Normothermia is protective during infrarenal aortic surgery

James R. Elmore, MD, David P. Franklin, MD, Jerry R. Youkey, MD, Jess W. Oren, MD, and **Carolin M. Frey, PhD,** *Danville, Pa*

Purpose: **Mild hypothermia has been suggested to be protective against tissue ischemia during aortic operations. However, recent studies have documented detrimental cardiac effects of hypothermia during a variety of operative procedures. The influence of different warming methods and the impact of hypothermia during standard aortic procedures was assessed.**

Methods: **One hundred patients who underwent repair of infrarenal aortic aneurysms or aortoiliac occlusive disease were prospectively randomized into 2 groups, receiving either a circulating water mattress or a forced air warming blanket. Adjuvant warming methods were standardized. The day before surgery, 48-hour Holter monitors were applied and interpreted by a cardiologist blinded to the treatment. Randomization resulted in equivalent groups with regard to patient history, indications for surgery, body mass index, length of surgery, and fluid requirements.**

Results: **Core temperatures were significantly warmer during surgery (36.3°C ± 0.7°C vs 35.4 ± 0.8°C) and after surgery (36.4°C ± 0.7°C vs 35.6°C ± 0.9°C) in patients with forced air warming ($P < .001$). The circulating water mattress group had significantly more metabolic acidosis perioperatively ($P = .03$). Postoperative length of stay, cardiac complications, and death rates were not significantly different. Subgroup analysis of 83 aneurysm patients comparing normothermia with hypothermia (temperature less than 36°C) on arrival to the recovery room identified decreased cardiac output ($P = .02$), thrombocytopenia ($P = .02$), elevated prothrombin time ($P = .04$), and inferior Acute Physiology and Chronic Health Evaluation (APACHE) II scores ($P < .001$) in the hypothermic group. Holter analysis revealed more sinus tachycardia (ST) segment changes and ventricular tachycardia in hypothermic aneurysm patients ($P = .05$).**

Conclusion: **Patients treated with forced air blankets had significantly less metabolic acidosis and were kept significantly warmer than those treated with circulating water mattresses. Patients with aneurysms that were kept normothermic had a significantly improved clinical profile, with fewer cardiac events on the Holter recordings. We therefore conclude that (1) normothermia is protective for infrarenal aortic surgical patients; and (2) forced air warming blankets provide improved temperature maintenance compared with circulating water mattresses. (J Vasc Surg 1998;28:984-94.)**

Aortic reconstruction for abdominal aortic aneurysms (AAAs) and aortoiliac occlusive disease results in tremendous fluid shifts that lead to hypothermia during lengthy operations. During these procedures, it has been traditional to attempt to maintain body temperature with a circulating water mattress, airway heating units, and intravenous fluid warmers. Despite this treatment, patients frequently become hypothermic until they gradually rewarm postoperatively.

The hypothermia that typically develops during aortic operations has been suggested to be protective against tissue ischemia and has therefore been thought to be potentially beneficial to patients by decreasing tissue metabolic rate and oxygen consumption.[1] However, recent studies have documented detrimental cardiac effects of hypothermia during a variety of operative procedures.[2-5] Hypothermia also results in peripheral vasoconstriction aggravating

From the Section of Vascular Surgery, Section of Cardiology (Dr Oren), and Section of Biostatistics (Dr Frey), Geisinger Medical Center, Penn State Geisinger Health System.

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Reprint requests: James R. Elmore, MD, Section of Vascular Surgery, Geisinger Medical Center, 100 North Academy Dr, Danville, PA 17822-2150.

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metabolic acidosis, leads to coagulopathies,[6,7] and shifts the oxygen-hemoglobin dissociation curve.[8] During rewarming, shivering frequently develops in patients, resulting in marked increases in metabolic rate and oxygen consumption aggravating cardiac ischemia.[9]

Because the largest body surface available for heat transfer during abdominal surgery is the patient's back, traditional methods of temperature maintenance have relied on the use of a circulating warm water mattress. A recent development, the forced air warming blanket, has been shown to be an improved method of heat transfer perioperatively, despite the smaller body surface accessible for application of the blanket during abdominal surgery.[10] The hypothesis that the forced air warming blanket would be a superior method of intraoperative warming for patients undergoing elective aortic surgery compared with a circulating water mattress was tested. A secondary aim concerned comparison of warming groups with respect to the occurrence and duration of cardiac ischemia and ventricular tachycardia identified by Holter monitoring, based on the premise that these silent events are predictive of clinically significant cardiac events.

PATIENTS AND METHODS

Before patient enrollment, the Geisinger Institutional Research Review Board approved the protocol and informed consent process. Written informed consent was obtained from all patients. Data were collected prospectively.

All patients undergoing elective infrarenal aortic surgery at the Geisinger Medical Center in Danville, Pa, from July 1994 to October 1997 were invited to participate in this research study. Patients undergoing suprarenal aortic surgery or renal artery revascularization were excluded. Patients with aortoiliac occlusive disease and infrarenal aneurysms were included.

