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Perioperative Hypothermia: Incidence and Prevention

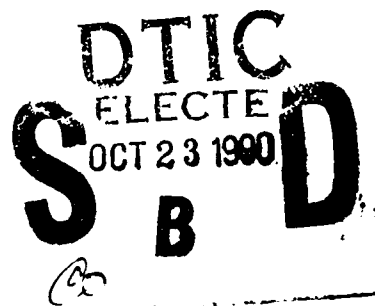
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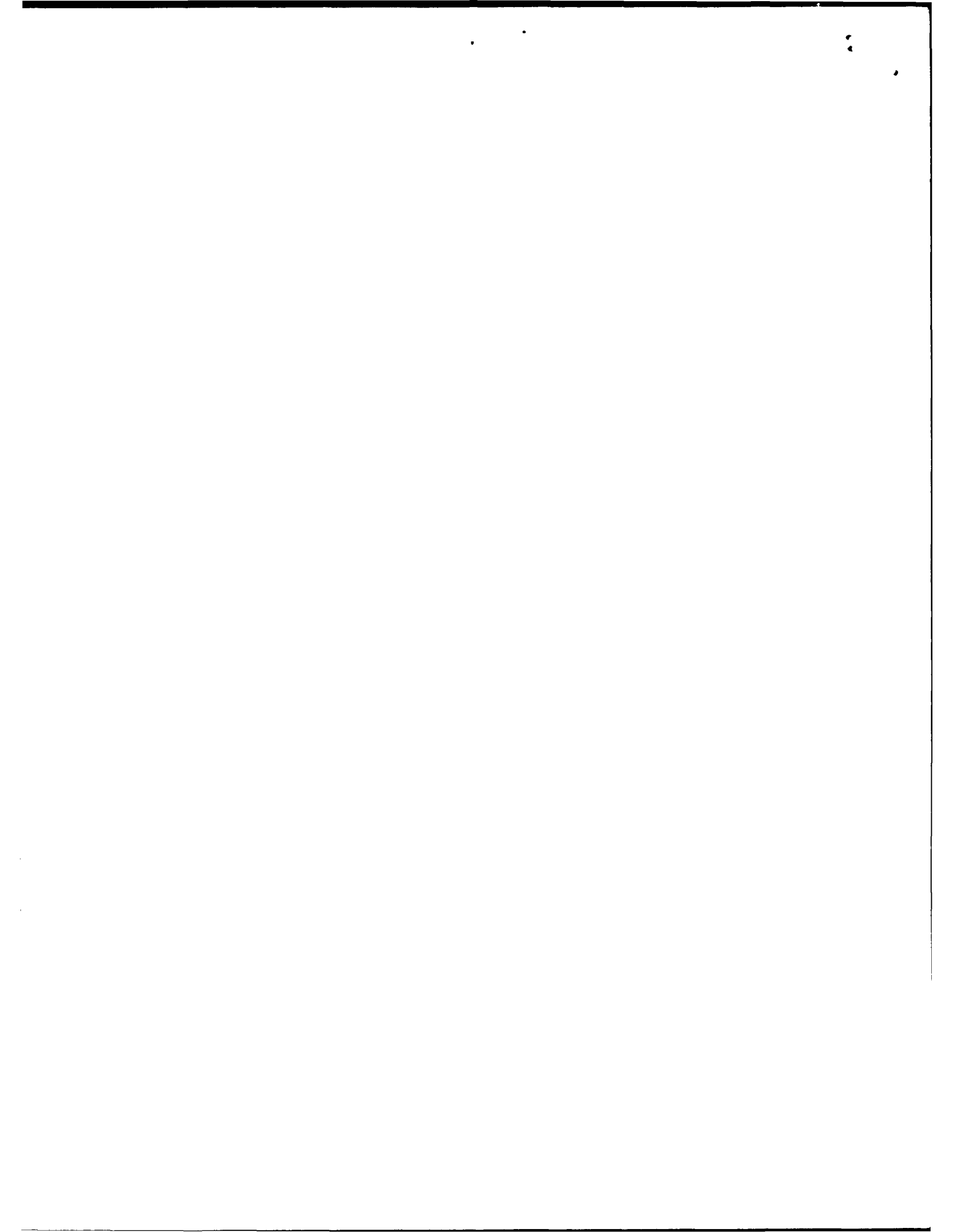
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PERIOPERATIVE HYPOTHERMIA: INCIDENCE AND PREVENTION

