Core Hypothermia and Skin-surface Temperature Gradients

Epidural Versus General Anesthesia and the Effects of Age

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Background: Inadvertent hypothermia occurs frequently during surgery and may be associated with adverse outcomes. Although various anesthetic agents have been shown to impair thermoregulation, the impairment with regional and general anesthetics has not been directly compared.

Methods: Thirty patients undergoing radical retropubic prostatectomy were randomly allocated to receive epidural (EA, n = 15) or general (GA, n = 15) anesthesia. Tympanic membrane measurements were used to assess core temperature. Forearm and calf skin-surface temperature gradients were used to assess thermoregulatory vasoconstriction (forearm minus fingertip > 4°C and calf minus toe > 6°C). The two groups were compared during the intraoperative and early postoperative periods to identify differences. Subgroup analysis was used to compare core temperatures and skin-surface gradients in younger (< 62 yr of age) and older (≥ 62 yr) patients in the EA and GA groups.

Results: Mean tympanic membrane temperatures were similar at all time periods in the EA and GA groups and were nearly identical at the end of the surgical procedure (EA, 35.5 ± 0.2°C; GA, 35.6 ± 0.2°C) (P = 0.68). Intraoperatively, the EA group maintained a significantly smaller skin-surface gradient compared to the GA group (P = 0.0001), whereas the calf gradients were minimal and were similar between groups. Postoperatively, both groups had comparable positive forearm gradients, whereas calf gradients were greater in the GA group (P = 0.001). Mean core temperatures and forearm gradients were not different between the younger and older patients receiving GA. In those receiving EA, the younger patients had greater mean core temperatures (P = 0.015) and greater forearm gradients (P = 0.05) for most of the perioperative period.

Conclusions: The EA and GA groups had virtually identical core temperature profiles during the intraoperative and postoperative periods. Comparison of skin-surface gradients suggests that EA is associated with less intraoperative upper-body thermoregulatory impairment but greater and persistent postoperative lower-body impairment. During EA, younger patients appeared to maintain thermoregulatory activity relative to the older patients. In patients receiving GA, the age-related differences were minimal. (Key words: Age factors; hypothermia. Anesthetics: epidural; general. Hypothermia. Temperature regulation. Vasoconstriction: thermoregulatory.)

WHEN defined as a body temperature of less than 36°C, inadvertent hypothermia occurs in 50–70% of surgical patients.¹⁻³ We have previously shown that one in three patients develops a core temperature of less than 35°C when no precautionary warming methods are used during surgery.¹ Not only does hypothermia occur frequently, but significant physiologic changes occur with cooling and rewarming and may adversely affect outcome. The risks of coagulopathy⁴⁻⁶ and prolonged drug effect⁷ are increased with hypothermia. In the postoperative period, rewarming and shivering may increase metabolic demands,⁸⁻¹⁰ and in high-risk patients, mild hypothermia has been associated with an increased incidence of early postoperative myocardial ischemia.¹⁰

Many general anesthetics have been shown to interfere with the homeostatic mechanisms that regulate body temperature.¹¹⁻¹³ This is most likely a result of suppression of thermoregulatory centers in the central nervous system. During general anesthesia (GA), both shivering and vasoconstriction are inhibited, and metabolic rate is significantly reduced. Regional anesthetics have minimal effects on the brain and brain stem, where thermoregulatory signals are integrated, and therefore should allow for less thermoregulatory inhibition. However, afferent thermal sensation and peripheral vasoconstriction are inhibited below the level of sympathetic blockade, and these effects may be responsible for some degree of thermoregulatory inhibition.

Previous studies comparing regional anesthesia and GA have shown conflicting results with regard to the
relative risk of hypothermia. Some investigators have shown a greater incidence of hypothermia with GA, others have shown a greater incidence with regional anesthesia, and still others have found no difference. Problems with these earlier studies include a lack of randomization, nonuniformity of surgical procedures, small sample size, and discontinuous collection of temperature data. Skin-surface temperature gradients have been used to assess thermoregulatory vasoconstriction. A positive proximal-distal gradient has been shown to correlate with reduced blood flow to the extremity, a reflex consistently triggered by core hypothermia. Although general anesthetics have been shown to inhibit thermoregulatory vasoconstriction, previous studies have not directly compared the skin-surface gradients that occur with GA and regional anesthesia. Both in the presence and absence of anesthetics, the ability of elderly patients to maintain body temperature is impaired, possibly because of an age-related reduction in thermoregulatory vasoconstriction. However, the effects of age on thermoregulation during anesthesia and surgery, and more specifically during regional anesthesia versus GA, have not been previously studied. In the current study, we compared intra- and postoperative core temperature changes in patients receiving epidural anesthesia (EA) or GA for radical prostatectomy. Forearm and calf skin-surface temperature gradients also were compared as indices of thermoregulatory activity. In addition, the effects of age on thermoregulatory activity during EA and GA were assessed by subgroup analysis.

