Maintaining intraoperative normothermia: A meta-analysis of outcomes with costs

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The present study used a meta-analysis to examine 4 questions about intraoperative hypothermia. The questions addressed were as follows: (1) Is the difference in adverse patient outcomes between normothermic and mildly hypothermic patient groups significant across studies and within studies? (2) What is the magnitude of the difference in adverse patient outcomes across studies? (3) What are the costs resulting from the difference in adverse patient outcomes? (4) Does a significant difference exist in effectiveness of modality for maintaining intraoperative normothermia?

The results of this meta-analytic study provide evidence that the difference in adverse patient outcomes between the normothermic and mildly hypothermic patients is significant across studies for all adverse outcomes examined. The magnitude of this difference and the costs resulting from these adverse outcomes are presented. In addition, a significant difference in effectiveness between warming modalities for maintaining intraoperative normothermia was found.

A significant increase in the risk of costly complications occurred when patient temperatures dropped a mean of 1.5°C. For example, patients who become mildly hypothermic are much more likely to receive blood transfusions and to develop infections; both of these outcomes result in increased costs. Minimizing adverse outcomes is critical to cost-effective patient care in today's competitive healthcare environment. The cost of preventing intraoperative hypothermia is much less than the cost of treating the adverse outcomes that affect patients experiencing intraoperative hypothermia.

Meta-analytic results allowed us to conclude that hypothermia averaging only 1.5°C less than normal resulted in cumulative adverse outcomes adding between $2,500 and $7,000 per surgical patient to hospitalization costs across a variety of surgical procedures. In conclusion, patients whose temperatures have been maintained at normal levels during the intraoperative period experience fewer adverse outcomes, and their overall hospital costs are lower. Intraoperative normothermia is maintained more effectively with the use of forced air warming.

Key words: Cost-effectiveness, hypothermia, intraoperative normothermia, meta-analysis, perioperative normothermia.

Introduction

Mild intraoperative hypothermia, or a core temperature of 34°C to 36°C, has adverse consequences reaching far beyond patient discomfort. The resulting complications have been well documented in numerous studies.[1-25] The mild intraoperative hypothermia addressed in the present analysis is unintentional, occurring quite commonly during surgical procedures as a result of numerous factors.[26] Fortunately, it can be prevented easily.[13]

Humans maintain a thermal core, which includes the brain and organs of the chest and abdomen, within a narrow range of temperature (near 37°C), even though they are subjected to large variations in environmental conditions. A large proportion of the total heat produced by a resting human is generated by the organs of the thermal core. Humans not only can produce heat, but they also have the ability under normal conditions to control the rate of heat loss from the body core. Within a narrow environmental temperature range called the thermoneutral zone, the metabolic rate of an endothermic animal is low and does not depend on the environmental temperature.[6,22]

Within this thermoneutral zone, temperature is regulated by autonomic responses that control the heat exchange between the body core and the environment. Vasomotor tone controls the transport of heat from the thermal core to the skin surface. Vasoconstriction reduces heat transfer, and vasodilation increases the transfer. Vasomotor responses will be produced if core temperatures deviate from normal. If core temperature increases, vasodilation results, and if core temperature drops, vasoconstriction results. Decreased core temperature results in an increased metabolic rate to produce more heat. However, humans have only a limited metabolic heat production potential. To increase heat production, humans rely primarily on shivering. Temperature that has increased above the thermoneutral zone results in the dissipation of excess heat by use of evaporative heat loss through sweating.[22]

Hypothermia is a core body temperature of less than 36°C, and *mild hypothermia* is 34°C to 36°C.[6] This condition represents a patient care issue because the intraoperative setting exposes the patient to several factors that contribute to heat loss. Unintentional intraoperative heat loss occurs as a result of low ambient temperatures in the surgical suite, an open exposed wound area, administration or other use of cool fluids, and most important, the compromising effect of general anesthesia on a patient's ability to regulate body temperature by responding to any temperature decreases. The redistribution of body heat from the core to the periphery decreases the core temperature 1.0°C to 1.5°C during the first hour of general anesthesia.[6] Drops in core temperature that have significant impact on patient outcomes can occur during even a short surgical procedure.