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ABSTRACT

Perioperative thermal regulation is discussed. A retrospective audit was conducted to identify the incidence and magnitude of hypothermia in abdominal surgical procedures under general anesthesia and to identify variables affecting thermal balance. One hundred and sixteen anesthetic records were reviewed from two major city hospitals. Data collected were length of procedure, temperature change, use of antihypothermia adjuncts, amount of fluids administered, temperature of fluids and gases given, and approximate incision length. Results showed a high incidence of hypothermia (80 percent). The degree of temperature drop was significantly related to incision length ($p<0.01$), length of procedure ($p<0.05$), and blood administered ($p<0.02$). Heating and humidifying inspired gases was the most successful antihypothermia adjunct to decrease the body temperature drops during these cases ($p<0.01$). The use of a combination of adjuncts is also effective in preventing temperature drops. Suggested guidelines for the prevention of perioperative hypothermia are presented.

INTRODUCTION

Incidental hypothermia, as defined by a core body temperature of less than 36 degrees celsius, occurs frequently after surgery. Despite the identification of variables that cause perioperative hypothermia and the techniques available to prevent it, studies still show an alarmingly high incidence of hypothermia in post-anesthetic care unit (PACU) admissions.¹⁻³ This high incidence of postoperative hypothermia appears to be associated with certain intraoperative variables such as the incision length and duration of surgery, among many.⁴ There have been several excellent reviews of the mechanisms of thermal balance during surgery^{5, 6} yet little evidence of the significance each variable plays in the maintenance of thermal balance in the surgical patient. The purpose of this study is two-fold. First to identify the heat loss mechanisms which are associated with hypothermia in the surgical patient undergoing abdominal procedures under general anesthesia and secondly, to identify anesthetic adjuncts that support the maintenance of thermal balance.

CONCEPTUAL FRAMEWORK

MECHANISMS OF HEAT LOSS

There are four major mechanisms by which a patient can lose heat in the operating room; conduction, convection, evaporation, and radiation. By understanding these mechanisms of heat loss, the anesthetist becomes more aware of antihypothermia adjuncts that can reduce the likelihood of heat loss in the surgical patient. The following is a review of these heat loss mechanisms with examples to help clarify their understanding.

Conduction is the transfer of heat (energy) from a warm object (patient) to a cooler object (O.R. table). Heat may also be conducted from the patient if a room-temperature blanket is applied. In fact, any object in contact with the patient that is cooler than the patient's temperature will cause heat loss. The operating room (O.R.) table is by far the most important factor in conductive heat loss. Conductive heat loss through the O.R. table can be completely eliminated if a heating blanket, set at 37 degrees celsius, is placed between the patient and table.⁷ Other important conductive heat loss mechanisms are the use of room temperature intravenous and irrigating

fluids, as well as patient contact with cool, wet sheets and drapes.

Convection refers to the loss of heat (energy) by the movement of a fluid over the surface of the body. Since air is considered a fluid, heat loss to the moving ambient air falls under convective heat loss. Air within the surgical suite is constantly moving with a minimum of 10 to 15 room volume changes each hour (up to 50-100 changes). Air velocity increases with patient and personnel movement. Of course, the degree to which convective heat loss impacts on the patient depends not only on the air velocity at the patient's skin surface but also on the amount of skin exposed to the air. Covering the patient with one or two layers of blankets significantly reduce the amount of convective heat loss. Although beyond the scope of this review, Edwards and his colleagues use formulas which can estimate loss of heat.⁸

Evaporative heat loss results from water vapor being lost to the drier ambient atmosphere. The body must keep the airways warm and moist by heating fluids within the respiratory passages. If this does not occur, the respiratory passages will dry up and become dysfunctional. Other causes of evaporative heat loss

are wet skin preparations and exposed membranes such as viscera, peritoneum and pleura to the dry ambient air.

Radiative heat loss is reported to be the mechanism of the most heat loss during surgery. Radiant heat loss accounts for 40-50 percent of intraoperative heat loss by the transfer of heat (electromagnetic waves) from the body to the surrounding cooler environment.⁷ The more the patient is exposed, the more heat will be lost.

