HUMIDITY IN ANAESTHESIOLOGY

III. HEAT AND MOISTURE PATTERNS IN THE RESPIRATORY TRACT DURING ANAESTHESIA WITH THE SEMI-CLOSED SYSTEM

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SINCE Seeley¹ and Cole² have shown that the nose is the principal organ which conserves heat and moisture, every condition bypassing this structure has been considered a threat both to the body water balance and to the physiological performance of the tracheobronchial mucosa. The clinician has been aware particularly of the high incidence of complications associated with laryngectomy and tracheostomy due to the deprivation of the nasal conditioning mechanisms. The sequence of the pathological manifestations induced by the excessive drying of the respiratory mucosa has been extensively studied and listed: arrest of ciliary activity and mucus flow, inflammatory changes, retention of tenacious mucus with crust formation, bacterial infiltration, and patchy atelectasis. The importance of humidification was recently and impressively emphasized by Benson,³ who, working in dogs during anaesthesia with a non-rebreathing system, suggested that the damage induced by the administration of a dry gas mixture reaching the alveolus leads to desiccation of its lining, impaired lung compliance, micro-atelectasis, and increased physiological shunting.

Anaesthesia is a field of medicine where major distortions in respiratory physiology are induced day after day in a very large population of patients. Endotracheal intubation, performed almost as a routine procedure, bypasses the warming, moistening and recondensing functions of the nose, thus creating a situation where the tracheal mucosa may become dehydrated.⁴ Moisture-free gas mixtures are delivered from cylinders or centralized sources, and further contribute to the poor conditioning of inhaled air. However, clinically, these adverse factors do not often seem directly involved in promoting respiratory complications, and millions of anaesthetic procedures have been performed with little concern for this particular aspect of the respiratory function.

Investigations on the evolution of heat and moisture in the respiratory tract during clinical anaesthesia have been sparsely reported in the literature. Most information relating to this matter have been derived either from calculations and extrapolations based on the humidity content of inspired air, or from measurement of the water balance between inspired and expired gas mixtures. Clark, Orkin and Rovenstine,⁵ working with the semi-closed circle, proposed that saturated gases return to the patient because of the water produced by the neutralization reaction between carbon dioxide and soda-lime. Tovell and D'Ambruoso⁶ predicted that, whenever an atmosphere saturated at 70° F. enters

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the body through the trachea and is warmed to 98.6° F., it has a relative humidity of only 40 per cent. In a previous paper⁷ we discussed the value of the semi-closed circle with large absorbers as a means of providing humidity to the inspired gases. Our results suggested that, under the conditions of our experiments, the relative humidity found in the inspiratory limb of the circle averaged 80 per cent at a temperature of 24° C. By simple extrapolation using these figures, one can assume that heating this mixture from 24° to 37° C. would result in a predicted relative humidity of 40 per cent in the lung. Whether or not these estimations really describe the actual conditions of humidity in the lung is a matter for careful consideration. It is, however, our belief that these assumptions must be regarded as less than satisfactory. More insight was gained from the work of Chase, Kilmore, and Trotta,⁴ who measured the respiratory water loss via anaesthesia systems. While some information can be obtained in this manner, it is impossible to follow the dynamic changes in relative humidity and temperature occurring within the respiratory tract itself.

This paper is a preliminary report of measurements of humidity and temperature obtained directly in the respiratory tract of patients during anaesthesia with the semi-closed circle absorption.

METHODS

Humidity and temperature measurements were made in twelve patients undergoing general anaesthesia for elective surgical procedures. Only good-risk patients, with no history of respiratory diseases, fever, dehydration, or electrolytic disturbances were selected for this investigation. These fasting patients received a preanaesthetic medication of 100 mg. of meperidine and 0.4 mg. of atropine within 90 minutes of induction. Operation time ranged from two to three hours. Anaesthesia was administered in the semi-closed system, using an Ohio Heidbrink Kinet-O-Meter with a fresh gas flow of 4 L./min. from the debimeters to the upper chamber of the large absorber no. 20. Either fresh Sodasorb or Calona lime were used to fill up the canister. Minute volume ventilation was standardized at 10 L., as delivered by an Ohio ventilator cycling 12 times per minute. Tidal volume was further measured with a Wright ventimeter located on the expiratory limb of the circle. The inspiratory-expiratory time ratio was kept at 1 : 1.5. In order to reach a steady state, temperature and humidity measurements were undertaken at least thirty minutes after induction.

