Cutaneous vascular responses and thermoregulation in relation to age

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1. Sympathetic vasoconstrictor responses to inspiratory gasp and contralateral arm cold challenge were assessed in fingertip skin in relation to age and were correlated with vasoconstrictor ability during body cooling. The above relationship was also examined in diabetic patients in whom vasoconstrictor responses to inspiratory gasp and contralateral arm cold challenge had been shown previously to be markedly impaired.

2. Vasoconstrictor responses to inspiratory gasp and contralateral arm cold challenge, measured by laser Doppler flowmetry, were significantly reduced in the elderly group, although individual responses varied from normal to absent, and they also had a considerably greater variability as measured on three separate occasions than seen in young subjects. Discriminant analysis showed that, from each of three occasions, 65% of vasoconstrictor responses were abnormal in the elderly group.

3. Body cooling was performed by reducing the environmental temperature from 40°C to 12°C, and the time taken for blood flow to fall to 75%, 50% and 25% of the pre-cooling level (VC75, VC50, VC25, respectively) was calculated. Vasoconstriction was rapid in young subjects and was consistent with good vasoconstrictor responses to inspiratory gasp and contralateral arm cold challenge. In the elderly group, vasoconstriction was slower, but only the VC25 value differed significantly [elderly group, 13.3 (7.9–31.0) min, young group, 5.7 (2.7–15.5) min; median (interquartile range); P<0.05]. A poor vasoconstrictor response to contralateral arm cold challenge did not always correlate with an impaired response to body cooling in the elderly group, but, importantly, a diminished vasoconstrictor response to contralateral arm cold challenge was associated with an impaired vasoconstrictor response to contralateral arm cold challenge. Diabetic patients all had markedly reduced vasoconstrictor responses to inspiratory gasp, contralateral arm cold challenge and body cooling.

4. It is concluded that elderly subjects have diminished sympathetic vasoconstrictor responses. This may be a significant factor contributing to thermoregulatory impairment in the elderly, thereby rendering them more susceptible to the harmful effects of cold weather.

INTRODUCTION

The decrease in thermoregulatory responses to cold stress with age [1–3], combined with cold housing [4], undernutrition [5] and poor financial status [6], can be potentially life-threatening to the elderly. Thermoregulatory dysfunction may be a consequence of diminished heat production [1, 7], reduced shivering [8] or impaired thermal perception [9]. Additionally, abnormalities in reflex adjustments to skin blood flow may impair thermoregulatory capacity and it is suggested that, in some elderly people, a reduced sympathetic vasoconstrictor response to cold stress may increase the propensity of developing hypothermia during cold weather [10]. An impairment of the vasoconstrictor response is consistent with an age-related decline in autonomic nervous function [11], yet the proposal of a general and substantial loss of reflex response in the elderly has been challenged [12]. Furthermore, the precise contribution of an impaired reflex response to hypothermia is difficult to elucidate because many cases of hypothermia are reported to be secondary to illnesses such as cardiopulmonary problems [13], and it has also been suggested that serious hypothermia is uncommon in Britain [12]. When hypothermia is due to inherent failure of normal thermoregulatory function, however, and there is no underlying illness, then the prognosis for long-term survival is poor [14]. It is important, therefore, to establish the integrity of reflex sympathetic vasoconstrictor responses in the elderly.

Methodological limitations in the past have meant that measurement of cutaneous vasoconstrictor responses have produced variable results [15–17]. Recently, we used a laser Doppler flowmeter to devise a test which had sufficient reproducibility for quantifying sympathetic vascular responses in fingertip skin [18]. Before stimuli, indirect body heating was employed to minimize the
variability of sympathetic vasoconstrictor responses. The test is based on quantifying the change in fingertip blood flow produced by inspiratory gasp (IG) and contralateral arm cold challenge (CC). The normal response is a rapid vasoconstriction with a subsequent decrease in fingertip blood flow which returns to its pre-stimulus value. The response has been shown to be impaired in diabetic patients, probably as a result of sympathetic dysfunction [18], and also in newly diagnosed leprosy patients [19]. In the present study, we have used the devised test procedure to investigate the integrity and variability of skin vascular responses in relation to age. In addition, the relationship between an impaired response to CC and to convective body cooling was determined.

