THE EFFECTS OF THE HEAT AND MOISTURE EXCHANGER ON HUMIDITY, AIRWAY TEMPERATURE, AND CORE BODY TEMPERATURE

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ABSTRACT

Findings from several studies have demonstrated that the use of a heat and moisture exchanger increases airway humidity, which in turn increases mean airway temperature and prevents decreases in core body temperature. Few studies however, described the effects of the HME on relative humidity, mean airway temperature and core body temperature. The purpose of this study was to describe the effects of the HME on airway humidity and temperature and core body temperature of anesthetized patients. After induction of general endotracheal anesthesia, 16 subjects received a routine general anesthetic, and were placed on a three liter per minute flow rate of N20/O2 using a standard rebreathing circle system. Forced air warming blanket set at 43…C was placed on each subject, and all intravenous fluids were warmed to body temperature (37…C). Each subject received a Gibeck 2S Humid-Vent¤ placed between the endotracheal tube and the Y-piece of the breathing circuit. Humidity and temperature of inspired gases along with core body temperatures were recorded at 10 minutes, and then every 30 minutes until the end of the procedure. Fifteen minutes after the insertion of the HME, absolute humidity increased 17%, relative humidity decreased by .29% and core body temperature increased from 35.54 (SD±.58) to 35.83 (SD±.35). Over time, absolute and relative humidity and mean airway temperature steadily increased. Core body temperature increased from 35.54 (SD±.58) to 36.02 (SD±.41). The use of an HME may prevent decreases in core body temperature, increase airway humidity and may be associated with a small increase in core body temperature.

Key Words: **Heat and moisture exchanger, airway humidity, airway temperature, core body temperature, hypothermia.**

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Introduction

It is extremely important to deliver warm humidified gases to patients who are mechanically intubated because tracheal intubation by-passes the upper respiratory tract that physiologically warms and humidifies inspired gases.

Breathing cool, dry gases leads to heat loss, damage to the bronchial stratified epithelium, and impairment of the mucociliary transporter (Chiaranda et al., 1993). Ideally, to prevent the adverse effects of inadequate heat and humidification of inspired gases, what is lost should be replaced. Heat and moisture exchangers can replace the heat and humidification that are otherwise lost to a patient with an intubated trachea.

Heat and moisture exchangers work in a similar fashion to the nasopharynx and are often referred to as artificial noses . During expiration, the heat and moisture exchanger condenses moisture on its internal elements and returns the moisture and latent heat on inspiration (Weeks, 1975).

While some researchers have questioned the ability and efficiency of heat and moisture exchangers to maintain body temperature, others have determined that it is as effective as the heated wire circuit when compared with no rewarming devices (McEnvoy & Carey, 1995).

One of the first researchers to study the effects of the heat and moisture exchanger on humidity and the temperature of inspired gases was Weeks (1974). He found that the heat and moisture exchanger used could meet the minimal requirements of humidity and that it could also increase the temperature of inspired gases delivered to the patient. However, several other researchers have concluded that the use of a heat and moisture exchanger increases airway humidification, which in turn increases airway temperature and therefore, could only prevent large decreases in mean body temperature (Bicker & Sessler, 1990; Bissonnette & Sessler, 1990; Schiffmann et al., 1997; Sottiaux, Mignolet, Damas, & Lamy, 1993).

The main findings are that heat and moisture exchangers increase humidity and mean airway temperature and there are few studies determining the effects of humidity and mean airway temperature on core body temperature. Therefore, the purpose of this study was to describe the effects that the heat and moisture exchanger has on humidity and mean airway temperature and to describe the effects on core body temperature.

Research Questions

1. What effect does the heat and moisture exchanger have on airway humidity and temperature of an anesthetized patient?

2. What effect does the heat and moisture exchanger have on the core body temperature of an anesthetized patient?

Conceptual/Theoretical Framework

Introduction

The frameworks for this study are both theoretical and conceptual. The theoretical component is based on Myra Levine s Conservation Model. The conceptual component deals with the physics of humidity and its effects on temperature. The application of this framework provided a better understanding of the purpose of this study.

Myra Levine s Conservation Model.

Myra Levine s Conservation Model is based on the concept of trophicognosis or a nursing care judgement based on the scientific method (Meleis, 1991). Her model focuses on individuals as holistic beings, and a major area of concern is maintenance of the person s wholeness. The model identified adaptation as the process by which the integrity or wholeness is maintained (Polit & Hungler, 1991).

Levine identified humans as adaptive beings in constant interaction with the environment whose behaviors are integrated wholes in response to internal and external stimuli. She believed that nurses are interested in the integrated responses of whole patients to noxious stimuli, particularly when the individual is not able to adapt behavior to environmental demands. Nursing is expected to create an atmosphere to promote adaptation (Meleis, 1991).

Levine defined three types of environment: the perceptual environment in which the individual responds to with the sense organs; the operational environment, which includes all that affects the individual physically; and the conceptual environment, which includes the cultural aspects of the individual.

The interaction between the internal and external environments is where a person s adaptation resides and where the nurse s responsibilities lie. There are four principles of conservation that the nurse may use to facilitate a patient s adaptation:

1. conservation of patient energy both physically and psychologically.
2. conservation of structural and functional integrity.
3. conservation of personal integrity or self-esteem.
4. conservation of social integrity (Kelly, 1985).

The anesthetized patient is chemically rendered incapable of responding to their environment so that autonomic defenses alone are available to respond to changes in temperature. As a result, anesthetized patients are poikilothermic, with body temperatures determined by the environment (Sessler, 1997). It is therefore, the responsibility of the anesthesia provider to conserve patient energy and maintain homeostasis until the recovering patient is able to independently adapt to environmental demands.

Physics of humidity and temperature.

The function of the upper airway is to heat and humidify incoming gases. During spontaneous nose breathing, the inhaled gases enter the airway at a temperature of 23°C with a relative humidity of 60%. These gases are rapidly warmed and humidified so that by the time the inspired gases reach the alveoli the temperature increases to 37°C and the relative humidity increases to 100% (Ramanthan, 1993).

Table 1.

Relative Humidity of the Upper and Lower Airways.

	Upper Airway				Alveolus			
	Temp°C		RH%		Temp°C		RH%	
	Inspir	Expir	Inspir	Expir	Inspir	Expir	Inspir	Expir
Nose	23	32	60	75	37	37	100	100
ETT	25	32	0	87	37	37	100	100

Temp°C - Temperature in degress celcius
RH% - Percent relative humidity
Inspir - Inspiration
Expir- Expiration
ETT - Endotracheal tube.

Humidity may be expressed in two ways, absolute and relative. Absolute humidity is the mass of water vapor present in a given volume of air. The maximum amount of water vapor that can be present in a given volume of air is directly proportional to the temperature. When the temperature increases, the amount of water that can be changed to a vapor also increases. Therefore, fully saturated air at 20°C

contains about 17g/m3. At 37°C air contains 44g/m3 when fully saturated (Davis, Parbrook, & Kenny, 1995). (See Figure 1).

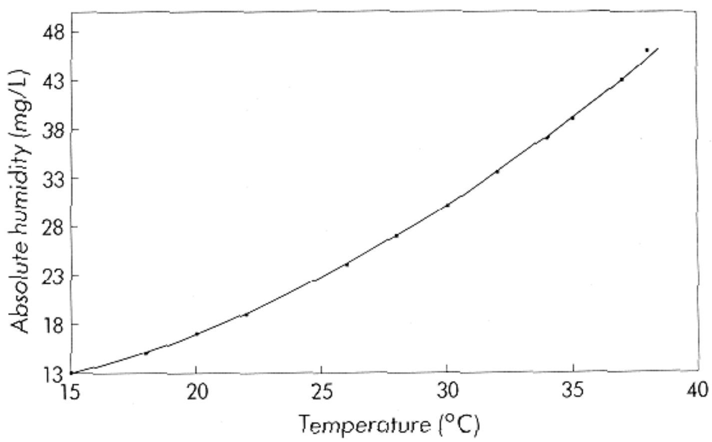

Figure 1.

The Relationship Between Absolute Humidity and Temperature.

A second way of measuring humidity is relative humidity. It is a comparative measure. Relative humidity is the ratio of the mass of water vapor in a given volume of air to the mass required to saturate that given volume of air at the same temperature. Relative humidity is expressed as a percentage.

Breathing dry gases during anesthesia leads to heat loss by two ways: (1) thermal energy is required to raise the temperature of the inspired gases to that of the body, and (2) energy is expended by the body to increase the water content of the unhumidified dry gases.

Conclusion

The inspired absolute humidity of 28-32mg/L is associated with minimal heat loss and damage to the tracheobronchial epithelium. For shorter surgeries (those lasting less than one hour) a humidity level of at least 17mg/L is required. Assuming that a patient who is intubated loses moisture at full saturation at 32°C (34mg/L of water), it is only logical to replace the moisture that is lost. Ideal environmental relative humidity is 40-60% at 22-23°C (Ramanthan, 1993).