Patients were randomized to receive either a circulating water mattress or forced air warming blanket, based on a computer-generated random list that was consulted immediately before each surgery. Preoperatively, patients were covered with warm cotton blankets. The operating room temperature was set at 68°F during all cases. All patients received inhaled gases warmed with the humidifier set at 38°C and received warmed fluids intravenously. Patients assigned to the circulating water mattress (Aquamatic K Thermia American Hospital Supply Corp, Cincinnati, Ohio) had the heating unit temperature set at the maximum setting of 41°C. Patients assigned to the forced air warmer (Bair Hugger, Augustine Medical, Eden Prarie, Minn) had application of an upper body blanket with the temperature set at high until the patient's temperature reached 37.5°C, and then the blanket was adjusted to medium to maintain this body warmth.

Swan-Ganz catheters were inserted in all patients, and core temperatures were recorded from these catheters during the surgical procedure. All patients received general anesthesia during the surgical procedure and an epidural catheter for postoperative pain management. Surgical procedures were transperitoneal in 95% of patients. Length of surgery and fluid resuscitation were recorded. Postoperatively, the patients with forced air warmers continued to be warmed with these blankets if the body temperature was less than 36.5°C. Patients assigned to the water circulating mattress group were covered with warm cotton blankets in the recovery room.

Body temperature was recorded at the time of induction, before aortic cross-clamp release and during closure of the surgical wound. Temperatures were also recorded on arrival at the recovery room, 1 hour later, and the next morning. In addition, cardiac output, systemic vascular resistance, heart rate, and blood pressure were recorded at each of the same time points. Arterial blood gas analysis and lactate levels were also obtained at these same intervals, except only 1 sample was obtained in the recovery room. A common femoral venous blood gas with lactate level was obtained immediately on aortic clamp release and reperfusion of the first lower extremity. Prothrombin time, partial thromboplastin time, and a complete blood count were obtained in the recovery room and the morning after surgery. APACHE II scores were calculated upon arrival in the recovery room and the next morning.[11]

Cardiac ischemia was monitored by the application of a Holter monitor the day before surgery. Holter monitoring was continued for a maximum of 48 hours, including a full 24 hours postoperatively. Patients were excluded from this study if they had a bundle branch block ($n = 12$), underlying pacemaker ($n = 5$), atrial fibrillation ($n = 6$), or malfunctioning or non-interpretable Holter recording ($n = 17$). The cardiologist who interpreted the Holter recordings was blinded to the warming method of each patient. Standard guidelines for defining ST segment events, which require at least 1 mm of depression or at least 2 mm of elevation, were used. Both the number of episodes and the total duration of each ischemic event was recorded. An episode of ventricular tachycardia was defined as 5 or more complex beats with a rate of greater than 100 per minute.

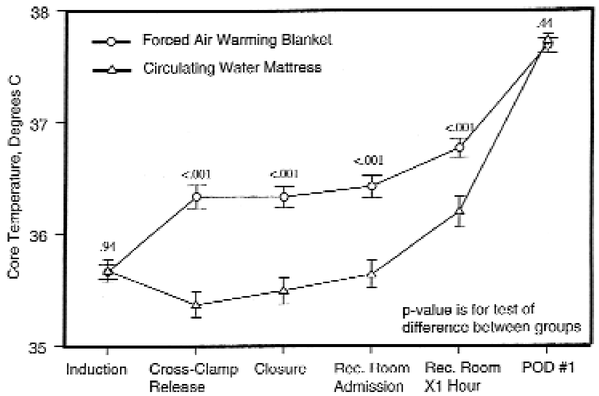

Fig 1. Mean core temperature in the 100 patients. Patients receiving the forced air warming blanket had significantly higher temperatures at all time points, except at baseline and the morning after surgery.

Ventricular tachycardia during Swan-Ganz catheter insertion was excluded in the analysis.

A postoperative cardiac event was defined as angina, myocardial infarction (MI), cardiac arrest, unstable ventricular tachycardia, or congestive heart failure (CHF). MI was defined as non-Q wave or Q wave infarction, based on electrocardiograms obtained immediately after surgery and for the first 2 postoperative days. Creatinine phosphokinase isoenzymes (CPK-MB) were measured immediately postoperatively and then every 8 hours, for 3 samples. CPK-MB was considered diagnostic for MI when the total CPK and the relative index were both higher than the reference range. The definition of significant angina for inclusion as a complication required a duration of at least 10 minutes and being unresponsive to initial sublingual nitroglycerin therapy. CHF was diagnosed when clinical symptoms of dyspnea associated with severe pulmonary edema were found by means of a chest radiograph. Mild or moderate fluid overload was not tallied as an episode of CHF. Refractory ventricular tachycardia was recorded when the patient was hemodynamically unstable or required cardioversion. This clinical definition of refractory ventricular tachycardia was distinct from the definition that was used for the Holter analysis.