THERMOREGULATION (thermal balance)

Humans are homeotherms. In other words, we possess the ability to maintain and control body temperature. We also possess the cognitive ability to change our environment in order that our bodies don't expend too much energy maintaining internal temperature in the face of environmental temperature extremes. The following paragraphs will briefly discuss human thermoregulation.

There are at least two types of peripheral or cutaneous thermo-sensitive receptors capable of sensing temperature changes in the surrounding environment. Warm-sensitive receptors are stimulated by temperatures above normothermia and cold-sensitive receptors are stimulated by temperatures below normothermia.

Peripheral or skin-surface temperature sensing receptors are thought to contribute only 20% of the afferent input to the central thermoregulatory center.⁹ Afferent impulses from stimulated peripheral thermoreceptors travel up the lateral spinothalamic tract to the hypothalamus. Other investigators have described thermoreceptors in the viscera, spinal cord, and lower brain stem.^{10, 11}

The hypothalamus and possibly the preoptic area of the anterior hypothalamus also contain core thermoreceptors that sense temperature changes of the blood that perfuses them.^{12, 13} Information from the thermoreceptors is processed in the hypothalamus and higher brain centers resulting in different responses to specific target organs. The effector organs effect physiologic and cognitive changes to assure maintenance of normothermia. Activation of these effector organs occur in response to perceived body temperature increases or decreases of only 0.1 degree celsius.¹⁴ Sessler and his colleagues point out that some of the regulatory responses to hypothermia do not occur until core temperatures dropped more than 2.5 degrees celsius during anesthesia.¹⁵

There are many different effector organs capable of assisting in thermoregulation. The sympathetic nervous system assists in thermoregulation by insulating blood from a cold environment. It does this by causing peripheral vasoconstriction to shunt blood to the body core to protect heat or by allowing the dissipation of heat by peripheral vasodilation. Another sympathetic nervous system effect on thermoregulation involves nonshivering thermogenesis in adipose tissue. Jessen reports that nonshivering thermogenesis results from an outpouring of noradrenalin from sympathetic nerve endings which activates energy production (heat) from fat stores in adipose tissue.¹⁶ The sympathetic nervous system also contributes to heat loss during hyperthermia episodes by causing sweating.

Efferent outflow from the hypothalamus via the portal system stimulates the pituitary gland to secrete more thyroid stimulating hormone (TSH). TSH, in turn, causes an increased production of T3 and T4 which increase basal metabolism with concomitant heat production. Certainly, this hormonal effect of thermoregulation is slower than the sympathetic nervous

system's effects but, none-the-less, plays a significant role in long term thermal regulation.

Perhaps, the most recognizable effect of efferent outflow from the thermoregulatory center involves shivering thermogenesis. This involves involuntary rhythmic contractions of skeletal muscle in most areas of the body. Only moderate amounts of heat are generated in the skeletal muscle as a result of this conversion of energy substrates to kinetic energy. Horvath concluded that shivering only produces about 11 percent of the total heat production necessary to maintain thermal balance.¹⁷

ADVERSE EFFECTS OF HYPOTHERMIA

There are two distinct periods in which the anesthetist is concerned with hypothermia in the surgical patient: intraoperative and postoperative. The following paragraphs describe the adverse effect of hypothermia within these two periods.

Intraoperative

Valeri described a reversible platelet dysfunction that occurs during hypothermia, as evidenced by prolongation of bleeding times.¹⁸ The reason for this platelet dysfunction may be the inhibition, by hypothermia, of thromboxane B₂ production at the site

of surgical trauma. Thromboxane B₂ is a platelet aggregating agent and a potent vasoconstrictor. Other contributing factors for the hypothermia induced coagulopathies deal with the enzymatic reactions involved in the coagulation process. All enzymatic reactions are temperature dependent and slow when the body temperature decreases. This slowing of enzymatic and cellular processes is also one of the reasons for decreasing MAC requirements with decreasing body temperature.