Variables of Interest

1. Heat and moisture exchangers
2. Medium gas flow rates
3. Ambient air temperature
4. Temperature of intravenous fluids
5. Type of surgical procedure
6. Absolute airway humidity
7. Mean airway temperature
8. Core body temperature

Conceptual and Operational Definitions

The following terms have been conceptually and operationally defined for the purposes of this study:

Heat and moisture exchanger. A small device attached to the breathing circuit that is used to humidify gases and conserve energy both physically and psychologically.

Operational definition. A Gibeck 2S heat and moisture exchanger placed between the end of the endotracheal tube and the Y piece of the breathing circuit.

Medium gas flow rate. Fresh gas flow rates between 2 and 5L/min.

Operational definition. Fresh gas flow rate of 3L/min used in the anesthesia cicuit.

Ambient air temperature. Temperature in the immediate environment. Operational definition. Temperature immediately surrounding the surgical patient who will have a bair hugger set at 43°C

Temperature of intravenous fluids. Intravenous fluids (IVFs) other than room temperature.

Operational definition. IVF s warmed to the same controlled temperature for each patient in the IV warmer for at least two hours prior to use.

Type of surgery. Abdominal laparoscopic procedures.

Operational definition. Abdominal laparoscopic procedures with anesthesia performed on adult patients meeting inclusion criteria.

Absolute airway humidity. The mass of water vapor present in the upper airway. Operational definition. The amount of humidity found in the upper airway on expiration as measured by the Gibeck Humid-Sensor which will be recorded from the Y piece of the anesthesia breathing circuit.

Mean Airway Temperature. Temperature found in the upper airway on inspiration.

Operational definition. Temperature of the expired gases as measured at the Y piece by the Gibeck Humid-Sensor.

Core body temperature. Balance between the heat production in the center of the body and heat lost through the outer surface of the body.

Operational definition. temperature measured with a esophageal thermometer placed at approximately 40-42cm from the lip of the patient

Limitations

Only one type of heat and moisture exchanger was used which limits the extent of conclusions that could be drawn.

CHAPTER II: REVIEW OF THE LITERATURE

Introduction

According to Myra Levine, man is an adaptive being who is constantly interacting with the environment. She believed that behaviors are integrated in response to internal and external stimuli. She also believed that nurses are interested in integrated responses of whole patients to noxious stimuli, particularly when the individual is not able to adapt behavior to environmental demands (Meleis, 1991, p. 382).

When a patient is intubated, the upper airway is bypassed. The function of the upper airway passage is to heat and humidify the incoming gases. Since anesthetized patients are unable to respond to their environment, the anesthesia provider must provide enough heat and humidity to maintain homeostasis and prevent deleterious effects.

Effects of Inadequate Heat and Humidity

Some of the deleterious effects of intubation are heat loss, impaired pulmonary defense mechanisms and tracheobronchial cell damage. Breathing cold, dry gases during anesthesia leads to heat loss because thermal energy is required to raise the temperature of gases inhaled at room temperature to that of the body and energy is expended by the body to increase the water content of the unhumidified dry gases. The impairment of pulmonary defense mechanisms is due to the fact that the mucociliary transporter in the upper airway normally functions efficiently at a relative humidity of 80-90% at 32-33°C (Ramanathan, 1993).

Chalon, Loew, and Malebrache (1972) found significant changes in tracheobronchial smears obtained from patients who breathed cool, dry gases for one hour. After three hours of cool, dry anesthetics 39% of cells had damage to the cilia and endplate and 39% had developed cytoplasmic changes in relation to their condition at the onset of anesthesia. The authors also found no significant changes in smears obtained from patients exposed to gases at 60% relative humidity at room temperature or gases saturated with water vapor at body temperature.

Ideally, to prevent the adverse effects of inadequate heat and humidification in inhaled gases, what is lost should be replaced. Because the larynx is normally exposed to 25-28mg/L of moisture, various authors have suggested that this level be maintained however, a minimum level of 23mg/L has been found to be sufficient (Weeks & Ramsey, 1983). Heat and moisture exchangers fulfill the major functions that are otherwise lost to the patient with an intubated trachea.

History of the Heat and Moisture Exchanger

Early heat and moisture exchangers consisted of humidifiers with metal elements designed with a large surface area. These proved efficient for use with a semi-closed rebreathing system. However, because of the high density and thermal conductivity of the metals used in the exchangers, an effective temperature gradient across the device was not achieved (Hedley & Allt-Graham, 1994).

Disposable heat and moisture exchangers replaced the earlier metal-element devices and were made of foam, plastic and paper. There are three types of disposable heat and moisture exchangers. Hygroscopic exchangers were developed in an attempt to increase moisture output by means other than simple condensation. They differ from conventional heat and moisture exchangers in that moisture was conserved chemically. The paper or foam elements were coated with calcium or lithium carbonate.

Hygroscopic condenser humidifiers were designed to condition dry air and simulate the moisture level of normal room air before it came in contact with the condenser element. These humidifiers consisted of a concentric cylinder with an outer hygroscopic layer with an inner felt-like exchanger element. Hydrophobic exchangers were originally designed as a pure filter, the element was made from a water-repellant ceramic membrane which was pleated to give a larger surface area.

Function of Heat and Moisture Exchangers

The heat and moisture exchanger works in the same fashion as the nasopharnyx and is referred to as an artificial nose. During expiration, the heat and moisture exchanger condenses moisture on the internal elements of the heat and moisture exchanger. During inspiration, heat and moisture are returned to the respiratory tract (Weeks, 1975).

The heat of vaporization of water is high, 580 calories per gram, and the specific heat of gas is low. Therefore, the vaporization of water requires considerably more heat than the warming of the gas. Conversely, condensation of water produces more heat than the cooling of a gas. Gas is normally exhaled from the lungs at 37¡C and at 100% relative humidity, or 44mg water per liter gas. When cooled, the absolute humidity of the gas will decrease, and the relative humidity will remain at 100%. By the time the exhaled gas reaches the end of the endotracheal tube, it has cooled to approximately 30¡C with an absolute humidity of 30mg water per liter gas.

Further cooling takes place in the heat and moisture exchanger. As water condenses on the heat and moisture exchanger surfaces, the latent heat that kept the water in a vaporized state is released. It is this latent heat that warms the exchanger, as the specific heat of the exhaled gas is too low to contribute substantially to the warming of the heat and moisture exchanger. If the exhaled gas leaves the heat and moisture exchanger at 20¡C, with an absolute humidity of 17mg water per liter gas, then 13mg water per liter gas has been deposited in the heat and moisture exchanger along with its associated latent heat. The greater the temperature difference between the two sides of the heat and moisture exchanger, the more heat and moisture will be deposited (Haslam & Nielsen, 1986).

Although some researchers have questioned the ability and efficiency of the heat and moisture exchangers to preserve body temperature, other researchers have determined that it is as effective as the heated wire circuit when compared with no rewarming devices (McEnvoy & Carey, 1995).

Pertinent Studies

One of the first clinical studies conducted on anesthetized patients was performed by Dr. D.B. Weeks, in 1974. The purpose of the study was to determine if heat and moisture exchangers produced sufficient humidity during anesthesia. His study population consisted of 28 patients requiring general endotracheal anesthesia for at least one hour. Temperature and humidity measurements were taken immediately after intubation and then at 10 minute intervals until a plateau was reached. A heat and moisture exchanger was added to the circle 10 minutes after endotracheal intubation to allow for the determination of baseline conditions.

Weeks (1974) found that without a heat and moisture exchanger the humidity at ambient temperatures reached approximately 20% and with a heat and moisture exchanger reached 100%. However, this value varied depending on the amount of residual moisture in the circle system. Mean airway temperatures of the inspired gases increased to 3.0(± 0.5)¡C above ambient temperatures present in the inspiratory side of the circle system. Weeks concluded the heat and moisture exchanger could meet minimal humidity requirements of 22± 8mg/L during endotracheal anesthesia and that the use of a heat and moisture exchanger could also increase the temperature of inspired gases. There were many flaws in Week s study and some important variables were not controlled.

Since Week s (1974) study, several other studies have concluded that the use of a heat and moisture exchanger increases airway humidification which in turn increases mean airway temperature and prevents large decreases in body temperature (Bissonnette & Sessler, 1989; Bicker & Sessler, 1990; Sottiaux, Mignolet, Damas, & Lamy, 1993; Schiffman, et al., 1997). Although the primary findings are that heat and moisture exchangers increase humidity and mean airway temperature and prevents losses in mean body temperature, several other variables needed to be considered.

