

Patients with Diabetic Neuropathy Are at Risk of a Greater Intraoperative Reduction in Core Temperature

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Background: Core hypothermia develops after the induction of general anesthesia, but intraoperative vasoconstriction usually prevents its progression. However, diabetes mellitus is often associated with autonomic neuropathy, which leads to abnormal peripheral neurovascular function. Accordingly, we tested the hypothesis that diabetic patients experience a greater reduction in core temperature during general anesthesia than nondiabetic patients.

Methods: We studied 36 nondiabetic patients (control group) and 27 diabetic patients (diabetic group) undergoing elective abdominal surgery. Both groups were divided into young (< 60 yr) and older age (\geq 60 yr) groups. Standard noninvasive autonomic tests (heart rate variation at deep periodical breathing, Valsalva maneuver, and head-up tilt) were carried out for each patient. The relation between the results of these tests of autonomic function and the tympanic membrane temperature during general anesthesia was assessed in relation to peripheral vasoconstriction.

Results: Thirteen patients in the diabetic group showed abnormal responses to two or more of the basal autonomic function tests (patients with autonomic dysfunction). Changes in core temperature among the groups were similar at 90 min after the induction of anesthesia. However, the core temperature of the diabetic patients with autonomic dysfunction was lower from 120 min (35.1°C) onward compared with the young or older nondiabetic patients and the diabetic patients with normal autonomic function. Peripheral vasoconstriction, evaluated using the forearm-fingertip skin surface temperature gradient,

was delayed in patients with autonomic dysfunction compared with the others.

Conclusions: The current results indicate that diabetic autonomic neuropathy is associated with more severe intraoperative hypothermia. We postulate that diabetic patients become more hypothermic because their peripheral neuropathy delays the onset of thermoregulatory vasoconstriction and reduces its efficacy once triggered. These patients may therefore fail to develop a normal core temperature plateau. (Key words: Anesthesia; diabetes; autonomic insufficiency; thermoregulation; vasoconstriction.)

PERIOPERATIVE hypothermia is common and causes several complications, including postoperative shivering, decreased drug metabolism and clearance, and impaired wound healing. Hypothermia initially results from core-to-peripheral redistribution of body heat and from heat loss exceeding heat production. Progression of hypothermia is prevented, however, by the reemergence of thermoregulatory vasoconstriction,^{1,2} which decreases cutaneous heat loss³ and retains metabolic heat in the core thermal compartment.⁴

Diabetes mellitus is often associated with autonomic dysfunction. It is known that skin and tissue blood flow are altered in diabetic patients,⁵ at least partly as a result of impairment of neurogenic control.^{6,7} Peripheral neurovascular function is disordered in diabetic patients,⁸ and it is possible that this abnormality prevents effective thermoregulatory vasoconstriction.¹⁰

In the current prospective study, we tested the hypothesis that the threshold for intraoperative vasoconstriction is reduced in patients with autonomic neuropathy and that these patients consequently become more hypothermic during surgery compared with patients without autonomic neuropathy.

Methods

The protocol was reviewed and approved by the ethics committee of our department. Informed consent was obtained from all patients. Thirty-six nondiabetic pa-

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Table 1. Demographic and Clinical Characteristics of the Patients

	Young Group	Older Group	All Controls	DAN-negative	DAN-positive
Number	19	17	36	14	13
Mean age (yr)	48 ± 28	69 ± 5*	58 ± 13	59 ± 12	62 ± 12
Body mass index (kg/m ²)	22.7 ± 2.6	21.8 ± 2.6	22.3 ± 2.6	23.4 ± 3.9	23.7 ± 4.2
Duration of surgery (min)	198 ± 42	185 ± 45	192 ± 43	210 ± 57	191 ± 36
Prior myocardial infarction (cases)	0	0	0	1	3
Retinopathy (cases)	0	2	2	1	3
Painful peripheral neuropathy (cases)	0	0	0	0	3
IDDM (NIDDM)				3 (11)	4 (9)
Mean duration of diabetes (yr)				4.9 ± 3.2	6.9 ± 4.7
HbA1C				6.8 ± 1.6	8.0 ± 1.2
Use of vasopressor (ephedrine) (cases)	1	3	4	3	6
Use of insulin (cases)	1	1	2	1	1
Transfusion requirement (cases)	4	6	10	4	4
Total fluid administered (ml/kg)	41.5 ± 10.7	36.7 ± 8.2	39.2 ± 9.8	40.8 ± 10.0	41.40 ± 11.5

Values are mean ± SD. Young group: young controls (<60 yr old), Older group: elderly controls (≥60 yr old), DAN: diabetic autonomic neuropathy; IDDM: Insulin-dependent diabetes mellitus; NIDDM: Non-insulin-dependent diabetes mellitus.

