The Catecholamine, Cortisol, and Hemodynamic Responses to Mild Perioperative Hypothermia

A Randomized Clinical Trial

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**Background:** Unintended hypothermia occurs frequently during surgery and may have adverse effects on the cardiovascular system. Although the mechanisms responsible for the cardiovascular manifestations of hypothermia are unclear, it is possible that they are sympathetically mediated. In this prospective study, relationships between body temperature, the neuroendocrine response, and hemodynamic changes in the perioperative period were examined.

**Methods:** Seventy-four elderly patients, undergoing abdominal, thoracic, or lower extremity vascular surgical procedures, were randomly assigned to either “routine care” (n = 37) or “forced-air warming” (n = 37) groups. Throughout the intraoperative and early postoperative periods, the routine care group received standard thermal care, and the forced-air warming group received forced-air skin-surface warming. Core temperature, forearm minus fingertip skin-surface temperature gradient, and plasma concentrations of epinephrine, norepinephrine, and cortisol were measured throughout the perioperative period, and the two groups were compared.

**Results:** The routine care and forced-air warming groups did not differ with regard to age, sex, type of surgical procedures, anesthetic techniques, or postoperative analgesia. Mean core temperature was lower in the routine care group on admission to the postanesthetic care unit (routine care, 35.3 ± 0.1°C; forced-air warming, 36.7 ± 0.1°C; P = 0.0001) and remained lower during the early postoperative period. Forearm minus fingertip skin-surface temperature gradient (an index of peripheral vasoconstriction) was greater in the routine care group in the early postoperative period. The mean norepinephrine concentration (pg/ml) was greater in the routine care group immediately after surgery (480 ± 70 vs. 330 ± 30, P = 0.02) and at 60 min (530 ± 50 vs. 340 ± 30, P = 0.002) and 180 min (500 ± 80 vs. 320 ± 30, P = 0.004) postoperatively. Mean epinephrine concentrations were not significantly different between groups. Mean cortisol concentrations were increased in both groups during the early postoperative period (P < 0.01), but the differences between groups were not significant. Systolic, mean, and diastolic arterial blood pressures were significantly higher in the routine care group.

**Conclusions:** Compared with patients in the forced-air warming group, patients receiving routine thermal care had lower core temperatures, a greater degree of peripheral vasoconstriction, higher norepinephrine concentrations, and higher arterial blood pressures in the early postoperative period. These findings suggest a possible mechanism for hypothermia-related cardiovascular morbidity in the perioperative period. (Key words: Hormones; cortisol, Hypothermia; perioperative. Sympathetic nervous system, catecholamines; epinephrine; norepinephrine. Thermoregulation: vasoconstriction.)

UNINTENDED perioperative hypothermia occurs in approximately one-half of all surgical patients1–3 and has been associated with cardiovascular complications. We previously demonstrated an increased incidence of early postoperative myocardial ischemia in vascular surgery patients with core temperatures less than 35°C; however, no clear mechanism was identified to explain this finding. The metabolic demands associated with shivering have been thought to be responsible for
cardiovascular stress in the perioperative period. Twenty-five years ago, Bay et al. hypothesized that patients with ‘cardiopulmonary disease’ may not tolerate the metabolic demands of shivering. Since then, however, little or no evidence has been presented to establish a relationship between perioperative shivering and adverse outcomes. Furthermore, in our previous study, the association between hypothermia and myocardial ischemia did not appear to be related to shivering. This suggests that a mechanism other than shivering is responsible for hypothermia-related cardiovascular stress.

The normal response to hypothermia includes activation of the sympathetic nervous system. Studies in healthy volunteers have demonstrated that even small changes in core temperature (≈0.2°C) are associated with thermoregulatory vasoconstriction. With exposure to cold ambient temperatures or total body immersion in cold water, epinephrine and norepinephrine concentrations are significantly increased. Animal studies indicate that adrenal hormones play an important role in maintaining normothermia during cold exposure. In addition, by activating glycogenolysis and providing substrate for metabolism, cortisol may play an integral role in the response to cold stress. These cold-induced hormonal responses could adversely affect the cardiovascular system if similar changes occur in surgical patients with underlying medical problems.