One of the variables to be considered is the type of ventilator circuit used. Turtle, Ilsley, Rutten, and Runciman (1987) conducted a clinical study designed to test the effectiveness of disposable heat and moisture exchangers in both the most challenging manner (used in a non-rebreathing circuit) and in a more conventional manner (used in a circle circuit). They found that the heat and moisture exchangers tested gave higher inspired humidities and temperatures when used in a rebreathing system than in the non-rebreathing system and that a steady state was usually reached in about half the time.

Another variable to consider was minute ventilation. The efficacy of all hydrophobic heat and moisture exchangers are significantly decreased when tidal volume increases and some heat and moisture exchangers are unable to provide adequate humidification at high tidal volumes (Martin, Thomachot, Quino, Viviand, & Albanese, 1995). In fact, several authors found a negative correlation between efficacy of heat and moisture exchangers and minute volume or tidal volume. The critical level of minute ventilation is usually 10L/min (Misset, Escudier, Rivara, Leclerq, & Nitenberg, 1991).

The last variable of interest concerns fresh gas inspired and minute ventilation. Small variations in humidity occur after changes in the fresh gas inspired and minute ventilation. An increase in the fresh gas inspired decreases inspired humidity, whereas an increase in minute ventilation increases inspired humidity. This is because increasing the fresh gas inspired decreases the humidity in the inspired side of the circle system so that gases reaching the patient do not have time to be fully humidified by the heat and moisture exchanger (Chalon, Markham, Mahgul, Ramanathan & Turndorf, 1984).

Haslam and Neilson (1986) conducted a controlled study to determine the effects of fresh gas flow rates on body temperature. All subjects in their study were adult men scheduled for extemity surgeries under general anesthesia. All subjects were ASA physical status I-III, and there was no significant difference in age among the groups. The operating room temperature was maintained between 20-21°C. Routine surgical draping was used but no other warming devices were allowed. Intravenous solutions were administered at room temperature.

Core body temperature was measured in all cases with the same esophageal probe and monitor. The probe was inserted at a depth of 40 cm from the teeth. The first reading was taken at five minutes after intubation and then the core and room temperature were recorded every fifteen minutes thereafter.

The 41 patients were randomly assigned to one of four groups to be studied. Group one consisted of 10 patients who received 3L of fresh gas flow rate. Group two consisted of 10 patients who received 6L fresh gas flow rate. In both of these groups a heat and moisture exchanger was placed between the endotracheal tube connector and Y piece of the anesthetic breathing system. Group three consisted of 11 patients who received 3L fresh gas flow rate and Group four consisted of 10 patients who received 6L fresh gas flow rate. A heat and moisture exchanger was not used with these groups.

The temperature data were analyzed by analysis of variance and covariance. Group one showed a decrease in core body temperature of 0.34(±0.12)°C. Group two had a temperature decrease in core temperature of 0.44(± 0.12)°C. Group three had a temperature of 0.62(± 0.12)°C. The study was unable to demonstrate any decrease in temperature fall with a 3L/min fresh gas flow rate of anesthetic gases when the heat and moisture exchanger was not used. Although the differences between the 3 and 6L/min fresh gas flow rate were not significant, the data suggested that using a low flow along with the heat and moisture exchanger was slightly more effective in conserving heat.

Henrikson, Sundling, and Hellman, (1997) studied the effects of flow rate and humidity on the temperature of inspired gases. The authors studied 60 patients scheduled for abdominal procedures. All patients were ASA I-III and were randomly assigned to one of six groups. Half of the 60 patients had a heat and moisture exchanger and half were without a heat and moisture exchanger. Thirty patients were further assigned into one of six groups: fresh gas flow rate at 1L/min (10 patients), 2L/min (10 patients), and

5L/min (10 patients). The anesthesia system used was a circle system with a low volume carbon dioxide absorber. The ventilator was converted for low-flow anesthesia. Thirty minutes after induction of anesthesia a control measurement of the relative humidity and temperature of the inspired gas was performed. After the control measurement was made a heat and moisture exchanger was added to the experimental group. Three more measurements were recorded at 10, 30 and 60 minutes after the insertion of the heat and moisture exchanger into the system or after the control measurement for the patients randomly assigned to a group without a heat and moisture exchanger. The results of the study verified that a fresh gas flow of <2L/min in the low flow anesthesia system had inherent humidifying properties which gave the inspired gas an absolute humidity of >20mg/L. At higher gas flows the humidifying properties of the breathing system was insufficient, but the addition of a heat and moisture exchanger provided adequate humidification of the inspired gases. In the experimental group, there was no difference in temperature. In the groups allocated not to have a heat and moisture exchanger there was a small but significantly lower inspired gas temperature in the group with a fresh gas flow of 5L/min as compared to the groups of 1 and 2L/min. The measurements of absolute humidity increased in all groups after the heat and moisture exchanger was inserted into the breathing system.

While several studies have supported the fact that the use of a heat and moisture exchangers can prevent decreases in body temperature. Eckerbom and Lindholm (1990) studied the effects of a heat and moisture exchanger on mean body temperature. Twenty patients scheduled for dental, oral or middle ear surgery were admitted into the study. Ten of these patients had a heat and moisture exchanger incorporated in the ventilator circuit (the experimental group) and 10 did not (the control group). Patients temperatures were measured with five fast-reacting temperature probes, four on the skin and one in the rectum. Temperature readings were made every 15 minutes. The results of the study showed that the change in mean body temperature in the heat and moisture exchanger group was +0.15(± 0.14)°C/hr and in the control group, —.05(± 0.21)°C/hr. The rectal temperature 20 minutes after the end of the anesthesia was 37.2(± 0.6)°C for the heat and moisture exchanger group and 36.6(±0.5)°C for the control group. Before the induction of anesthesia the rectal temperature in the experimental group was 36.7(±0.5)°C and in the control group was 36.6(± 0.2)°C. The authors found that the mean body temperature decreased 0.2°C/hr less in the heat and moisture exchanger group than in the control group and that the body heat losses differed significantly between the two groups. The results indicated that the heat and moisture exchanger helped to reduce heat losses during anesthesia and surgery and that small amounts of additional heat was conserved as well.

Conclusion

This review of the literature addressed the beneficial effects of heat and moisture exchanger to increase the relative humidity of inspired gases, as well as to increase mean airway temperature. However, there were few studies which examined the ability of the heat and moisture to maintain body temperature in a clinical setting (Yam & Carli, 1990). No study was found that described the effects of relative humidity and mean airway temperature on core body temperature with the use of a heat and moisture exchanger. This gap in knowledge was addressed in this study.

CHAPTER III: METHODS

Research Design

In order to describe the effects of absolute humidity, relative humidity, and mean airway temperature on core body temperature, a descriptive experimental research design was used.

Sample

This study took place in the operating rooms at a military medical center on the ease coast. An adult sample of 16 males and females scheduled for abdominal laparoscopic procedures was used

Procedures

All subjects scheduled for abdominal laparoscopic procedures undergoing general anesthesia were approached for inclusion this study. . Potential subjects were informed of the study as well as the risks and benefits associated with participation, and informed consent was obtained.

The abdominal laparoscopic procedure was chosen because hypothermia secondary to the insufflation of carbon dioxide gas flow has been shown to be a significant cause of heat loss during abdominal laparoscopic surgeries (Huntington & LeMaster, 1997).

After the induction of anesthesia, each subject received a routine general anesthetic, placed on a three liter/minute flow rate and placed on a standard rebreathing circle system.

Because it is impossible to control or standardize the ambient air temperature of the operating room, several measures were taken to control the temperature surrounding the patient. These measures included a forced air warming blanket and heated intravenous fluids.

Each subject received a forced air warming blanket or Bair Hugger (Augustine Medical, Courtelary, Switzerland). The Bair Hugger was used to maintain the ambient air temperature surrounding the subject. The blanket was placed on the subject in the operating room and set on 43°C.

All intravenous fluids were warmed to body temperature (37°C) for each subject and was supplied to the subject based on the subject s requirements as this was the standard of care at Malcolm Grow Medical Center.

Core body temperature was measured by an esophageal thermometer prior to the start of the surgical procedure and again prior to insufflation of the abdomen. This provided a baseline measurement for comparison. Esophageal temperature provides one of the most reliable direct readings of core temperature, and is probably the modality most commonly employed in the operating room because it directly reflects core temperature (Yamakage, Kawana, Watanabe, & Namiki, 1993).

Ten minutes after the insufflation of the carbon dioxide gas into the abdomen, humidity and temperature of the inspired gases along with core body temperature were recorded.

Then, each subject received a Gibeck Humid-Vent 2S placed between the endotracheal tube and the Y piece of the breathing circuit. According to a technical report released by the Journal of Medical and Engineering Technology (1987) the Gibeck Humid-Vent was able to maintain the mean humidity in the airway on the patient side of the heat and moisture exchanger above the environment level of 10 mg/l at minute volumes up to 30 l, but does not maintain the higher level of 30mg/l at any flow.

Humidity falls rapidly as minute volume is increased, but the heat and moisture exchanger efficiency remains constant.

