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The Threshold for Thermoregulatory Vasoconstriction during Nitrous Oxide/Isoflurane Anesthesia Is Lower in Elderly Than in Young Patients

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Background: **Thermoregulatory vasoconstriction minimizes further core hypothermia during anesthesia. Elderly patients become more hypothermic during surgery than do younger patients, and take longer to rewarm postoperatively. These data indicate that perianesthetic thermoregulatory responses may be especially impaired in the elderly. Accordingly, the authors tested the hypothesis that the thermoregulatory threshold for vasoconstriction during nitrous oxide/isoflurane anesthesia is reduced more in elderly than in young patients.**

Methods: **The authors studied 12 young patients aged 30–50 yr and 12 elderly patients aged 60–80 yr. All were undergoing major orthopedic or open abdominal surgery. Anesthesia was induced with thiopental and fentanyl, and maintained only with nitrous oxide (70%) and isoflurane (0.6–0.8%). Core temperature was measured in the distal esophagus. Fingertip vasoconstriction was evaluated using forearm minus fingertip, skin-temperature gradients. A gradient of 4° C identified significant vasoconstriction, and the core temperature triggering vasoconstriction identified the thermoregulatory threshold.**

Results: **The vasoconstriction threshold was significantly less in the elderly patients (33.9 ± 0.6° C) than in the younger ones (35.1 ± 0.3° C) ($P < 0.01$). The gender distribution, weight, and height of the elderly and young patients did not differ significantly. The end-tidal isoflurane concentration at the time of vasoconstriction did not differ significantly in the two groups.**

Conclusions: **These data indicate that thermoregulatory responses in the elderly are initiated at temperatures ≈ 1.2° C less than that in younger patients. Thus, it is likely that elderly surgical patients become more hypothermic than do younger patients, at least in part, because they fail to trigger protective thermoregulatory responses. (Key words: Age. Brain: hypothalamus. Temperature, hypothermia. Thermoregulation.)**

THE elderly are the fastest-growing segment of the United States population. Because they are prone to a variety of illnesses, the elderly represent a large, and rapidly increasing, segment of the surgical population. Intraoperative core body temperature decreases more in elderly patients than in middle-aged and young patients.[1,2]

Hypothermia during surgery results, initially, from redistribution of body heat from the thermal core to peripheral tissues.[3] Subsequently, hypothermia results simply from heat loss exceeding metabolic heat production.[4] In patients becoming sufficiently hypothermic to trigger thermoregulatory vasoconstriction,[5,6] further reduction in core temperature is limited by decreased cutaneous heat loss and constraint of metabolic heat to the thermal core.[7]

Factors contributing to exaggerated hypothermia in the elderly include their often frail condition, relatively low metabolic rate, and little subcutaneous fat. Furthermore, they frequently require relatively large and long operations. An additional potential etiology is impaired thermoregulation in the elderly. Because thermoregulatory vasoconstriction during anesthesia is effective in minimizing further core hypothermia,[7] impaired vasoconstriction in the elderly would contribute to the observed hypothermia in these patients. Consistent with exaggerated thermoregulatory impairment,

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the elderly shiver less postoperatively (despite generally having lower core temperatures)[2,8] and take longer to rewarm.[9] Accordingly, we tested the hypothesis that the thermoregulatory threshold for vasoconstriction during nitrous oxide/isoflurane anesthesia is reduced more in the elderly than in younger patients.

Materials and Methods

With approval from our local Ethical Committee, we studied 24 ASA Physical Status 1–3 patients undergoing elective orthopedic or abdominal surgery. None was obese, was taking medication, or had a history of smoking, thyroid disease, dysautonomia, or Raynaud's syndrome.

Twelve young patients were aged 30–50 yr, and 12 elderly patients were aged 60–80 yr. Six in each group were undergoing total hip arthroplasty or proximal femoral tumor resection, and six required open abdominal surgery. The orthopedic surgeries were conducted in a laminar flow room.

