Passive and Active Inspired Gas Humidification in Infants and Children

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The hypothesis that both active and passive airway humidification prevents hypothermia in infants and children, but that neither decreases the duration of postoperative recovery was tested. Twenty-seven ASA physical status 1 or 2 patients were studied who weighed between 5 and 30 kg, underwent superficial operations, were anesthetized with halothane and 70% N₂O, and whose lungs were ventilated via a Rees modification of an Ayre’s t-piece. The children were randomly assigned to receive active airway humidification and warming using an MR450 Servo® airway heater and humidifier set at 37° C (n = 10), passive airway humidification using the HumidVent® heat and moisture exchanger placed between the Ayre’s t-piece and the endotracheal tube (n = 8), or no airway humidification and heating (control, n = 9). Distal tracheal and tympanic membrane temperatures and airway humidity were recorded during the first 90 min of surgery. Rectal temperature was measured during the postanesthetic recovery period. Relative humidity of inspired respiratory gases was approximately 30% in the control group and approximately 90% in the group given active airway humidification. Initial inspired humidity in the passive humidification group (50%) increased to approximately 80%, a level not significantly different from that in the active group after 80 min of anesthesia. Central body temperature increased 0.25° C during active airway humidification and heating, whereas temperature decreased 0.25° C during passive humidification and 0.75° C without airway humidification. Distal tracheal temperature was significantly higher in the groups given passive and active humidification than in the control group. Recovery was rapid in all patients and did not correlate with the type of humidification. Heat and moisture exchangers are less effective than active heating and humidification but significantly better than no humidification. (Key words: Anesthesia: pediatric. Anesthesia, systems: Ayre’s t-piece. Anesthetics, inhaled: halothane. Gases: nitrous oxide. Hypothermia. Recovery: duration. Temperature, measurement: airway; rectal; tympanic. Ventilation: humidification; inspired gases.)

INTRAOPERATIVE AIRWAY humidification prevents tracheal damage from dry inspired gases,¹ increases tracheal mucus flow,² and minimizes respiratory heat loss.³,⁴ Respiratory gases can be conditioned actively by evaporative or ultrasonic humidifiers or passively by heat and moisture exchangers (artificial noses). Active systems increase airway temperature and humidity in adults⁵ and children⁶ but are expensive, difficult to set up, and have been associated with complications.⁷ Both active and passive gas conditioning prevent intraoperative hypothermia in adults,⁸ but the ability of heat and moisture exchangers to minimize hypothermia in children has not previously been documented. The influence of airway humidification on duration of postanesthetic recovery in adults is controversial⁹,⁸ and has not been evaluated in small children.

Small tidal volumes increase the effectiveness of heat and moisture exchangers,⁹ suggesting that this type of gas conditioning may be especially useful for pediatric patients. However, many of these heat and moisture exchanging filters cannot be used safely in infants because they introduce excessive dead space (e.g., 60–100 ml) into the anesthesia circuit. Using a heat and moisture exchanger with minimal dead space (e.g., 6 ml), we compared central and airway temperatures, airway humidity, and duration of postanesthetic recovery in children given active, passive, or no respiratory gas humidification.

Methods

With approval from the Ethical Committee of the Hospital for Sick Children, we studied 27 unpremedicated ASA physical status 1 or 2 pediatric patients after obtaining written, informed consent from their parents. All patients weighed between 5 and 30 kg and were scheduled for peripheral surgery lasting 1–3 h. None had a history of problems with the tympanic membrane or middle ear.

Anesthesia was induced with halothane and 70% N₂O in O₂, and the trachea of each patient was intubated without administration of muscle relaxants. Muscle relaxation during surgery was maintained with iv vecuronium 0.1 mg/kg. Anesthesia was maintained during surgery with halothane and 70% N₂O administered via a Rees modification of an Ayre’s t-piece. No barbiturates or opioids were given during surgery. Patients were mechanically ventilated using fresh gas flows based upon the formula of Rose and Froese;¹⁰ respiratory rate (≈30/min) and tidal volume (≈12 ml/kg) were adjusted to maintain an end-tidal P⁵⁰ near 35 mmHg. Endotracheal tube sizes were chosen to permit an air leak between the tube and the trachea at pulmonary pressures between 15 and 20 cmH₂O in accordance with current practice. Because gases
lost around the endotracheal tube slightly decrease the effectiveness of passive airway humidifiers,\textsuperscript{11} we maintained peak airway pressures below those required to cause a leak.