Accordingly, we studied the relationship between perioperative changes in body temperature and plasma levels of stress hormones. Using a prospective randomized design, body temperature, catecholamine and cortisol responses, and hemodynamic changes were compared in patients receiving routine thermal care or forced-air skin-surface warming during the intraoperative and early postoperative periods.

Materials and Methods

With approval by the Committee on Clinical Investigation and after obtaining written informed consent, 74 patients were enrolled. All three of the following inclusion criteria were required for enrollment: (1) age older than 60 yr; (2) scheduled thoracic, abdominal, or lower extremity vascular surgery; and (3) the presence of two or more risk factors for coronary artery disease, according to criteria used in previous studies. Exclusion criteria were a preoperative tympanic temperature of <36°C or >38°C measured by the infrared technique (Thermoscan, San Diego, CA), a history of Raynaud’s syndrome, or a known thyroid disorder. Patients were randomly assigned to receive either ‘routine care’ (n = 37) or ‘forced-air warming’ (n = 37) in the perioperative period. Randomization was stratified on type of surgery.

Treatment Protocols

All patients received their usual chronic medications (e.g., antihypertensives, antianginals) before surgery. All patients were monitored with electrocardiogram, pulse oximetry, and radial intraarterial catheters for continuous display of blood pressure throughout the study.

Routine care was delivered according to the following protocol. The thermostat in the operating room was set to ≈21°C. Intravenous fluids and blood were warmed (Fenwal model BW-5, Deerfield, IL). A heat-moisture exchanger (Thermovent 600, Portex, Keene, NH) was used in the respiratory circuit for those patients receiving general anesthesia. After the surgical field was prepped and draped, the patient was covered above and below the field with one layer of paper drapes. In the postoperative period, either one or two warmed cotton blankets were placed over the patient at the postanesthetic care unit (PACU) nurse’s discretion.

Patients in the forced-air warming group were treated as follows. The thermostat in the operating room was set to ≈21°C. Fluids and blood were warmed (Fenwal) and a heat-moisture exchanger was used (Portex) in the respiratory circuit for those patients receiving general anesthesia, as in the routine care group. Depending on the surgical site, an upper or a lower body forced-air warming blanket (Warm Touch, Mallinckrodt, St. Louis, MO) was placed over the patient and connected to a forced-air blower (Warm Touch). During the first 2 h of postoperative care, a full body forced-air warming blanket covered the patient’s legs and trunk. During the intraoperative and postoperative periods, both the temperature and airflow were set to “high” or adjusted to “medium” to maintain core temperature at or near 37°C. If core temperature exceeded 37°C, the blower was turned off and the blanket left in place. After the initial 2 h postoperatively, care was similar to that used for patients in the routine care group.

Anesthetic Technique

Patients received premedication with midazolam (up to 5 mg) and/or morphine (up to 0.1 mg/kg) given
intramuscularly. Either a general or regional anesthetic regimen was used, in most cases determined by the surgical procedure. General anesthesia was chosen for patients undergoing abdominal surgical procedures. This included thiopental (4–6 mg/kg), fentanyl (3–10 μg/kg) and/or morphine (0.1–0.2 mg/kg), and pancuronium or vecuronium, all given intravenously, nitrous oxide (up to 70%), and isoflurane or enfurane (0.2–2.0%). All patients were tracheally intubated during surgery, and the trachea was extubated at the end of the surgical procedure unless standard extubation criteria were not met. These criteria include the return of consciousness, reversal of neuromuscular blockade, and ability to follow commands and ventilate spontaneously. For patients receiving general anesthesia, analgesia was provided during the initial 18–24 h postoperatively with intravenous morphine sulfate delivered by patient-controlled analgesia with a background infusion of 1 mg/h, a bolus dose of 1 mg, and a lockout interval of 6 min.