Several hematologic and chemical changes occur with hypothermia. The buffering capacity of blood is reduced with decreasing temperature.¹⁹ There is a left shift in the oxyhemoglobin dissociation curve with hypothermia resulting in greater affinity of the hemoglobin molecule for oxygen and a decrease in oxygen release to the tissues. Total body metabolism decreases proportionately to the decreasing body temperature as reflected by a decreasing oxygen consumption. There is approximately, a 6% reduction in oxygen consumption for every degree-celsius drop in body temperature.²⁰ This metabolic slowing also accounts for prolonged drug responses during hypothermia. Hypothermia significantly prolongs the

duration of action of vecuronium as well as the time periods to recovery after the administration of neostigmine.²¹ Atracurium is partially metabolized by Hoffman elimination which is absolutely temperature dependent.

At 32 degrees celsius, blood flow to the liver is reduced to about 85 percent of normal and renal blood flow is reduced to 60 percent of normal.²² All pharmacologic agents metabolized by the liver and excreted via the kidneys will have prolonged durations of actions.

The hypoxic pulmonary vasoconstriction (HPV) response is attenuated during hypothermia. In the canine model, the HPV response decreased to 50 percent at a body temperature of 31 degrees celsius.²³ In patients with pulmonary disease during general anesthesia, this reduced HPV response can lead to significant shunting of blood through poorly ventilated lung regions resulting in hypoxemia.

Many of the physiologic effects of hypothermia are masked by general anesthesia. Intraoperatively, shivering and the sympathetic nervous system response to a falling body temperature are attenuated with the use of muscle relaxants, narcotics and inhalational

anesthetics. These effects do appear in the postoperative period with detrimental consequences, and will be discussed later.

Cardiac output begins to decrease at 32 degrees celsius.²⁴ At temperatures less than 31 degrees celsius, dysrhythmias begin to appear. Resistant ventricular fibrillation may occur at 30 degrees celsius, but can occur earlier in the atherosclerotic heart or in an irritated myocardium from central venous or pulmonary artery catheters. Hypothermia causes either a shift of intravascular fluid into the tissues or a trapping of fluid in small vessels which results in an increase in the hematocrit and a elevation in blood viscosity.^{25, 26} Increasing blood viscosity may cause sluggish tissue perfusion. This, along with a left shift in the oxyhemoglobin curve, will reduce oxygen delivery to the tissues.

Arterial blood gas (ABG) measurements are affected by decreasing body temperature. Severinghaus reported ABG values at levels of hypothermia.²⁷ Both the partial pressure of oxygen (PO₂) and carbon dioxide (PCO₂) decrease with decreasing temperature and the pH rises. When blood gases are drawn during hypothermia and corrected for temperatures, the results will show

hypoxemia and alkalosis. Wong concludes that both the alkalosis and hypocarbia are defended by physiologic mechanisms and the physical properties of gases during hypothermia.²⁸ Wong, as well as other authors, suggest that uncorrected values for pH, PCO₂ and temperature be used for management of ventilation during hypothermia.²⁹⁻³¹

Along with producing dysrhythmias, even mild hypothermia can cause a significant depression of ventricular contractility. Green and his associates demonstrated declines in regional work of myocardial muscle during hypothermia.³² It is well known that hypothermia causes an increased systemic vascular resistance (SVR). This increased SVR coupled with myocardial dysfunction leads to low output states and increased myocardial stress.

POSTOPERATIVE CONSEQUENCES

Many studies have reviewed the adverse effects of hypothermia in the postoperative period. Shivering is the most recognizable effect of hypothermia with the most significant consequences. Shivering causes increases in oxygen consumption (VO₂) and carbon dioxide production (VCO₂).³³ Increasing VCO₂ leads to increases in heart rate (HR), mean arterial pressure,

and rate pressure product (RPP). Rodriguez and colleagues also found increases in myocardial VO_2 in response to shivering.³⁴ These increases in VO_2 are occurring at a period of time when the patient is recovering from an anesthetic. In the immediate postoperative period, the patient will have residual effects of narcotics and inhalation agents, all of which depress respirations resulting in hypoxemia. Hypoxemia, reflected by desaturation of the arterial blood (falling SaO_2), is a frequent postoperative occurrence. Kaplan also reports that increases in HR, MAP, and RPP will cause an increase in myocardial oxygen consumption.³⁵ This scenario is not well tolerated by the elderly or those with coronary artery disease.