* $P < 0.05$ compared with young group.

tients (control group: 19 men and 17 women) and 27 diabetic patients (diabetic group: 15 men and 12 women) with no history of smoking who were scheduled for elective abdominal surgery participated in this study. Patients with a body mass index in excess of 28% were excluded. The age range was wide, but the average ages of the control and diabetic groups were comparable. The diabetic and control groups were each divided into young and older groups (< 60 yr of age and ≥ 60 yr of age, respectively). The criteria for diabetes mellitus were treatment with insulin or oral hypoglycemic agents and an elevated fasting glucose level on checkup before surgery defined as plasma level of 140 mg/dl or higher and whole blood level of 120 mg/dl or higher. Each patient underwent a preoperative evaluation which included history, physical examination, 12-lead electrocardiogram (ECG), chest radiograph, and biochemistry screening tests.

Basic demographic and clinical data were obtained preoperatively, and physical examination was done with a focus on abnormalities of the pulmonary, cardiac, endocrine, neurologic, and vascular systems. None of the patients were being treated with β-adrenergic antagonists, peripheral vasodilators, diuretics, or central sympatholytic agents. Four diabetic patients had Q waves on resting ECG but had not previously evident ischemic episodes. None had signs or symptoms of heart failure or unstable cardiac symptoms. Four diabetic patients and two control subjects had retinopathy. Among the diabetic patients, three had chronic painful peripheral neuropathy. There were seven type I and 20 type II diabetic patients, and the time from the diagnosis of diabetes to

the current study averaged 5.9 yr (range, 5 months–2 yr). The mean HbA1c level in the 27 diabetic patients was $7.5 \pm 1.5\%$ (table 1).

Autonomic Function Tests

All subjects were evaluated no more than 1 day before surgery. Three standard noninvasive autonomic tests (heart rate variation at deep periodical breathing, Valsalva maneuver, and head-up tilt) were carried out for each patient.¹¹ The subject was asked to rest comfortably in the supine position in a quiet room with dim lighting. The ECG and the tonometric blood pressure of the radial artery were monitored continuously (ANS-508; Colin Electronics, Komaki, Japan). Heart rate (HR) was detected from lead II of the ECG. A 2-min period of quiet breathing was observed with the ECG displayed on an oscilloscope, followed by a period of forceful breathing for 3 min which consisted of 1 min of maximum inspiratory and expiratory efforts (each 5 s in duration) at a frequency of 6 breaths/min. The ratio of the maximum respiratory rate (RR) interval during expiration to the minimum RR during inspiration (E/I ratio) was calculated for each breath. The mean E/I ratio during the second minute was calculated as the average of the six E/I ratios recorded during this time, and the maximum E/I ratio was defined as the single largest ratio during the second minute. Values less than 1.10 were considered abnormal.

A 10-min supine recovery period was observed, followed by two consecutive Valsalva maneuvers. These consisted of blowing into a mouthpiece connected to a sphygmomanometer to maintain a pressure of 30 mmHg

for 10 s. Practice sessions were conducted to teach the subject how to perform this test. Measurements were taken after a 2-min rest period between trials. The Valsalva ratio was calculated as the ratio of the longest RR interval after Valsalva release (phase IV) to the shortest RR interval during the procedure (phase II), and the higher ratio for two trials was reported. Values less than 1.10 were considered abnormal.

The head-up tilt response was studied after a 5-min recovery period. The subject was tilted to 60 degrees on an electrically driven tilt table with a foot support while blood pressure (BP) and HR were monitored. BP and the HR were determined every 60 s during a 6-min control period and a 6-min head-up tilt. The BP and cardiac intervals were averaged during the control and tilt periods. The subject was then returned to the supine position, and BP and HR were allowed to return to baseline. Premature termination of the tilt test was required in three diabetic patients with autonomic neuropathy and two patients from the older control group because of nausea or lightheadedness. Those cases and a decrease of diastolic blood pressure of more than 5 mmHg after head-up tilt were considered abnormal.

