Anesthesiology
50:195–198, 1979

Humidity and the Anesthetized Patient

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Damage to the ciliated cells of the tracheobronchial tree and incidence of postoperative pulmonary complications were measured by point-scoring systems in 202 patients who breathed dry and humidified anesthetic gases for 225 ± 78 min. The incidence of postoperative pulmonary complications decreased as the humidity of administered anesthetic gases increased from 0 to 32.5 mg H_2O/l. A similar relationship was found between the amount of inhaled moisture and the damage to the ciliated epithelium of the tracheobronchial tree. These results appear to indicate that a high inspired humidity is beneficial for operations on normothermic patients, and that cellular damage caused by dryness is a possible contributory factor in the production of the pulmonary atelectasis that follows stoppage of the mucociliary transport system in the immediate postoperative period. (Key words: Airway: cilia. Humidification. Lung: diseases; mucus.)

BURTON was among the first to suggest that dry anesthetic gases have a deleterious effect on the respiratory mucous membrane.[1] We have shown abnormal cytomorphologic changes in tracheobronchial epithelia in washings from patients who breathed unhumidified anesthetic gases, compared with those from subjects who inhaled gases with various amounts of humidification,[2] and have correlated cellular damage caused by smoking with the incidence of postoperative pulmonary complications.[3] Déry[4] explained the effect of dryness by measuring the water debt incurred by the tracheobronchial mucosa in the face of insufficient inhaled moisture. Marfia *et al.*[5] confirmed the cytomorphologic changes described by us in histologic studies of the respiratory epithelia of rabbits that inhaled dry gases. They showed that the damage sustained by the tracheobronchial tree extended as far as the pulmonary alveoli and caused pulmonary atelectasis.

Animal and cytologic studies, though highly suggestive, do not offer evidence that dry anesthetic gases cause a higher incidence of postoperative pulmonary complications[2,5] in clinical circumstances. We, therefore, undertook a study in which we tried to correlate cytomorphologic changes caused by lack of inhaled moisture with the incidence and severity of postoperative complications assessed by a point-scoring system.[3] Our results show that increasing damage to the ciliated epithelium is associated with a concomitant increase in postoperative pulmonary complications. In addition, since approximately 12 per cent of body temperature is lost through the lung,[6] we also tried to correlate heat loss and incidence of postoperative shivering with decreases in inhaled moisture.

Patients and Methods

Subjects of the study included 202 consenting patients, aged 18 to 87 years, about to undergo general anesthesia via endotracheal tube for surgical procedures. Of these, 104 were women and 98 were men. All were free from cardiopulmonary disease. None was scheduled to undergo an intracranial or intrathoracic operation. The age, sex, weight, height, smoking habit and relevant medical history of every patient was assessed during a preoperative visit. We did not include in the study any patient whose weight was 10 per cent more than the estimated weight for the appropriate height at age 18 according to sex,[7] or who had sustained an increase in temperature diagnosed by the surgical staff as due to wound infection or extrathoracic infection. Anesthesia was induced with thiopental, 3 mg/kg, and succinylcholine, 1 mg/kg, and maintained with nitrous oxide in oxygen with or without halothane or a nondepolarizing muscle relaxant and a narcotic. Tracheobronchial washings were obtained immediately after the onset of anesthesia and 5 min before extubation of the trachea, by instilling 5 ml of physiologic saline solution down the endotracheal tube and suctioning for return within 30 sec. The transparent suction catheter was cut where it was seen to contain secretions, which were retrieved with an applicator stick, smeared on slides, sprayfixed at once, and stained (Papanicolaou). Cellular integrity was assessed by a point-scoring system,[2] one point being given for each of the following six factors: 1) presence of normal cilia, 2) presence of endplate, 3) normal cytoplasmic color (blue), 4) normal cytomorphologic

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Received from the Department of Anesthesiology, New York University Medical Center, 550 First Avenue, New York, New York 10016. Accepted for publication May 19, 1978. Supported by Grant #725, The Council for Tobacco Research-USA, Inc. Presented in part at the Annual Meeting of the American Society of Anesthesiologists, New Orleans, October 1977, and in full at the Annual Meeting of the Association of University Anesthetists, Tucson, Arizona, April 1978.

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TABLE 1. Humidification Administered According to Smoking Habits of the Patients*

	Humidification					
	Dry		Humidified		Saturated	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Nonsmokers	39	56	39	63	40	57
Smokers						
1–9 cigarettes/day	12	17	8	13	11	16
10–19 cigarettes/day	8	11	7	11	8	11
20 or more cigarettes/day	11	16	8	13	11	16
TOTAL	70	100	62	100	70	100

* The numbers of patients in the three smoking categories were not significantly different.