Materials and Methods

After approval from the Committee of Clinical Investigation of the Johns Hopkins Hospital and written informed consent had been obtained, 30 men undergoing radical retropubic prostatectomy for prostate cancer were enrolled in the study. No patient had a history of thyroid disorder, Raynaud’s disease, or significant preoperative fever. All patients were ASA physical status 1 or 2, and no patient had significant cardiac or pulmonary disease. Patients were randomized to receive either EA or GA, and randomization was stratified on the surgeons performing the procedure to ensure equal distribution among the two anesthetic groups.

Anesthetic Protocol

All patients, regardless of anesthetic assignment, received midazolam 1–3 mg intravenously upon arrival in the operating room. Before induction of anesthesia, both groups received an intravenous fluid bolus of lactated Ringer’s solution (20 ml/kg) delivered at ambient temperature. Fluids administered subsequently were warmed to 37°C. A lumbar epidural catheter was placed (L3–L4 or L4–L5) in all patients, regardless of anesthetic group, for the provision of postoperative analgesia as described below. A 3-ml test dose of 2% lidocaine with epinephrine 5 µg/ml was then given.

Patients in the GA group were given intravenous morphine 0.2 mg/kg, sodium thiopental 4–6 mg/kg, and succinylcholine 1 mg/kg for induction. Tracheal intubation was performed, and anesthesia was maintained with nitrous oxide 70% in oxygen and isoflurane 0.2–0.8%. Pancuronium 0.1 mg/kg was given intravenously after induction, followed by 1–2 mg as needed to maintain one or two twitches in a train-of-four. At the end of the surgical procedure, the tracheal tube was removed from all patients.

EA was initiated with epidural bupivacaine 0.5% (0.26 ml/kg). Anesthesia was maintained with a continuous bupivacaine 0.125% infusion at a rate of 0.1 ml·kg⁻¹·h⁻¹. Sensory level was assessed every 15–30 min during surgery using a pinprick stimulus.

Postoperative analgesia was delivered according to protocol. All patients, regardless of anesthetic group, received epidural fentanyl 100 µg in 10 ml saline during skin closure. Before discharge from the postanesthesia care unit (PACU), approximately 1 h after the end of surgery, all patients received patient-controlled epidural analgesia with bupivacaine 0.0625% and fentanyl 5 µg/ml at a baseline infusion of 2 ml/h, bolus dose of 4 ml, and a lockout interval of 10 min.

Ambient temperature in the operating room was controlled as much as possible to minimize differences between groups. Thermostats in the operating room were adjusted to an ambient temperature of approximately 21°C. Ambient temperature was measured at a site removed from the heat-generating monitoring equipment and is reported as the average temperature for the intraoperative period and for the postoperative period.

After the surgical incision, all fluids and blood were delivered through a warming device (model BW-5, Fenwall, Deerfield, IL). Respiratory gases were humidified and warmed to approximately 38°C in the GA group. Patients were covered above and below the surgical field with one layer of paper surgical drapes. In the postoperative period, one or two cotton blankets were used at the PACU nurses’ discretion. No extra-
neous heating devices were used during the intraoperative or postoperative periods.

The maintenance of intravascular volume, including blood and crystalloid administration, was controlled by protocol. After the initial fluid load, blood loss was replaced with 3 ml lactated Ringer’s solution for every 1 ml of estimated blood loss. Autologous whole blood was administered as needed to maintain hematocrit above 27%.

### Temperature Monitoring

Approximately 15–20 min after arrival in the operating room, after the application of patient monitors and placement of the epidural catheter, body and ambient temperature monitoring was begun. Core temperature was measured using tympanic membrane thermocouple probes (Mon-a-therm, Mallinckrodt, St. Louis, MO) placed by one of the investigators. Placement was confirmed by the patient when a scratching sound was heard.

Skin-surface thermocouple probes (Mon-a-therm) were used to measure skin temperatures. Forearm minus fingertip skin-surface temperature gradients exceeding 4°C identified significant thermoregulatory vasconstriction. Forearm temperature was measured on the radial aspect of the forearm, halfway between the elbow and the wrist. Fingertip temperature was measured on the index finger with the probe placed opposite the nail bed. No intravenous infusions and no intraarterial catheters were placed in the arm that was used for temperature monitoring.