Protocol

On arrival in the operating suite, 10 ml/kg of unwarmed intravenous fluid was administered. Without any premedication, anesthesia was then induced with fentanyl (100 μg) and sodium thiopental (4–6 mg/kg). Intubation of the trachea was facilitated by administration of vecuronium bromide (0.1 mg/kg). Mechanical ventilation was maintained with a circle system having a fresh gas flow of 6 l/min, and adjusted to maintain end-tidal P_{CO_2} near 35 mmHg. No airway heating or humidification was provided. No additional thiopental or opioid was administered.

Anesthesia was maintained with nitrous oxide 70% and isoflurane at an end-tidal concentration of 0.6–0.8%. In preliminary studies, we determined that this isoflurane concentration provided adequate control of hemodynamic responses in most patients, and a range of threshold temperatures not requiring unacceptable hypothermia in the elderly patients. Vasodilating medications were given to four elderly patients who became hypertensive at 0.8% end-tidal isoflurane concentration; their data were excluded from analysis.

Supplemental vecuronium was administered as needed to maintain 1–2 twitches in response to supramaximal stimulation of the ulnar nerve at the wrist. At least 10 $ml \cdot kg^{-1} \cdot h^{-1}$ fluid was given intravenously, and blood products were replaced to maintain the hematocrit between 25–32%. Administered fluids were warmed to 37° C in the patients undergoing orthopedic surgery, but administered at ambient temperature in those having abdominal surgery.

The patients were covered with a single layer of surgical draping; no other warming measures were taken during the initial portion of the study. Six patients never vasoconstricted because the duration of surgery was inadequate to produce sufficient hypothermia; their data were excluded from analysis. Twenty minutes after significant vasoconstriction was observed, patients were actively rewarmed using a forced-air system (Bair Hugger, Augustine Medical, Eden Prarie, MN).[4,10] Subsequent anesthetic management was left to the discretion of the responsible anesthesiologist.

Monitoring

Ambient temperature was measured using a bare-wire thermocouple positioned at the level of the patient, well away from any heat-producing equipment. Core temperature, before induction of anesthesia, was measured at the tympanic membrane. The aural probe was inserted until the patients felt the thermocouple touch the tympanic membrane; appropriate placement was confirmed when they easily detected a gentle rubbing of the attached wire. The probe was then taped in place, the aural canal occluded with cotton, and the external ear covered with a gauze pad. Tympanic membrane temperatures correlate well with distal esophageal temperatures during anesthesia.[11,12] After induction of anesthesia, core temperature was recorded from the distal esophagus.

Mean skin temperature was calculated from four sites: $0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{calf})$.[13] Fingertip blood flow was evaluated using forearm minus fingertip, skin-surface temperature gradients. There is an excellent correlation between skin-temperature gradients and volume plethysmography.[14] Temperatures were measured using Yellow Springs Instruments thermistors (Yellow Springs, OH).

Heart rate was monitored continuously using three-lead electrocardiography. Blood pressure was determined oscillometrically at 5-min intervals. Respiratory gas concentrations were quantified using a calibrated end-tidal gas analyzer (Datex Medical Instrumentation, Tewksbury, MA). All other data were recorded at 10-min intervals, starting immediately before induction of anesthesia ("initial" values).

Data Analysis

As in previous studies,[15,16] we considered a gradient of 4° C to indicate significant thermoregulatory vasoconstriction. The distal esophageal temperature triggering significant vasoconstriction was considered the thermoregulatory threshold. The preinduction fluid bolus was not considered part of the intraoperative fluid balance. Fluid administered to the time of vasoconstriction was divided by the elapsed time of vasoconstriction to produce the fluid administration rate. Ambient temperature in each case was averaged over time from induction of anesthesia until vasoconstriction.

Morphometric data, initial core temperature, ambient temperature, and fluid administration rate were compared using two-tailed, unpaired t tests. Isoflurane concentration, vasoconstriction threshold, time of constriction, mean skin temperature, heart rate, and arterial blood pressure at the time of constriction also were compared using two-tailed, unpaired t tests. All values are expressed as means ± SD; differences were considered significant when $P < 0.01$.