The autonomic tests for specific assessment of cardiac vagal integrity consisted of heart rate variation at breathing and the Valsalva ratio. The tests that were primarily, but not solely, related to the sympathetic nervous system consisted of the HR increase during Valsalva strain and head-up tilt and the diastolic blood pressure increase provoked by the head-up tilt test.

Anesthetic Technique

The anesthetic technique was standardized for each patient. No premedication was given. Fentanyl (2 $\mu\text{g}/\text{kg}$) and propofol (1 to 2 mg/kg) were used for the induction of anesthesia. Vecuronium (0.1 mg/kg) was used to facilitate tracheal intubation. Mechanical ventilation was maintained with a circuit system having a fresh gas flow of 6 l/min, which was adjusted to maintain the end-tidal P_{CO_2} near 35 mmHg. No airway heating or humidification was provided. The operation was begun, and anesthesia was maintained with 70% nitrous oxide and isoflurane at an end-tidal concentration of 1.0–3.0%. Supplemental vecuronium was administered as needed to maintain one to two twitches in response to supramaximal stimulation of the ulnar nerve at the wrist. Intravenous fluid was administered at a basal rate of 10–15 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$. In addition, 4 ml of crystalloid was given to compensate for each estimated 1 ml of intraoperative blood loss, and blood product replacement was done to maintain the

hematocrit at 25–32%. Fluids were not warmed. Reversal of residual muscle paralysis was achieved with neostigmine (1.5–2.5 mg) and atropine (0.5–1.0 mg).

The intraoperative blood glucose level ranged from 130–280 mg/dl. Patients who had blood glucose values higher than 250 mg/dl were treated with intravenous human insulin (Humulin R, 4 units). Ephedrine was administered if the systolic blood pressure was lower than 90 mmHg, and the use of any other pharmacologic agents was recorded.

The patients were covered with a single surgical drape in a 23°C environment during this study. The arm used to test vasoconstriction was not covered. A forced-air warmer (Warm Touch model 5200, Mallinckrodt Medical, St. Louis, MO) was used to rewarm the patients after the study.

Intraoperative Monitoring

The core temperature before the induction of anesthesia was measured at the tympanic membrane. The aural probe was inserted until the patient felt the thermocouple touch the tympanic membrane; appropriate placement was confirmed when the patient easily detected gentle rubbing of the attached wire. The probe was then taped in place, the auditory canal was occluded with cotton, and the external ear was covered with a gauze pad. The mean skin temperature was calculated by the following formula using data from four sites: $0.3(T_{\text{chest}} + T_{\text{arm}}) + 0.2(T_{\text{thigh}} + T_{\text{calf}})$.¹² Fingertip blood flow was evaluated using the forearm minus fingertip skin surface temperature gradient, because there is an excellent correlation between skin temperature gradient and volume plethysmography.¹³ The gradient was recorded from the arm that had no intravenous cannula or blood pressure cuff. A skin temperature gradient of 0°C (corresponding to a finger flow of ≈ 1 ml/min) is reported to coincide with the core temperature plateau⁴; therefore, we defined a gradient exceeding 0°C as significant vasoconstriction.

Previous studies have demonstrated that the cutaneous contribution to vasoconstriction is linear.^{14,15} Therefore, we used the measured threshold skin and core temperatures (°C) to calculate the threshold core temperature that would occur at a designated skin temperature ($T_{\text{core(calculated)}}$):

$$T_{\text{core(calculated)}} = T_{\text{core}} + (\beta/1 - \beta)(T_{\text{skin}} - T_{\text{skin(designated)}})$$

where β is the fractional contribution of the mean skin temperature at the threshold, T_{core} is the measured

Table 2. Autonomic Function Data of the Study Patients

	Young Group	Older Group	All Controls	DAN-negative	DAN-positive
Number	19	17	36	14	13
Mean E/I	1.35 ± 0.14	1.14 ± 0.07	1.26 ± 0.16	1.14 ± 0.10	1.05 ± 0.03†‡#
Maximum E/I	1.39 ± 0.12	1.19 ± 0.09	1.30 ± 0.15	1.18 ± 0.05	1.08 ± 0.03†‡\$#
Valsalva ratio	1.47 ± 0.23	1.31 ± 0.11	1.40 ± 0.20	1.12 ± 0.09	1.05 ± 0.10†‡\$#
Head-up tilt*					
Change in DABP	4.3 ± 2.2	1.7 ± 0.9	3.2 ± 2.2	1.3 ± 2.5	-3.5 ± 3.3†‡\$#
HR	10 ± 3	7 ± 3	9 ± 3	8 ± 3	7 ± 3

Values are mean ± SD.