Epidural anesthesia was used for patients undergoing lower extremity vascular surgery unless there was a contraindication (anticoagulation, spinal fusion, or patient refusal), in which case general anesthesia was employed. Epidural anesthesia was delivered through a lumbar catheter using 2% lidocaine or 0.5–0.75% bupivacaine to achieve a T6–T10 sensory level. Midazolam and/or fentanyl sedation was given intravenously during the intraoperative period as needed. Postoperative analgesia was provided with a patient-controlled analgesia infusion of 0.0625% bupivacaine with 5 μg/ml fentanyl, using a background infusion of 2–4 ml/h, a bolus dose of 2 ml, and a lockout interval of 10 min.

Patients having thoracic surgical procedures received general anesthesia as described above. Instead of intravenous morphine by patient-controlled analgesia infusion, an intrathecal dose of 0.5 mg morphine was given shortly before induction of anesthesia. This general/regional anesthetic technique will be referred to subsequently as “combined” anesthesia.

Postoperative pain was assessed at 30 and 90 min postoperatively and in the morning of the first postoperative day. Pain was evaluated using a ten-point oral analog scale, with 0 = no pain and 10 = severe pain.

**Temperature Monitoring**

On arrival in the operating room, body temperature monitoring was initiated with an Iso-thermex electronic thermometer (Columbus Instruments, Columbus, OH).

Eight body sites were monitored: two core sites and six skin-surface sites. Core temperature was measured using a tympanic membrane thermocouple probe (Mona-Therm, Mallinckrodt) inserted until a scratching sound was reported by the patient. A second core temperature was measured in the urinary bladder using a catheter that incorporates a thermocouple probe (Mona-Therm). If the tympanic probe became dislodged during the study, the bladder temperature was used as the core temperature. Skin-surface temperatures were measured with thermocouple probes (Mon-a-Therm) on the anterior chest, the lateral mid-upper arm, the anterior radial side of the mid-forarm, the index fingertip (opposite the nailbed), the lateral mid-thigh, and the lateral mid-calf. The forearm minus fingertip skin-surface temperature gradient was used as a measure of vasoconstriction as previously described and was measured in the arm that was not used to administer intravenous fluids. Mean skin temperature was calculated using the following formula: \(0.3(\text{chest + upper arm}) + 0.2(\text{thigh + calf})\) \(^{17}\). Temperatures were recorded onto a hard disk at 5-min intervals until the morning of the first postoperative day (\(\approx 24\) h). All temperature data were analyzed, and the two groups were compared at the following times: preoperatively, at the end of surgery, on admission to PACU, at 30, 60, 90, and 180 min postoperatively, and in the morning of the first postoperative day. Care was taken to prevent direct warming of the tympanic membrane, forearm, and fingertip thermocouple probes by the forced-air warming blanket. In the postoperative period, the blanket was placed over the patient’s legs and trunk while the monitored arm remained exposed.

**Catecholamine and Cortisol Measurements**

Plasma epinephrine, norepinephrine, and cortisol concentrations were measured five times during the perioperative period: preoperatively, after insertion of the arterial catheter, before induction of anesthesia, on admission to the PACU, at 60 and 180 min postoperatively, and in the morning of the first postoperative day. These times were selected because thermoregulatory activity is most significant during rewarming in the early postoperative period. Arterial blood samples were drawn into tubes containing EDTA, cold-centrifuged, and the plasma was stored at \(-80^\circ\text{C}\). Catecholamines were measured using high-pressure liquid chromatography with electrochemical detection after alumina extraction as previously described. \(^{18}\) The sensitivity of this assay is 20 pg/ml,
and the intra- and interassay coefficients of variability are 3–5%. Cortisol concentrations were determined by radioimmunoassay.18