As the patient awakens from anesthesia, the hypothalamus recognizes the hypothermia and begins to initiate physiologic responses. As discussed earlier, sympathetic nervous system outflow causes vasoconstriction in peripheral tissues leading to the frequent postoperative occurrence of hypertension. Peripheral vasoconstriction can mask the symptoms of hypovolemia while the patient is hypothermic, resulting in normotension. As the body warms, the SNS response

subsides and the peripheral vasculature returns to normal dimensions. Blood flow is increased into the peripheral tissues from the core. Core blood volume drops resulting in hypovolemia with its concomitant consequences.

REVIEW OF LITERATURE

Many variables interplay in the mechanisms of thermal balance and heat debt. The four mechanisms of heat loss were described earlier. Factors that counterbalance those heat loss mechanisms must come from the patient or be administered by the anesthetist using antihypothermic adjuncts. General anesthesia attenuates the thermoregulatory response to hypothermia in the surgical patient.³⁶ Thus, the anesthetist becomes the necessary supplier of antihypothermia adjuncts.

More than 60 percent of PACU admissions are hypothermic.² All patients undergoing major abdominal procedures in one study ended with temperatures below 36 degrees celsius.³⁷ Undoubtedly, perioperative hypothermia continues to be a frequent but preventable occurrence.

Joachimsson and associates report that it is possible to prevent any heat loss in the surgical patient by utilizing the combined adjuncts of heated humidified gases, heating mattresses, reflective blankets, warmed intravenous fluids and warm operating theaters.³⁷ Another study confirms this concept.³⁸

The application of heat and humidification to inspired gases during anesthesia is related to a reduction in the drop of body temperature.³⁹ In infants, who are extremely susceptible to perioperative hypothermia, heating and humidifying the inspired gases is more successful in preventing drops in body temperature than passive airway humidification using artificial noses.^{40, 41}

It has been thought that ambient temperature of the operative theater can affect the incidence and extent of hypothermia. In procedures not involving the abdominal or thoracic cavities, body temperature was maintained when the room temperature was kept at 21 degrees celsius or higher but decreased when the room temperature was below 21 degrees celsius.⁴²

Roisen and colleagues discovered that during abdominal procedures, the patients tended to have the same postoperative temperatures independent of whether

they were in warm or cold rooms.⁴³ Their patients all were given warmed intravenous fluids and placed on a heated mattress. The complaints of discomfort of operating room personnel must never be placed over the optimum care needs of the patient.

Several studies have shown that heated mattresses alone heated to 34 to 37 degrees celsius are ineffective in preventing body temperature drops.^{44, 45} Newman showed a reduction in the body temperature drop from 3.3 degrees celsius to only 0.8 degrees celsius with the use of an electric heating blanket set at 40-42 degrees celsius.⁴⁶ The use of heated mattresses has been discouraged by other authors because of the incidence of thermal injuries and their ineffectiveness.^{45, 47}

Radiant heat loss contributes to a major portion of heat loss during the prepping period when the patient is exposed. Henneberg and colleagues reduced postoperative increases in oxygen consumption, shivering and catecholamine levels in hypothermic patients by applying radiant heat from a thermal ceiling.⁴⁸

There is a paucity of studies which determine the extent to which certain intraoperative variables, such as the amount of fluids administered, temperature of irrigating fluids, or blood loss contribute to perioperative hypothermia. The fact that there are so many variables interplaying in the scheme of thermal balance it may be almost impossible to accurately determine the contribution each variable plays.

METHODS

One hundred and sixteen anesthetic records were reviewed retrospectively from 2 major hospitals. Information for statistical analysis was obtained from these anesthetic records. Only anesthetic records of abdominal procedures performed under general anesthesia were used for this study in order to eliminate some of the variables that affect heat loss during surgery such as operative site and type of anesthetic. If the patients were febrile, they were excluded from this study.

Data statistically analyzed include the types of antihypothermic adjuncts that were used and their temperatures, blood loss, fluids administered and their temperatures, length of incision, and duration of surgery. All temperature measurements were taken using

esophageal thermistors placed immediately after induction of anesthesia. Trends in temperature drop were used for statistical analysis instead of actual temperatures. Data were statistically analyzed using the Mymstat statistical computer program.

RESULTS

A retrospective audit presents certain disadvantages not inherent in experimental research. Some data may not be available to review. Care was taken to eliminate cases where a lot of information was missing.