DAN = diabetic autonomic neuropathy; E/I ratio = the ratio of the maximum RR interval during expiration to the minimum RR during inspiration; DABP = diastolic arterial blood pressure; HR = heart rate.

* Only 15 and 10 patients in older and DAN-positive groups, respectively, were able to perform these tests.

† $P < 0.05$, all controls versus DAN-positive group.

‡ $P < 0.05$, young group versus DAN-positive group.

\$ $P < 0.05$, older group versus DAN-positive group.

|| $P < 0.05$, young group versus older group.

$P < 0.05$, DAN-negative group versus DAN-positive group.

core temperature, T_{skin} is actual skin temperature, and $T_{\text{skin}(\text{designated})}$ is designated skin temperature. On the basis of previous studies, we used a β value of 0.2 for vasoconstriction.^{14,15} The designated skin temperature was set at 34.0°C, a typical intraoperative value.^{16,17} Using this equation, the threshold core temperature for vasoconstriction could be calculated for a single designated mean skin temperature, even when the skin temperature was manipulated during the study.

The HR was monitored continuously using three-lead ECG, and the BP was determined oscillometrically at 5-min intervals. Respiratory gas concentrations were quantified using a calibrated end-tidal gas analyzer (Ultima, Datex, Helsinki, Finland). All other data were recorded at 15-min intervals, starting immediately before the induction of anesthesia.

Data Analysis

Power analysis of test showed that 13 patients per group were necessary to obtain a β value of 80%. The baseline subject characteristics and the data obtained were compared using one-way analysis of variance when the variance was similar between groups or the Kruskal-Wallis test when within-group variance differed between groups. The autonomic test data were averaged for each group and were compared using analysis of variance and the unpaired t test. Two-way analysis of variance for repeated measurements was used to assess changes over time within as well as between groups. The statistical analysis compared on each established point of the study. Bonferroni analysis was applied to correct P values for multiple group comparisons. Data are expressed

as the mean ± SD. A probability value less than 0.05 was taken as significant. The diabetic and control groups of patients were also divided into young (< 60 yr) and older (\geq 60 yr) groups for comparison.

To determine whether intraoperative hypothermia was related to autonomic insufficiency among the diabetic patients, they were classified as having autonomic dysfunction if there were abnormal responses to two or more of the three tests.

Results

The demographic and clinical characteristics of the patients are shown in table 1. The ages of the control and diabetic groups were similar. Each patient group was divided into young and older age groups, and statistical analysis was then performed. We were unable to discern a significant age effect among the diabetic patients with respect to the autonomic test results or the intraoperative data; thus, further analyses were performed comparing the diabetic patients with and without autonomic dysfunction to the young and older control patients. The body mass index, number of subjects administered intravenous vasopressor or insulin, and intravenous fluid infusion rate did not differ significantly among the groups. The duration of surgery was also comparable for each group, with 70–90% of the operations lasting more than 2 h. Mean blood loss during surgery was 265 ml (range, 180–650 ml), and no blood transfusion was required. The ambient temperature did not differ significantly.