Hemodynamic Measurement and Management

Blood pressures were obtained by intraarterial measurements from a 20-G, 3.3-cm radial artery catheter connected by 23 cm of arterial pressure tubing to a disposable transducer (Cobe, Lakewood, CO). A bedside monitor (Marquette series 7010, Milwaukee, WI) with a frequency band width of 0–40 Hz displayed a pressure waveform and digital readout continuously. All visible air bubbles were purged from the system, and the zero reference was confirmed with electronic calibration preoperatively and on admission to the PACU. The transducer was set at the level of the right atrium (mid-axillary line). Heart rate and systolic and diastolic arterial blood pressure were recorded in all patients during the postoperative period. Mean arterial blood pressure measured intraarterially was available for 49 of the 74 patients. Heart rate and blood pressure were measured by one of the coinvestigators during the preoperative visit. Preoperative blood pressure was measured in both arms using the Korotkoff technique, and measurements from the arm with the highest systolic blood pressure19 were used in the analysis comparing the two groups over time. Preoperative mean blood pressure was determined by the formula (diastolic + 1/3(systolic – diastolic)).

Appropriate upper and lower limits for systolic blood pressure were determined before surgery based on three preoperative blood pressure measurements, as we described previously.20 The number of hours the blood pressure exceeded the upper limit in the postoperative period was determined by reviewing the hemodynamic flow sheet. Drug therapy for hypertension was determined by protocol20 to maintain arterial blood pressure within predetermined limits. The requirement for antihypertensive therapy in the first 24 h postoperatively was recorded. The hemodynamic treatment protocols were carried out by the house staff in the surgical intensive care unit.

Data Analysis

Chi-square and unpaired Student’s t tests were used to compare the two groups demographically. Analysis of variance for repeated measures was used to compare differences between and within the two groups for the variables measured over time. Multivariate analyses were used to determine the effect of randomized treat-

Results

There were no significant differences between the two groups with regard to patient age, sex, height, weight, history of diabetes, hypertension, or preoperative β-adrenergic blocker therapy (table 1). A comparable percentage of patients in each group underwent abdominal, thoracic, and lower extremity vascular surgical procedures, and a similar percentage of patients received general, regional, and combined anesthetic techniques. The percentage of patients requiring postoperative mechanical ventilation was similar in both groups. The mean duration of ventilatory support was 16 ± 6 h for patients who required mechanical ventilation. The proportion of patients receiving epidural or intravenous patient-controlled analgesia in the postoperative period was similar in both groups. The analgesia protocols provided comparable degrees of pain relief in both groups, as indicated by pain scores. Antihypertensive medication was required for 30% of patients in the routine care group and 19% of patients in the forced-air warming group (P = 0.28).

Preoperative core temperature measured at the tympanic membrane was similar in the two groups (fig.
PERIOPERATIVE HYPOTHERMIA AND STRESS HORMONES