The children were randomly assigned to receive active airway humidification and warming using a MR450 Servo\textsuperscript{®} airway heater and humidifier (Fisher and Paykel Ltd., Auckland, New Zealand) set at 37°C (n = 10), passive airway humidification using the Humid-Vent\textsuperscript{®} I (Gibeck Respiration, Inc., Schaumburg, Illinois) heat and moisture exchanger placed between the Ayre's t-piece and the endotracheal tube (n = 8), or no airway humidification and heating (control, n = 9). A plastic spacer was placed between the Ayre's t-piece and the endotracheal tube in the active and control groups to assure comparable dead space in all patients.

Temperatures were monitored using disposable thermocouples and Model 6500 digital thermometers (Mon-a-Therm, Inc., St. Louis, Missouri). These thermometers require no user calibration and have a precision of 0.1°C when used with Mon-a-Therm disposable thermocouples. The cotton-covered tympanic thermocouples were placed in contact with the tympanic membrane under direct vision using an otoscope. Rectal probes were inserted to a depth of 5 cm and taped in place. The airway thermocouple was passed through the endotracheal tube and taped in a position estimated to be \( \approx 2 \) cm above the carina.\textsuperscript{12} Tympanic, airway, and ambient temperatures were recorded every 10 min throughout surgery.

Because there is considerable variation in normal body temperature, the best definition of hypothermia is a decrease in an individual's temperature. Consequently, we defined hypothermia as a decrease in central body temperature \( \geq 0.2 \)° C; 0.2° C was chosen because it is the temperature change usually needed to provoke thermoregulatory responses in unanesthetized humans.

Inspired relative humidity was measured using a rapidly responding Humicap\textsuperscript{®} (Vaisala, Inc., San José, California) (90% response in \(< 1 \) s) placed between the Humid-Vent\textsuperscript{®} I (or spacer) and the endotracheal tube. The Humicap\textsuperscript{®} was calibrated using saturated and dry gases before and after each application. Drift in the calibration measurements never exceeded 2% during a study. Induction of anesthesia was defined as time zero, and the first measurement of each parameter was at 10 min.

Postoperatively, we administered 5–10 ml 0.25% bupivacaine in or around the surgical incision to minimize discomfort during the recovery period. The tympanic thermocouple was removed at the end of surgery because preliminary studies showed that most children pulled the probe from the ear canal shortly after awakening. The patients' tracheas were extubated when each demonstrated sufficient alertness by opening his or her eyes.

Ambient temperatures were thermostatically controlled at \( \approx 21 \)° C during postanesthetic recovery; rectal temperatures were recorded every 15 min during this period. The presence or absence of postoperative tremor was qualitatively evaluated at 15-min intervals. Fitness for discharge was based on standard criteria which included: 1) rectal temperature \( \geq 36 \)° C; 2) a minimum recovery duration of 30 min; 3) patient alert with stable vital signs; and, 4) no surgical problems. Patients were released from the recovery area by an anesthesiologist unaware of the type of airway humidification used.

Differences among groups were compared using one-way analysis of variance and Student-Newman-Keuls tests. Differences were considered significant when \( P < 0.05 \).

| Table 1. Mean Age, Weight, Ambient Temperature during Surgery, and the Duration of Postanesthetic Recovery in Patients Assigned to Receive Active, Passive, or No Airway Humidification |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|
|                                                               | Control         | Passive         | Active          |
| Number                                                         | 9               | 8               | 10              |
| Age (yr)                                                       | 3.2 ± 2.6       | 3.8 ± 2.6       | 4.5 ± 2.0       |
| Weight (kg)                                                    | 15.0 ± 5.9      | 15.7 ± 8.5      | 18.6 ± 4.9      |
| Intraoperative ambient temperature (°C)                        | 22.5 ± 1.0      | 22.7 ± 1.4      | 21.6 ± 0.5      |
| Recovery time (min)                                           | 88 ± 5          | 81 ± 8          | 82 ± 11         |

All values are means ± SD. There were no statistically significant differences between the groups.