Results

The gender, weight, and height of the elderly and young patients did not differ significantly. Also, the ambient operating room temperature, end-tidal isoflurane concentrations, and administered fluid volume did not differ significantly in the two groups. The heart rate was significantly greater in the elderly; however, there was no clinically important difference in the two groups. Hypothermia developed at comparable rates in the elderly (0.9 ± 0.2° C/h) and young (1.0 ± 0.1° C /h) patients.

The vasoconstriction threshold was significantly less in the elderly (33.9 ± 0.6° C) than in younger patients (35.1 ± 0.3° C) (fig. 1). Approximately 1.6 h longer was required to trigger constriction in elderly than in younger patients, and the mean skin temperature was ≈ 1° C less when vasoconstriction did occur (table 1). Responses were similar in men and women; they also were similar in patients undergoing orthopedic and abdominal surgery.

Discussion

Even without anesthesia, thermoregulatory responses to cold are impaired in the elderly. Accidental hypothermia (in the absence of drug use) is more common

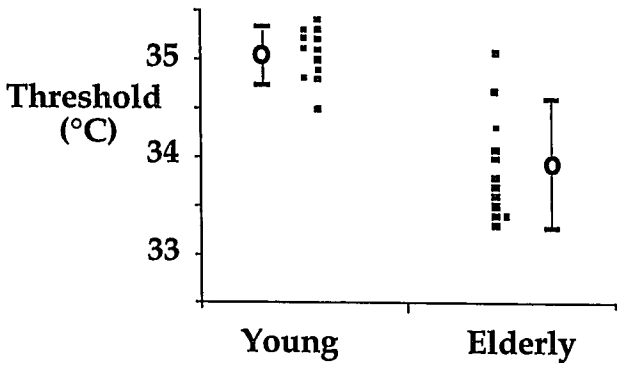

Fig. 1. The vasoconstriction threshold was significantly less in the elderly (33.9 ± 0.6° C) than in younger patients (35.1 ± 0.3° C) ($P < 0.01$). Filled squares indicate the vasoconstriction threshold in each patient; open circles show the mean and standard deviations in each group.

in elderly than in young individuals,[17] and a large fraction of elderly hypothermia victims display diminished response to experimental cold exposure.[18] Apparently, impaired thermoregulatory responses are not limited just to hypothermia victims; middle-aged and elderly men become more hypothermic during cold exposure than young men and boys.[19]

In contrast to diminished response to cold, thermoregulatory responses to heat stress appear relatively independent of age; magnitude of sweating and active forearm vasodilation were similar in fit elderly and young adults, but somewhat less in sedentary elderly subjects.[20] Similarly, another study failed to detect an age dependence for thermoregulatory responses to 40% maximal exercise in desert heat.[21]

Consistent with age-dependent impairment of thermoregulation in unanesthetized individuals, our data indicate that the threshold for thermoregulatory vasoconstriction during nitrous oxide/isoflurane anesthesia is ≈ 1.2° C less in elderly than in younger patients. (At the other end of the age spectrum, thermoregulatory vasoconstriction is well preserved in anesthetized infants and children.[22,23]) Because vasoconstriction during anesthesia minimizes further core hypothermia,[7] such substantial impairment of thermoregulatory constriction in the elderly probably contributes to the exaggerated hypothermia observed in these patients.

We actively rewarmed patients soon after significant vasoconstriction was observed; consequently, we were unable to determine if vasoconstriction produced a core temperature plateau in the elderly, as it does in younger individuals. Thus, it remains possible that the

Table 1. Morphometric Data, Initial Core Temperature, Ambient Temperature, Isoflurane Concentration, Rate at Which Fluid Was Administered, and the Vasoconstriction Threshold, Time of Constriction, and the Mean Skin Temperature, Heart Rate, and Arterial Blood Pressure at the Time of Vasoconstriction