Past medical history, indications for surgery, body mass index, preoperative dobutamine stress echocardiographic results, and length of stay were analyzed. All postoperative complications were recorded. Outpatient charts were reviewed within 3 months after surgery to identify all late wound infections. Infections were defined by the presence of either purulent drainage or cellulitis.

This research study was planned to include a total of 100 subjects, based largely on power analysis. Pilot data from 16 patients provided a standard deviation of 0.6°C in measurement of core temperatures during surgery. The power to detect a 0.5°C temperature difference between the 2 warming method groups at any single time point with 100 subjects and a 0.05 alpha-level was estimated to be 98%. To accommodate multiple *t* tests of group difference in temperature at each of 6 time points, a Bonferroni correction with an adjusted alpha-level of $0.05/6 = 0.008$ for each test was used. No further attempt was made to control test-wise alpha-levels for the numerous secondary and exploratory tests conducted. The evaluation of secondary endpoints had nearly 100% acquisition of all data points, except for preoperative dobutamine stress echocardiography (84%) and recovery room cardiac output (80%). Study power was expected to be less than 80% for detecting differences in secondary end points defined by means of the incidence of electrocardiographic changes of the same magnitude as previously reported.[2] However, these secondary end points remained of interest.

SAS, Inc, (Cary, NC) version 6.12 was used for statistical analyses. Group differences between binary variables were summarized by frequencies and compared with χ^2 or Fisher exact test if any cell frequencies were 5 or less. Group differences for continuous valued variables, except as follows, were summarized with means and standard deviations (as displayed in tables and figures) and compared with the 2-sample *t* test. Postoperative length of hospital stay, Apache II scores, cardiac output, platelet count, and prothrombin time were summarized with medians with group differences compared by the Wilcoxon 2-sample test.

Analyses were repeated after defining normothermia as a temperature of at least 36°C on a patient's admission to the recovery room. This threshold was chosen because it is the generally accepted definition of hypothermia[1] and evenly divided the patients into 2 groups. To ensure greater homogeneity of subjects in this post-hoc analysis, only those subjects undergoing AAA surgery were included.

RESULTS

Outcomes for randomized aneurysm and occlusive patients. Patients randomized to the 2 warming groups were equivalent in age, medical history, preoperative dobutamine stress echocardiography, indication for surgery, body mass index, length of surgery, and fluid requirements (Table I). The duration of Holter monitoring in the 2 groups was

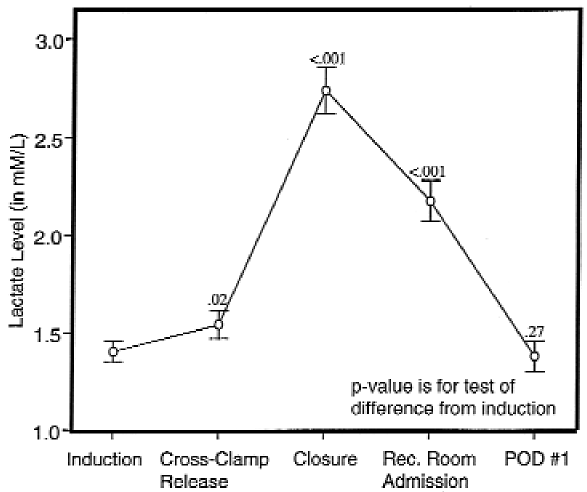

Fig 2. Lactate levels of the 100 patients. Lactate levels were not significantly different between the 2 groups, and therefore, the data are combined for clarity. There was a significant incidence of lactic acidosis compared with baseline.

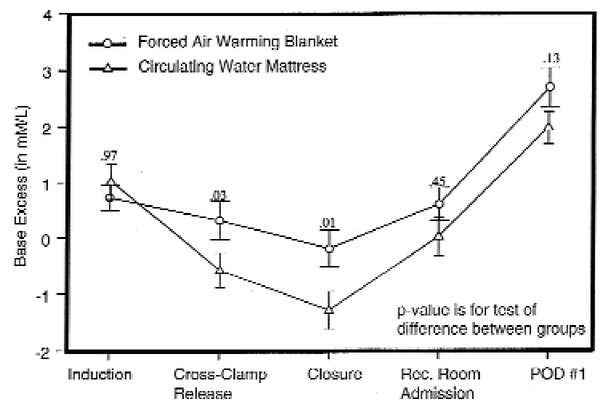

Fig 3. Metabolic acidosis in the 100 patients. There was significantly more metabolic acidosis in those patients with a circulating water mattress, as reflected by the negative base excess values.

similar. The incidence of preoperative ST changes or ventricular tachycardia was not significantly different between the 2 groups (Table I).

