Volume 52, No. 4
April 1980

THE JOURNAL OF Anesthesiology
THE AMERICAN SOCIETY OF ANESTHESIOLOGISTS, INC.

Anesthesiology
52:291–295, 1980

Humidity in Children and Adults Using the Controlled Partial Rebreathing Anesthesia Method

Robert L. Rayburn, M.D., and Col. Robert L. Watson, M.D., US Army†*

The authors examined inspired humidity using a controlled partial rebreathing anesthesia method (CPRAM) and a circle system in 16 healthy adults and five healthy children. The patients were divided into five study groups (A–E). All patients except those in Group E were anesthetized with fentanyl, pancuronium, nitrous oxide–oxygen, 66–33 per cent, and their lungs were mechanically ventilated; patients in Group E received halothane and nitrous oxide–oxygen, 66–33 per cent, with spontaneous ventilation. Group A (five children) had inspired humidity measured within a modified coaxial (Bain) anesthesia circuit using CPRAM. Groups B and C (five adults each) had humidity measured within the modified coaxial circuit and at the end of a non-modified coaxial circuit using CPRAM. Groups D and E (three adults each) had humidity measured in the semiclosed and closed circle systems, respectively. Initial, mid-, and end-inspired humidity were measured in all groups for two hours by interrupting the controlled ventilation at 30-min intervals, except in patients of Group E, who had humidity measured at similar intervals for two hours during spontaneous ventilation. No significant difference was found among initial, mid-, or end-inspired humidity, nor was there a significant difference between inspired humidities in children and in adults using CPRAM. The humidity measured in adults within the circuit near the endotracheal tube was not significantly different from that measured distal to the fresh gas flow. The humidities in all CPRAM patients exceeded those of both the semiclosed and closed circle systems, stabilizing within 30 min and remaining constant between 24 and 26 mg H_2O/l. (Key words: Equipment, circuits: coaxial; partial rebreathing; semi-open. Humidification.)

In 1978, a new concept for ventilating the lungs of children using a coaxial (Bain) circuit was reported.[1] This concept, presently referred to as the controlled partial rebreathing anesthesia method (CPRAM)‡ permits the anesthesiologist to use fresh gas flow to control arterial carbon dioxide tension (Pa_{CO_2}). Provided minute ventilation is at least three times fresh gas flow, the fractional concentration of mixed expired carbon dioxide ($F\bar{E}_{CO_2}$) may be measured near the anesthesia machine with a capnograph and used to estimate Pa_{CO_2}. The purpose of this study was to measure the humidity contents of inspired gases using CPRAM in normocapnic children and adults and compare these results with humidity obtained in normocapnic adults using the semiclosed and closed circle systems.

Methods

Informed consent was obtained from all patients or their parents and approval for the study was obtained from the Human Investigation Committee.

Inspired humidity was studied in 16 healthy adults and five healthy children who underwent operative procedures not involving the chest or upper abdomen. The patients were divided into five study groups. The CPRAM groups A, B, and C consisted of five patients each, and the circle system groups D and E consisted of three patients each. Premedication consisted of glycopyrrolate, .005 mg/kg, alone (Groups A and E), or in combination with meperidine, 50–100 mg, or morphine, 5–10 mg (Groups B, C and D), given one hour prior to operation. Anesthesia was induced with nitrous oxide–halothane in children and with thiopental and succinylcholine in adults. Fentanyl, 1–4 μg/kg, and pancuronium, 0.1 mg/kg, with nitrous oxide–oxygen, 66–33 per cent, were used for maintenance anesthesia in all groups except Group E, in which spontaneous ventilation with halothane at .65

* Staff Anesthesiologist; Assistant Director of Respiratory Therapy and Intensive Care, Primary Children's Medical Center, Salt Lake City, Utah.

† Assistant Chief of Anesthesiology, Brooke Army Medical Center, San Antonio, Texas. Current address: Professor and Chairman, Department of Anesthesia, Uniformed Services University of Health Sciences, and Chief of Anesthesia and Operative Services, Walter Reed General Hospital, Washington D. C. 20012.

Received from the Departments of Anesthesiology of Primary Children's Medical Center, 320 Twelfth Avenue, Salt Lake City, Utah 84103, and Brooke Army Medical Center, Fort Sam Houston, San Antonio, Texas 78234. Accepted for publication August 13, 1979.

Address reprint requests to Dr. Rayburn.

‡ A term suggested by James F. Black, M.D., Tripler Army Medical Center.