Anesthetic agents impair the body's ability to control and conserve heat by inhibiting vasoconstriction and the shivering response. Anesthetics increase the range that will trigger the thermoregulatory defenses to 20 times the normal range of 0.2°C to a 4°C.[6] Nerve blocks prevent the regional activation of sweating, vasoconstriction, and shivering. Spinal and epidural anesthetics cause peripheral inhibition of these defenses due to disruption of nerve conduction to more than half the body.[6]

Maintaining normothermia during surgery is important not only for patient comfort, but also for prevention of the complications that result from hypothermia. These complications have been well documented in numerous studies.[1-23] The complications include reduced resistance to surgical wound infection,[4] protein wasting,[27] decreased synthesis of collagen,[4] reduced platelet function,[28] increased intraoperative loss of blood and need for allogeneic transfusion during elective primary hip arthroplasty,[5] and metabolism of most drugs.[29,30] A prospective randomized study[3] found that a core temperature drop of 1.5°C tripled the incidence of ventricular tachycardia and morbid cardiac events. The duration of postoperative recovery also has been shown to be prolonged by mild hypothermia.[21]

Numerous advances in the knowledge of the process of intraoperative thermoregulation and the technology available for treatment of patients during the intraoperative period provide the ability to maintain normothermia of patients' core temperatures. However, the optimal management of patient core temperature may require new guidelines for the provision of patient care. This is such an important issue that a Consensus Conference on Intraoperative Thermoregulation was convened in February 1998 to develop and evaluate such guidelines. The meeting was attended by experts in anesthesiology, surgery, critical care, malignant hyperthermia, temperature physiology, and research. The organizations participating included the American Society of PeriAnesthesia Nurses, American Society of PeriAnesthesia Nurses Foundation, American Association of Critical Care Nurses, American Association of Nurse Anesthetists, Academy of Medical-Surgical Nurses, American College of Surgeons, American Society of Anesthesiologists, Association of Nurse Executives, Association of Operating Room Nurses, and Malignant Hyperthermia Association of the United States. A task force was assigned the responsibility for developing clinical practice guidelines for the assessment and management of intraoperative thermoregulation.[31]

Patient care delivery models are changing constantly. Changes, which have occurred historically to improve the quality of patient care, have accelerated during the past decade. Unfortunately, some of the more recent changes in patient care delivery models have been driven by findings in studies of costs alone. Today's healthcare environment is in constant flux. Changes have occurred in available technological interventions, administrative systems, clinical environments, patients' demands, and the health insurance industry. These changes necessitate careful analysis of patient well-being in combination with cost-effectiveness.

Information that synthesizes the quality of patient outcomes and costs is important because it enables healthcare practitioners to maintain their decision-making authority for providing optimal patient care. Without data to support decisions about the provision of care that improve the quality of patient outcomes, practitioners increasingly are faced with loss of decision-making authority based on cost-cutting measures alone. The obvious solution it seems, is to provide information on improved patient outcomes and the cost savings that result from the improved outcomes.

The present study of maintaining normothermia during the intraoperative period provides informative data from those outcomes. The literature provides scant information on differences in the cost of care between normothermic and mildly hypothermic patient groups. One goal of the present meta-analysis was to analyze the differences in outcomes across studies between hypothermic and normothermic patient groups. Costs (not charges) were then calculated using average cost data collected from institutions across the United States.

No published quantitative analysis has combined these separate research findings to compare the effect of mild intraoperative hypothermia on either the probability or magnitude of adverse health outcomes. The effect of the rate of hypothermia is not the question addressed in the present study. Rather, the question of interest is "What are the outcomes once the patient has become hypothermic during the intraoperative period?" The goal of the present study was to provide information generalizable to many different surgical situations; therefore, we used the meta-analytic technique, which is defined in the "Methods" section.

Methods

One of the problems with estimating cost differences has been a lack of aggregate data for large numbers of patients on the adverse patient outcomes that result from mild intraoperative hypothermia. Studies frequently present different findings resulting from small sample sizes, different designs, and unique experimental settings. Of the numerous studies of mild intraoperative hypothermia, the majority included fewer than 100 patients. No published quantitative analysis has combined these separate research findings to compare the effect of mild intraoperative hypothermia with the probability or magnitude of the occurrence of adverse health outcomes.