The humidity and temperature of the inspired gases along with core body temperature were recorded at ten minutes and every thirty minutes until the end of the procedure. The measurement device used was the Humidity Sensor System (Gibeck, Sweden). The data collected by the system was then be entered into to a personal computer and absolute humidity was calculated from relative humidity and temperature.

The data from the Humidity Sensor System and the temperature recordings obtained was entered into a Statistical Package for the Social Sciences for analysis. The first measurement of core body temperature was taken prior to the start of induction. The second measurement (core body temperature, mean airway temperature and humidity) was taken at ten minutes after the insufflation of the carbon dioxide gas into the abdomen. The heat and moisture exchanger was then inserted. Then the core body temperature, mean airway temperature and humidity was then be recorded again every thirty minutes after the insertion of the heat and moisture exchanger.

<u>Equipment and Materials Utilized</u>

The heat and moisture exchanger placed in the anesthesia breathing circuit was the Gibeck Humid-Vent 2S which is the same heat and moisture exchanger utilized at the institution where the data was collected. It is composed of a scroll of absorbent paper housed in a rigid plastic holder. The insert is impregnated with calcium chloride (Journal of Medical and Engineering Technology, 1987). This heat and moisture exchanger is able to maintain the mean humidity in the airway at minute volumes up to 30L but can not maintain the higher level of 30mg/L at any flow rate. Humidity does fall with increased minute volume but the efficiency remains constant.

The ambient air temperature surrounding the patient was controlled with the use of a Bair Hugger. The Bair Hugger is a form of convective warming therapy which transfers heat to patients by blowing warm air through microperforations on the under side of a plastic paper blanket which is placed on the patient. This self-supporting warming cover forms a thermally controlled environment which surrounds and warms the patient and maintains body temperature. It is also routinely used for the cases at this institution. The Bair Hugger has been found to be more effective than the warming water mattress, infrared lighting or thermal ceiling (Ouellette, 1993).

The humidity and temperature of the inspired gases was measured with the Humidity Sensor System (Gibeck, Sweden). The sensor works on a capacitative principle. The stated system accuracy is ±4% relative humidity and ±1% temperature. The response times are 1.4s for a 90% relative humidity response and <150ms for a 90% temperature response (Henriksson, et al, 1997). The obtained data was then entered into to a personal computer for humidity calculations and a graphic display was then generated.

Core body temperature was measured in each subject with an esophageal thermometer. It is believed that when the thermometer is inserted correctly, it is one of the most reliable direct readings of core body temperature (Yamakage, Kawana, Watanabe, & Namiki, 1993).

Validity and Reliability

Validity refers to the degree to which an instrument measures what it is intended to measure. In this study, the variables of mean airway temperature and humidity was measured with the Humidity Sensor System (Gibeck, Sweden). The stated accuracy and reproducibility of this system is ±4% for relative humidity and 1% for temperature (Henriksson, et al, 1997). The third variable, core body temperature will be measured with an esophageal thermistor. The esophageal readings are reproducible at an accuracy of ±0.2°C (Ehrenworth & Eisenkraft, 1993).

Reliability is defined as the degree of consistency with which an instrument measures the attributes it is designed to measure. Another way of defining reliability is in terms of accuracy (Polit & Hungler, 1991). The accuracy and reproducibility of the measurement tools stated above are adequate to justify the validity and reliability of the measurement instruments.

Protection of Human Rights

Institutional Review Board approval was obtained from the Uniformed Services University of the Health Sciences and from Malcolm Grow Medical Center prior to the initiation of this study. Participation in this study was voluntary, and each participant was free to withdraw at any time, without consequence. Informed consent was obtained. Inclusion criteria include all participants adult age (18- 65) and scheduled for laparoscopic procedures under general anesthesia. All data was numerically coded and participants identities were kept private.

Risks associated with the treatment measure (heat and moisture exchanger) were minimal and included a potential for a 5ml increase in the dead space.

Data Analysis

The data (absolute humidity, relative humidity, mean airway temperature and core body temperature) obtained from this study were analyzed descriptively to determine statistical significance.

Conclusion

In this chapter, a descriptive research design was explained and methodology for data collection discussed. After Internal Review Board approval from the Uniformed Services University of the Health Sciences and from Malcolm Grow Medical Center, Andrews Air Force Base, 16 participants scheduled for abdominal laparoscopic procedures were recruited to participate in this study.

Data collection were conducted over a two month period and entered into a personal computer. The collected data was then entered into a software package for the social sciences. It was expected that the data collected would explain the effects of a heat and moisture exchanger on core body temperature over time.

CHAPTER IV: PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

Study Sample

The study sample consisted of 16 patients (11 females, 5 males), half had an ASA classification I, and the other half had an ASA classification of II. The average age of the sample was 42 years with a range of 20-62 years. The laparoscopic procedures under investigation consisted of cholecystectomies (7 cases), hernia repairs (4 cases), diagnostic laparoscopies (2 cases), nissen fundiplication (1 case), vaginal hysterectomy (1case), and total colectomy (1 case). The average length of the surgical procedure was 104 minutes (range 80-170 minutes). There were no intraoperative complications or delays for any of the cases.

Absolute Humidity

Absolute humidity was defined as the mass of water vapor present in a given volume of air. Fully saturated air at 37°C contains 44g/m3 of water vapor. An inspired absolute humidity of 28-32 mg/L of water vapor has been associated with minimal heat loss and airway damage (Davis, Parbrook, & Kenny, 1995).

After induction, all subjects had a mean absolute humidity of 27.61mg/L (SD±4.75) and over time, these values increased. At one hour after the insertion of the HME, the absolute humidity increased from 27.61mg/L to 33.94mg/L (SD±7.77) (See Table 2 & Figure 2). The use of the HME was associated with an increase in absolute humidity in all subjects.

Table 2.

Recorded Means Over Time.

Time in minutes	Mean airway temperature°C	Absolute humidity%	Relative humidity%	Core body temperature°C
0.0	29.62	27.61	92.14	35.54
15.0	32.63	32.50	91.91	35.83
30.0	32.69	33.22	94.03	35.94
60.0	32.63	33.94	96.06	36.02

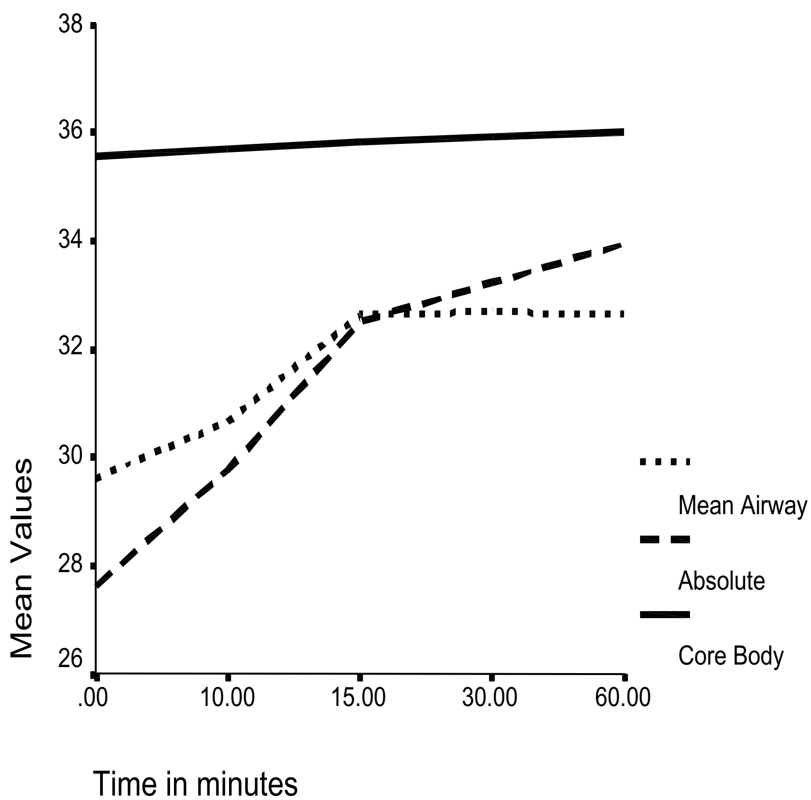

Figure 2.

Relationship Between Absolute Humidity, Mean Airway Temperature and Core Body Temperature.

Relative Humidity and Airway Temperature

Relative humidity is a comparative measure of the ratio of the mass of water vapor in a given volume of air, to the mass required to fully saturate that given volume at the same temperature. The maximum amount of water vapor that can be present in a given volume of air is directly proportional to the temperature. When the temperature increases, the amount of water that can be changed into a vapor also increases. With an intubated trachea, the inhaled gases enter the airway at a temperature of 25°C with a relative humidity of 0%. On expiration, the temperature of the expired gases increases to 32°C with a relative humidity of 87% (Ramanthan, 1993).