Table 1. Clinical Characteristics of the Study Patients

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Routine Care (n = 37)</th>
<th>Forced-air Warming (n = 37)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male sex</td>
<td>70 ± 1</td>
<td>71 ± 1</td>
<td>0.64</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167 ± 2</td>
<td>170 ± 2</td>
<td>0.28</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73 ± 3</td>
<td>74 ± 3</td>
<td>0.82</td>
</tr>
<tr>
<td>Diabetes</td>
<td>8 (22)</td>
<td>8 (22)</td>
<td>1.00</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>22 (59)</td>
<td>20 (54)</td>
<td>0.64</td>
</tr>
<tr>
<td>Preoperative β blocker</td>
<td>8 (22)</td>
<td>11 (30)</td>
<td>0.42</td>
</tr>
<tr>
<td>Surgical procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vascular</td>
<td>12 (32)</td>
<td>11 (30)</td>
<td>0.62</td>
</tr>
<tr>
<td>Abdominal</td>
<td>21 (57)</td>
<td>19 (51)</td>
<td>0.57</td>
</tr>
<tr>
<td>Thoracic</td>
<td>4 (11)</td>
<td>7 (19)</td>
<td>0.55</td>
</tr>
<tr>
<td>Anesthetic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>25 (68)</td>
<td>24 (65)</td>
<td>0.59</td>
</tr>
<tr>
<td>Regional</td>
<td>8 (22)</td>
<td>6 (16)</td>
<td>0.79</td>
</tr>
<tr>
<td>Combined</td>
<td>1 (11)</td>
<td>7 (19)</td>
<td>0.79</td>
</tr>
<tr>
<td>Requirement for postoperative mechanical ventilation</td>
<td>8 (22)</td>
<td>6 (16)</td>
<td>0.55</td>
</tr>
<tr>
<td>Postoperative epidural analgesia</td>
<td>10 (27)</td>
<td>9 (24)</td>
<td>0.79</td>
</tr>
<tr>
<td>Postoperative intravenous patient-controlled analgesia</td>
<td>29 (78)</td>
<td>29 (78)</td>
<td>1.00</td>
</tr>
<tr>
<td>Postoperative morphine requirement (mg/24 h)</td>
<td>32 ± 5</td>
<td>23 ± 5</td>
<td>0.19</td>
</tr>
<tr>
<td>Pain scores (0–10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 min postoperatively</td>
<td>6 ± 1</td>
<td>4 ± 1</td>
<td>0.18</td>
</tr>
<tr>
<td>90 min postoperatively</td>
<td>6 ± 1</td>
<td>5 ± 1</td>
<td>0.44</td>
</tr>
<tr>
<td>Postoperative day 1</td>
<td>4 ± 0</td>
<td>3 ± 0</td>
<td>0.13</td>
</tr>
<tr>
<td>Time above systolic blood pressure limit (h)</td>
<td>4.6 ± 0.9</td>
<td>3.3 ± 0.9</td>
<td>0.32</td>
</tr>
<tr>
<td>Requirement for antihypertensive therapy</td>
<td>11 (30)</td>
<td>7 (19)</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Values in parentheses indicate percentage.

1). On admission to the PACU, core temperature was significantly lower in the routine care group (35.3 ± 0.1°C) than in the forced-air warming group (36.7 ± 0.1°C; P = 0.0001). Core temperature remained lower in the routine care group throughout the first 180 min postoperatively but was similar between groups in the morning of the first operative day. Mean skin temperature was significantly lower in the routine care group on PACU admission, remained lower for the first 180 min postoperatively (P = 0.0001), but was similar in the morning of the first postoperative day. Forearm minus fingertip skin-surface temperature gradient was significantly greater in the routine care group on admission to the PACU, remained higher for the first 180 min postoperatively (P = 0.0001), but was similar between groups in the morning of the first postoperative day. Significant vasoconstriction, defined by a mean forearm fingertip gradient greater than 4°C, was present in the routine care group but not in the forced-air warming group during the early postoperative period. Five patients did not maintain adequate tympanic temperature probe placement for the duration of the study and bladder temperature was substituted.

Mean norepinephrine, epinephrine, and cortisol concentrations were similar in the two groups preoperatively and on postoperative day 1 (fig. 2). The norepinephrine response was significantly greater in the routine care group than in the forced-air warming group (P = 0.008). Mean norepinephrine concentrations were greater in the routine care group on admission to the PACU (P = 0.02) and at 60 (P = 0.003) and 180 min (P = 0.004) postoperatively. Within the routine care group, norepinephrine concentrations were significantly greater than the preoperative baseline level on admission to the PACU, at 60 and 180 min postoperatively, and in the morning of postoperative day 1 (P < 0.05).

The epinephrine response was not significantly different between groups (P = 0.23). Within the routine care group, however, mean epinephrine concentration was greater than the preoperative baseline level on admission to the PACU and at 60 and 180 min postop.
Heart rate and blood pressure were comparable between groups in the preoperative period (fig. 3). Heart rate was significantly lower in the routine care group ($P = 0.05$) in the early postoperative period, but the difference between groups was less than 10 beats/min at any given time. Arterial blood pressure was higher.