**EXPERIMENTAL**

**Subjects**

Twenty-eight elderly subjects (six males, 22 females) with a mean (SD) age of 68 (4) years and 20 young subjects (10 males, 10 females) with a mean (SD) age of 26 (5) years gave their informed consent to the test procedure, which was approved by the local Ethical Committee. Young subjects were recruited from the student and staff population of the hospital, and elderly subjects were enrolled from a senior citizen keep-fit class, where they were requested strongly to undergo a medical examination by their general practitioner before starting. Subjects were non-smokers, were free from medication and were symptomatically free from cardiovascular disease. Morning urine samples were negative for glycosuria (Multistix). The mean (SD) body weight was 70.4 (6.1) kg and 56.8 (5.1) kg for male and female young subjects, respectively, and 72.8 (6.8) kg and 61.6 (5.0) kg for male and female elderly subjects, respectively. The mean (SD) resting blood pressure for young and elderly subjects was 116/72 (10/9) mmHg and 135/78 (15/8) mmHg, respectively. In addition, nine diabetic patients, mean (SD) age 49 (16) years, in whom vasoconstrictor responses to IG and CC had been shown previously to be diminished [18], were exposed to body cooling and were used as positive controls. All were insulin-dependent and the mean (SD) duration of diabetes was 17 (7) years (range 8–28). Haemoglobin A_1 values, measured in five diabetic patients, were 11.2 (1.0)% [mean (SD)]. Subjects were requested to refrain from food, drink and exercise for at least 2 h before experimentation.

**Methods**

Core temperature was measured by a zero-gradient aural thermometer (type 8151.1; Addison Process Control Ltd, Beckenham, Kent, U.K.) and the temperature of the left middle fingertip was measured with a skin thermistor (YSI model no. 4098, YSI) and an infra-red bolometer (KT–41; Heimann, Hanover, Germany) during protocols I and II, respectively.

Blood flow in the left index fingertip was assessed continuously using a laser Doppler flowmeter (Perimed, Stockholm, Sweden). The fingertip was chosen because its abundant arteriovenous anastomoses are richly innervated with sympathetic fibres [20]. The principles of laser Doppler flowmetry have been described elsewhere [21, 22]. Essentially, light reflected back to the probe comes from a substantial portion of the upper dermis, which includes the feeding arterioles and venules as well as the superficial plexus of the reticular dermis. The Doppler-shifted component of the reflected signal will be derived largely from moving erythrocytes in the superficial plexus and capillary loops in the dermal papillae, but also includes arteriolar and shunt flow in the lower dermis. The amplitude of this Doppler-shifted component depends on the velocity and number of moving blood cells observed and the output signal is proportional to the product of the number and mean velocity of moving blood cells in the measured volume of tissue. Blood flow values in this study are expressed in V. All measurements were made at gain 3 (full-scale deflection = 10 V), 12 kHz bandwidth and 0.2 s time constant. The output signal was recorded continuously on a pen recorder (BBC SE120; Goetz, Metrawatt, Austria).

**Assessment of skin vasoconstrictor responses (protocol I)**

Experiments were conducted in a temperature-controlled laboratory set at 25 (1°C [mean (SD)] and with a mean relative humidity of 55 (15)% [mean (SD)]. Subjects wore light clothing and were encouraged to relax during 30 min of equilibration. They were seated comfortably with the left arm supported at heart level. At the end of the equilibration period fingertip blood flow was averaged over 5 min before commencement of indirect body heating. In this procedure the right arm was placed up to the elbow for several minutes in a water bath maintained at 43°C, inducing a higher and relatively stable fingertip blood flow (termed FTBF_m). The increase in blood flow is directed mainly through arteriovenous anastomoses [23], but capillary blood flow also increases owing to raised local tissue temperature as a consequence of high shunt flow. This heating procedure was important to minimize the variability of vasoconstrictor responses which might arise if subjects exhibit different degrees of skin vaso-motor tone [15, 24].