Lower-extremity temperature gradients were monitored using the calf minus toe skin-surface temperature gradient. A calf–toe gradient greater than 6°C has been shown previously to reflect thermoregulatory activity and to correlate with significant upper-extremity gradients during hypothermia.

Temperatures at all sites were recorded at 2-min intervals using a multichannel thermometer (Isothermex, Columbus Instruments, Columbus, OH) linked to a laptop computer and stored on a hard disk. Temperature monitoring was begun just before the start of anesthesia and was discontinued upon discharge from the PACU, after approximately 2 h of postoperative care. Patients were discharged from the PACU when full motor strength returned to the lower extremities for patients in the EA group or when patients were fully awake and alert after GA. A core temperature of >35.5°C was required for consideration of discharge from the PACU.

Core temperatures and upper- and lower-extremity skin-surface temperature gradients in the two anesthetic groups were compared at the following time intervals: at preinduction; 15, 30, and 60 min after induction; 30 min before the end of surgery; at the end of surgery; upon arrival in the PACU; 30 and 60 min after arrival in the PACU; and upon discharge from the PACU. The time required to rewarm to 36°C was compared between the two groups to assess the rate of rewarming.

### Statistical Analysis

Demographic variables were compared using unpaired two-tailed Student’s t tests. Anesthetic and age groups were compared with regard to temperature changes over time using analysis of variance for repeated measures with post hoc analysis by Bonferroni correction. Patients were divided into younger and older age groups for subgroup comparison. The median age for all patients included in the study (62 yr) was used to define these two age groups. All data are presented as means ± standard error of the means. For all analyses, P < 0.05 was used to determine significance.

### Results

A demographic comparison of the two groups is given in Table 1. The groups did not differ with respect to age, body weight, or duration of surgery. Including all pa-

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Table 1. Demographics

<table>
<thead>
<tr>
<th>Anesthetic</th>
<th>Age (yr)</th>
<th>Weight (kg)</th>
<th>Duration of Surgery (min)</th>
<th>Crystalloid (ml)</th>
<th>Blood Transfusion (U)</th>
<th>Ambient OR Temperature (°C)</th>
<th>Ambient PACU Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidural (n = 15)</td>
<td>61 ± 2</td>
<td>82 ± 2</td>
<td>207 ± 10</td>
<td>3,900 ± 200</td>
<td>1.7 ± 0.2</td>
<td>21.7 ± 0.4</td>
<td>23.3 ± 0.3</td>
</tr>
<tr>
<td>General (n = 15)</td>
<td>62 ± 2</td>
<td>87 ± 2</td>
<td>203 ± 10</td>
<td>4,600 ± 200</td>
<td>2.3 ± 0.2</td>
<td>22.0 ± 0.4</td>
<td>23.0 ± 0.3</td>
</tr>
</tbody>
</table>

P = operating room; PACU = postanesthesia care unit.
patients enrolled in the study, the range in patient age was 48–70 yr (median 62 yr). The patients were equally distributed in the age subgroups (GA: younger, n = 7 and older, n = 8; EA: younger, n = 8 and older, n = 7). Crystalloid administration (P = 0.01) and transfusion requirements (P = 0.06) were greater in the GA group. Mean ambient operating room temperatures were 21.7 ± 0.4 and 22.0 ± 0.4°C for the EA and GA groups, respectively (P = 0.44). Mean PACU ambient temperatures were 23.3 ± 0.3 and 23.0 ± 0.3°C for the EA and GA groups, respectively (P = 0.44). The two groups were comparable with regard to the distribution of cases among the attending surgeons.

In patients receiving EA, the median highest sensory block level was T3 (range T1–T7), and the median level of sensory block at the end of the surgical procedure was T5 (range T2–L1). In the younger subgroup the median highest level was T3 (range T1–T5) and in the older subgroup was T4 (range T2–T7).

At no time during the intraoperative or postoperative period was there a significant difference in core temperatures (fig. 1). Mean core temperatures at the end of the surgical procedure were 35.5 ± 0.2 and 35.6 ± 0.2°C in the EA and GA groups, respectively (P = 0.68). The EA and GA groups required 62 ± 15 and 56 ± 15 min, respectively, to rewarm to a tympanic temperature of 36°C (P = 0.80).