The sampling procedure was identical in all the experiments. First the pulmonary ventilation and respiratory rate were determined. Then a flexible micro-thermistor probe, 30 inches long, from Yellow Springs Instruments, was inserted to the site to be sampled. The time response of the latter is shorter than 0.8 second, and it has a sensitivity index of 0.25° F. Temperature was registered for one minute during both the inspiratory and the expiratory phases. The length of insertion was measured, this distance being further used as a reference for the exact location of the hygrometer sampling tube. Relative humidity determinations were obtained with a modified dew-point hygrometer; the actual instrumentation and technique used have been recently described in some detail.⁸ In brief, the

sampling tube of the hygrometer was fed down the airway for a known distance. By means of a resistance wire running inside its lumen, this tubing was constantly kept at a sampling temperature 1 to 2° C. higher than the gas to be sampled. This prevented water condensation along the sampling assembly and probably induced no significant distortion in dew-point readings, the reference temperature at the sampling site being obtained prior to the insertion of the heated tubing. The thermistor tip, of the banjo type, measuring 4 mm. in diameter, was connected with an insulated extension wire of very small gauge, permitting insertion down the airway without significant impedance of flow rate. The hygrometer sampling tube had a diameter of 4 mm. also. However, this width was uniform for the whole length of the tubing and thus prohibited its use with endotracheal tubes of small calibre. In our experiments, cases were selected where large-bore endotracheal catheters could be conveniently inserted.

Samples were drawn through the previously flushed test chamber of the hygrometer, by aliquots of 30 c.c. of gas for ten consecutive phases of the respiratory cycle. To prevent contamination while sampling either inspired or expired air, care was taken to draw the plunger of the sampling syringe only at mid-course either of inspiration or of expiration. Thereafter, the cocks at both ends of the hygrometer were closed and the instrument was brought to the laboratory where the dew point was measured and the water vapour pressure of the gas sample determined.

Samples were obtained from the following sites along the respiratory tract: in the trachea, approximately 4 cm. below the tip of the endotracheal tube; in the connecting joint between the endotracheal tube and the swivel valve of the circle; then in the inspiratory limb of the circle, close to the directional valve. In a few cases, samplings were obtained from the lower respiratory tract, 10 cm. below the carina. Most samples were drawn during the inspiratory phase of the respiratory cycle. In a few cases, expired air aliquots were analysed from the same sites and from the expiratory limb of the circle.

Although body temperature and barometric pressure were monitored, variations were insignificant. For the convenience of our report, a standard body temperature of 37° C. and a barometric pressure of 760 mm. of mercury will be assumed.

RESULTS

In accordance with formal teaching and with many references expressed in textbooks of anaesthesiology, we were left with the impression that the inhaled atmosphere was conditioned to body temperature at 100 per cent relative humidity at a very high level in the respiratory tract. Great was our surprise, indeed, when we noticed wide temperature variations between inspiration and expiration even in the lower airway. Figure 1 discloses the temperature curve obtained during the withdrawal of the microthermistor electrode from its "wedge" position in the bronchial divisions through to the swivel valve at the head of the circle. A closer analysis of this curve brings to light many considerations which are of paramount importance in the appreciation of the behaviour of the bronchial tree as an "air conditioner."

FIGURE 1. Withdrawal temperature curve from the lower airway through to the inspiratory limb of the circle, during anaesthesia with the semi-closed system. The upper peaks on the curve represent temperature in expiration.

When the thermistor tip was located at a point 15 cm. below the carina (this location was visually confirmed during a bronchoscopic procedure), the temperature read $35.9^{\circ}\text{C}.$, with almost imperceptible changes between inspiration and expiration. The calibre of the electrode tip prevented us from obtaining temperature readings in the small peripheral bronchi. We have no doubt, however, that a smaller electrode located a few centimetres lower in the airway should have read a temperature equal to body temperature and constant at both phases of the respiratory cycle.