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MAC and nitrous oxide–oxygen, 66–33 per cent, was used according to the method of Lowe.§ After induction of anesthesia, every patient had a 22-gauge catheter inserted percutaneously into a radial artery for determination of blood-gas values. The fractional concentrations of mixed expired CO_2 ($F\bar{E}_{CO_2}$) in Groups A, B and C and the fractional concentrations of end-tidal CO_2 ($F_{ET_{CO_2}}$) in Groups D and E were measured during ventilation using capnographs and converted to the respective partial pressures. Using the partial pressure of mixed expired CO_2 ($P\bar{E}_{CO_2}$) or the partial pressure of end-tidal CO_2 ($P_{ET_{CO_2}}$) with the arterial blood-gas values we adjusted the fresh gas flow (Groups A, B, and C) or the minute ventilation (Groups D and E) to assure normocapnia.

In Group A we examined the inspired humidity provided by CPRAM in normocapnic children. The patients ranged in age from 9 months to 13 years and weighed 8–52 kg. After establishment of anesthesia, control values for room temperature, barometric pressure and humidity (average of values from wall hygrometer and Hygrosensor®¶), and patient esophageal temperature (Yellow Springs® thermistor probe #401), blood pressure, pulse rate, and blood-gas values were recorded. The patients were then switched from the induction circuit to a dry modified (Hygrosensor chamber built into the circuit) coaxial (Bain) circuit, which included a ventilator with hose and bellows, and circuit bag mount. This circuit with elbow adapter removed was attached directly to the patient's endotracheal tube (fig. 1). Fresh gas flow was initially set at 2,500 ml/m²/min, and minute ventilation was set as closely as possible to three times this value (7500 ml/m²/min),[1] using a tidal volume estimate from the ventilator bellows. Immediately after switching to the dry circuit, humidity was measured within the circuit near the endotracheal tube during initial, mid-, and end-inspiration by stopping the ventilator at the appropriate portion of the respiratory cycle. Leakage of gases into or out of the circuit was prevented by closing the pop-off valve, clamping the endotracheal tube and ventilator hose, and diverting the fresh gas flow with a three-way stopcock. The dry Hygrosensor, which was placed in a specially designed airtight Hygrosensor port outside the circuit, was then inserted into the Hygrosensor chamber without gas loss by withdrawing the plastic slide. Simultaneously the temperature of the trapped gases was recorded by averaging the measured values obtained by using both a thermistor in the Hygrosensor and a thermistor probe (Yellow Springs #401) inserted into the breath-

§ Lowe HJ, MacKrell TN, Mostert JW, et al: Quantitative closed circuit anesthesia. Anesthesiology Review 1:16–19, 1974.

¶ Type TH-3 KW Class A narrow-range hygrosensors (for use with atmospheres containing hydrocarbons and condensation). Temperature range +20 to +140 F. Accuracy ±1.5 per cent relative humidity, American Instrument Company, 8030 Georgia Ave., Silver Spring, Maryland 20910.