	Young	Elderly
Age (yr)	40 ± 7	73 ± 6*
Weight (kg)	73 ± 12	69 ± 10
Height (cm)	175 ± 10	172 ± 11
Gender (M/F)	7/5	6/6
Inital core temperature (° C)	36.8 ± 0.1	36.7 ± 0.2
Ambient temperature (° C)	21.7 ± 0.7	21.9 ± 0.7
End-tidal isoflurane (%)	0.75 ± 0.04	0.73 ± 0.06
Fluid administration rate (ml/h)	775 ± 120	740 ± 113
Vasoconstriction threshold (° C)	35.1 ± 0.3	33.9 ± 0.6*
Vasoconstriction time (h)	1.8 ± 0.5	3.4 ± 0.6*
Skin temperature (° C)	33.2 ± 1.2	31.9 ± 0.8*
Heart rate (beats/min)	62 ± 7	71 ± 6*
Mean blood pressure (mmHg)	94 ± 8	99 ± 5

All data except the morphometric values, initial (pre-induction) core temperature, ambient temperature, and fluid administration rate were recorded at the time of vasoconstriction. Values are expressed as mean ± SD.

* Statistically significant differences between the groups ($P < 0.01$).

elderly not only fail to appropriately trigger vasoconstriction, but that the gain (rate of increase) and/or maximum constriction intensity may be impaired. To the extent that response intensity is reduced in the elderly, they will be less able to protect core temperature by decreasing cutaneous heat loss and constraining metabolic heat to the core.

Thermoregulatory impairment is only one cause of intraoperative hypothermia. Independent of their impaired thermoregulatory vasoconstriction, the elderly are also especially prone to hypothermia because they often have a frail constitution, reduced metabolic rate, and reduced subcutaneous fat layer. Documented adverse effects of perioperative hypothermia include prolonged drug action,[24] negative postoperative nitrogen balance,[25] and impaired coagulation.[26] Although the age dependence of these hypothermia-induced complications remains unknown, they are unlikely to be less harmful in the elderly than in younger patients.

The rate at which hypothermia developed was similar in our two study groups (≈1° C/h). Because the core temperature triggering vasoconstriction was less in the elderly than in the younger patients, the elderly patients required longer to reach the thermoregulatory threshold. Although the time dependence of thermoregulatory responses during anesthesia has not been specifically evaluated, we have not observed such dependence in our previous studies, and do not believe that this factor contributes to our results. In contrast, both the rate of skin temperature changes[27] and the direction of core temperature perturbations[28] may significantly alter thermoregulatory responses.

Our elderly patients were relatively healthy (*e.g.*, not taking medication) and had body compositions similar to those in the younger patients. It is likely that the vasoconstriction thresholds would be even less in this group if we had included frailer patients.

In a constant environment, changes in skin temperature generally reflect changes in core temperature. As expected from the lower threshold temperature in the elderly patients, their mean skin temperature was ≈ 1° C less than in the younger patients. Skin temperature contributes to thermoregulatory responses, but is 5–20 times less important than core temperature.[27,29] Consequently, we can predict that, if skin temperature were kept similar in the two groups, the difference between the thresholds would have been ≈ 0.1° C larger.

By design, end-tidal isoflurane concentrations were comparable in the two groups. As in our previous studies of thermoregulatory responses in infants and children,[22,23] we did not alter the inspired anesthetic concentration to provide equal age-adjusted MAC fractions in the young and elderly patients. We made no effort to keep relative anesthetic potency similar, because there is no *a priori* reason to assume that thermoregulatory impairment and anesthetic action are similarly altered by age. The relative potency of isoflurane is reduced ≈ 10% by the age difference in our patients.[30] A 10% increase in effective isoflurane concentration is unlikely to explain the 1.2° C reduction in the vasoconstriction threshold observed in the elderly patients.[11]

In summary, we determined the threshold for thermoregulatory vasoconstriction during nitrous oxide/isoflurane anesthesia in 12 patients aged 30–50 yr and in 12 others aged 60–80 yr. The vasoconstriction threshold was significantly less in the elderly patients (33.9 ± 0.6° C) than in the younger ones (35.1 ± 0.3° C). Thus, thermoregulatory responses in the elderly are initiated at temperatures ≈ 1.2° C less than those in younger patients. Therefore, it is likely that elderly surgical patients become more hypothermic than younger ones, at least in part, because they fail to trigger protective thermoregulatory responses.

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