Results

The three study groups did not differ significantly in mean age, weight, or intraoperative ambient temperature (table 1). The types of surgery also did not differ markedly. Most were hypospadias repairs or peripheral orthopedic procedures.

The humidity of the inspired gas was approximately 90% in patients given active airway humidification and approximately 30% in those given unconditioned gases (fig. 1). Airway humidification was significantly higher in the passive and active groups than in the control group at all times. In those patients in whom the heat and moisture exchanger was used, airway humidity increased from approximately 50% at the beginning of anesthesia to approximately 80% after 90 min; after 80 min, inspired humidity due to the heat and moisture exchanger did not differ significantly from that produced by active airway humidification.

Tympanic membrane temperatures increased approximately 0.25° C in the patients given active airway humidification, decreased approximately 0.25° C in those given passive humidification, and decreased approximately 0.75° C in the control group. After 70 min of anesthesia, tympanic membrane temperatures differed significantly among groups. (fig. 2). Mean airway temperatures (measured approximately 2 cm above the carina)
FIG. 1. Mean inspired relative humidity in 27 infants and children given active (n = 10), passive (n = 8), or no airway humidification (control, n = 9). Vertical bars illustrate the standard deviations. The humidity of the inspired gas was approximately 90% in patients given active airway humidification and approximately 30% in those given unconditioned gases. The heat and moisture exchanger increased airway humidity from approximately 50% at the beginning of anesthesia to approximately 80% after 90 min; after 90 min, inspired humidity due to passive humidification did not differ significantly from that produced by active airway humidification. At other times, humidity in each of the groups differed significantly (P < 0.05).

No children required analgesics before discharge from the recovery area and none demonstrated postoperative tremor. Mean rectal temperatures during the postanesthetic recovery period are shown in figure 4. Children in each group returned to approximately 34.5°C (P > 0.05), and the mean duration of postanesthetic recovery did not differ significantly among the groups (table 1). All patients remained in the recovery area at least 60 min. No problems attributable to the tympanic membrane thermocouples were observed.

Discussion

Thermal steady state (constant mean body temperature) occurs when environmental heat loss equals metabolic heat production. Normally, humans adjust heat production (nonshivering thermogenesis, shivering) and heat loss (peripheral vasoconstriction, sweating, behavioral compensation) to maintain thermal equilibrium. However, patients do not compensate for the unusual heat losses occurring during surgery because anesthesia inhibits the thermoregulatory responses to cold until central temperatures decrease to approximately 34.5°C. Therefore, anesthetized patients will remain normothermic only when the anesthesiologist assures that heat loss does not exceed heat production.

The heat capacity (specific heat) of gases is low; consequently, only a small amount of heat is needed to warm gases from ambient to body temperature. This low heat capacity makes it difficult to actively transfer significant amounts of heat to patients via the respiratory system without risking burns. Approximately 65–85% of respi-
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Rulatory heat loss is insensible and results from the high latent heat of vaporization of water (the insensible fraction depends on the type of anesthesia circuit, fresh gas flows, minute ventilation, etc.). Thus, humidification of inspired gases is more important than heating them. Our results indicate that passive heat and moisture exchangers always provided greater humidification than in the control patients and that relative humidity was similar to that provided by active humidifier/heaters after 80 min of anesthesia.

Adults breathing gases from a circle system expend approximately 10–12 kcal/h (representing approximately 15% of metabolic heat production) to warm and humidify inspired gases. Minute ventilation is higher in infants and children and is roughly proportional to their metabolic rate. Therefore, the fraction of metabolic heat loss via respiration in anesthetized infants and children is similar to that lost by adults. Although these respiratory heat expenditures are small compared with conductive, convective, and evaporative losses from skin and surgical incisions, clinically significant hypothermia can result from respiratory heat loss. In our patients, the Humid-Vent® conserves sufficient heat to prevent significant hypothermia.