The same experiment was repeated in the dog under endotracheal anaesthesia with the semi-closed circle absorption. A constant temperature of $38^{\circ}\text{C}.$ was obtained at a point located 37 cm. below the upper incisor teeth (body temperature: $38^{\circ}\text{C}.$). Incidentally, the relative humidity measured at this particular point in the dog was 100 per cent. Increasing the tidal volume and lowering the relative humidity of inspired air both resulted in a downward shift of this saturation point.

In the anaesthetized man, when the electrode was progressively withdrawn, a wider temperature gradient between inspiration and expiration became obvious; it averaged $2.2^{\circ}\text{C}.$ along the distance from the carina to the inspiratory flap of the swivel valve. As soon as the inspiratory limb of the circle was reached, the oscillations in temperature ended abruptly and remained constant thereafter at $24^{\circ}\text{C}.$ From the tracheal end of the endotracheal tube to the "wedge" point of the electrode, a heat gain of $6.9^{\circ}\text{C}.$ occurred. This heating capacity of the trachea

and bronchi, although modest, should be remembered. Particular attention must also be paid to the fact that expired air is not, as often assumed and expressed, at 37° C. In our experiments, expired air underwent a mean decrease of 2.9° C. from the aforementioned "wedge" point to the carina; a further fall of 3.9° C. occurred from the carina to the outer end of the endotracheal tube (over-all length: 30 cm.). In addition, one more degree was lost while passing the valve.

A direct relationship was shown to exist between inspiratory temperature at a given point in the trachea and the tidal volume ventilated over this area. However, the temperature of expired air, when measured at the same site, remained remarkably constant for wide variations in tidal volume. At a point located 23 cm. below the upper incisor teeth, the expired air temperature remained unchanged at 34° C. for variations in tidal volume between 200 to 1000 c.c. Meanwhile, inspired air temperature decreased linearly from 32.5° C. at a tidal volume of 200 c.c. to 30.5° C. at 1000 c.c. of tidal air.

Determinations of relative humidity during the expiratory phase of ventilation, from sampling sites located 10 cm. below the carina to the expiratory limb of the circle, disclosed a monotonous result of 100 per cent and consequently were not repeated in every patient included in the present investigation. The measurements obtained while sampling inspired air are summarized in Table I. The results disclosed the impressive fact that, instead of decreasing as the temperature of inspired air progressively rose, the relative humidity followed, quite paradoxically, the pattern of a steady increase from the upper airway to the lower. From a mean of 77.4 per cent at 23.9° C. in the inspiratory limb of the circle, the relative humidity rose to 82.7 per cent at 26.7° C. at the outer end of the tracheal tube. Just above the carina, at a mean temperature of 30.8° C. during inspiration, the relative humidity readings averaged 85.8 per cent. In patients 3 and 5, where samples of inspired air were obtained from a site located 10 cm. below the tracheal cannula, the relative humidity read 91.3 per cent at a sampling temperature of

TABLE I
TEMPERATURE AND HYGROMETRY IN THE RESPIRATORY TRACT OF TEN PATIENTS
DURING ANAESTHESIA WITH THE SEMI-CLOSED CIRCLE ABSORPTION*

Subject no.	Inspiratory limb of the circle		Outer end of the tracheal tube		In the tracheobronchial tree, below the tracheal tube			
					at 4 cm.		at 10 cm.	
	T. (°C.)	R.H.	T. (°C.)	R.H.	T. (°C.)	R.H.	T. (°C.)	R.H.
1	24.2	79.3	25.4	94.5	32.9	95.7		
2	23.8	76.5	25.8	82.2	32.8	91.9		
3	24.0	75.0	27.3	88.5	29.2	87.4	33.2	91
4	25.1	66.9	28.9	63.6	30.1	87.0		
5	23.5	75.0	27.0	95.1	30.3	91.0		
6	24.0	79.0	27.1	73.9	30.4	81.2	33.0	91.7
7	23.6	78.9	26.1	85.0	28.0	81.6		
8	23.8	82.0	26.4	84.2	30.2	80.0		
9	24.0	79.0	27.0	81.0	32.4	88.0		
10	23.5	82.5	26.0	79.0	29.8	74.4		
Means	23.9	77.4	26.7	82.7	30.6	85.8	33.1	91.3

*Readings were obtained during inspiration.