Before the insertion of the HME, subjects exhaled mean airway temperature was 39.61°C (SD± 2.09) with an exhaled relative humidity of 92.14% (SD± 10.36). Fifteen minutes after the insertion of the HME, the relative humidity decreased by 0.23% but at thirty minutes increased by 2.12% and continued to increase thereafter (See Table 2 and Figure 3), up to 60 minutes when data collection stopped. There was a steady increase in mean airway temperature from 29.61 to 32.69 (SD± 2.35) at 30 minutes after the insertion of the HME. However, at 60 minutes, there was a small decrease (0.06°C) in mean airway temperature. (See Table 2 and Figure 2).

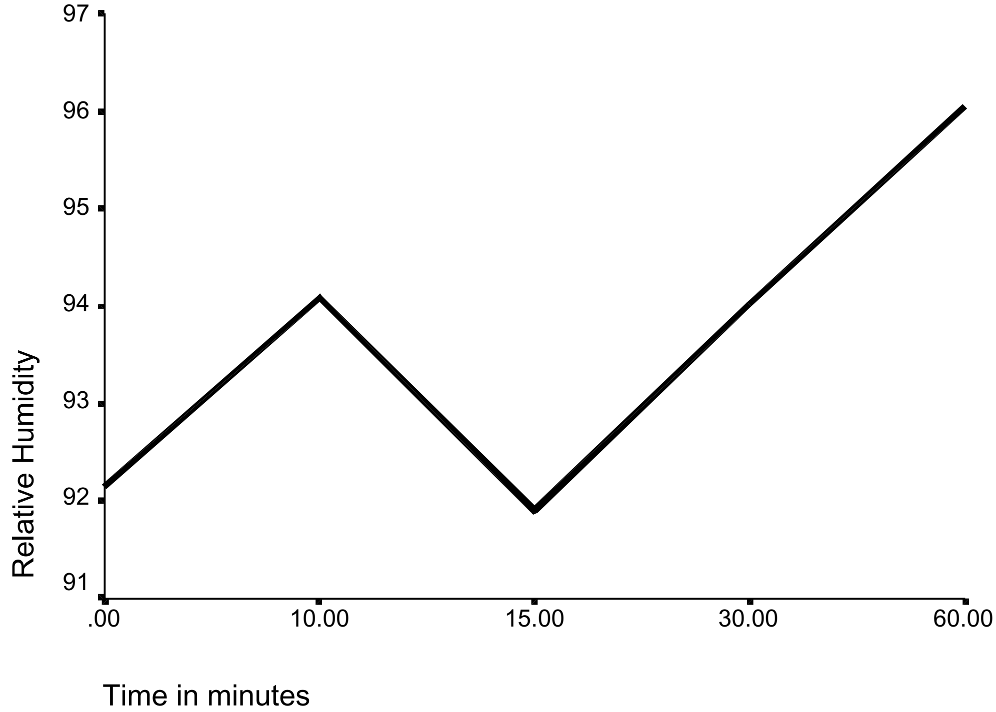

Figure 3.

Relative Humidity Over Time.

<u>Core Body Temperature</u>

After induction, the mean esophageal temperature for the 16 subjects was 35.54°C (SD± 0.58). There was then a small but steady increase in mean esophageal temperature over time, so that at one hour after the insertion of the HME, the core body temperature had increased to 36.02°C (SD± 0.41) (See Table 2 & Figure 2).

<u>The Relationship Between Airway Humidity and Temperature and Core Body Temperature</u>

In this study there was an association between absolute humidity and core body temperature, with both increasing over time (See Figures 4 and 5).

There was a slight decrease in relative humidity 15 minutes after insertion of the HME but this was not associated with a decrease in core body temperature at this time, or thereafter (See Figures 4 and 6).

Mean airway temperature increased steadily but at one hour after insertion of the HME decreased by 0.06°C. This decrease was not reflected by the core body temperature as it continued to show an increase of 0.08°C at one hour (See Figures 4 and 7).

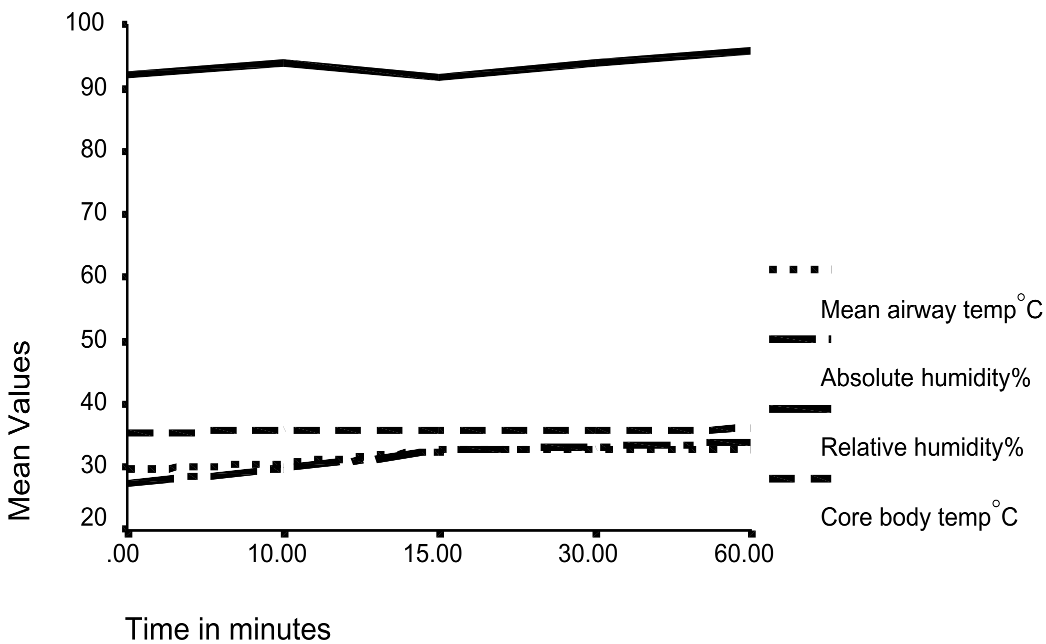

Figure 4.

<u>The Relationship Between Humidity and Mean Airway Temperature on Core Body Temperature.</u>

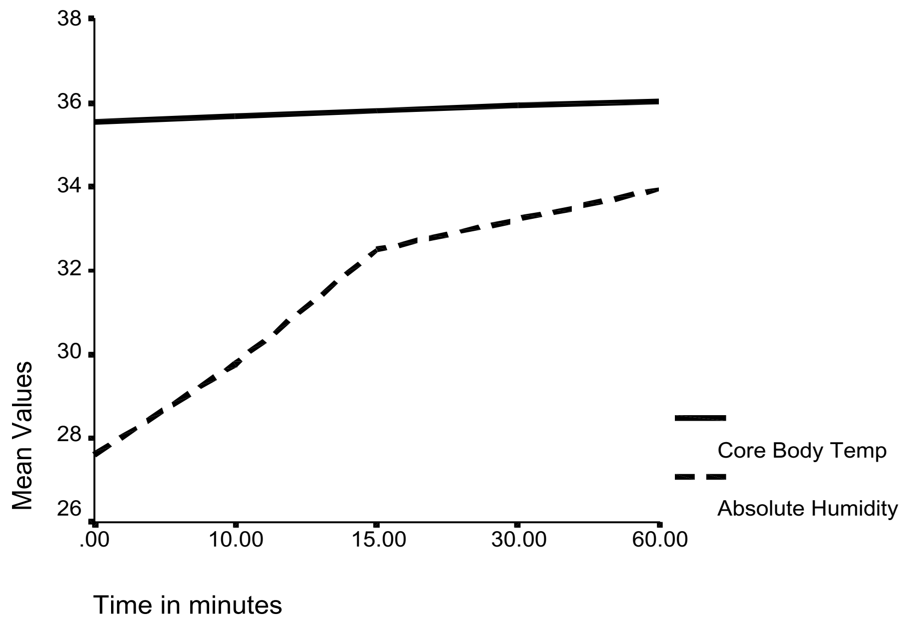

Figure 5.