The integrity of the vasoconstrictor reflex response was assessed by IG, which consisted of a sudden deep breath as a consequence of high shunt flow. An index of the vasoconstrictor reflex (VR) was obtained using the equation:

$$VR = \frac{FTBF_{m} - FTBF_{min}}{FTBF_{m}}$$

where FTBF_{min} is the minimum fingertip blood flow value after IG and CC, and FTBF_{m} is as described above (Fig.
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*Fig. 1.* Laser Doppler signals showing the stable pre-stimulus fingertip blood flow (FTBF.), pulse amplitude (PA) and the vasoconstrictor response (minimum blood flow value, FTFB.min.) after IG and CC in tracings from (a) a typical young subject and (b) an elderly subject with an impaired response

1). Each subject was tested on three separate occasions to evaluate the variability of VR values.

Vasoconstrictor responses to body cooling (protocol II)

These experiments took place on a separate occasion from those for protocol I. Experiments were performed in a temperature-controlled environmental chamber situated in a laboratory maintained at 25 (1)°C [mean (SD)]. Subjects were seated comfortably in the chamber and were allowed to equilibrate for 20 min. The arm, resting at heart level, and head were kept outside the chamber and were exposed to room temperature for the duration of the experiment.

The chamber was then heated to 40°C to induce central dilatation and a relatively stable fingertip blood flow value. The chamber was cooled subsequently to 12°C, which took approximately 10 min, and the cool temperature was maintained for a further 20 min. This 30 min cooling induced minimum fingertip blood flow values in most young subjects, which fell to within the range 0.3–0.7 V, but generally took longer in elderly subjects and diabetic patients. Body cooling was extended, therefore, in those subjects who failed to reduce blood flow to minimum values during the 30 min cooling period. The following blood flow parameters were measured: (1) blood flow value averaged over 3 min after equilibration (BF<sub>eq</sub>); (2) steady-state blood flow after body heating (BF<sub>sst</sub>); (3) the minimum blood flow value was subtracted from the BF<sub>eq</sub> value and the time taken for blood flow to fall to 75%, 50% and 25% of this difference, denoted as VC<sub>75</sub>, VC<sub>50</sub> and VC<sub>25</sub>, respectively, was calculated.

Statistical analysis

The differences in blood flow and temperature measurements between young and elderly groups were compared by using a Wilcoxon test. The variability of VR values between and within subjects was determined by using a one-way analysis of variance and is expressed as the so. The relationship between VR values for IG and CC in each group was tested by using a Spearman rank correlation. Discriminant analysis was used to determine the relative cut-off region between VR values for the young and elderly group. Individual VR values for IG and CC were combined and the position of the optimal separating line was calculated [25]. The line separating the two groups defines the linear discriminant function which is a formula for combining VR values for IG and CC into a single discriminant score. On this basis it would be possible to classify a subject with an abnormal reflex if the pair of VR values lies below the line.

RESULTS

Assessment of skin vasoconstrictor responses (protocol I)

Differences in blood flow measurements, skin and core temperatures between young and elderly subjects are presented in Table 1.

After equilibration, the blood flow trace in young subjects often displayed vasoconstrictor bursts, which were less apparent in many elderly subjects. Fingertip and core temperatures were similar after equilibration in both groups.

During contralateral arm warming the median (interquartile range) increase in blood flow was 1.2(0.6–2.2) and 0.7(0.4–1.6) V in young and elderly subjects, respectively. There were accompanying rises in fingertip temperature of 1.3(0.5–2.7) and 1.0(0.5–3.3)°C, respectively. Indirect body heating provoked a significantly greater increase in core temperature in elderly than in young subjects, 0.6(0.4–0.7) and 0.4(0.2–0.6)°C (P<0.05), respectively, and consequently, the pre-stimulus core temperature was significantly greater in elderly subjects (P<0.02).