Fig. 1. Body temperature data are shown over the intraoperative and postoperative periods for the routine care and forced-air warming groups. Core temperature, measured at the tympanic membrane, was significantly lower at the end of the surgical procedure in the routine care group and remained lower for 180 min postoperatively. Mean skin temperature was lower in the routine care group. This difference was greatest at the end of surgery, but the groups remained significantly different at 180 min postoperatively. Forearm minus fingertip skin-surface temperature gradient was significantly greater in the routine care group at the end of surgery and remained greater at 180 min postoperatively, indicating a greater degree of vasoconstriction. *$P < 0.01$ versus routine care.

Cortisol concentrations in both groups were significantly increased in the early postoperative period relative to the preoperative baseline ($P = 0.14$). Differences between the groups were not statistically significant ($P = 0.51$).

Fig. 2. Plasma norepinephrine, epinephrine, and cortisol levels were measured in arterial blood, and the routine care and forced-air warming groups were compared. Norepinephrine levels were significantly greater than the preoperative baseline in the routine care group on admission to the postanesthesia care unit (PACU), at 60 and 180 min postoperatively, and in the morning of postoperative day 1. Between-group comparison showed norepinephrine levels to be significantly greater in the routine care group on admission to the PACU and at 60 and 180 min postoperatively. Epinephrine levels were significantly elevated above the preoperative baseline in the routine care group on admission to the PACU and at 60 and 180 min postoperatively. Comparison between groups showed no significant differences. Postoperative cortisol levels were increased above the preoperative baseline in both groups. The differences in cortisol levels between groups were not significant. *$P < 0.01$ versus forced-air warming, $P < 0.05$ versus preoperative.
first 180 min postoperatively. The >50% group had significantly higher arterial blood pressures upon admission to the PACU and at 30 and 60 min postoperatively. This increased blood pressure was noted for systolic ($P = 0.003$), mean ($P = 0.004$), and diastolic ($P = 0.02$) blood pressures. Heart rate was not significantly different in these two groups. When 100% and 150% increases in norepinephrine were used to define the response, similar differences were noted in arterial blood pressure, but these differences were less dramatic.

Multivariate analyses were performed to determine independent predictors of the catecholamine and cortisol responses at each of three different times: PACU admission and at 60 and 180 min postoperatively. Randomization was a significant independent predictor of the norepinephrine response by multivariate testing at these three times. For the epinephrine response, there were no significant independent predictors. The randomized group to which the patient was assigned was not correlated with epinephrine level at any of the three times. The only significant independent predictor of the cortisol response was anesthetic technique. General anesthesia was associated with higher cortisol concentrations at all three times.

**Discussion**

In this randomized clinical trial, a decrease in core temperature of $\approx 1.5 ^\circ\text{C}$ was associated with higher norepinephrine concentrations in the early postoperative period. In contrast, thermal maintenance had little effect on the epinephrine or cortisol responses. This degree of hypothermia was accompanied by vasoconstriction and higher arterial blood pressures, both of which indicate a clinically significant effect of norepinephrine on the peripheral vasculature. Higher norepinephrine concentrations in the colder patients may represent a component of the thermoregulatory response. Although prior studies have established a relationship between "cold stress" and catecholamines, this adrenergic response to mild perioperative hypothermia has not been previously studied in a prospective randomized fashion.

Prior studies have been unable to establish a relationship between hypothermia and the catecholamine response in the perioperative period. Previous investigators, however, did not use a randomized design to assess the effects of temperature. Halter et al. studied eight patients undergoing abdominal surgery. All pa-
patients had increased epinephrine and norepinephrine concentrations in the first 2 h of the postoperative period, which they attributed to afferent pain stimuli. In this small series, without randomization or standardized postoperative analgesia, it is not surprising that no effect of temperature on the catecholamine response was observed.