Heat and moisture exchangers increase inspired gas humidity in adults. Most exchangers (including the Humid-Vent®) use a hygroscopic membrane to prevent moisture from leaving the endotracheal tube into the expiratory portion of the anesthesia circuit. Warm water is absorbed by the hygroscopic membrane during expiration; this moisture is then available to warm and humidify dry inspired gases. The amount of water absorbed depends on the type of membrane and its size. Because the membrane can become saturated before a large expiration is complete, heat and moisture exchangers are most effective when tidal volumes are small. For this reason, they may be particularly useful in children. Our results support this supposition because the Humid-Vent® significantly increased airway humidification and, after 80 min of anesthesia, provided humidification similar to that provided by an active humidifier. Both methods of humidification provided ≥50% relative humidity, which is sufficient to prevent mucosal damage from dry inspired gases. Even when saturated with water vapor, airway resistance produced by a heat and moisture exchanger even smaller that the Humid-Vent® is minimal.

Recovery was rapid in all patients and did not correlate with intraoperative central temperature changes or type of humidification. This finding contrasts with a previous study in adults, in which the control group (no humidification) was only 0.4°C colder than the treatment group upon admission to the recovery area but required significantly longer to recover from anesthesia and surgery than comparable patients given active humidification. However, subsequent studies have shown that the duration of recovery was not influenced by active or passive airway humidification in adults. Our results suggest that in children, as in adults, duration of postoperative recovery is minimally influenced by airway humidification.

Temperature increased approximately 0.7°C during recovery, even in the groups who did not become hypothermic. However, actual preoperative temperature is probably higher than our first measurement (at 10 min) because central temperature decreases rapidly immediately following induction of anesthesia (from central redistribution of cool peripheral blood). Furthermore, mild postoperative fever is common, presumably resulting from atelectasis and/or surgically induced tissue trauma. Because awake infants and children rarely tolerate tympanic membrane probes, rectal temperatures were measured during recovery. Rectal and tympanic membrane temperatures are similar in this patient population.

Humidity measured between the Humid-Vent® (or spacer) and the endotracheal tube varies considerably on a breath-by-breath basis. No currently available humidity monitor responds rapidly enough to provide accurate measurements throughout the entire respiratory cycle. The largest measurement errors occur during the initial phase of expiration because the humidity flux is greatest at that time. Because gas flow also is greatest during initial inspiration, exact water (and thus heat) loss cannot be determined, even when a Humicap® is paired with a
pneumotachometer. More accurate estimates of water loss in patients requires that expired gases be collected and humidity determined under steady state conditions. We did not measure humidity in this manner because the relatively simple technique used in this study demonstrated that both passive and active methods provided adequate airway humidity to prevent tracheal mucosal damage.

Although we evaluated only patients anesthetized with halothane, it is unlikely that a physical process, such as respiratory heat loss, is significantly influenced by anesthetic drugs. However, our patients were generally healthy, weighed 5–30 kg, and underwent peripheral surgery; it is likely that results would differ in other patient populations. Additionally, anesthetic circuit design significantly changes airway humidity,§ but the changes are smaller than generally expected.15

In summary, 27 infants and children were randomly assigned to active, passive, or no intraoperative airway humidification and warming. The Humid-Vent® heat and moisture exchanger significantly increased airway humidification and temperature compared with no humidification. After 80 min of anesthesia, it provided humidification close to that provided by an active humidifier/heater. Passive airway humidification minimized the decrease in body temperature, whereas active humidification and heating increased central body temperature. Recovery was rapid in all patients and did not correlate with type of humidification. Heat and moisture exchangers appear to be a reasonable alternative to active airway humidification in infants and children. They immediately supply enough humidity to prevent tracheal damage and, after approximately 1.5 h of anesthesia, provided nearly as much airway humidification as active systems.

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References

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