Forearm–fingertip skin-surface temperature gradients in the two anesthetic groups were compared over time (fig. 1). The groups had similar gradients before induction of anesthesia: 3.8 ± 1.0 and 3.2 ± 1.0°C for EA and GA, respectively (P = 0.68). Throughout the intra- and postoperative periods, significant vasoconstriction (>4°C gradient) was maintained in the EA group (P = 0.0001 vs. GA). In the GA group, however, the gradient decreased soon after induction, and a significant gradient did not return until admission to the PACU. In the postoperative period, both groups had similar and significant upper-extremity gradients.

The calf–toe skin-surface gradients in the two groups were compared over time (fig. 1). Both groups had a significant positive gradient (>6°C) before induction of anesthesia and a decrease in the gradient soon after induction. The gradient returned during emergence in the GA group, but in the EA group, the gradient did not return until more than 1 h after the postoperative period had begun (P = 0.001, GA vs. EA).

Figure 2 illustrates the results of the subgroup analysis for the younger and older patients. In patients receiving GA, the two age groups had similar core temperatures and forearm–fingertip skin-surface temperature gra-

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Fig. 1. Comparison of core temperatures and upper- and lower-extremity skin-surface temperature gradients in patients undergoing radical prostatectomy under epidural (EA) or general (GA) anesthesia. The time periods shown correspond to the following times, respectively: preinduction; 15, 30, and 60 min after induction; 30 min before the end of surgery; the end of surgery; arrival in the postanesthesia care unit; 30 and 60 min after arrival in postanesthesia care unit; and discharge from the postanesthesia care unit. Mean tympanic temperatures were not significantly different between anesthetic groups at any time period. A positive forearm–fingertip gradient was maintained in the GA group but was absent in the GA group during the intraoperative period. In the postoperative period both groups had similar positive gradients. A positive calf–toe gradient was present in both groups before induction and was absent in both groups soon after induction. A positive calf–toe gradient developed in the GA group during emergence and remained significantly greater in the GA group throughout the postoperative period. *P < 0.001 versus EA.
Fig. 2. Comparison of core temperatures and forearm-fingertip skin-surface temperature gradients in the younger and older patient subgroups during the perioperative period. The median age for all patients in the study (62 yr) was used to divide the two age groups, which were compared separately for those receiving epidural (EA, left) and general (GA, right) anesthesia. The time periods shown correspond to the following times, respectively: preinduction; 15, 30, and 60 min after induction; 30 min before the end of surgery; the end of surgery; arrival in the postanesthesia care unit; 30 and 60 min after arrival in the postanesthesia care unit; and discharge from the postanesthesia care unit. Mean tympanic membrane temperatures and forearm-fingertip gradients were not significantly different between younger and older patients receiving GA at any time period. In patients receiving EA, there were significant differences between the two age groups. The older patients had lower mean tympanic membrane temperatures shortly after induction and at the end of the surgical procedure, and they remained hypothermic relative to the younger patients for most of the postoperative period. With EA, the younger patients had greater forearm-fingertip gradients during most of the study. *P < 0.01 versus older patients; #P < 0.05 versus older patients.

In the EA group, the younger patients had greater mean core temperatures ($P = 0.015$) and greater forearm-fingertip gradients ($P = 0.05$) for most of the perioperative period.

There was no correlation between volume of intraoperative crystalloid administration and tympanic temperature at the end of the surgical procedure in the EA or the GA groups. Transfusion requirements and tympanic temperatures were not significantly correlated in the EA or the GA groups.

All patients had an uneventful recovery after surgery, and there was no identifiable morbidity related to the degree of hypothermia seen in these patients.

**Discussion**

Despite significant differences in upper- and lower-extremity skin-surface temperature gradients, changes in core temperatures were similar in the EA and GA groups. The intraoperative period was characterized...
by maintenance of upper-body vasoconstriction in the EA relative to the GA group and absence of lower-body vasoconstriction in both groups. In the postoperative period, upper-body vasoconstriction was maintained in both groups, and lower-body vasoconstriction was significantly greater in the GA group. The effects of age were significant; thermoregulatory activity was reduced with advanced age during EA, but no age-related differences were found during GA.

Previous studies have compared regional and general anesthetic techniques to identify differences in the incidence and severity of hypothermia. The current study is unique in that both core temperature and skin-surface temperature gradients were used to compare thermoregulatory activity in the two anesthetic groups. In addition, all patients were undergoing similar surgical procedures and were allocated randomly to the two groups. Previous studies have not shown a consistent difference in the incidence and severity of hypothermia with regional compared to GA. Of the randomized studies, one found GA and two found EA to be associated with a greater degree of hypothermia. In a larger randomized series, which accounted for differences in ambient temperature, we identified a greater degree of hypothermia with GA at a low ambient temperature but no difference between the two anesthetics at a higher ambient temperature. In the largest series comparing the two anesthetics (198 patients, nonrandomized), there were no differences in core temperature at the end of the surgical procedures. The latter investigators did not include data regarding blood loss or fluid requirements and did not specify the type of regional anesthesia (spinal or epidural).