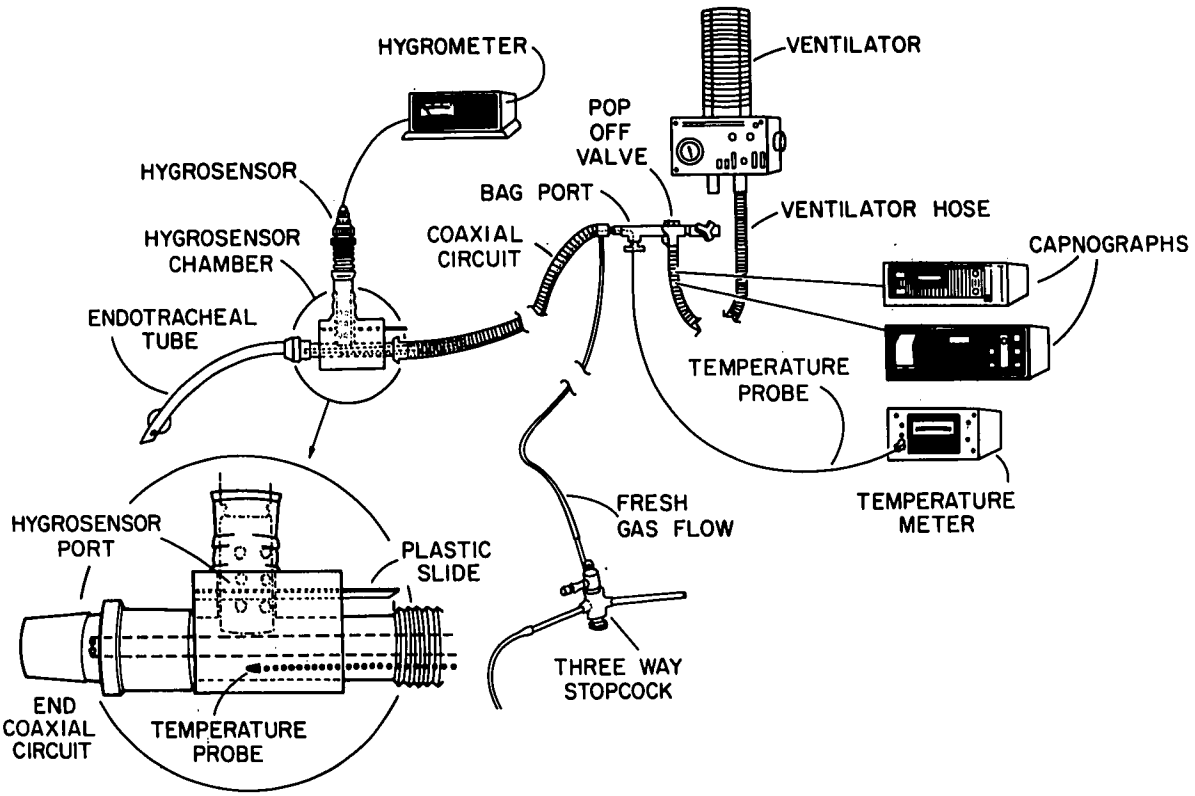

FIG. 1. Modified anesthetic system for measurement of humidity within the circuit using controlled partial rebreathing anesthesia method (CPRAM).

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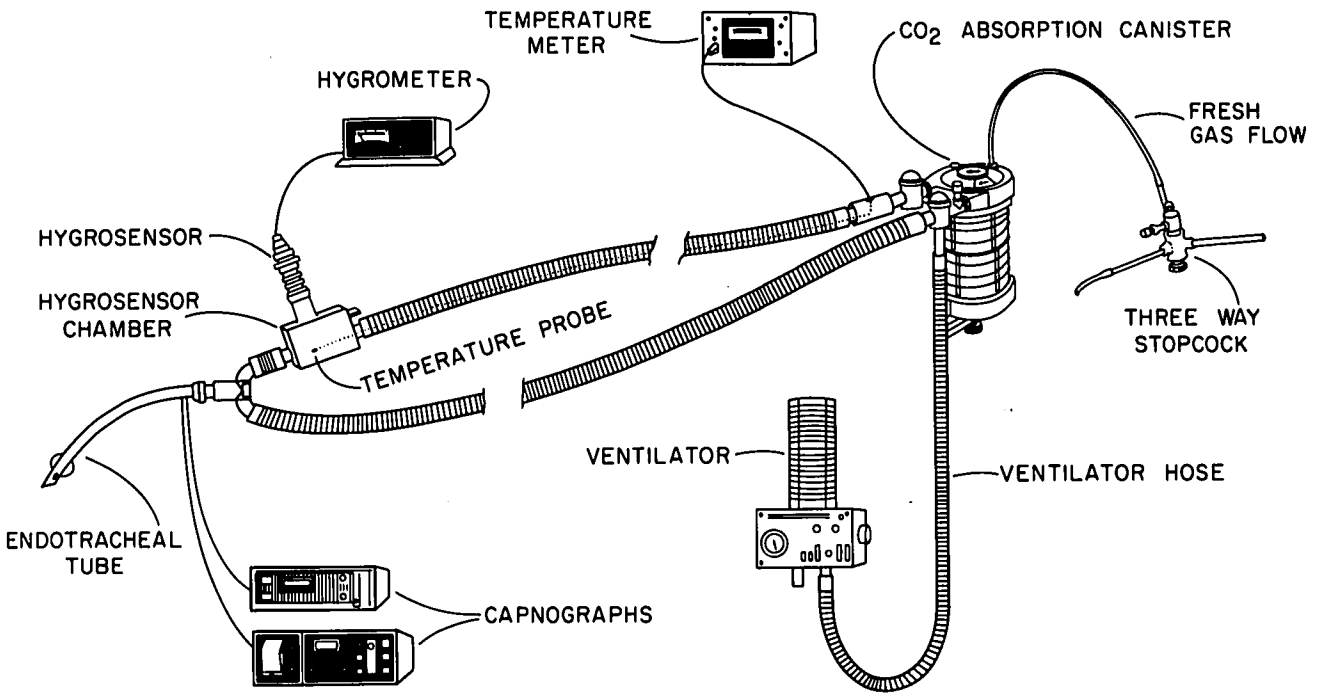

FIG. 2. Anesthetic system for measuring humidity within the circuit using the semiclosed circle method.

ing circuit through a rubber stopper placed at the bag port of the circuit bag mount. Equilibration time for the thermistors and Hygrosensor was approximately 30 to 50 sec. The temperature of the trapped gases and the relative humidity obtained with the Hygrosensor were used to calculate the absolute humidity.[2] Since changes in absolute room humidity (7–13 mg H_2O/l) showed a positive correlation with changes in inspired humidity, standardization of room humidity was performed by linear regression such that the inspired absolute humidity was calculated as the fitted value of the regression curve at 10 mg H_2O/l room humidity.