33.1° C. It remains unfortunate that, because of the relatively large diameter of our temperature sensor and humidity sampling device, no saturated inspired gas at body temperature could be obtained from the lower segments of the bronchial tree.

DISCUSSION

From the aforementioned figures, it can be assumed that, under the conditions of our experiments, inspired air eventually reaches the alveoli with an ideal conditioning both in temperature and in relative humidity. Heat gain along the airway, once past the inspiratory limb of the circle, is linear and averages one degree centigrade per five centimetres of airway at a mean inspired tidal volume of 850 c.c. Involved in this positive heat balance are many factors and variables which are worth mentioning. Heat gain, facilitated by the low specific heat of gases, is due to the intimate contact of tidal volume with the valve and the endotracheal tube both previously heated by expiration. Further heat is absorbed by radiation from the walls of the trachea and bronchi. Heat loss results mainly from two disproportionate sources: one is convective and radiative heat loss, admittedly of little importance; the other is evaporative heat loss, which amounts to approximately 560 calories per gramme of water. The latter can be divided into two distinct processes, evaporation of the moisture deposit previously laid down during expiration, and insensible perspiration, better termed transpiration, which is the evaporation of water that diffuses through the mucosa.

Breathing through an endotracheal tube, although bypassing the warming, moistening, and recondensing functions of the nose and pharynx, does not necessarily mean tracheobronchial cooling and dehydration. Our investigation demonstrated that the same functions of warming, moistening, and recondensing are at work along the whole length of the airway. We shall now try to define clearly the performance of these accessory mechanisms and their efficiency in compensating for the nose during endotracheal anaesthesia with the semiclosed system.

Let us assume alveolar air as ideally conditioned at 37° C. and saturated with water vapour at this temperature. This proposition should be easily accepted for the two following reasons. First, our experiments during anaesthesia in the dog demonstrated that the inspired air reached saturation at body temperature somewhere between the second and third bronchial divisions. Moreover, this fact is strongly supported by our determinations, in the anaesthetized man, of a "wedge" temperature of 35.9° C. in bronchial divisions of approximately 5 mm. in diameter. According to Stutz,⁹ this bronchial calibre should be found in the third bronchial divisions. Doing bronchographic studies on the distribution of the bronchial branchings in the living, the same author described about eight divisions between bronchi of the third division and the smallest bronchi (1 mm. in width). According to the observations of Von Hayek,¹⁰ there must be about one thousand of these smallest bronchi in the whole lung, each dividing in 20 terminal bronchioles. There is, in our view, plenty of space below the tip of our "wedged" electrode for a temperature gain of one degree centigrade.

In its retrograde way to the outside, alveolar air comes in close contact with a

mucosa that has been previously cooled by evaporative and radiative heat losses during inspiration. Owing to the temperature gradient between expired air and the mucosa, two important events follow: first a cooling of expired air by radiation, then water condensation all over the mucosa, occurring by the superposition of very thin layers of mist. The wider the temperature gradient, the heavier will be the dew deposit over the mucosal surface. In the same way, whenever expired air reaches the inner surfaces of the endotracheal tube and the directional valve, both at a lower temperature owing to the previous passage of inspired air, a dew deposit also grows inside these "nose substitutes." This is readily evident when transparent material is used. This condensation of water over the whole surface of the airway, including the tracheobronchial mucosa, is, in our view, a fundamental phenomenon which is of paramount importance in humidity regulation.