TABLE 2. Types and Durations of Operations

Operations Involving	Humidification					
	Dry		Humidified		Saturated	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Extremity	18	26	14	23	15	21
Head and neck (thyroid)	0	0	1	2	1	3
Abdomen	51	73	38	61	45	59
Chest wall (breast cancers and melanomas)	1	1	9*	15	9*	17
TOTAL	70	100	62	100	70	100
Duration of operation (min) ($\bar{X}$ ± SD)	223 ± 71		229 ± 83		222 ± 78	

* $P < 0.01$ compared with the dry-gas group. There was no other significant difference among the groups.

features, 5) normal nuclear size, and 6) normal nuclear shape and texture. Thus, each cell could score 0 to 6 points. Since 200 cells were examined in each group of slides obtained from the same tracheobronchial washing, the total score per specimen could range from 0 to 1,200 points.

All patients were visited once during the first three and once on the fourth to seventh postoperative days. The severity of postoperative pulmonary complications was assessed by a point-scoring system[3]: 1) one point was given for an increase in temperature to 101 F (38.3 C) or more; 2) two points for the presence of positive physical signs in the chest (moist rales not shifting on coughing, diminished air entry, dullness on percussion, altered vocal fremitus and increased voice resonance other than in the right upper lobe); 3) three points for positive findings on the roentgenogram of the chest. Each score was assigned only once on the basis of events occurring at the time of the visit between days 1 to 3 or 4 to 7. Seventy patients breathed dry anesthetic gases, confirmed by hygrometry, through a nonrebreathing system, and 132 breathed humidified gases. A modified circle system in which the fresh-gas inflow could be directed either through the soda lime, or into the inspiratory dome valve, or through both, was used for 62 of the 132. Fresh-gas pathways and flow rates were selectively adjusted to maintain inspiratory limb relative humidity at 60 per cent at ambient temperature (20–23 C) (humidified gases). The other 70 patients inspired gases saturated with water vapor (saturated gases) by use of the method of Weeks and Broman[8] (maintaining the temperature in the inspiratory limb at the Y piece at 32 C, by regulating the thermostat of a Cascade** humidifier inserted at the machine end of that limb). Nasopharyngeal temperatures of all patients were measured at 15-min intervals throughout operation by telethermometry.

The cytologic evaluation of specimens was carried out blindly by J.C. and C.-K.T. on groups of slides that had been tagged by the rest of the study group. The mean of the readings of the two observers was used in the final analysis of data. Postoperative visits were made by the investigators who had not administered the anesthesia and who were unaware of the amounts of humidity used during anesthesia. Their observations were compared with those of the surgical staff. When a discrepancy existed, a medical consultation was requested to settle the matter. All roentgenograms were examined by a member of the radiology department. Roentgenograms were routinely obtained on the third postoperative day and repeated when necessary.

Mean values, standard deviation, and standard error were calculated for all groups or subgroups studied. Statistical significance was assessed by commonly used variance techniques (t test, chi-square), $P < 0.01$.

Results

There was no statistically significant difference in the numbers of subjects in the three smoking categories divided by type of humidity used (table 1). There was also no significant difference in the mean durations of the operations performed in the three humidity categories (table 2). The only difference among the groups studied was that more patients underwent chest-wall operations in both humidified series than in the dry-gas group (table 2).

** Bennett Respiration Products, Santa Monica, California.

Both for patients who breathed dry gases and for those who inhaled humidified gases, the mean cellular scores (table 3) decreased significantly at the end of anesthesia (861 ± 15 to 631 ± 18, and 845 ± 17 to 757 ± 17, respectively), but this was not true for the patients who breathed saturated gases. However, the difference between the mean scores at the onset and termination of anesthesia in each group was significantly decreased as inspired moisture was increased. The differences were 230 ± 17 for patients who breathed dry gases, 88 ± 17 for humidified gases and 7 ± 8 for saturated gases.

The pulmonary complication score (table 3) for patients who breathed dry gases (1.3 ± 0.1) was significantly higher than that found for those who breathed humidified gases (0.6 ± 0.1), which in turn was significantly higher than that for those who inhaled saturated gases (0.3 ± 0.1).

The mean decrease in body temperature during operation for patients breathing dry anesthetic gases was 3.3 ± 1.7 C; that for patients breathing humidified gases was 1.8 ± 0.5 C; that for patients breathing saturated gases was 0.3 ± 0.5 C. No patient in the high-humidity group shivered after anesthesia. Postanesthetic shivering was more common when inspired humidity was decreased. It was found in 39 per cent of subjects who breathed humidified gases and in 74 per cent of those who breathed dry anesthetic gases.