■ *Meta-analysis.* Meta-analysis is designed to synthesize data or evidence across studies to result in population parameter estimates. A meta-analysis uses the results from a large number of studies to answer specific questions quantitatively. The most common use of meta-analysis is to provide information by integrating large amounts of data, most frequently for decision-making applications, such as changes in practice. Kassirer stated that "in the 10 years or so since meta-analysis began to have an impact on the medical literature, dramatic progress has been made in the use of this technique, and the usefulness of the method is generally accepted."[32]

The usefulness of meta-analysis increases when individual studies are very small, i.e., fewer than 100 persons, as is the case in many medical studies. In fact, the results of many diverse smaller studies may reflect the natural heterogeneity of treatment effectiveness found in day-to-day clinical practice.[33] The findings of any one small study may not represent the true population parameters but may result from chance alone. The population parameters of the "mother population" can be estimated by using meta-analysis to integrate all small group findings. In the absence of mega-trials, a well-conducted meta-analysis may reflect the best synthesis of available evidence. Generalizations made from meta-analytic findings have a much sounder basis than those made from single small studies. This is important because, as Tukey[34] states, science typically does not begin with a tidy question, nor does it end with a tidy answer.

The present analysis offers an information base derived from an aggregation of adverse health outcome data available in the literature. The quantitative analysis addresses 4 specific questions:

1. Is the difference in adverse patient outcomes between the normothermic and mildly hypothermic patient groups significant *across* studies and *within* studies?

2. What is the magnitude of the difference in adverse patient outcomes *across* studies?

3. What are the costs resulting from the difference in adverse patient outcomes?

4. Does a significant difference exist in effectiveness of modality for maintaining intraoperative normothermia?

These questions can be answered by analyzing the data from available studies. The choice of measures for the health outcome and for the effect of the intervention on the health outcome was determined by the data available in the literature.[35] Adverse health outcomes were compared by using the clearest measure available: the actual difference in rate of occurrence or effect size. Using the difference in rate of occurrence results in eliminating measurement error from any one study because it affects the treatment and control groups. This measure provides the most meaningful information for decision making because it is generalized most readily.

Individual studies included in the meta-analysis examined the preexisting and comorbid conditions of normothermic and hypothermic patient groups. The two patient groups did not differ significantly on any other measures (eg, age, body surface area, length of anesthesia). Differences between groups in final outcomes were, therefore, attributed to the temperature difference between groups.

The present meta-analysis addressed possible sources of bias when information was available to do so. Threats to internal validity were addressed by controlling for differences in preexisting conditions. We assumed that errors in measurement were random, and, therefore, did not result in biases. We considered this assumption reasonable because of the number of different clinical settings from which data were collected. In addition, all studies were examined carefully to assure that the same data were not used more than once in the meta-analysis, even if the data were published more than once. The population bias threat to external validity must be addressed when the final outcomes are used in decision-making processes by individual clinicians. They must decide whether results of the present meta-analysis are appropriate to generalize to their patient populations.

Different experimental settings and investigators observed varying levels of adverse health outcomes, an expected finding since randomness alone results in some variance in outcomes among settings. Clinicians most likely will be interested in applying the results of the present meta-analysis to patients in settings that differ from those of the experiments analyzed. Therefore, we used the random effects model to perform the meta-analysis on the studies included.

A random effects model can be used to estimate the outcomes that might be observed in new settings (eg, the "next patient") when outcomes may be affected by the randomness between experimental settings. This model assumes that each of the studies that are combined is a random sample from the distribution of true values in the entire population of interest.[36] Support for this assumption is derived from the fact that these studies cover a broad spectrum of clinical settings, practitioner training and specialties, patient groups, and geographical areas. "Heterogeneity of treatment effects across studies is common and should be incorporated into the analysis. The random effects model incorporates this heterogeneity, however small, in the analysis of the overall efficacy of the treatment."[37]

The parameter of interest, the actual difference (effect size) of adverse health outcomes occurring, was calculated with a wider range of uncertainty in the random effects model than with other models. In a statistical sense, this results in the most conservative, or cautious, interpretation of the data available.