We studied the stress response in patients undergoing peripheral vascular surgery who were randomized to receive epidural or general anesthesia. In contrast to the present study, we did not find body temperature to be related to the catecholamine response. As previously mentioned, without a randomized design with respect to temperature management, it is difficult to draw conclusions regarding the effects of temperature. Age may have been a confounding variable. The elderly had higher preoperative norepinephrine concentrations and less change from baseline in the postoperative period. Elderly patients are also more likely to develop hypothermia. Another possible explanation for the disparity between the results of our previous and current studies may be that skin-surface temperatures were higher in the active warming group in the current study than in the “normothermic” patients in the prior study, when no active warming measures were employed. By using aggressive skin-surface warming in the current study, both the skin and the core were maintained at higher temperatures. Increased catecholamine secretion during exposure to cold ambient temperatures has been demonstrated in healthy young volunteers. Both epinephrine and norepinephrine urinary excretion have been shown to be increased with ambient temperatures between 6.5°C and 15°C. As might be expected in young individuals with an active thermoregulatory response, core temperature was not significantly altered (<0°C decrease) during cold exposure in these studies. However, mean skin temperature was decreased by 4°C during 15°C cold exposure. These results suggest that skin-surface cooling was responsible for initiating the adrenergic response.

Johnson et al. studied young healthy volunteers who were immersed in a cold-water bath (10°C) for 1 h. Epinephrine was not measured, but norepinephrine increased twofold in the first 2 min of exposure and increased three- to fourfold after 45 min. Although core temperature eventually decreased to 34.5°C, the rapid norepinephrine response preceded changes in core temperature. At the end of the 1-h period, the volunteers were immersed in a 40°C water bath to assess the effects of skin-surface rewarming on the norepinephrine response. This resulted in a transient increase in norepinephrine (about 5 min duration), followed by a dramatic decrease to baseline levels within 20 min of the warm immersion. Because core temperature was slow to change, the investigators concluded that skin temperature was strongly correlated with the catecholamine response.

One of the earliest recognized models of a cold-induced adrenergic response is the cold pressor test. The test is performed by immersion of the hand in a cold ice bath (usually 4°C) for 2 min. In earlier studies, the response to cold pressor was assessed by changes in heart rate and blood pressure, both of which were significantly increased. In subsequent studies, these changes were shown to result from a sudden increase in circulating concentrations of epinephrine and norepinephrine. The cold pressor test has been shown to increase coronary vascular resistance and reduce coronary perfusion in patients with ischemic heart disease. This response is prevented by α-adrenoceptor blockade, suggesting that norepinephrine mediates cold-induced coronary vasoconstriction. This effect on coronary blood flow provides insight into potential mechanisms of cold-induced cardiovascular morbidity in surgical patients and may explain the greater incidence of early postoperative myocardial ischemia that we previously described in high-risk patients who develop unintended hypothermia during surgery.

In the current study, the cortisol response was not affected by temperature management. In accordance with previously published results, patients receiving general anesthesia had greater postoperative cortisol levels relative to those receiving combined or regional anesthetics. Although cortisol release is controlled by the hypothalamic-pituitary-adrenal system which involves corticotropin releasing hormone and adrenocorticotropic hormone, the afferent pain stimuli that trigger this response are attenuated by either neuraxial narcotics or regional conduction blockade. Thus we conclude that the cortisol response is determined primarily by anesthetic technique and not by the relatively small changes in body temperature that we observed. Perhaps temperature changes of a greater magnitude would be associated with a significant cortisol response, but further studies will be necessary to identify such an effect.