The previous measurements were repeated at 30-min intervals for two hours. The order of measurement of initial, mid-, and end-inspired humidity was rotated, and approximately 90 sec of ventilation occurred between successive humidity measurements. Fresh gas flow was adjusted to keep Pa_{CO_2} near 40 torr, based upon $P\bar{E}_{CO_2}$ and $PaCO_2$ determinations, and minute ventilation was assured to be three times the fresh gas flow by intermittent use of the Wright respirometer, which was removed from the circuit before the next 30-min equilibration period.

In Group B we measured, the inspired humidity provided by CPRAM in normocapnic adults. The adults ranged in age from 16 to 62 years and weighed 60–86 kg. All study methods were identical to those used for Group A. The protocol for Group C was identical to that for Group B except that we measured inspired humidity distal to the fresh gas flow (*i.e.*, between the end of the coaxial circuit and the endotracheal tube).

In Group D we measured the inspired humidity in adult normocapnic patients using a standard semiclosed circle system under the same conditions as those applied to the CPRAM groups. Following induction, the endotracheal tube was attached to a dry dual-chamber (Ohio) circle absorber system with the elbow removed (fig. 2). Ventilation was set using a tidal volume of 12 ml/kg, confirmed with a Wright respirometer, and the fresh gas flow was 5 l/min using nitrous oxide–oxygen, 66–33 per cent. Respiratory frequency (f) was adjusted to keep Pa_{CO_2} near 40 torr. In Group E we measured the inspired humidity in normocapnic adults using a closed circle system under the same conditions as those used for the other groups.

Results

Groups A, B, C and D showed no significant difference among initial, mid- and end-inspiratory humidities (fig. 3). There was no significant difference between the humidity measured distal to the fresh gas flow (Group C) and that measured within the circuit itself (Groups A and B), nor was there a significant difference between the humidity for children (Group A) and that for adults (Group B and C). Humidity was initially between 21 ± 1 and 22 ± 1 mg H_2O/l in the CPRAM groups, increased rapidly over the first 30 min, and then remained relatively stable between 24 ± 0.3 and 26 ± 1 mg H_2O/l for the remainder of the two-hour study. Group D had the poorest humidification, with essentially no improvement from the initial adjusted value of 10 ± 0.4 mg H_2O/l. Group E showed a progressive increase in humidity

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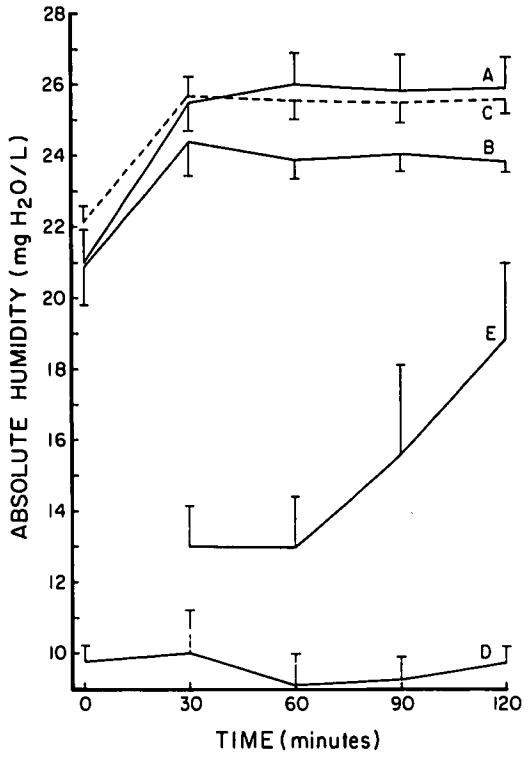

FIG. 3. Mean absolute humidity and standard errors for the two-hour study period are shown for Groups A through E. Group A = children exposed to →CPRAM. Group B = adults exposed to →CPRAM. Group C = same as Group B with inspired humidity measured distal to the fresh gas flow. Group D = adults exposed to a standard semiclosed circle system. Group E = adults exposed to a closed circle system. Values shown for Groups A–C are mean values for five patients; those for Groups D and E are mean values for three patients.

over the two hours from 13 ± 1 mg H_2O/l at 30 min to 19 ± 2 mg H_2O/l at two hours. Blood pressure, pulse rate and blood-gas values were similar in all groups and did not change significantly during the study. The average esophageal temperature of all patients exposed to CPRAM and the closed circle system showed no significant change during the study, whereas the patients exposed to a semiclosed circle system showed an average decrease of 0.6 C.