Studies included were provided by literature search of several types: computerized search, consulting a librarian specializing in clinical topics, examining reviews, and checking references in trials found. Bibliographies received from well-known research authors in the field of hypothermia were examined to increase coverage. All studies identified in this manner from peer-reviewed journals published in the English language that contained data comparing normothermic and mildly hypothermic patients on one or more of the adverse health outcomes were included. Published refereed abstracts that contained data on one or more of the adverse health outcomes also were included. The inclusion of abstracts addresses, at least in part, the frequently mentioned "file drawer" or publication bias issue.[37-41] More than 200 articles were examined, and only those included in the present report fit the criteria and provided any outcome data.

■ *Search strategy.* Several research strategies were used: standard medical on-line searches, the Cochrane Collaboration's optimal MEDLINE search strategy, manual library searches, consultation with a medical topic specialist librarian, and appropriate topic journal searches. Reference sections and bibliographies of all retrieved articles and refereed proceedings (from professional organizations in which abstracts undergo blinded peer review) were examined for additional studies. Inclusion criteria were as follows:

1. Published or abstracted with data results in the English language between 1989 and 1997.
2. Study reported maintaining normothermia intraoperatively.
3. Temperature change for treatment and control group.
4. Patient population did not include cases of extreme hypothermia.

This strategy yielded 18 published articles with data on adverse patient outcomes.[1-5,7-9,11-20] Summary information about study characteristics is presented in Table 1. All data available for the

Table 1. **Study characteristics***

Study/group	Age (y)	Randomized	Type of surgery	Duration of surgery (min)	Device	Postoperative temperature (°C)
Bush et al[1] (N = 262)		No	Abdominal aortic aneurysm repairs		BH, circ alch	
1 (n = 66)	73.1 ± 1.0			371 ± 14		34.0
2 (n = 196)	70.3 ± 1.3			334 ± 9		36.1
Frank et al[3] (N = 300)		Yes	Abdominal, vascular, thoracic		WT, none	
1 (n = 158)	71 ± 1			204 ± 66		35.5 ± .04
2 (n = 142)	71 ± 1			216 ± 54		36.7 ± 0.5
Frank[20] (N = 74)		Yes	Vascular reconstruction		WT, none	
1 (n = 37)	70 ± 1			300 ± 24		35.3 ± 0.1
2 (n = 37)	69 ± 1			342 ± 18		36.7 ± 0.1
Kurz et al[13] (N = 99)		Yes	Maxillofacial, hip arthroplasty, pelvic or femoral osteotomy		BH, circ water	
1 (n = 49)	54 ± 18			NA		35.4 ± 0.1
2 (n = 50)	50 ± 22			NA		36.7 ± .01
Kurz et al[12] (N = 74)		Yes	Several hour experiment, no surgery		BH, none	
1 (n = 35)	59 ± 14			210 ± 78		NA
2 (n = 39)	57 ± 15			198 ± 66		NA
Kurz et al[12] (N = 200)		Yes	Colon resection		BH, none	
1 (n = 96)	59 ± 14			213 ± 65		34.7 ± 0.6
2 (n = 104)	61 ± 15			203 ± 65		36.6 ± 0.5
Murat et al[14] (N = 51)		Yes	Posterior spinal fusion		BH, none	
1 (n = 26)	14.9 ± 2.2			348 ± 120		34.8 ± 0.6
2 (n = 25)	14.7 ± 1.7			288 ± 72		35.6 ± 0.5
Onik et al[15] (N = 72)		No	Hepatic cryosurgery		BH, none	
1 (n = 28)	NA			NA		34.2 ± 0.2
1 (n = 44)	NA			NA		35.3 ± 0.2
Borms et al[8] (N = 20)		Yes	Total hip arthroplasty		BH, Sblkt	
1 (n = 10)	68 ± 10			135		35.4 ± 0.6
2 (n = 10)	69 ± 5			135		36.4 ± 0.6
Smith et al[18] (N = 127)		Yes	Arthroscopic surgery		BH, none or Cblkt	
1 (n = 58)	34 ± 1.9			53 ± 2.6		34.9 ± 0.3
2 (n = 69)	35 ± 1.5			56 ± 1.9		36.1 ± 0.1
Russell and Freeman[17] (N = 40)		Yes	Liver transplantation		Eblkt, Ablkt, WT	
1 (n = 20)	45 ± 8			324 ± 49		34.9 ± 0.4
2 (n = 20)	46 ± 8			315 ± 58		36.8 ± 0.3
Ouellette[16] (N = 60)		Yes	Lumbar laminectomy		BH, hum, Sblkt	
1 (n = 48)	54 ± 17			126 ± 34		35.7 ± 0.6
2 (n = 12)	56 ± 17			117 ± 27		36.3 ± 0.4
Chandon et al[9] (N = 18)		Yes	Knee arthroscopy		BH, Eblkt, none	
1 (n = 9)	67 ± 4			60		35.3 ± 0.2
2 (n = 9)	67 ± 4			60		36.2 ± 0.1
Camus et al[2] (N = 22)		Yes	Abdominal		BH, BH+, none	
1 (n = 11)	51.4 ± 4			1,184 ± 13		34.6 ± 0.3
2 (n = 11)	46 ± 4			195 ± 134		36.4 ± 0.1
Bennett et al[7] (N = 30)		Yes	Hip arthroplasty		BH, Sblkt	
1 (n = 15)	74 ± 7			150 ± 36		NA
2 (n = 15)	73 ± 7			138 ± 18		NA
Schmied et al[5] (N = 37)		Yes	Hip arthroplasty		BH, none	
1 (n = 18)	63 ± 10			87 ± 24		35.0
2 (n = 19)	63 ± 10			85 ± 31		36.6
Kelley et al[11] (N = 22)		Yes	Liver transplantation		BH, many	
1 (n = 11)	NA			NA		34.7 ± 0.2
2 (n = 11)	NA			NA		35.6 ± 0.2
Stapelfeldt et al[19] (N = 67)		No	Liver transplantation		No method	
1 (n = 33)	NA			60		≥35
2 (n = 34)	NA			60		<35
Total (N = 1,575)						
1 (n = 728)						
2 (n = 847)						