Inspired air then enters the airway at a temperature of 24° C., with a mean relative humidity of 80 per cent. It comes in contact first with the directional valve and the endotracheal tube which have been warmed by outflowing expired air. Heat gain and moisture gain both occur simultaneously, the first by radiation, the latter, owing to a convenient gradient of temperature and water vapour tension, by evaporation of the dew deposit. The evaporative process from the inner surface of the airway occurs within a few millimetres of this surface, so that most of the heat required for evaporation is supplied by the walls. The outcome is a heat loss at the walls of the inert airways, the importance of which is highly dependent upon their specific heat. In practice, using an endotracheal tube and a valve both made of plastic material, a net gain in heat and moisture has been demonstrated, occurring progressively from the upper to the lower airway.

As soon as inspired air reaches the trachea and the bronchial tree, water and heat uptake becomes easier owing to the addition of physiological regulating factors. First, heat gain is favoured by radiation from vasomotor activity in the vascular sub-mucosal network. Moisture gain, once the dew deposit evaporation is over, is further promoted by water extraction from transpiration through the mucosa. These thermodynamic and physiological factors, acting together, should ensure ideal conditioning of inspired air long before it reaches the alveoli.

Calculations from our data permitted us to appreciate further the contribution of each part of the airway (valve, tracheal tube, respiratory tract) to this conditioning function. Knowing the temperature, the minute volume of ventilation, and the relative humidity at each level, it became simple to translate our results in absolute humidity. This artificial translation from relative to absolute humidity is not fully acceptable on scientific grounds, but it probably holds reasonably well in practice. Nevertheless, some figures are worth mentioning. Under the conditions of our experiments, the swivel valve, in a way very identical to an artificial nose, could contribute approximately 2 gm. of water per hour to the 600 L. of inhaled gas. In the meantime, the endotracheal tube likewise contributed an additional 3.6 gm. of water. We must remember at this point that inspired air leaving the absorption head holds an average of 11 gm. of water per hour. Total water from these sources amounted to 16.6 gm.; to this result must be added a certain amount of water recaptured in the lower airway. Water loss through the expiration was measured in a volunteer breathing dry oxygen and found to average 20 c.c. per

hour. Water balance calculated from these figures would indicate a net water loss of approximately 3 c.c. per hour, using the semi-closed circuit. This result compares advantageously with the insensible water loss in the conscious subject breathing through his nose; this physiological loss is generally evaluated at 10 to 15 gm. per hour in the normoventilating individual.¹¹

In fact, we are not far from believing that the surface offered to water condensation by our artificial airways (endotracheal tube and valve) was equivalent to that of the nose. From the studies of Cramer¹² and Cole,¹³ it has been proposed that the intranasal structures were primarily concerned with body heat regulation, and only secondarily with humidity control. The humidifying capacity of the nose would be in great part due to the recapture of water condensed during the previous expiration. It is a widely accepted opinion that the nose can condition inspired air to an ideal standard of 37° with a 100 per cent relative humidity. This opinion no longer holds in view of experimental evidence. Cramer¹² has shown that, in the conscious subject breathing through his nose at a temperature of 22° C. and a relative humidity of 45 per cent, inspired air reached the rhinopharynx at a temperature of 32.2° C. with 80 per cent relative humidity. Perwitzschki¹³ similarly reported humidity readings of 79 per cent in the human trachea. These results, obtained in patients breathing through the nose, closely approximate those we obtained during inspiration at the distal end of the endotracheal tube in patients anaesthetized with the semi-closed circle absorption. This clearly suggests that, although bypassing the nose, the artificial airways used during anaesthesia can evolve heat and moisture just as well as the nose can. In other words, they are artificial noses, the air-conditioning capacity of which is not far from that of the nose under the aforementioned conditions.

We may now speculate about the possibility that damage may be induced in the respiratory mucosa of patients anaesthetized with the semi-closed system. The influence of atmospheric humidity and temperature on ciliary activity was investigated by Delham in 1956.¹⁴ These experiments were performed in rats. At a 30 per cent humidity, ciliary movements ceased only three to five minutes after tracheal exposure. At 50 per cent relative humidity, movement ceased after eight to ten minutes. At a range of relative humidity between 70 and 100 per cent, there was no discernible reduction in ciliary activity during observation periods from 60 to 120 minutes. Wylie and Churchill-Davidson¹⁵ reported that the optimum temperature range for ciliary movement in excised human nasal mucosa was between 28 and 33° C. Once again, these figures agree with those we described in the trachea of intubated patients. Obviously, if we leave out of consideration the direct effect of anaesthetic drugs on ciliary activity, we can see that the semi-closed system apparently maintains physiological conditions of heat and moisture for the respiratory mucous membranes.