A unique feature of the current study is the high level of epidural block (T3) that was obtained relative to our previous study with a block level of T8-T10. Because only the area above the level of the sympathetic block can actively vasoconstrict, approximately 70% of the entire skin surface remained vasodilated. This may explain the similar degrees of hypothermia in the EA and the GA groups, despite evidence for a more consistently maintained upper-extremity thermoregulatory vasoconstriction in the EA group.

An additional factor that may have contributed to significant heat loss is the open body cavity during surgery and the exposed abdominal viscera. Previous studies in animal models have shown a significant evaporative heat loss with an open peritoneal cavity. In an anesthetized pig model, for a given exposed surface area, there was a 14-fold greater heat loss (watts per square meter) from the open abdominal cavity than from the exposed skin surface.

The older patients demonstrated more thermoregulatory impairment relative to the younger patients in the EA group, whereas age-related differences were minimal in the GA group. This finding is consistent with previous studies that have shown elderly patients to be more susceptible to hypothermia. Because all patients had prostate cancer, the population did not include many young patients. Even within the age range that was studied (48-70 yr), there appears to be a predisposition to hypothermia during EA with increasing age. The significant correlation between advanced age and hypothermia in the EA group confirms the results of our previous study and suggests that the normal effect of age on body temperature regulation is less altered by EA than by GA. Nonanesthetized elderly patients have been shown to have a decreased ability to maintain normothermia when exposed to cold ambient temperatures as well as a blunted vasoconstriction response when exposed to cold stress.

Kurz et al. have recently shown that during GA, older patients (mean age 73 yr) require a lower core temperature to trigger thermoregulatory vasoconstriction compared to that required by younger patients (mean age 40 yr). Because this represents a greater age spread between the younger and older patients, it is not surprising that age had a significant effect during GA in that study but not in ours. In our population, mean age was 57 yr in the younger group and 67 yr in the older group. Furthermore, we did not attempt to measure thermoregulatory thresholds but rather to compare the effects of age on core temperature and skin-surface temperature gradients during EA and GA.

Although transfusion and fluid requirements were greater in the GA group, these do not seem to represent confounding variables in the current study, given the lack of association between these variables and hypothermia. That lack of association may be related to the efficacy of the fluid warmers or perhaps to the amount of crystalloid used, which was not extraordinary for any patient.

A 3-4°C forearm skin-surface temperature gradient was measured in both anesthetic groups at baseline just before induction of anesthesia, indicating that patients were vasoconstricted at the outset of the study. This may be explained by the mild hypothermia that developed before the induction of anesthesia during placement of the epidural catheter and intraoperative monitors. This 20-40-min period included the infusion of 20 ml/kg intravenous fluid that was not delivered.
through the fluid warmer. Stoeck and Sessler have shown that nonanesthetized patients develop significant thermoregulatory vasoconstriction at core temperatures similar to those that we measured just before the start of anesthesia (36.6°C)\textsuperscript{11}.

A possible limitation in the current study is the use of a combination of anesthetic drugs; previous studies addressing thermoregulation have primarily used inhalational agents.\textsuperscript{12,23,24} For postoperative analgesia, all patients received patient-controlled bupivacaine–fentanyl infusions before discharge from the PACU. Although the bupivacaine may have altered sympathetic activity in the lower extremities, patients were started on this analgesic regimen approximately 1 h after admission to the PACU, and only the last time period would reveal an effect. In addition, all patients, regardless of anesthetic group assignment, received the same postoperative analgesia protocol, and therefore any differences between groups were most likely related to the intraoperative anesthetic management.

In conclusion, the observed changes in core temperature were almost identical in patients receiving EA or GA, despite evidence of greater upper-body thermoregulatory activity with EA. The similarity in core temperatures may have been due to the relatively high level of epidural block compared to that of previous studies\textsuperscript{4} or perhaps due to the open body cavity during surgery. With EA, thermoregulatory impairment appeared to be more significant in older patients, whereas no age-related differences were evident with GA. Based on the relatively similar degrees of hypothermia that occurred in both anesthetic groups, it can be concluded that core temperature should be monitored in patients undergoing major surgical procedures during either regional anesthesia or GA.

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References