*Group 1 is the hypothermic group, group 2, normothermic. Data are given as mean or mean ± SD.

Ablkt—air blanket; NA—not available; BH—Bair Hugger (Augustine Medical, Inc., Eden Prairie, Minn); BH+—Bair Hugger (plus cotton blanket); Cblkt—cotton blanket; Sblkt—space blanket; Eblkt—electric blanket; circ—circulating water or alcohol (alch); WT—Warm Touch, Mallinckrodt (St. Louis, Mo), forced air; hum—humidified air or humidistat

Table 2. **Effectiveness of maintaining normothermia: Continuous outcomes***

Outcome of interest	Hypothermic group	Normothermic group	Effect size, ie, difference	Percentage decrease	No. of studies	No. of patients
Red blood cells (units)	1.167 (0.0867)	0.1170 (0.0247)	1.05† (0.0315)	85.7	5	859
Plasma (units)	1.40 (0.2031)	0.30 (0.092)	1.10† (0.0189)	78.6	1	262
Platelets (units)	0.90 (0.0559)	0.20 (0.0113)	0.70† (0.0189)	77.8	1	262
Length of stay (d)	19.44 (0.1600)	11.77 (0.1047)	7.67† (0.2059)	40.0	3	762
Intensive care unit time (h)	9.70 (0.1712)	5.51 (0.0863)	4.19† (0.1561)	43.2	2	462

*Data are given as mean (SD) for the control and treatment groups.
†$P<0.05$; significant between normothermic and hypothermic groups.