At all time points, patients receiving the forced air warming blankets were significantly warmer than patients receiving a circulating water mattress ($P <$ .001), except at induction and the morning after surgery (Fig 1). The 2 groups began surgery at the same hypothermic temperature of 35.7°C. During the surgical procedure, patients in the forced air warming blanket group experienced increasing temperatures after induction (Fig 1). This contrasts with patients in the circulating water mattress group, who had further decline in temperature only to eventually rewarm in the recovery room. On admission to the recovery room, mean core temperature was 36.4°C in the forced air warming blanket group, compared with 35.6°C in the circulating water mattress group.

Mean lactate levels were not significantly different between the 2 groups, and therefore, the results are combined in Fig 2. There was a significant development of lactic acidosis during the procedure in all 100 patients. The circulating water mattress group had significantly more metabolic acidosis perioperatively (P = .03), as displayed in Fig 3. The remaining variables were obtained in the arterial blood gas, and venous blood gas samples were not significantly different between the 2 groups. Cardiac output and systemic vascular resistance were equivalent between the 2 groups. Cardiac output ranged from 4.8 to 5.8 L/min, and systemic vascular resistance ranged from 1096 to 1288 dyne sec/cm^{-5} at the different time points.

Incidence of postoperative clinical complications and length of stay were not significantly different between the 2 groups (Table II). The causes of the deaths were liver failure and a stroke after respiratory arrest. The 2 cardiac complications were CHF and a non-Q wave MI (Table II).

Postoperative Holter recordings revealed no statistically significant difference in ST segment analysis and ventricular tachycardia between the 2 groups, although there were more silent cardiac events in the water mattress group (TableII). Median APACHE II scores were not significantly different between the 2 groups in the recovery room or the morning after surgery (Table II). Superficial postoperative wound infections were similar in the 2 groups and occurred in 3 patients in the forced air group and in 1 patient treated with the water mattress (Table II). There were no differences in coagulation factors between the 2 groups.

Outcomes for normothermic vs hypothermic aneurysm patients. Subgroup analysis of the 83 patients with aneurysms was performed comparing normothermia with hypothermia (temperature less than 36°C) on arrival at the recovery room. These patients were not analyzed as to their method of warming, but as to their ultimate temperature at the time of arrival at the recovery room. The temperature of 36°C was chosen as the breakpoint, because this is the generally accepted definition of hypothermia and evenly divided the patients into 2 groups.

A comparison of baseline values for normother-

Table I. Clinical variables and preoperative Holter analysis in 100 randomized patients

Clinical variables	*Forced air warmer (n = 50)*	*Water mattress (n = 50)*	*P value*
Age, years	68 ± 6	68 ± 8	.74
Male, %	86	84	.78
Aneurysm surgery, %	80	86	.42
Weight, kg	82 ± 18	80 ± 16	.64
Body mass index	27 ± 5	27 ± 4	.58
History of angina, %	30	24	.50
History of myocardial infarction, %	34	22	.18
History of coronary revascularization, %	20	18	.80
EKG with Q waves, %	26	24	.82
Diabetes, %	8	8	1.0
Smoking history, %	96	92	.68
Preoperative dobutamine echo			
Total echos, *n*	43	41	N/A
Resting ejection fraction, %	52 ± 9	54 ± 8	.36
Peak ejection fraction, %	62 ± 13	64 ± 11	.47
Fixed defect, %	53	41	.27
Inducible defect, %	23	29	.53
Preoperative Holter analysis			
Monitoring, hours	19 ± 4	19 ± 3	.41
Ventricular tachycardia	2	6	.62
Sinus tachycardia depression/elevation, %	18	12	.40
Ventricular tachycardia or sinus tachycardia change, %	21	14	.37
Operative procedures			
Length of surgery, hours	4.2 ± 1.2	4.0 ± 1.1	.57
Cell saver, mL	837 ± 598	807 ± 602	.80
Crystalloid, mL	5839 ± 1471	5668 ± 1849	.61

N/A, Not applicable.

Table II. Clinical outcome and Holter results in 100 randomized patients

Clinical outcome	*Forced air warmer (n = 50)*	*Water mattress (n = 50)*	*P value*
Cardiac complications, %	4	0	.49
Death, %	4	0	.49
Cardiac complication or death, %	8	0	.12
Postoperative median ICU stay, days	2	2	.70
Postoperative median length of stay, days	5	5	.66
APACHE II score: Recovery room	7	8	.28
APACHE II score: Postoperative day 1	6	6	.88
Wound infections, %	6	2	.62
Postoperative Holter analysis			
Monitoring, hours	24 ± 4	24 ± 3	.44
Ventricular tachycardia, %	6	14	.32
Sinus tachycardia depression/elevation, %	28	38	.29
Ventricular tachycardia or sinus tachycardia changes, %	35	45	.30

mic vs hypothermic patients appears in Table III. Patients in the hypothermic group were significantly older, but other clinical parameters and preoperative Holter results were similar between the 2 groups (Table III). As expected, more patients in the normothermic group were treated with the forced air warming blanket (Table III). Patients were also evaluated based on the specific warming method used and their ultimate temperature with regard to body mass index and body weight. Within a specific warming method, no statistical difference could be identified between body mass data and ultimate temperature. For example, patients in the forced air warming group who were hypothermic at the end of surgery were not statistically thinner patients (P = .41). Similarly, the patients in the standard water mattress group who were ultimately normothermic at the end of surgery were not statistically heavier (P = .34).