Because of the random, retrospective design of this study, demographic data is not presented because many of the charts did not have patients age. The incidence of postoperative hypothermia was 80% in this study. Fifty percent of all cases had a temperature change greater than 0.5 degrees celsius. All cases were then divided into incision size to look at the extent to which it impacts on hypothermia. Fifty three cases used small incisions (approximately 15 cm) and had an average temperature drop of 0.37 degrees celsius. Another 23 cases had medium size incisions (approximately 20 cm) and had an average temperature drop of 0.63 degrees celsius. Forty cases used large

incisions (approximately 25 cm) and recorded an average temperature drop of 1.37 degrees celsius. Increasing incision size correlated with an increase in temperature drop ($p>0.01$). Of the 116 cases reviewed, 17 of them did not have any antihypothermic adjuncts used (see figure 1). Without any antihypothermia adjuncts, the results show significant differences in the amount of temperature drop between small incision procedures and large incision procedures. Procedures involving small incisions (15 cm) lost an average of 0.2 degrees celsius for a 150 minute procedure while those with large incisions (25 cm) lost an average of 1.3 degrees celsius for the same duration of procedure. During 27 cases, heated gas humidifiers were used as one of the antihypothermia adjuncts. Temperature drops in this group of patients were significantly smaller than in the group using other antihypothermia adjuncts (see figures 2, 3). Temperatures at the end of the cases tended to increase towards beginning temperatures after 3.5 hours. Twelve out of the total number of cases lost 2 or more degrees celsius (see figure 4).

The use of a warming mattress, warmed IV fluids or a heat and moisture exchanger (artificial nose) were not significantly related to the prevention of

hypothermia. The administration of increasing amounts of intravenous (IV) fluids did not correlate with the incidence of hypothermia or the extent of temperature drop. The amount of blood administered did correlate with extent of temperature change ($p < 0.02$). The more blood that was administered, the greater the temperature change (see figure 5). All blood was administered via blood warmers set between 36 and 37 degrees celsius. There was a significant correlation in the prevention of hypothermia if the anesthetist warmed IV fluids along with heating and humidifying inspired gases ($p < 0.02$). Looking at all the variables; blood loss, IV fluid and blood administration, as they increased, there was a significant positive correlation with temperature decrease ($p < 0.001$). The use of a heat and moisture exchanger alone did not significantly correlate with hypothermia prevention. The length of the surgical procedure was significantly associated with greater temperature decreases ($p < 0.002$).

DISCUSSION

This study confirmed reports by other authors, previously cited, that hypothermia occurs in the majority of PACU admissions. Thus, it continues to be

an area for further concern for the anesthetist, especially when it has been proven to be a preventable surgical/anesthetic consequence. The use of the esophagus as an accurate and precise indicator of core temperature was proven by Cork and his associates.⁴⁹

Maintaining thermal balance in the operative patient involves developing a plan of care that provides antihypothermia adjuncts to counterbalance heat lost through the mechanisms of convection, conduction, evaporation and radiation. The variable that affected heat loss most significantly was incision length. Larger abdominal incisions lose more heat than smaller incisions. This concept is consistent with the fact that the procedures with larger incisions tend to have more of the viscera exposed to the cool ambient air. There is greater moist surface area exposed than when the viscera is kept inside the abdomen and retracted away from the surgical site in cases such as cholecystectomies or abdominal hysterectomies.

Heating and humidifying inspired gases is an effective antihypothermia adjunct by itself or in conjunction with other adjuncts.³⁹ A patient can lose 5.2 kcal per hour and 7.8 ml of water vapor per hour when exposed to an adult semiclosed circle anesthetic

breathing circuit.^{50, 51} This represents approximately 8% of basal heat production of the body. Prevention of this respiratory heat loss has been proven by this study as well as others to significantly reduce temperature decreases in the surgical patient.

The fact that increasing amounts of blood administration correlates with decreasing temperatures in the surgical patient may not be easily explained. It is proposed that blood administration tends to occur more frequently in surgeries with larger incisions or those involving longer periods of time. Both of these factors are significant correlates with temperature drops in the patient. Administered blood, if needed in large amounts, is usually administered at rapid rates that prevent adequate heating by blood warmers.