DIABETIC NEUROPATHY AND INTRAOPERATIVE HYPOTHERMIA

Table 3. Anesthesia Data and Vasoconstriction Threshold

	Young Group	Older Group	All Controls	DAN-negative	DAN-positive
Number	19	17	36	14	13
Intraoperative isoflurane (MAC/h)	1.8 ± 1.0	1.6 ± 0.8	1.7 ± 1.0	1.7 ± 0.9	1.6 ± 1.0
Vasoconstriction (number)	16	13	29	9	5*†‡
Vasoconstriction threshold (°C)	35.5 ± 0.6	35.3 ± 0.7	35.4 ± 0.6	35.4 ± 1.2	34.6 ± 1.0*†‡
Time to threshold (min)	108 ± 24	131 ± 31	119 ± 29	126 ± 25	157 ± 26*†
Skin temperature at threshold (°C)	30.6 ± 1.4	30.1 ± 1.3	30.4 ± 1.3	30.1 ± 1.4	29.8 ± 1.6
Rate of core temperature decrease					
Before vasoconstriction (°C/h)	0.80 ± 0.20§	0.80 ± 0.21§	0.78 ± 0.20§	0.76 ± 0.22§	0.84 ± 0.30§
After vasoconstriction (°C/h)	0.16 ± 0.06	0.13 ± 0.06	0.15 ± 0.06	0.13 ± 0.08	0.23 ± 0.12
Calculated threshold (°C)	34.7 ± 0.6	34.3 ± 0.8	34.6 ± 0.8	34.4 ± 1.0	33.5 ± 1.0*†‡

Values are mean ± SD. The anesthesia data did not differ significantly among the groups. Vasoconstriction threshold is the compensated core temperature triggering a skin-temperature gradient = 0°C. Patients who vasoconstricted and those remaining vasodilated are both included. Vasoconstriction threshold (and other parameters) were determined only in patients who had vasoconstriction.

DAN = diabetic autonomic neuropathy.

* $P < 0.05$, all controls versus DAN-positive group.

† $P < 0.05$, young group versus DAN-positive group.

‡ $P < 0.05$, older group versus DAN-positive group.

§ $P < 0.05$, before versus after vasoconstriction in each group.

|| $P < 0.05$, DAN-negative group versus DAN-positive group.

The basal autonomic function test results are shown in table 2. In the control group, there was a significant age-related effect on the HR response to deep breathing, but not the Valsalva ratio or the head-up tilt test. The diabetic patients with autonomic dysfunction showed an impaired HR response to deep breathing, the Valsalva maneuver, and head-up tilt compared with the other groups. The diastolic blood pressure of the diabetic patients with autonomic dysfunction decreased during head-up tilt, whereas the controls and diabetic patients without autonomic neuropathy showed an increase in the diastolic pressure. These responses were significantly different.

The intraoperative anesthetic parameters are shown in table 3. The minimum alveolar concentration hours of isoflurane were comparable among the groups.

The baseline core and skin temperatures were not significantly different among the groups. The core temperatures fell significantly in all groups after the induction of anesthesia. The changes in core temperature in the five groups were similar at 75 min after the induction of anesthesia, but the core temperature of the diabetic patients with autonomic dysfunction group was significantly lower from 120 min onward compared with the other groups (fig. 1). A core temperature plateau was seen at 35.2–35.4°C after 135 min in the controls. In the diabetic patients with autonomic dysfunction, the core temperature fell steadily to 34.6°C at 180 min. Comparison of the older and young patients showed that the

core temperature of the older group was lower only at 180 min.

Vasoconstriction was present in most patients in the immediate preoperative period, but vasodilation was observed in every patient shortly after the induction of anesthesia. The core and mean skin temperatures at the time of vasoconstriction and the thresholds calculated from these values are shown in table 3. In 16, 13, 9, and 5 patients from the young controls, older controls, diabetic patients without autonomic dysfunction, and diabetic patients with autonomic dysfunction, respectively, vasoconstriction (skin temperature gradient = 0°C) was observed intraoperatively. The vasoconstriction threshold and the calculated threshold were significantly lower and the time to vasoconstriction was significantly longer in the diabetic patients with autonomic dysfunction than in the other groups. The rate of core temperature decrease was higher in each group before vasoconstriction than after vasoconstriction (fig. 1; table 3).