Fig 4 shows the mean temperature between these 2 groups at the 6 time points. There were significant differences in body temperatures throughout the procedure and in the recovery room. The temperatures were significantly different even at the beginning of surgery.

Holter monitoring (Table IV) revealed a combined higher incidence of ST changes and ventricular tachycardia in the hypothermic group (48% vs 27%, *P* = .05). Median APACHE II scores were significantly lower for the hypothermic patients in the recovery room and even the next morning. The difference in the recovery room could be related to differences in body temperature that are part of the APACHE II score. However, the morning after surgery, body temperatures were not significantly different, and therefore, the lower APACHE II score reflects other physiologic changes that are occurring in these hypothermic patients. There were no cardiac complications or deaths in the normothermic group. There was 1 death, but no cardiac complications, in the hypothermic group (Table IV). Median length of stay was not significantly different between the 2 groups. Other parameters that were obtained at the time of admission to the recovery room identified a decreased cardiac output (5.0 vs 6.1 L/min, *P* = .02) in the patients who were hypothermic. Hypothermic patients also had a greater incidence of thrombocytopenia (139,000 vs 150,000 platelets/mm^3, *P* = .02) and an elevated prothrombin time (13.5 vs 13.2 seconds, *P* = .04). These differences were not present the morning after surgery. Arterial and venous blood gas results, lactate levels, other hemodynamic variables, and wound infections were not significantly different between the 2 groups.

Postoperative Holter events were not only associated with body temperature, but also with preoperative Holter events. For example, patients that had preoperative Holter changes had a 76% incidence of postoperative Holter events, as compared with only a 32% incidence if there was no preoperative Holter events (*P* < .001). The influence of temperature on these different subgroups is shown in Table V. The specific numbers of patients in each category are too small for statistical review, but certainly indicate a trend of correlating preoperative events with postoperative events. The hypothermic group without preoperative events has a greater incidence of postoperative Holter events as compared with the normothermic group without preoperative Holter changes.

DISCUSSION

Patients treated with forced air warming blankets were kept significantly warmer than those treated with circulating water mattresses. These warmer patients had significantly less metabolic acidosis. No significant difference could be identified in the rates of silent ischemia, although there was a trend of

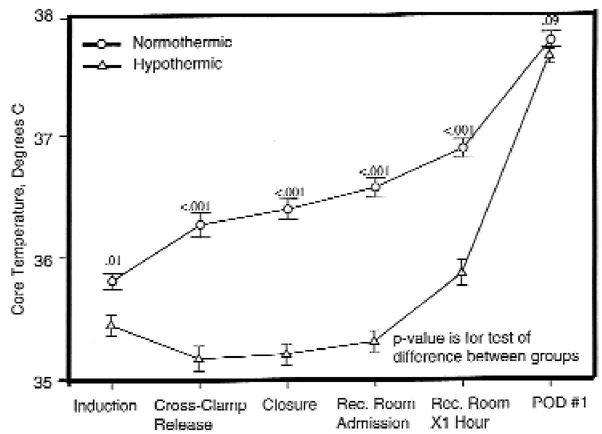

Fig 4. Subgroup analysis of the 83 patients with aneurysms. The temperature curves for the 2 groups were significantly different at all time points, except the morning after surgery.

increased events in the circulating water mattress group. The clinical outcome was similar for the 2 randomized groups, including both patients with aneurysm and those with occlusion. During data analysis, it was apparent that the patients with aortoiliac occlusion had more cardiac events on the Holter monitors and that including these patients introduced heterogeneity into the analysis.

Subgroup analysis of the 83 patients with aneurysms was therefore performed to evaluate a homogeneous group of patients. These patients were divided by their ultimate temperature on arrival at the recovery room to determine the risks and benefits of hypothermia, not to analyze a specific warming method. The hypothermic patients with aneurysm had more Holter monitor events and had inferior APACHE II scores. In the recovery room, these patients were more coagulopathic and had worse cardiac output. These results suggest that hypothermic patients are at greater risk for adverse clinical outcomes, although no such differences were observed in this study. In a study of this size, it was anticipated that there would be no clinical difference between these 2 groups, and this was the reason for choosing Holter monitoring as a means of detecting silent cardiac ischemia.