Table 3. **Effectiveness of maintaining intraoperative normothermia***

Outcome of interest	Hypothermic group*	Normothermic group*	Effect size, % (hypothermic/ normothermic, %)	Decrease in probability of occurrence (%)	No. of studies	No. of patients
Infection	19.07 (3.97)	6.95 (2.15)	12.12† (3.66)	63.57†	2	258
Myocardial infarction	4.07 (1.34)	2.30 (0.88)	1.77† (0.78)	43.59†	2	562
Transfused (probability)	24.19 (4.57)	14.43 (3.14)	9.76† (3.12)	40.36†	2	237
Ventilation (mechanical)	18.62 (3.17)	12.20 (2.33)	6.42† (2.77)	34.46†	2	411
Mortality	6.01 (1.73)	2.70 (0.85)	3.31† (1.47)	55.04†	2	562

*Data are given as mean (SD) for the control and treatment groups.
†$P<.05$; significant between normothermic and hypothermic groups.

clinical markers were extracted from articles. Individual authors were contacted if standard deviations or other measures necessary for the meta-analysis were not published in original documents.

Results

Table 2 gives several specific adverse effects of hypothermia that relate to excessive bleeding and the resultant blood therapy, as well as length of stay in intensive care unit and overall hospital stay. In these studies, the number of units of red blood cells, plasma, and platelets needed for transfusion for surgical patients was increased significantly ($P < .05$) for the hypothermic group. As body temperature drops, the number of circulating platelets decreases, and their function is inhibited progressively. A 2°C drop in temperature produces a 100% increase in bleeding time. Hypothermia also slows the enzyme-driven clotting cascade and activates the fibrinolytic system.[23,42-44] These adverse effects increase the chance that allogeneic blood may be needed by the hypothermic patient. The use of allogeneic blood has inherent risks, including infection, transfusion reaction, and immune suppression. In addition, the religious beliefs of some patients dictate that blood components never be used.[45]

The importance of maintaining normothermia during the operative experience is clear. An analysis of these studies showed not only that patients in the normothermic group required fewer transfusions of blood components than patients in the hypothermic group, but also that the length of hospital stay in days and intensive care unit time in hours was significantly less ($P < .05$). Patients in whom normothermia was maintained during surgery required 86% fewer units of red blood cells, 79% fewer units of plasma, and 78% fewer units of platelets than patients in the hypothermic group. Patients in the normothermic group were discharged from the hospital 40% earlier and spent 43% less time in the intensive care unit.

Table 3 gives the significant ($P < .05$) difference between hypothermic and normothermic groups in relation to infection, myocardial infarction, the probability of receiving transfusions, mechanical ventilation, and mortality. In all instances, the hypothermic groups had a significantly greater probability that each adverse event would occur. Even mild hypothermia decreases the migration of

Table 4. Lowest core temperature reached: Forced air warming versus alternative therapies*

Alternative treatment	Control group (°C)	Treatment group: forced air warming (°C)	Difference (°C)	*P*	No. of patients	No. of studies†
All studies (combined)	34.49 (0.0173)	35.99 (0.0040)	1.50‡	1.5×10^{-15}	1,575	20
Passive (no treatment)	35.01 (0.0308)	36.25 (0.0172)	1.24‡	1.6×10^{-12}	779	9
Circulating water blanket	34.30 (0.1673)	36.00 (0.0040)	1.70‡	3.1×10^{-9}	99	1
Humidified air	35.50 (0.1616)	36.20 (0.1277)	0.70‡	0.0005	36	1
Space blanket	35.50 (0.2151)	36.40 (0.2510)	0.90‡	0.0009	44	2
Method not specified	34.20 (0.0218)	35.40 (0.0197)	1.20‡	2.1×10^{-14}	648	7

*Data are given as mean (SD) for the control and treatment groups.
†18 published papers are included; more than 1 study is included in 2 of the articles, therefore, 20 studies are included.
‡$P < .05$; significant between treatment and control groups.

polymorphonuclear leukocytes to infection sites and impairs cell-mediated immunity. Mild hypothermia at the time of the bacterial challenge suppresses the immune response and increases the incidence of infections.[4,46-49] Intraoperatively, increased conduction disturbances and a negative inotropic effect caused by cold are compounded by inhalation anesthetics. It is hypothesized that the adrenergic and metabolic response to hypothermia, ie., shivering, which increases oxygen consumption and release of norepinephrine, which causes systemic vasoconstriction, upsets the balance between myocardial oxygen supply and demand and leads to myocardial ischemia or infarction.[1,3,10,50-52] The adverse effects of cold on intraoperative blood loss and coagulopathy have been discussed. In a study conducted in the intensive care unit, 24% of the patients who remained hypothermic for 2 hours died compared with 4% of patients who remained normothermic.[1,53,54] When patients were kept normothermic, nosocomial wound infections occurred 64% less often, myocardial infarction rates were 44% lower, and the probability of needing a transfusion was 40% less. Patients in normothermic groups were 34% less likely to need mechanical ventilation and had a 55% lower mortality rate.