Discussion

Adequate humidification of anesthetic gases has been recommended both for the prevention of pulmonary damage during endotracheal anesthesia and for the maintenance of body temperature, especially in pediatric patients.[3,4] Circle and nonrebreathing systems frequently lack adequate humidity,[5–8] and numerous methods have been devised for improving their humidification.[4,9–13] However, humidification in anesthesia appears not to have gained wide acceptance, as most humidification methods require additional equipment, which may be cumbersome, might become contaminated, or may be associated with risk to the patient.[14–16] Also, many humidification studies have involved laboratory models, and questions might be raised as to their applicability to the clinical situation.

The humidity provided by CPRAM in adults and children exceeded the humidity provided in adults by both the semiclosed and closed circle system techniques. Our humidity values for the semiclosed system of 9.8 to 10 mg H_2O/l, when corrected to a mean room humidity of 10 mg H_2O/l, fall within the range of 9.0 to 16.8 mg H_2O/l reported by others[5,6,13,17] and attest to the accuracy of our method. The reason our results fall within the lower portion of the range is possibly that previous investigators have not tried to standardize the effects of environmental absolute humidity, or that some cooling of the gases may have occurred during humidity measurements. The mean temperature of the circuit gases in Groups A, B, and C decreased 2.5 C from that value recorded during continuous ventilation. Therefore, the humidity reported for these groups may be slightly low, possibly by as much as 3.8 mg H_2O/l. In Group D, the gas-to-room temperature difference was less, and any possible error would be smaller than that in the CPRAM groups.

Modifications of existing anesthesia apparatus have been devised for improving humidity. In adult and infant circle systems, passing the fresh gas flow through the soda lime before it goes to the patient[6,10,13,18] and use of heat and moisture exchangers (HME)[17] have been tried. Humidity in these modified systems is frequently low in small patients[18] because humidity is dependent upon the $\dot{V}_{CO_2}$ of the patient, the fresh gas flow rate, and the duration of anesthesia. The HME is not recommended for use in small children due to its dead space.[17]

Humidity in nonrebreathing systems has been shown to be low[8] and water loss from the patient excessive.[7] Methods for improving humidification have consisted of the use of humidifiers,[11] atomizers,[9] or vaporizers,[12] and all have disadvantages. Annoying condensation may form in the delivery tube, with possible obstruction to flow.[11,19] Contamination of the humidifying equipment,[14,15] and with heated apparatus, overhydration, tracheal burns, or heat retention, are possible complications.[14,16]

Use of coaxial circuits with Bain's method provides humidity between 12 and 21 mg H_2O/l,[19,20] causing many anesthesiologists to use a HME or humidifier to achieve higher humidity reliably.

Adequately humidified gases should probably contain 14 to 30 mg H_2O/l, with the more optimum values in the upper portion of this range.[21] This clinical study demonstrates that CPRAM provides

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adquate humidity in both children and adults without the need for auxiliary devices. Humidity is superior to that provided by all previously described systems, except those incorporating an ultrasonic nebulizer or humidifier with heating element.[9,10] CPRAM does not require an equilibration time before acceptable humidity is reached, as may be the case with circle systems. It is not dependent upon carbon dioxide production, artificial heating apparatus, vaporizers, or humidifiers. Excessive condensation does not form in the inner tube, thus avoiding obstruction as well as possible overhydration or heat retention. Precipitation forms in the large outer tube (which delivers most of the tidal volume) and avoids the continuous noise that hinders monitoring when a humidifier is used with coaxial circuits. Absolute humidity is stable 30 min after induction, and overheating of patients is unlikely without excessive environmental heat or humidity.

In conclusion, CPRAM is a technique that provides adequate humidity and avoidance of temperature change in adults and children during two hours of anesthesia without modification of existing apparatus.

The authors thank Theodore H. Stanley, M.D., and Richard A. Elwyn, M.D., for critical evaluation of the manuscript, and Ms. Dorit Carmelli, Ph.D., for the statistical analysis.

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