<u>The Relationship Between Absolute Humidity and Core Body Temperature.</u>

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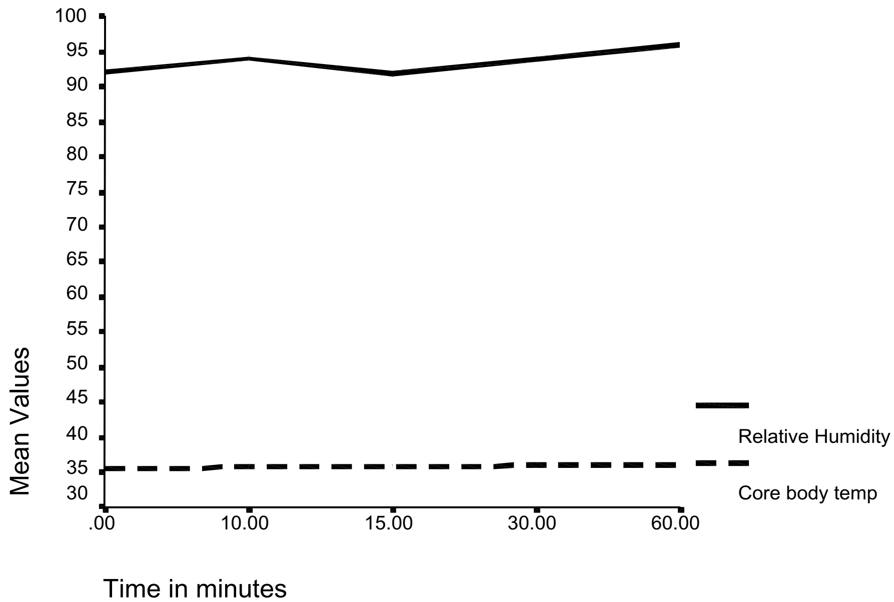

Figure 6.

<u>The Relationship Between Relative Humidity and Core Body Temperature.</u>

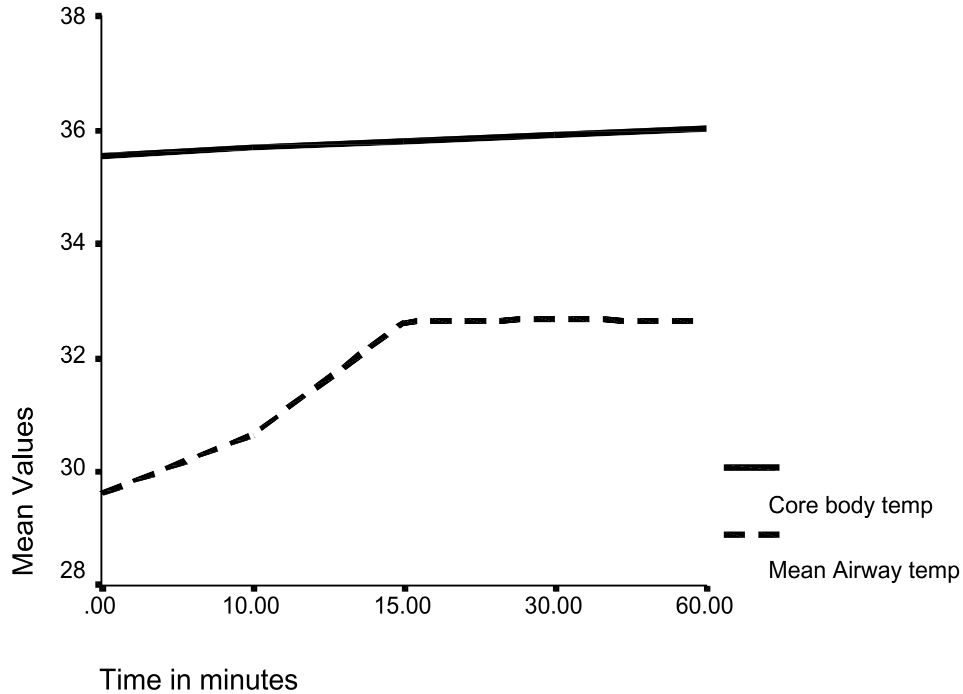

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Figure 7.

The Relationship Between Mean Airway Temperature and Core Body Temperature.

CHAPTER V:SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

Anesthetized patients commonly experience perioperative hypothermia. This is caused by an inhibition of thermoregulation induced by anesthesia and patients exposure to a cool environment. Perioperative hypothermia is associated with numerous complications including coagulopathies, morbid cardiac events, and a decreased resistance to wound infection (Sessler, 1997).

General endotracheal anesthesia causes loss of body heat, in part, because the upper airway which normally heats and humidifies inspired gasses is bypassed with an endotracheal tube. This heat loss is caused by both the evaporation of water and the patients heating of their inspired gases.

The heat of vaporization is high, 580 calories per gram, and the specific heat of gas is low (for air, it is 0.0003 calories per gram). Therefore, the vaporization of water requires considerably more heat than the warming of gas. Conversely, condensation of water produces more heat than the cooling of a gas (Haslam, 1986).

Based on this concept, one of the preventive measures used by anesthesia providers to prevent heat loss is the heat and moisture exchanger. Heat and moisture exchangers work much like the nasopharynx. During expiration, the heat and moisture exchanger condenses exhaled moisture on its internal elements and returns this moisture and latent heat on inspiration. Several researchers have concluded that the use of the heat and moisture exchanger increases airway humidification which in turn increases mean airway temperature and prevents decreases in core body temperature.

In this study the effects of the use of the heat and moisture exchanger on airway humidification (relative and absolute), and mean airway temperature on core body temperature were evaluated.

Research Questions

The first research question in this study was What effect does the heat and moisture exchanger have on airway humidification and temperature of anesthetized patients?

Results were that fifteen minutes after insertion of the heat and moisture exchanger, relative humidity decreased by 0.23% whereas absolute humidity and mean airway temperature increased. This small decrease in relative humidity may have been due to the fact that patients must use their own humidity to saturate the heat and moisture exchanger, leading to a small initial decrease in relative humidity. After this initial decrease, relative humidity steadily increased and by one hour after insertion, had increased by 3.92%.

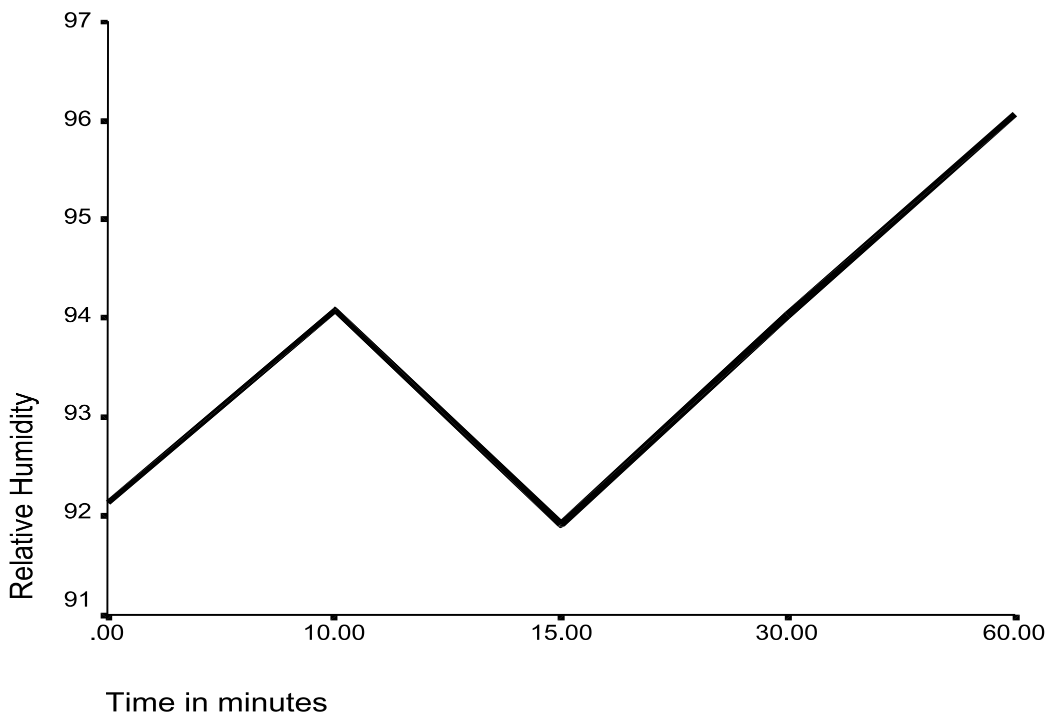

Figure 3.

Relative humidity over time.

Absolute humidity increased steadily from baseline (27.61 mg/L), and one hour after insertion, had increased by 6.33mg/L (See Figure 3).

Gas is normally exhaled from the lungs with a relative humidity of 100% (44mg/L). When cooled, the absolute humidity of the gas will decrease and the relative humidity will remain the same. By the time the exhaled gas reaches the end of the endotracheal tube the absolute humidity decreases to 30mg/L (Haslam, 1986).

The fact that the heat and moisture exchanger increases airway humidity has been supported by several studies (Bissonnette & Sessler, 1989; Bicker & Sessler, 1990; Sottiaux, Mignolet, Damas, & Lamy, 1993; Schiffmann, et al, 1997) and supports the conclusion that the observed increase in airway humidity in this study was due to the insertion of the heat and moisture exchanger.