Table 4 provides the results of the meta-analysis of effectiveness of different patient temperature management strategies. For all studies combined, the lowest core temperature reached was, on average, 1.5°C warmer for the forced air group. Forced air warming was more effective than all other methods studied for maintaining intraoperative patient temperatures. The alternative methods included passive warming or no treatment, circulating water blanket, humidified air, space blanket, and methods unspecified, such as warmed operating rooms. All alternative methods of patient warming with data available in the literature were included.

Discussion

The evidence provided by the present meta-analysis answers the questions posed. The difference in adverse patient outcomes between normothermic and mildly hypothermic patient groups was significant across studies. The significance and magnitude of this difference in adverse patient outcomes across studies is presented in Tables 2 and 3. The costs resulting from these differences in adverse patient outcomes are presented in Tables 5

Table 5. Cost-effectiveness of maintaining normothermia: High end cost assumptions*

Outcome of interest	Effect size (%)	Unit cost ($)	Cost savings ($)
Red blood cells (units)	1.05	218.50	229.43
Plasma (units)	1.10	69.91	76.90
Platelets (units)	0.70	54.38	38.07
Length of stay (d)	7.67	600.00	4,602.00
Intensive care unit time (h)	4.19	75.00	314.25
Infection (%)	12.12	14,000.00	1,696.80
Myocardial infarction (%)	1.77	5,097.60	90.23
Transfused (%)	9.67	2.00	0.20
Ventilation (%)	6.42	400.00	25.68
Total cost savings	–	–	**7,073.56**
After mortality	–	–	6,839.55

*Per patient basis

Table 6. Cost-effectiveness of maintaining normothermia: Low end cost assumptions*

Outcome of interest	Effect size (%)	Unit cost ($)	Cost savings ($)
Red blood cells (units)	1.05	112.00	117.60
Plasma (units)	1.10	65.00	71.50
Platelets (units)	0.70	54.38	38.07
Length of stay (d)	7.67	200.00	1,534.00
Intensive care unit time (h)	4.19	25.00	104.75
Infection (%)	12.12	4,500.00	545.40
Myocardial infarction (%)	1.77	3,823.33	67.67
Transfused (%)	9.76	0.75	0.07
Ventilation (%)	6.42	250.00	16.05
Total cost savings	–	–	**2,495.11**
After mortality	–	–	2,412.57

*Per patient basis

and 6. The significant difference in effectiveness of warming modalities for maintaining intraoperative normothermia is presented in Table 4.

The present meta-analysis of 20 studies (in 19 articles[1-5,7-9,11-20]) with a combined total of 1,575 patients provides evidence that the patients treated with forced air warming leave surgery with temperatures 1.5°C higher, on average, than those treated with other modalities. Maintaining normothermia decreases the risk of adverse outcomes and saves time and money for patients, providers, and payers.[1-21] Table 4 shows that in 20 studies,[1-5,7-9,11-20] forced air warming was more effective at maintaining normothermia than other warming modalities, whether passive (space blanket)[7,16] or active (circulating water mattress[13] or heated humidified air[16]). Clearly, the warming modality selected has a major effect on patient outcomes and costs.