Pulse amplitude, defined as the difference between the systolic and diastolic blood flow value with each heart beat, was significantly larger in elderly subjects (P<0.05). The most striking example of this was seen in an elderly female subject with an average pulse amplitude of 1.9 V.

VR values for IG and CC were significantly reduced in the elderly group (P<0.001 and P<0.001, respectively, Fig. 1), although individual responses varied from normal
Table I. Fingertip blood flow, reflex response and skin and core temperatures in 20 young subjects and 28 elderly subjects and the significance of the difference between groups (Wilcoxon test). Results are shown as medians (interquartile range). Values are averages from each of three occasions. Abbreviation: NS, not significant.

<table>
<thead>
<tr>
<th></th>
<th>Young subjects</th>
<th>Elderly subjects</th>
<th>P</th>
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<tbody>
<tr>
<td><strong>After equilibration</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fingertip temperature (°C)</td>
<td>33.0 (31.4-33.5)</td>
<td>32.2 (30.5-33.6)</td>
<td>NS</td>
</tr>
<tr>
<td>Core temperature (°C)</td>
<td>36.4 (36.2-36.6)</td>
<td>36.4 (36.2-36.7)</td>
<td>NS</td>
</tr>
<tr>
<td>Fingertip blood flow (V)</td>
<td>3.6 (2.5-4.6)</td>
<td>4.5 (3.9-4.9)</td>
<td>NS</td>
</tr>
<tr>
<td><strong>After indirect body heating</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fingertip temperature (°C)</td>
<td>34.2 (33.8-34.5)</td>
<td>34.0 (33.7-34.4)</td>
<td>NS</td>
</tr>
<tr>
<td>Core temperature (°C)</td>
<td>36.8 (36.7-36.9)</td>
<td>37.0 (36.9-37.1)</td>
<td>&lt;0.02</td>
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<tr>
<td>Fingertip blood flow (V)</td>
<td>5.3 (4.5-5.7)</td>
<td>5.4 (4.9-6.0)</td>
<td>NS</td>
</tr>
<tr>
<td>Pulse amplitude (V)</td>
<td>0.3 (0.2-0.4)</td>
<td>0.4 (0.4-0.5)</td>
<td>&lt;0.05</td>
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<tr>
<td>VR for IG</td>
<td>0.75 (0.71-0.84)</td>
<td>0.51 (0.26-0.63)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>VR for CC</td>
<td>0.77 (0.74-0.86)</td>
<td>0.58 (0.44-0.70)</td>
<td>&lt;0.001</td>
</tr>
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to absent. Some elderly subjects with an absent response had negative VR values (Fig. 2). If individual vasoconstrictor reflexes from each separate occasion are considered, then five elderly subjects had at least one negative VR value.

Eighteen elderly subjects (64%) had abnormal VR values, averaged from three occasions, for IG and for CC on the basis that these values were less than the mean − 1.96 sd (0.61 and 0.62, respectively) for the young group. In contrast, one young female subject (5%) had an abnormal VR value for CC only (0.6).

Fig. 3 shows a scatterplot of VR values for IG against VR values for CC on each of three separate occasions and the cut-off region between young and elderly subjects as determined by discriminant analysis. These data indicate that 55 (65%) VR values for the elderly and three (5%) VR values for the young group could be considered abnormal. Thus, there is a 65% probability that an otherwise normal elderly person will have a vasoconstrictor response considered abnormal for healthy young subjects.

The variability in VR values between and within subjects was considerably greater in the elderly group than in the young group. Analysis of variance showed that within- and between-subject variabilities in the elderly group, expressed as sds, were 0.17 and 0.27 for IG and 0.17 and 0.23 for CC, respectively. In the young group, VR within-subject variabilities were 0.06 and 0.07 for IG and CC, respectively, and between-subject variabilities were 0.07 for both.

VR values for IG and CC were well correlated in young and elderly groups (r = 0.67 and r = 0.69, respectively).
Vasoconstrictor responses to body cooling (protocol II)

Blood flow and temperature measurements in all groups are shown in Table 2. As in protocol I, blood flow and fingertip temperature after equilibration and after heating in a 40°C chamber were similar in young and elderly subjects but tended to be lower in diabetic patients.