Discussion

The current study shows that preexisting diabetic autonomic dysfunction, as measured by several autonomic tests, is associated with more severe intraoperative hypothermia. In general, the core body temperature is precisely regulated by effective thermoregulatory responses, which are initiated by small thermal perturbations. Heat stress provokes sweating¹⁸ and active precap-

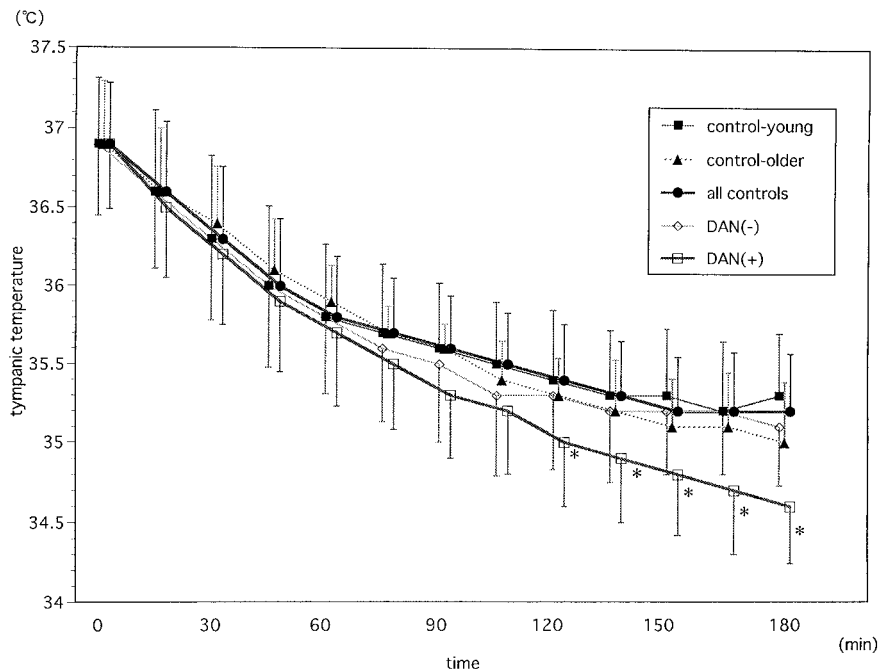


Fig. 1. Changes in core temperature during general anesthesia in diabetic patients (with and without autonomic dysfunction), control young or older patients and all controls. The core temperature fell significantly from baseline in all groups ($P < 0.001$). In the diabetic patients with autonomic dysfunction, the core temperature was significantly lower from 120 min onward after the induction of anesthesia compared with the other groups. DAN = diabetic autonomic neuropathy. * $P < 0.05$.

illary vasodilation,¹⁹ whereas cold stress initiates arteriovenous shunt vasoconstriction,²⁰ nonshivering thermogenesis (in infants),²¹ and shivering.²² The interthreshold range is defined by the core temperatures between the sweating and vasoconstriction thresholds that do not trigger autonomic thermoregulatory responses.²³ This range is usually only 0.2°C,²⁴ but typical doses of all general anesthetics tested thus far increase the range by 10- to 20-fold. Volatile anesthetics increase the sweating threshold,²⁵ but the interthreshold range is mostly augmented by a reduction in the vasoconstriction threshold.^{1,26} Our main finding was that the vasoconstriction threshold decreased in relation to autonomic insufficiency in diabetic patients.

Intraoperative core hypothermia develops in three characteristic phases: (1) Core-to-peripheral redistribution of body heat that is most prominent during the first hour after the induction of anesthesia and is mediated by the peripheral vasodilation induced by volatile anesthetic agents; (2) a subsequent slow linear decrease of core temperature that largely results from heat loss exceeding metabolic heat production; and (3) a core temperature plateau that occurs when thermoregulatory vasoconstriction decreases cutaneous heat loss and retains metabolic heat in the core thermal compartment. Although the same pattern was observed in each group in the current study, the core temperature of the diabetic patients with autonomic dysfunction was lower from

120 min onward compared with that in the other groups. Accordingly, the core temperature probably continued to decrease in the diabetic patients with autonomic neuropathy because vasoconstriction was delayed and less effective than in the patients with normal autonomic function (table 3).

The core temperature triggering the constriction of thermoregulatory arteriovenous shunts is designated as the threshold for vasoconstriction. A high threshold is generally desirable because vasoconstriction helps prevent further core hypothermia by decreasing cutaneous heat loss and retaining metabolic heat in the core compartment. In this study, we confirmed that the rate of core temperature decrease was lower in each group after vasoconstriction than before vasoconstriction (table 3). Vasoconstriction was not observed in 16% of the young control group, 30% of the older control group, 35% of the diabetic patients without autonomic dysfunction, and 62% of the diabetic patients with autonomic dysfunction. The influence of age that we detected supports the findings of a previous study²⁷ that the threshold for thermoregulatory vasoconstriction is lower and vasoconstriction is less likely to occur in elderly patients than in young patients. Our results demonstrate that the elderly controls were more similar to the diabetic patients than the young controls.