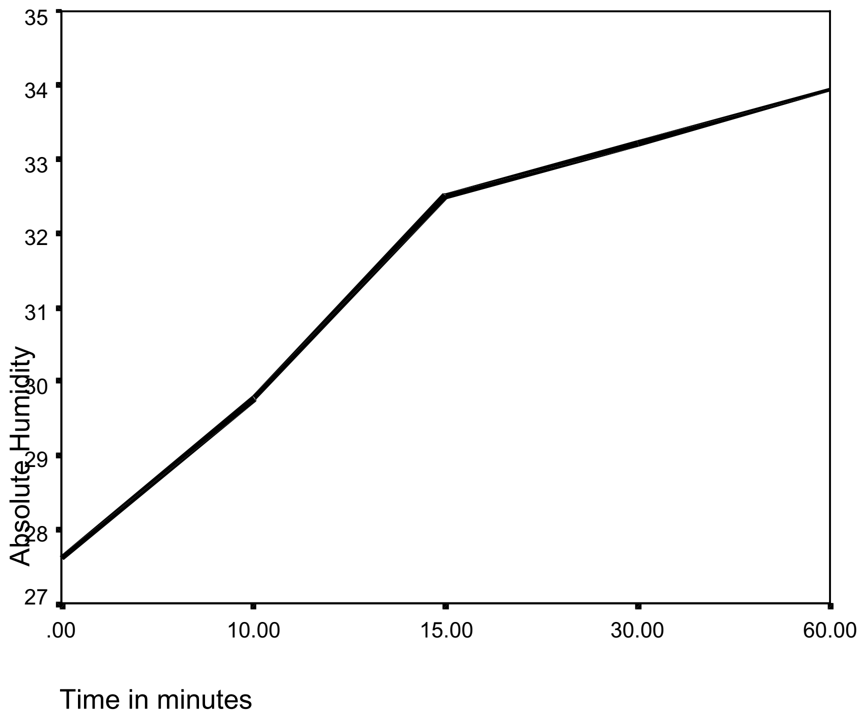

Figure 8.

<u>Absolute Humidity Over Time.</u>

Ciliated cellular morphologic condition and function of the respiratory tract are preserved during exposure to humidity of no less than 14-22mg/L, while alterations in lung mechanics are prevented when an absolute humidity of 17-30mg/L is maintained (Weeks, 1981).

One hour after insertion of the heat and moisture exchanger, absolute humidity increased from 27.61mg/L to 33.94 mg/L. The heat and moisture exchanger provided more than an adequate amount of absolute humidity.

Mean airway temperature also increased from baseline 29.62°C to 32.63°C one hour after insertion This increase in mean airway temperature was positively related to the increase in airway humidity. Gas is normally exhaled from the lungs at 37.0°C. By the time the expired gas reaches the end of the endotracheal tube it cools to approximately 30°C. Further cooling takes place in the heat and moisture exchanger surfaces, the latent heat that kept the water in a vaporized state is released. It is this latent heat that warms the heat and moisture exchanger as the specific heat of the exhaled gas is too low to contribute to the warming of the heat and moisture exchanger (Haslam, 1986).

Results were that an increase in absolute humidity was positively associated with an increase in mean airway temperature until one hour after insertion, when the mean airway temperature decreased slightly by 0.06°C. It was unclear why the this small decrease was observed but it is not clinically significant (See Figure 9).

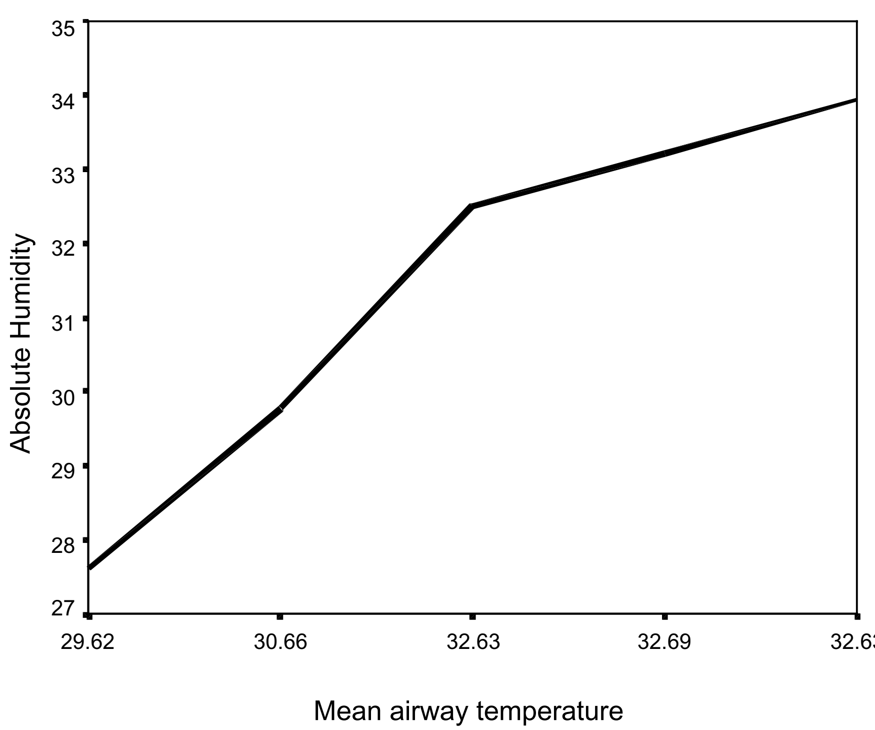

Figure 9.

<u>The Relationship Between Absolute Humidity and Mean Airway Temperature.</u>

The second research question addressed was, What effect does the heat and moisture exchanger have on the core body temperature of an anesthetized patient?

Results were that core body temperature increased over time so that at one hour after insertion, mean core body temperature increased by 0.48°C from baseline. Sessler (1997) demonstrated that hypothermia follows a typical pattern during a general anesthetic with the core body temperature decreasing approximately 1.5°C during the first hour of surgery followed by a 0.5°C decrease per hour for the next two to three hours until the body temperature reaches a plateau. These decreases were not seen in this sample.

Less than 10% of metabolic heat is lost via respiration even when patients are ventilated with a cool, dry gas. Heat and moisture exchangers can prevent most of this heat loss. Chalon et al. (1984) studied the effects of heat and moisture exchangers on core body temperature of patients undergoing abdominal surgery. Results from that study were that upon leaving the operating room, there was no significant decrease in core body temperature in the patients who had received the heat and moisture exchanger (35.4°C±0.2). The control group however, had a significant decrease in core body temperature (34.0°C±.02). Neither group received any other warming devices except for cotton blankets.

Eckerbom and Lingholm, (1990) also found that mean body temperature decreases 0.2°C less per hour in patients who receive a heat and moisture exchanger. Heat and moisture exchangers do help to reduce heat loss during anesthesia, however, the additional amount of heat conserved is minimal.

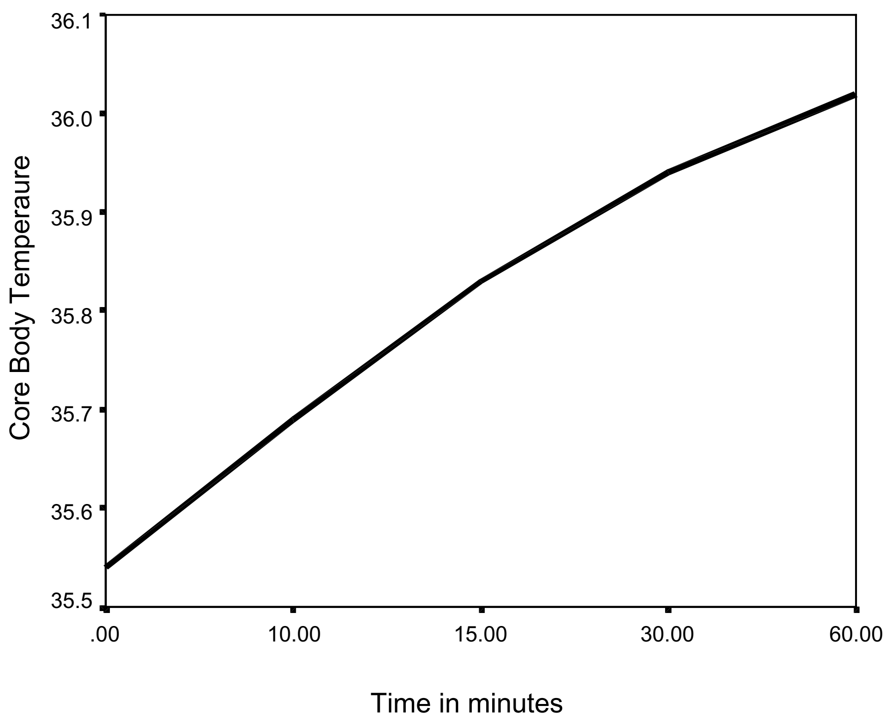

Figure 10.

<u>Core Body Temperature Over Time.</u>

Results of this study were similar to other cited studies. It was expected that the heat and moisture exchanger would prevent decreases in core body temperature. Although not clinically significant, it also was associated with small increases in temperature.