Hypothermia is a common problem in patients undergoing aortic surgery. The normal thermoregulatory process is altered by anesthesia and is further insulted by the effects of fluid resuscitation and surgery. Hypothermia then leads to numerous alterations in metabolic functions. The body's normal response to hypothermia adds additional stresses as

Table III. Clinical variables and Preoperative Holter analysis in 83 patients with aneurysms

Clinical variables	*Normothermia (n = 42)*	*Hypothermia (n = 41)*	*P value*
Age, years	67 ± 7	71 ± 7	.03
Male, %	90	88	.70
Aneurysm size, cm	5.5 ± 0.9	5.5 ± 1.0	.92
Weight, kg	86 ± 17	80 ± 16	.12
Body mass index	28 ± 4	27 ± 4	.25
History of angina, %	31	22	.35
History of myocardial infarction, %	33	24	.37
History of coronary revascularization, %	19	20	.96
EKG with Q waves, %	24	27	.75
Diabetes, %	7	5	1.0
Smoking history, %	95	90	.43
Forced air warmer, %	67	29	<.001
Preoperative dobutamine echo			
Total echos, *n*	35	37	
Resting ejection fraction, %	51 ± 9	54 ± 7	.26
Peak ejection fraction, %	61 ± 12	64 ± 12	.34
Fixed defect, %	54	46	.48
Inducible defect, %	26	27	.90
Preoperative Holter analysis			
Monitoring, hours	19 ± 3	19 ± 3	.52
Ventricular tachycardia, %	2	8	.36
Sinus tachycardia depression/elevation, %	7	17	.17
Ventricular tachycardia or sinus tachycardia changes, %	10	20	.23
Operative procedures			
Length of surgery, hours	4 ± 1.0	3.7 ± 1.2	.82
Cell saver, mL	917 ± 690	792 ± 527	.36
Crystalloid, mL	5439 ± 1646	5863 ± 1756	.26

Table IV. Clinical outcome and Holter results in 83 patients with aneurysms

Clinical outcome	*Normothermia (n = 42)*	*Hypothermia (n = 41)*	*P value*
Cardiac complications, %	0	0	N/A
Death, %	0	2	.49
Cardiac complications or death, %	0	2	.49
Postoperative median ICU stay, days	2	2	.26
Postoperative median length of stay, days	5	5	.20
APACHE II score: Recovery room	6	8	<.001
APACHE II score: Postoperative day 1	5	7	.004
Wound infections, %	5	2	1.0
Postoperative Holter analysis			
Monitoring, hours	24 ± 5	24 ± 3	.62
Ventricular tachycardia, %	7	15	.31
Sinus tachycardia depression/elevation, %	21	39	.08
Ventricular tachycardia or sinus tachycardia changes, %	27	48	.05

N/A, Not applicable.

the patient attempts to rewarm by both shivering and non-shivering thermogenesis.[1] Circulating water mattresses are not adequate at keeping patient body temperatures normothermic, as seen in this study. With the development of the new forced air warming blanket, patient body temperatures are kept closer to 37°C throughout the operative procedure. The upper body blanket was used in this study, because it is applied to areas outside the surgical field and maximizes heat transfer through the head. The superiority of the forced air warming blanket for temperature maintenance has been previously demonstrated in other randomized prospective studies.[4,10] Kurz et al[4] have specifically demonstrated that patients undergoing colorectal surgery have a decreased incidence of wound infections if body temperatures are maintained with forced air warming blankets.

In patients undergoing aortic surgery, the beneficial aspects of hypothermia with decreased metabolic rate and decreased oxygen consumption must be balanced against potentially adverse effects from

Table V. Interaction between preoperative and postoperative Holter events

	Preoperative Holter event	*Postoperative Holter events (n = patients)*	*Total number of patients (n = 80)**	*Postoperative Holter events (%)*
Hypothermia group	Yes	6	8	75
	No	13	32	41
Normothermia group	Yes	3	4	75
	No	8	36	22

*Three patients with missing Holter data excluded.

cardiac ischemia. In Hertzer's classic coronary angiography study[12] of patients with aneurysms, 65% of patients had severe coronary artery disease, and 95% of patients had moderate or severe coronary artery disease. The stress of surgery in vascular patients has previously been documented with Holter monitor analysis and prompted our use of Holter monitoring to evaluate silent ischemia in this project.

Pasternack et al[13] evaluated 120 patients who underwent AAA or lower revascularization procedures and found that 60.8% of the patients had silent ischemia on their Holter monitor analysis, either preoperatively, intraoperatively, or postoperatively. Postoperative myocardial infarction was significantly more common in those patients who had changes on the Holter recordings. Raby et al[14] prospectively studied 176 patients undergoing a mix of vascular surgery procedures. Eighteen percent of patients had preoperative ST segment changes that were clearly correlated with postoperative cardiac events. These studies support the importance of avoiding coronary ischemia in vascular surgery patients to minimize adverse cardiac outcome.