Common sense would indicate that if one adjunct alone is moderately effective in preventing hypothermia, more adjuncts should be even more effective. This concept is confirmed by this study as well as many others previously cited. The understanding that heat may be lost from the body via more than one mechanism helps the anesthetist to recognize that heat loss can be prevented using several different adjuncts.

Heat loss through convection and conduction can be virtually eliminated by using a heating mattress, covering the patient with at least one warm blanket, warming the ambient environment, and warming intravenous fluids. Radiant heat loss may be only partially minimized by covering the patient and applying radiant heat via lamps. Evaporative heat loss through the airway can be eliminated if heated humidifiers are placed in the anesthetic circuit. Evaporative heat loss through exposed viscera can be partially minimized by using plastic bowel bags and warmed irrigating fluids.

Some areas of heat loss can be completely prevented and others, only partially minimized. With the concerted effort of all participating personnel, thermal balance can and should be maintained in the surgical patient. Certainly, the patient's well being and comfort must be the major reason why perioperative hypothermia should be prevented. For those who do not consider the physiologic and emotional consequences of hypothermia to be of significance, the idea of cost management in the face of DRGs and runaway health care costs may be significant. Conahan and his associates conclude that using antihypothermia adjuncts

significantly reduce the amount of time patients stay in the recovery room which reflects in lower hospital costs.⁵²

RECOMMENDATIONS

Much research has been conducted in the areas of hypothermia and should be continued. Undoubtedly, anesthesiologists are aware of the complications associated with perioperative hypothermia and the cost involvement related to prolonged recovery times due to postoperative hypothermia. The best recommendation would be to communicate this information to department administrators so that funds can be made available to purchase sufficient numbers of antihypothermic adjuncts such as warming blankets for each operating room table, heated humidifiers, radiant heat lamps, and reflective blankets.

Also, it seems prudent to educate the operating room personnel and the surgical staff of the importance of keeping the patient more properly covered during the prepping period. Data suggest that this period of time is where the quickest drop in body temperature occurs.³⁹

Hypothermia can create serious physiologic and emotional consequences in the surgical patient. Prevention is the key principle. Every patient that comes to the operating theater must be provided the best quality of care from all personnel in order to prevent or attenuate adverse consequences related to the procedure. Emphasis is placed on "everybody" because it is not just the responsibility of the anesthetist to prevent hypothermia. The operating room nurses, surgeons and anesthesia personnel must make a concerted effort in providing this kind of optimal care.

Certainly, there are several variables that were not included in the statistical analysis that affect thermal balance in the operative patient. Age is an important determinant of thermal balance. Body surface area also affects thermal balance, especially in pediatrics.

SUGGESTED GUIDELINES

INTRAOPERATIVE

Every patient should be given at least one warm blanket upon entering the O.R. The O.R. temperature should be set at the highest comfortable setting. Warming blankets should be placed on every O.R. table

for all cases. The patient should be covered during induction of anesthesia. Exposure of skin during prepping should be limited to surgical site only. If large areas of skin must be prepped, radiant heat lamps should be used. Blood warmers and heated gas humidifiers must be available in every O.R. Fluid warmers and heated humidifiers should be used on all cases which will have large areas exposed or large cavities entered.

POSTOPERATIVE

All wet linen or clothing should be removed from the patient immediately after initial assessment is completed. All patients should be covered with at least one warm blanket. Patients who are hypothermic should receive warmed IV fluids. Patients with cardiopulmonary disease, at risk for hypothermic sequela should be paralyzed and ventilated with warm humidified gases and actively warmed until core temperature returns to normothermia.

These guidelines are only responsible suggestions and should not be used as absolute care plans. Every patient must have individualized plans of care that extend into the postoperative period in order to optimize the perioperative experience.

SUMMARY

A review of perioperative thermoregulation is presented. This study presents a retrospective review of 116 anesthetic records of abdominal surgery procedures conducted under general anesthesia. Statistical analysis showed that increases in incision length, length of procedure, and the amount of blood administered positively correlated with degree of hypothermia.

The only antihypothermia adjuncts that significantly prevented hypothermia was heated and humidified inspired gases. Combinations of multiple adjuncts also prevented hypothermia. Suggested guidelines to prevent perioperative hypothermia are presented.

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