In the light of our results, we would like to comment on the use of heat and moisture generators during general anaesthesia with the semi-closed system. These devices are generally set to deliver inspired air saturated with water vapour at 37° C. During the first inspiration, dew is deposited all over the airway which soon equilibrates at body temperature. During the following expiration, no further condensation occurs on the walls of the respiratory tract, obviously because of the

absence of a water vapour gradient. Expired air is blown out at a temperature of 37° C., an occurrence which is, of course, exceptional in the conditions of normal life. The following respiratory cycles meet a mucosa that is in a state of "adiabatic saturation," that is, it is at the true dew point and accordingly covered with a light dew deposit which, by definition, is neither growing nor evaporating. Water vapour gradients and temperature variations no longer exist. Theoretically, if we ignore the tremendous absorptive capacity granted to the alveolar wall by Starling's equilibrium, water that is blown in during inspiration is blown out in the same amount during expiration. Water balance in the bronchial tree has reached an equilibrium. A static state has replaced dynamic physiological mechanisms.

Adiabatic saturation would be suitable to the patient with bronchial problems and thick mucus. In this situation, maximum wetting of the tracheobronchial mucosa is obtained without any water drops. Comroe¹⁸ stressed the fact that large water droplets can prevent evaporation of water from the mucosa.

It is, however, our belief that in the normal patient undergoing anaesthesia with the semi-closed system, adiabatic saturation as produced by moisture generators induces a distortion in the physiological mechanisms for the defense of the lung. We do not believe that this should lead to pathologic consequences and constitutes a hazard to the patient. However, we suggest that favourable conditions are offered for mucosal maceration.

For the time being, as demonstrated by our experimental work and as confirmed by clinical experience, it seems likely that anaesthesia with the semi-closed system prevents drying of the respiratory membranes and provides an inhaled atmosphere with heat and moisture patterns that closely imitate physiological air conditioning within the respiratory tract.

SUMMARY

Experimental data have been presented which suggest that bypassing the nose with artificial airways is well compensated by the ability of these airways to imitate the heat and moisture exchange normally occurring in the nose. The lower airway can also carry on during anaesthesia the same heating, moistening, and recondensing functions that it apparently performs during normal life.

Our results, obtained during clinical anaesthesia with the semi-closed circle absorption, indicate that the heat and moisture patterns disclosed along the airway are similar, in practice, to those found in the conscious subject breathing through his nose. This is so mainly for the following reasons: (1) inspired gas mixtures enter the airway with a water vapour tension higher than that usually found in ambient air; (2) moisture from expired air is conserved by condensation all along the airway and is recaptured during the next inspiratory phase. The high concentrations of water made available through these processes reduce the burden laid upon the respiratory mucosa to transudate further amounts of water.

Wide temperature oscillations between inspiration and expiration occur in the respiratory tract until the lower airway is reached. These variations are important features in the physiological mechanisms of water condensation in expiration and

water recapture in inspiration. Through these temperature changes, the respiratory tract mucosa, the endotracheal tube, and the swivel valve adjust the amount of water conserved during expiration and contribute significantly to water economy and balance during the anaesthesia with the semi-closed circle.

RÉSUMÉ

Depuis que les physiologues ont précisé les normes optimales que doit rencontrer l'air inspiré afin de préserver l'activité ciliaire et le libre écoulement du mucus à la surface de l'arbre respiratoire, les anesthésistes se sont préoccupés de connaître les conditions de température et d'humidité offertes en cours d'anesthésie dans les voies respiratoires du patient. A première vue, il semble qu'un climat de sécheresse soit de règle dans les tubulures d'anesthésie, comme le laisse prévoir l'admission à la source de gaz déshydratés; la condition semble encore se détériorer à l'entrée des voies respiratoires, lorsque le tube endotrachéal vient court-circuiter le nez. Certains anesthésistes ont d'ailleurs commencé à incorporer des saturateurs dans les circuits anesthésiques. En revisant la littérature sur le sujet, nous nous sommes aperçus que peu de données étaient disponibles sur l'évolution de la température et de l'humidité dans les voies respiratoires en cours d'anesthésie. Certes, la recherche dans ce domaine est demeurée quasi prohibitive en raison de difficultés techniques et expérimentales qui ne font que commencer à être surmontées. Nous avons voulu, dans cette étude, faire un pas dans ce sens.