Unintentional hypothermia was shown to be associated with postoperative myocardial ischemia in a study by Frank et al.[2] In this study, 100 patients undergoing lower extremity revascularization procedures had Holter monitors for 24 hours postoperatively. On arrival at the intensive care unit, patients were divided into 2 groups. Hypothermia was defined as a temperature of less than 35°C. The hypothermic group had a statistically significant increased incidence of myocardial ischemia of 36%, as compared with the normothermic group, which had a 13% rate of ischemia.

The high complication rate associated with hypothermia has also been evaluated by Bush and colleagues[3] in patients undergoing aortic surgery at the Cornell University Medical College. Two hundred sixty-two patients with AAA were carefully studied for complications associated with hypothermia. Patients were divided into 2 groups based upon their admission temperature in the recovery room. Hypothermia in the Cornell study[3] was defined as a temperature of less than 34.5°C. Patients with hypothermia had significantly greater fluid requirements and inotropic support. The incidence of organ dysfunction and length of stay was significantly greater in the hypothermic group. The hypothermic group had a 12% incidence of death, compared with 1.5% in the normothermic group ($P < .01$).

The most recent study to evaluate cardiac ischemia and hypothermia was a prospective randomized trial by Frank et al.[5] Three hundred patients were randomized to receive a forced air warming blanket for the normothermic group and no adjunctive warming blanket or mattress in the hypothermic group. Both groups received warmed intravenous fluid and warmed humidified air in the respiratory circuit. Patients in this study[5] underwent a mix of abdominal, vascular, and thoracic procedures. Approximately 40% of these patients underwent vascular surgery procedures. An increased incidence of cardiac ischemia and ventricular tachycardia was revealed in the hypothermic group by means of postoperative Holter monitoring, as compared with the normothermic groups. Mean core temperature after surgery in the hypothermic group was 35.4°C, compared with 36.7°C in the normothermic group, nearly identical to the temperatures in our study. Morbid cardiac events were significantly increased in the hypothermic group (6.3%), as compared with the normothermic group (1.4%). In Frank's study,[5] cardiac ischemia, as defined by the ST changes alone, was found to be not statistically different between the 2 groups. Only when cardiac ischemia on the Holter monitor included ST changes and the occurrence of ventricular tachycardia on the Holter monitor could a statistical difference be identified. This same trend was seen in our data, as shown in Table IV.

From this research project, as well as a literature review, we support normothermia as the new goal for patients undergoing aortic reconstruction. Mild hypothermia has significant risks associated with it, and we can demonstrate no benefit. The development of the forced air warming blanket allows surgeons and anesthesiologists to keep most patients normothermic at the very modest cost of $14 per disposable blanket. It is well recognized that the first hour of surgery is when patients rapidly lose body heat. In our study, patients were hypothermic at the very beginning of surgery, as a reflection of their body temperature dropping during insertion of catheters by anesthesia staff and skin preparation by the nursing staff. The results of this study suggest that the forced air warming blanket should be applied as soon as the patient arrives in the operating suite to minimize this temperature drop. Although some patients will be able to maintain their body temperature perioperatively, the complexity and duration of the vascular procedure will affect body temperature. Because it is impossible to predict with certainty which patients are apt to become hypothermic, we feel that all infrarenal aortic surgical patients should be treated to maintain body temperature perioperatively. Patients whose body temperatures are maintained will have less metabolic acidosis, improved cardiac function, superior coagulation factors, and fewer cardiac events. The maintenance of normothermia should be the goal for vascular surgeons, and the use of a forced air warming blanket is recommended for all elective infrarenal aortic surgery patients.

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DISCUSSION

Dr Harry L. Bush Jr. (New York, NY). Thank you, Dr Jarrett, Dr Veith, members, and guests. I want to thank you, Dr Elmore, for your lucid presentation of your prospective, randomized study showing that forced air warming was significantly more efficient than a circulating water mattress in preserving core body temperature during aortic surgery. Earlier studies had shown that severe hypothermia is associated with adverse outcomes. Four years ago, I presented to this Society a study of 262 patients undergoing aortic aneurysm repair that demonstrated that severe hypothermia of less than 34.5°C was associated with increased length of stay, multiple organ dysfunction, and increased mortality. In contrast to poor control of body temperature resulting in severe hypothermia, this study today addresses the next logical questions: that is, what is the optimal technique for controlling core body temperature, and does mild hypothermia, defined as a temperature less than 36°C, result in a less optimal clinical outcome?

Their study demonstrates that forced air warming is a more efficient technique to control core body temperature during aortic surgery; the question is why? Would a circulating water mattress function better if the water temperature was increased or if the mattress covered the patient as the forced air blanket does?

In addressing the second question, mild hypothermia was not detrimental in the combined series of patients with aneurysmal and occlusive disease. Whereas, with the subgroup of patients with aneurysms, you do show the negative influence of mild hypothermia. Do you have an explanation for the discrepancy in these 2 groups?