Recommendations

This was a descriptive study and no control group was used. This study could be repeated with a control group (no heat and moisture exchanger) for comparison. The amount of airway humidity and temperature lost or core body temperature decreases might better help describe the relationship among all the variables.

In an attempt to control for extraneous variables, a forced air warming blanket and warm intravenous fluids were used. It was therefore difficult to determine with certainty if the small increase in core body temperature was due to the use of the heat and moisture exchanger and not due to the use of these other warming techniques or the combined effect of all three interventions. Future studies could examine the relationships and compare the interactions among these three warming devices.

All study participants were middle-aged adults in an ASA category I or II. Although not intentional, there were no geriatric subjects or subjects with major medical problems. Geriatric patients (age> 65 years) are more susceptible to hypothermia , due to a reduction in body heat production with simultaneous impairment of the autonomically mediated thermoregulatory vasoconstriction (Barash, 1997). It would be of interest to describe the effects of the heat and moisture exchanger in the elderly as prevention of intraoperative hypothermia is critical.

The surgical procedure in this study was abdominal laparoscopy lasting an average of 104 minutes. The use of the heat and moisture exchanger in different surgeries, or surgeries of a of longer duration could help describe the effects of the heat and moisture exchanger over longer periods of time.

It is known that most of the heat lost during surgery occurs during the first hour. Body temperature reaches a plateau, usually three hours after the start of anesthesia (Sessler, 1997). It would be interesting to know if the use of the heat and moisture exchanger produces even greater increases in core body temperature at this time.

Goldberg et al. (1988) suggested that perhaps a critical time is required before any benefit is seen from heating and humidifying inspired gases. In this study it was 15 minutes. If the heat and moisture exchanger used during surgery were to be replaced two to three hours into the surgery, would there be a similiar initial decrease in airway humidity and temperature and if so, would this decrease be reflected in the core body temperature?

Conclusion

According to Myra Levine, humans are adaptive beings in constant interaction with the environment. Our behaviors are integrated wholes in response to our internal and external environments. Levine believed that nurses are interested in the integrated responses of patients to noxious stimuli, particularly when individuals are unable to adapt behavior to environmental demands (Meleis, 1991).

Anesthetized patients are chemically rendered incapable of responding to their environment so that autonomic defenses alone are available to respond to changes in temperature. As a result, anesthetized patients are poikilothermic with body temperatures determined by the environment (Sessler, 1997).

The anesthetized, endotracheally intubated patient will warm and humidify inspired gases and in doing so will lose 7.8ml of water vapor per hour and 5.2kc/L per hour, which represents 7.6% of the basal heat production (Stone, 1981). It is therefore, the responsibility of the anesthesia provider to help patients conserve energy and maintain homeostasis until they are able to independently adapt to environmental demands.

This study demonstrated an increase in absolute and relative humidity as well as an increase in mean airway temperature when the heat and moisture exchanger was used. These increases were associated with increases in core body temperature. Because the ambient temperature surrounding the patient, and the temperature of the intravenous fluids were controlled, heat lost by the subjects should have been minimal. However, this also made it impossible to determine if the observed increases in core body temperature were due to the heat and moisture exchanger alone or to the combination of these other warming devices. Nonetheless, the results support the use of the heat and moisture exchanger in the surgical patient to prevent the deleterious effects of inadequate heat and humidification to the respiratory tract and to prevent intraoperative heat loss.

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APPENDICES

APPENDIX A

INFORMED CONSENT

Informed Consent Form

THE EFFECTS OF THE HEAT AND MOISTURE EXCHANGER ON HUMIDITY, AIRWAY TEMPERATURE ANDCORE BODY TEMPERATURE.

My name is 1LT Maryann Delventhal. I am a Nurse Anesthesia graduate student conducting research for my master s thesis. You are being asked to take part in a research study. Before you decide to be a part of this research study, you need to understand the risks and benefits so that you can make an informed decision. This is known as informed consent. This consent form provides information about the research study, which has been explained to you. Once you understand the study and the tests it requires, you will be asked to sign this form if you desire to participate in the study. Your decision participate is voluntary. This means that you are free to choose if you will take part in the study.

Purpose and Procedures

The Department of Nursing Anesthesia of the Uniformed Services University of the Health Sciences is carrying out this research study to describe the effects of the use of a heat and moisture exchanger at medium gas flow rates and humidity on core body temperature.

The study procedure will consist of placing a heat and moisture exchanger between your breathing tube and the anesthesia machine tubing. This is routinely used on all cases at this institution. The use of a heat and moisture exchanger helps prevent heat loss that occurs during general anesthesia.

After the placement of the heat and moisture exchanger, measurements will be taken throughout your surgical procedure with a thermometer and a humidity sensor. You will not be aware of the heat and moisture exchanger or the temperature recordings. You will not be expected to do anything and the quality of your anesthesia will not be affected by this study.

Benefits

The benefits of this study will be to add to the current body of anesthesia knowledge and practice. The use of the heat and moisture exchanger will also maintain or increase your core body temperature so that your body temperature will not drop during your procedure.

Time Commitment

The time commitment for this study will last the duration of the surgical procedure for which you are scheduled. You will not be aware of the study while you are under anesthesia.

Risks, Inconveniences, Discomforts

The potential risks of this study may include a small (5ml) increase in unused air space. This consists of a small space in the lungs in which no gas exchange occurs, which could lead to a decrease in oxygen in the blood. This risk is negligible.

Cost of Participation

None to you.

Research Related Injury

This study should not entail any physical or mental risk beyond those described above. We do not expect complications to occur, but if, for any reason, you feel that continuing this study would constitute a hardship for you, we will end your participation in the study.

If at any time you believe you have suffered an injury or illness as a result of participating in this research project you should contact the Office of Research Administration at the Uniformed Services University of the Health Sciences, Bethesda, MD 20814 at (301) 295-3303. This office can review the matter with you, can provide you information about your rights as a subject, and may be able to identify resources available to you. Information about judicial avenues of compensation is available from the University s General Counsel (301) 295-3028.

Privacy of Records

All information that you provide as a part of this study will be kept private and will be protected to the fullest extent of the law. Information that you provide and other records related to this study will be kept private, accessible only to those persons directly involved in conducting this study and members of the Uniformed Services University of the Health Science s Institutional Review Board, who provide oversight for human use protection.

Withdrawal

I understand that I may at any time during the course of this research study revoke my consent, and withdraw from the study without prejudice. I have been given an opportunity to ask questions concerning this research study, and any such questions have been answered to my complete satisfaction. If you have any concerns or questions, call 1LT Maryann Delventhal at (301) 515-5348 or Maura S. McAuliffe Ph.D., CRNA at 301-295-6565, chair of my thesis committee. If you have any questions about your rights as a research subject, you should call the Director of Research Programs in the Office of Research at the Uniformed Services University of the Health Sciences at (301) 295-3303. This person is your representative and has no connection to the researchers conducting this study.

I do hereby volunteer to participate in a research study entitled: THE EFFECTS OF THE HEAT AND MOISTURE EXCHANGER ON HUMIDITY, AIRWAY TEMPERATURE, AND CORE BODY TEMPERATURE. The implications of my voluntary participation: the nature, duration and purpose; the methods and means by which it is to be conducted; and the inconveniences and hazards to be expected have been thoroughly explained to me by

By signing this consent form you are agreeing that the study has been explained to you and that you understand this study. You are signing that you agree to take part in this study. You will be given a copy of this consent form.
I have been given the opportunity to ask questions concerning this study, and any such questions have been answered to my full and complete satisfaction.

______________________________ ______________________________

Signature Date

______________________________ ______________________________

Signature (witness) Date

I Certify that the research study has been explained to the above individual, by me and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered.

______________________________ ______________________________

Investigator Date

June 28, 1998
IRB. Protocol Number: T06176-01
Subject initials________
Witness initials________

APPENDIX B

DATA COLLECTION SHEET

THE EFFECTS OF THE HEAT AND MOISTURE EXCHANGER ON HUMIDITY, AIRWAY TEMPERATURE, AND CORE BODY TEMPERATURE.

Name:________________________________ SSN#_____-___-_____

Sponsor s name:_____________________________ SSN#_____-___-_____

Age:_____ ASA Classification:______

Type of Surgical procedure:_________________________________

Type of anesthesia:________________________________ Flow Rates:__________

Minute Ventilation:_______________________ Date:____________________

	Esophageal Temperature	Airway Temperature	Airway Humidity
After induction before insufflation and insertion of the HME	Time:______	N/A	N/A
10 minutes after insufflation of CO2 gas into the abdomen	Time:_______		
Insertion of the HME	N/A Time:______	N/A	N/A
10 minutes after insertion of the HME	Time:______		
30 minutes after insertion of the HME	Time:_______		
60 minutes after insertion of the HME	Time:______		
30 minutes thereafter	Time:______		
30 minutes thereafter	Time:______		

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