexes during anaesthesia. In this regard, long-term inhalation of 100% water-saturated air at 30 °C under anaesthesia is considered to be slight over-humidification, while at 25 °C without anaesthesia it is considered to be rather poor humidification.

We conclude that, when the upper respiratory tract is bypassed, the optimal humidification of inspired air is 100% water-saturation between 25 and 30 °C.

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REFERENCES


HUMIDIFICATION OPTIMALE DE L'AIR
ADMINISTRÉE PAR UNE TRACHEOTOMIE
SUR DES CHIENS

Microscopie électronique par balayage et études des agents tensioactifs

RESUME

On a étudié sur des chiens, sur lesquels on avait effectué une trachéotomie, l'effet de l'inhalation d'air séché (moins de 40% de saturation d'eau) ou d'air humidifié (100% de saturation d'eau) sur les chiens qui avaient inspiré de l'air sec et humidifié de l'air saturé d'eau à 25 °C, sans anesthésie. On en a conclu que la gamme d'humidité optimale est une saturation d'eau à 100% entre 25 et 30 °C.