Table 3. Cellular Scores ($\bar{X}$) at Onset and Termination of Anesthesia and Mean Complication Scores ($\bar{Y}$) during the Postoperative Period

Humidification	Number of Patients	Cellular Score at Onset of Anesthesia (Mean ± SE)	Final Score (Mean ± SE)	Postoperative Complication Score ($\bar{Y}$ ± SE)
Dry	70	861 ± 15	631 ± 18*	1.3 ± 0.1
				}*
Humidified	62	845 ± 17	757 ± 17*	0.6 ± 0.1
				}*
Saturated	70	880 ± 11	873 ± 11	0.3 ± 0.1

The chi-square method and t test for paired data were used to compare variations in the same groups of patients and the chi-square method and t test for unpaired data for variations between groups. Results obtained by the two methods were identical.
* $P < 0.01$.

Discussion

It seems that there may exist a relationship between cytologic decay during the course of anesthesia and the development of postoperative complications. We feel that the use of dry anesthetic gases for operations that last more than an hour may be deleterious to the health of the patient.[1] The ideal humidification appears to be that which returns to the patient the precise amount of water lost during expiration (saturated humidity at 32 C). This has the triple advantage of: 1) decreasing damage to the tracheal mucosa, 2) lowering postoperative complication rate, and 3) virtually eliminating postanesthetic shivering. An exception to this rule will of course be found in the case of fulminant hyperpyrexia, when it is desirable to increase heat loss by all possible means.

Knudsen *et al.*,[9] who failed to find significant differences in the postoperative complication rates of patients who breathed dry and humidified anesthetic gases, examined only 84 patients, and used different criteria. Their main concern was the discovery of positive roentgenographic findings, and they did not employ coefficients to grade the severity of the pulmonary complications they evaluated. Their average durations of anesthesia were, however, 66 min longer than ours for the high-humidity group and 86 min longer for the dry-gas group. Their scores included intrathoracic surgical cases, which we specifically avoided.

An apparent flaw in our methodology was the inclusion of larger proportions of chest-wall operations in both humidified series than in the dry-gas group. However, randomly decreasing the number of these cases by eight patients in each humidified series did not affect any other statistical significance. Another method by which the series could have been equalized would have been to add patients undergoing chest-wall operations to the dry-gas series. However, preliminary analyses conducted before the study was completed had already shown the increased morbidity associated with this method of administering anesthesia, and we were, therefore, reluctant to use it again.

Since approximately 12 per cent of body heat is lost through the lungs,[6] a theoretical anesthetized patient producing 70 kilocalories (Cal) per hour would lose $(70 \times 12) \div 100 = 8.4$ Cal/hour by this route. Similarly, the same patient breathing a gas mixture with 60 per cent relative humidity will exhale 32.5 mg H_2O/l and inhale approximately 12 mg H_2O/l, for a net loss in calories of $8.4 - [(8.4 \times 12) \div 32.5] = 5.3$ Cal/hour. Assuming that the mean caloric outputs and mean weights of the patients studied were the same as those of the theoretical patient mentioned above, the ratio of the heat loss through the lung should approximate that of the decrease in temperature during anesthesia. In this instance these ratios would be $8.4/5.4 = 1.6$ and $3.3/1.7 = 1.9$, which is close. Since no heat is lost through the lung when an absolute humidity of 32.5 mg/l is inhaled, the ratios of the mean temperature losses sustained during anesthesia by this group, over the groups inhaling dry anesthetic gases and humidified gases, would be high. They are, in fact, 0.09 and 0.2 respectively. These arbitrary figures do not take into account the various factors that influence body temperature during anesthesia, which include: 1) the size of the patient and his metabolic rate, 2) the depth of anesthesia, 3) the extent of surgical stimulation, 4) the amount of cutaneous perfusion, 5) the extent of draping and the number of surgical assistants, 6) the wattage of the overhead lights, 7) room temperature, 8) the size of the mechanical dead space of the system that acts as a heat and moisture exchanger, and 9) the mechanically controlled minute volume. Some of these variations will no doubt have accounted for differences between the theoretical and measured values mentioned above.

Existing circle absorber systems waste much of the heat and moisture generated by the removal of carbon dioxide.[10] Appropriate modifications[11,12] can restore most of it to the patient. Future efforts by the designers of these systems should, therefore, not be restricted to their efficiency in eliminating rebreathing of carbon dioxide, but should also consider the most efficient way of increasing and controlling the humidity output. This should be well below the humidity and temperature delivered by to-and-fro systems (98 per cent at 40 C or 49 mg H_2O/l), which may cause convulsions in stress environments (room temperature of 28 C or higher with high ambient humidity).[6]

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