The standard autonomic tests employed in the current study were reasonably sensitive. Noninvasive tonometric

blood pressure was monitored continuously so that hemodynamic changes could be identified during the Valsalva maneuver and the head-up tilt test.^{28,29} Peripheral vasoconstriction may be affected by peripheral dermatosympathetic responses. A high specificity (low false-positive rate) was obtained when several autonomic tests were combined to define dermatosympathetic responses in diabetic patients.^{30,31} It is probable that some simple form of autonomic screening combined with clinical history may prove useful in this respect.

Autonomic neuropathy is reported to be present in 20–40% of all diabetic patients.^{32,33} In the present study, we had only seven insulin-dependent cases. If the criteria for the diabetic group had been more strict, a more evident result might have been produced. A significant proportion of the patients with diabetes mellitus facing surgical treatment may have been so affected; however, 52% had an abnormal response to deep breathing, and 44% had an abnormal response to standing. Our controls were similar in many respects to the diabetic group except for the absence of diabetes (*e.g.*, similar with regard to body mass index, hypertension, and thyroid function). Because aging is known to be associated with diminished autonomic reflexes,^{34,35} we divided the patients into young and older subgroups. Only patients scheduled for abdominal surgery were included in this study because such surgery is associated with significant intraoperative changes in body temperature, and it was thought to be more likely that any effect of autonomic derangement on temperature regulation would be detected with such operations.

The current data indicate that the period of highest risk for hypothermia in diabetic patients with autonomic dysfunction is from 120 min onward after the induction of anesthesia. In the controls and the diabetic patients with normal autonomic function, the reduction in core temperature was smaller than that in the diabetic patients with autonomic dysfunction (*fig. 1*). The peripheral sympathetic efferent response may be primarily related to underlying autonomic neuropathy in diabetic patients, because the vasoconstriction threshold and the calculated threshold were low. Preexisting autonomic insufficiency may preclude the occurrence of appropriate vasoconstriction during surgery.

In this study, we found that the rate of cooling, or the vasoconstriction threshold, was significantly related to the presence of autonomic dysfunction. Although studies on a larger number of subjects are necessary, it is also important to assess whether the autonomic insufficiency was central or peripheral. However, because the central

and peripheral nervous systems complement each other,^{30,31} we speculate that the presence of autonomic insufficiency could predispose diabetic patients to more severe intraoperative hypothermia.

Impaired peripheral regulation of blood flow has been implicated in the development of diabetic neuropathy.³⁶ However, it is uncertain whether the dysfunction of small unmyelinated nerve C-fibers^{37,38} is a cause or a consequence of impaired microvascular function.^{39,40} The current results show only that autonomic dysfunction impairs thermoregulatory vasoconstriction in diabetic patients. It is important to note that the incidence of intraoperative hypothermia during general anesthesia may be greater in dysautonomic diabetic patients than in patients with normal autonomic function. The current data indicate that autonomic compensation for hypothermic vasoconstriction might be impaired in diabetic patients, and it is thought that not only the presence of vasoconstriction, but also the magnitude of vasoconstriction, is dependent on peripheral regulation of blood flow. The number of subjects was too small for multivariate analysis in this study. Although our present findings require confirmation in a larger population, the data are sufficiently strong to warrant careful perioperative monitoring of diabetic patients with autonomic abnormalities.

The current investigation was limited by its reliance on noninvasive cardiovascular measurement techniques that lacked sensitivity to small, transient hemodynamic changes and did not permit the simultaneous determination of multiple physiologic variables influencing blood pressure. However, use of invasive techniques was not feasible in our subjects.

We observed that diabetic autonomic neuropathy is associated with an increased risk of intraoperative hypothermia. Our data also suggest that preoperative autonomic screening tests can identify diabetic subjects at risk of developing intraoperative hypothermia. Although the routine autonomic screening of diabetic patients may be impractical, the information obtained from such testing could prove useful to the anesthesiologist when planning the anesthetic management of these patients.

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