Until recently, patients were allowed to become hypothermic in the operating room and were given cotton blankets, usually preheated, to counter the intense shivering often experienced after surgery. Cotton blankets produce only a small reduction in heat loss. The sensation of warmth, even when blankets are heated, dissipates quickly. Studies show that other passive modalities are essentially equal in that they may stop further temperature decreases, but they are ineffective at restoring warmth to the body core.[54,55] Other active modalities also cause problems. Circulating water mattresses are cumbersome, and the combination of heat and pressure from the weight of the patient's body on the mattress increases the risk for burns.[55] Fluid warming is effective when used with forced air warming, but it is insufficient on its own to prevent hypothermia or to restore normothermia expeditiously.[13,17-19]

During the past decade, these conventional, but ineffective, modalities have given way to widespread use of forced air warming. Forced air warming is used in more than two thirds of U.S. acute care hospitals and a growing number of surgical centers and outpatient facilities. Numerous studies show that forced air warming decreases the risk of adverse outcomes, resulting in decreased costs incurred by patients, healthcare providers, and third-party payers.[1-5,7-9,11-20]

The present meta-analysis did not address patient comfort. It is very difficult to derive cost figures for patient comfort even though most care providers believe the benefit of keeping patients normothermic should be apparent. There are many possible sources of increased costs when patients experience discomfort; some possibilities are increased use of pain medications, increased requirements for nursing intervention, and a negative effect on the institution's reputation. Patients who experience fewer adverse outcomes are not as ill and have a hospital experience that includes fewer invasive procedures. These same patients also are most likely to need more resources, and, therefore, they incur more costs during hospitalization. Increased levels of resource use that result from an increase in adverse outcomes is partially reflected in the cost data presented in Tables 5 and 6.

Patients who require additional and otherwise unnecessary healthcare interventions due to ineffective temperature management may be less satisfied. Most published studies of patient satisfaction resulting from hypothermia have been conducted during the postoperative period. They do not publish information on preoperative temperature (ie, intraoperative temperature change cannot be conducted) nor information on adverse outcomes that develop.

Implications for future research

The results of the present meta-analysis reveal several issues related to inadvertent intraoperative hypothermia that require additional research. The most striking is that the majority of the studies on hypothermia do not include the final end points or patient outcomes. A plethora of studies examined and reported temperature changes and the physiologic mechanisms causing the changes. Far fewer studies examined or reported the effect of this temperature change on the patient in terms of final end points or outcomes. Important information for patients and medical decision makers alike would be provided if quantitative information about the effect of hypothermia on adverse outcomes was addressed. Some examples of these outcomes are probability of transfusion, use of blood products, probability of myocardial infarction, and length of stay. Patients and their families are able to understand these outcome measures. Healthcare managers without education in healthcare fields also may understand these more readily, particularly when costs of these adverse outcomes are included.

Patient comfort and satisfaction and its possible significant effect on costs and outcomes basically has not been addressed in the literature. A study that quantifies the correlation between patient comfort and expressed satisfaction with adverse outcomes and the costs of the outcomes would provide valuable information for care providers and patients. Nowhere does the literature specifically quantify the additional resources used when certain passive forms of warming are used to attempt to maintain normothermia. Even with the use of continually warmed cotton blankets, labor is involved, as are utility costs to heat the blankets. The labor of care providers most often has been discounted as if it had no cost.

Accurate cost information is invaluable to informed decision-making processes in today's healthcare market, as many decisions may be made based on costs of equipment, technology, or labor alone. Research providing complete and accurate cost information and linking patient comfort with the cost of outcomes would offer care providers data to provide the best care, in terms of patient's perceptions and cost-effectiveness, possible for their patients. Such data would provide valuable information to nonhealthcare professionals making decisions about the process and method of patient care provided.

Conclusion

The present meta-analysis allowed us to conclude that hypothermia averaging only 1.5°C less than normal resulted in adverse outcomes that negatively affected the quality and even the length of patients' lives. These cumulative adverse outcomes added between $2,500 and $7,000 (depending on cost assumptions; refer to Tables 5 and 6) per surgical patient to hospitalization costs across a variety of surgical procedures. Patients in whom normothermia has been maintained during the intraoperative period experience fewer adverse outcomes with a resulting decrease in costs. Intraoperative normothermia is more effectively maintained by using forced air warming.

Note: Specific equations and functional forms used to produce the parameter estimates and the list of articles reviewed but not included because of a lack of outcome data are available on request. Write to Christine Brown Mahoney, RN, PhD, MS; HR/IR Dept., Room 3-285; Carlson School of Management; 321 19th Ave. South; Minneapolis, MN 55455 or email (cmahoney@csom.umn.edu).

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