In the subgroup of patients with aortic aneurysms, mild hypothermia was associated with postoperative coagulopathy plus cardiac dysfunction and ischemia. However, there was no change in the length of stay or mortality. This suggests that mild hypothermia causes homeostatic changes for which the body can easily compensate, whereas our prior study showed that severe hypothermia is clearly linked to adverse outcomes that are frequently irreversible.

How sensitive and specific was the preoperative Holter monitoring diagnosis of myocardial ischemia as a means of predicting the postoperative ischemia and ventricular tachycardia? Did the postoperative ischemia or tachycardia develop only in the patients with preoperative changes? And how did normothermia protect the patients from similar postoperative changes?

With APACHE II scoring, you include temperature as a variable, and therefore, the elevated scores in the hypothermic patients may be misleading. Did you try to recalculate the APACHE II scores to eliminate temperature as one of the variables to see if the evidence of organ dysfunction was still present in the patients with mild hypothermia?

I would like to commend Dr Elmore and his colleagues for bringing this well-designed, prospective and randomized study to our attention. The overall clinical results are excellent, but its importance is to emphasize the role of core body temperature in the optimal care of patients undergoing aortic surgery. The practical application of a warm operating theater, warmed intravenous fluids, and the use of an exogenous warming device can control body temperature during vascular reconstruction. I commend their well-written manuscript to your reading.

I would like to thank this Society for the honor of discussing this paper. Thank you.

Dr James R. Elmore. It is impressive how well the forced air warmer maintains body temperature in these patients. The mechanism of action relates to the principle that our mothers taught us when we were children on the importance of wearing a hat to stay warm.

The water mattress was set at the maximum safe temperature of 41°C. When you compare our temperature results with the study by Frank et al, the temperature at the conclusion of our procedures with the circulating water mattresses was the same as that in their patients who had no warming method at all. This questions the value of the circulating water mattress in patients undergoing aortic surgery.

In the group of 100 patients, there were no significant differences in the Holter monitor results. However, there was a trend developing of a greater rate of ST and ventricular tachycardia occurring in the circulating water mattress group. I believe that in these 100 patients, the temperature split was not great enough to detect a statistically significant difference in the Holter results. The AAA subgroup analysis divided patients by their ultimate temperature on admission to the recovery room, and then a statistical difference was seen.

The clinical parameters that were statistically different in the recovery room included the decreased platelet count, prolonged prothrombin time, and decreased cardiac output. These differences were of minor clinical significance, and this explains why there was no adverse clinical impact in these patients.

One of the big differences between Dr Bush's study and the present study is that he had many people that had a temperature of less than 34.5°C, whereas we had only 4 patients that were that cold at the end of surgery. The 2 studies looked at a slightly different group of patients, and therefore, the results are complementary, but not identical.

The Holter monitor is very sensitive preoperatively and did correlate with postoperative changes.

The APACHE II score does incorporate temperature as one of the variables that is measured. If temperature was deleted from the recovery room APACHE II score, then no difference would be detected. The morning after surgery, temperature is the same between the 2 groups, but the hypothermic group still has a worse APACHE II score.

Patients did get cold at the beginning of surgery. In the future, it would seem reasonable that these warming methods should be first applied in the preoperative holding area.

Dr Anil Hingorani (Brooklyn, NY). Do you think you would have seen any difference if you had a larger group of retroperitoneal patients?

Dr Elmore. I don't know how that would have impacted the temperature curves. Our preferred mode of reconstruction uses a midline incision, so I can't answer that question.

Dr Jens Eldrup-Jorgensen (South Portland, Me). I enjoyed your presentation, Jim. I'd like to add a practical consideration. It seems that the traditional scenario has been that as the temperature dropped during the course of the operation, anesthetists would turn the room temperature up, which didn't really get through the drapes and affect the core temperature of the patient, but just made the surgeons very uncomfortable as they finished up their last anastomosis. As we're all well aware, there is a lot that goes on before induction these days. Anesthetists put in arterial lines, epidural catheters, and Swan-Ganz catheters before the general anesthetic. That's when we see the big temperature drop. You mentioned that you keep the room temperature at 68°F. Our own preference has been to keep it much higher than that, up in the 70s or even the 80s, until it is almost intolerable. I think that helps maintain the body temperature in the exposed patient.

I have one other question, and that is based upon the Holter monitor data that you demonstrated. We used to sometimes ask the nurses to put Nitropaste on the patients on-call to the operating room. Should we now have the patients put Nitropaste on when they leave the house in the morning?

Dr Elmore. It was interesting to review the preoperative Holter monitor results and correlate ST changes with preoperative anxiety. Just 5 years ago, all these patients were in-house the night before surgery and were transported on a litter after receiving sedation. And once again, I agree on the importance of trying to rewarm patients preoperatively; whatever works I think is going to be the answer. I think that it would be adequate to warm patients by putting on the forced air warmer in the preoperative environment.

Because when anesthetists have them on their side, that Bair Hugger would be in their way. So there is going to be a limit to how much you can put that on preoperatively.