The beneficial effects of perioperative patient warming have been proposed in previous studies. Forced-air warming in the immediate postoperative period has
been shown to restore normothermia more rapidly and to reduce the incidence of shivering compared with conventional methods (cotton blankets).\textsuperscript{36,37} Despite the hypothesis that shivering may be detrimental to patients with cardiopulmonary disease,\textsuperscript{5} the literature does not provide evidence for shivering-related morbidity. Furthermore, in contrast to older studies reporting up to a fourfold increase in oxygen consumption with shivering,\textsuperscript{5} we have shown in preliminary work a much smaller increase in total body oxygen consumption (\textasciitilde30\%) in postoperative shivering patients.\textsuperscript{58} This relatively small increase in oxygen consumption may be related to the partial inhibition of shivering by opioid analgesics\textsuperscript{39} or to age-related thermoregulatory impairment\textsuperscript{24,25} (mean age 70 yr). Given these small changes in oxygen consumption, it is likely that mechanisms other than shivering may be responsible for hypothermia-related cardiovascular complications. We hypothesize, based on the results of the current study, that norepinephrine may play a role.

Despite the hemodynamic protocols that were used to define and treat hypertension in the postoperative period, blood pressure measured intraarterially was significantly higher in the routine care group. This observation most likely reflects vasoconstriction in response to norepinephrine. The percentage of patients requiring antihypertensive treatment in the routine care group (30\%) was not significantly greater than the percentage requiring treatment in the skin-surface warming group (19\%). Although the difference in requirement for antihypertensive medication was not significant, these treatment protocols may have resulted in an underestimation of the increased blood pressure in the hypothermic patients.

The relationship between core temperature, vasoconstriction, and arterial blood pressure has been reported by Hynson et al.\textsuperscript{40} In that study, systolic, diastolic, and mean blood pressures were lower in warmed volunteers than in those who developed thermoregulatory vasoconstriction during exposure to 21°C ambient temperature. Although the Hynson et al. study nicely demonstrates the effects of vasoconstriction and warming on arterial blood pressure, the effects of core hypothermia are not evident because the volunteers were anesthetized when hypothermia developed. Our results are consistent with those from this previous study but differ in that we report the hemodynamic effects of postoperative hypothermia in elderly surgical patients. In addition, our inclusion criteria resulted in over one-half the patients having a history of hypertension requiring treatment with medication. Thus, the hemodynamic effects of hypothermia may be specific for this subset of patients and may not apply to younger normotensive individuals.

In the same study, Hynson et al. present data to suggest that intraarterial measurements in vasoconstricted patients result in a falsely elevated systolic blood pressure when compared with measurements taken by the oscillometric technique.\textsuperscript{40} Our findings indicate that, in addition to differences in systolic blood pressure, mean and diastolic blood pressures were increased in the hypothermic patients. When measured by intraarterial catheters, mean and diastolic pressures correlate with oscillometric measurements and are likely to reflect true blood pressure, even in the presence of vasoconstriction.\textsuperscript{40}

It is possible that arterial blood samples do not reflect the true magnitude of the norepinephrine response. Compared to arterial blood, venous blood has been shown to contain higher concentrations of norepinephrine.\textsuperscript{41} This may be explained by the release of norepinephrine at the sympathetic nerve terminals, which is taken up as the blood passes from the arterial to the venous circulation. Both arterial and venous samples are likely to underestimate the peripheral sympathetic release of norepinephrine, because the measured concentrations represent only "spillover" into the circulation. Thus, the arterial norepinephrine levels that we measured may have underestimated the true magnitude of the adrenergic response in patients who develop inadvertent hypothermia.

In conclusion, we have demonstrated in a prospective randomized study that, compared to patients who are maintained at normothermic temperatures, patients developing mild hypothermia during surgery have a greater increase in norepinephrine concentrations, more significant vasoconstriction, and an increased arterial blood pressure in the early postoperative period. In contrast, the epinephrine and cortisol concentrations were not significantly altered by thermal management in the range of temperatures that were observed. Although it is possible that the adrenergic response may play a role in the development of cold-induced cardiovascular complications, further work will be necessary to determine the relationship between stress hormones and perioperative morbidity in patients who develop hypothermia.

The authors acknowledge support from Susan Kelly, for assistance with all aspects of the study; William Sommers, for assistance with...
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