Au moyen d'un microthermistor flexible, nous avons pu tracer la courbe de température telle qu'elle existe dans l'arbre respiratoire en cours d'anesthésie avec le circuit semi-fermé; cette courbe soulève des points d'intérêt. Les oscillations cycliques de la température entre le temps inspiratoires et expiratoires se retrouvent jusqu'à un niveau profond de l'arbre trachéo-bronchique. L'air inspiré se réchauffe en moyenne d'un degré centigrade par cinq centimètres d'airway franchi. Enfin, l'air expiré, loin de quitter les voies respiratoires à 37° C., subit en cours de route de lourdes pertes thermiques par radiation et par convection.

Les déterminations d'humidité relative que nous avons pu effectuer en cours d'anesthésie clinique chez 12 patients nous ont également conduits à des résultats stimulants. Il ressort de ces chiffres que l'humidité relative, déjà près de 80 pour cent à 24° C. dans le bras inspiratoire du circuit d'anesthésie, non seulement ne s'abaisse pas d'une façon catastrophique lorsque l'air inspiré se réchauffe à 37°, mais encore continue de s'accroître progressivement tout le long du tube endotrachéal et sur une longue distance en bas de la carène, jusqu'à ce que soit atteint un niveau optimal de conditionnement hygroscopique et thermique, soit 100 pour cent d'humidité relative à 37° C. Au bout externe du tube endotrachéal, immédiatement après la valve directionnelle, l'humidité relative se lit à 82.7 pour cent à une température moyenne de 26.7° C.; à son bout trachéal, la température s'est élevée à 30.6° C., pendant que l'humidité relative, d'une façon à première vue paradoxale, a atteint 85 pour cent. A 10 cm. en bas du tube endotrachéal, notre électrode thermique lit 33.1° C. en inspiration et notre hygromètre donne au même moment une lecture de 91 pour cent. La grosseur de cette électrode et le

diamètre du tube d'échantillonnage de l'hygromètre nous ont empêché d'obtenir, à un niveau plus bas dans les bronches, des lectures nous permettant d'affirmer qu'il existe un conditionnement idéal de l'air inspiré avant son admission dans l'alvéole. Nous l'avons cependant démontré avec succès chez le chien.

Une étude analytique de nos résultats nous a permis de comprendre mieux les phénomènes de recondensation d'eau qui se produisent en expiration sur une vaste étendue de l'airway, et l'importance que revêt la recapture de cette eau en inspiration. En réalité, la valve et le tube endotrachéal se comportent comme de véritables nez artificiels et leur efficacité semble devoir se comparer, dans nos conditions expérimentales, à celle du nez lui-même. Enfin, les phénomènes de réchauffement, d'humidification et de condensation qui se retrouvent normalement idéalement au niveau du nez existent également sur une longueur appréciable de trachée et de bronches.

Comparaison faite de nos résultats avec ceux de Cramer, Cole et Perwitzschky, qui ont décrit l'évolution de la température et de l'humidité chez l'individu normal respirant par son nez, nous sommes en mesure de proposer, comme conclusion, que les conditions d'humidité et de température rencontrées dans l'arbre trachéo-bronchique en cours d'anesthésie en circuit semi-fermé sont à toutes fins pratiques identiques à celles décrites par ces auteurs précités en cours d'activité physiologique normale du tractus respiratoire. L'adjonction d'un saturateur sur le bras inspiratoire du circuit anesthésique conduit pour sa part à un état de saturation adiabatique dans l'arbre respiratoire et les propriétés prophylactiques de cette condition sont encore loin d'être reconnues.

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