In contrast to protocol I, core temperature after equilibration was significantly higher in young subjects than in elderly subjects \( (P<0.05) \), but was similar in both groups after body warming. Body cooling resulted in an increase in core temperature in all groups. Median core temperatures were similar at the end of 30 min of body cooling: 37.1°C, 37.0°C and 37.1°C in young subjects, elderly subjects and diabetic patients, respectively.

Shivering was not observed during body cooling. Vasoconstrictor responses to body cooling varied considerably in the elderly group, with some subjects demonstrating rapid vasoconstriction, whereas others responded like the diabetic patients with poor vasoconstrictor ability. One elderly subject had a constant blood flow throughout the cooling period with the result that VC values could not be calculated. Median VC values were longer in the elderly group compared with those in the young group but only VC25 was significantly different \( (P<0.05) \). Nine (30%) elderly subjects (four males, five females) had a VC25 longer than 30 min and in five of these, it was greater than 45 min. Two of these subjects displayed marked blood flow oscillations during the cooling period. Fig. 4 shows fingertip blood flow over the initial 30 min cooling period in diabetic patients and elderly subjects \( (n=9) \) with VC25 greater than 30 min and in all young subjects. It can be

<table>
<thead>
<tr>
<th>After equilibration</th>
<th>Young subjects</th>
<th>Elderly subjects</th>
<th>Diabetic patients</th>
<th>Young subjects vs elderly subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fingertip temperature (°C)</td>
<td>29.4 (24.8–31.9)</td>
<td>30.1 (24.6–32.7)</td>
<td>28.4 (24.6–30.2)</td>
<td>NS</td>
</tr>
<tr>
<td>Core temperature (°C)</td>
<td>36.5 (36.2–36.6)</td>
<td>36.2 (36.0–36.4)</td>
<td>36.2 (35.6–36.5)</td>
<td>( P&lt;0.05 )</td>
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<tr>
<td>BF(_{15}) (V)</td>
<td>3.5 (1.2–4.6)</td>
<td>3.3 (2.0–4.1)</td>
<td>1.3 (1.0–2.4)</td>
<td>NS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After body heating</th>
<th>Young subjects</th>
<th>Elderly subjects</th>
<th>Diabetic patients</th>
<th>Young subjects vs elderly subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fingertip temperature (°C)</td>
<td>34.1 (33.1–34.5)</td>
<td>34.0 (33.2–34.6)</td>
<td>33.6 (32.8–34.5)</td>
<td>NS</td>
</tr>
<tr>
<td>Core temperature (°C)</td>
<td>36.7 (36.5–36.8)</td>
<td>36.5 (36.3–36.8)</td>
<td>36.9 (36.3–37.2)</td>
<td>NS</td>
</tr>
<tr>
<td>BF(_{15}) (V)</td>
<td>5.1 (4.6–5.9)</td>
<td>5.1 (4.0–5.7)</td>
<td>3.7 (2.6–6.3)</td>
<td>NS</td>
</tr>
<tr>
<td>VC(_{15}) (min)</td>
<td>2.3 (0.8–7.5)</td>
<td>4.2 (1.9–10.9)</td>
<td>15.2 (7.1–19.7)</td>
<td>NS</td>
</tr>
<tr>
<td>VC(_{25}) (min)</td>
<td>3.6 (1.6–12.5)</td>
<td>9.1 (3.0–21.6)</td>
<td>21.8 (16.4–28.7)</td>
<td>NS</td>
</tr>
<tr>
<td>VC(_{25}) (min)</td>
<td>5.7 (2.7–15.5)</td>
<td>13.3 (7.9–31.0)</td>
<td>25.2 (23.0–25.6)</td>
<td>( P&lt;0.05 )</td>
</tr>
<tr>
<td>Core temperature after 30 min cooling (°C)</td>
<td>37.1 (36.9–37.2)</td>
<td>37.0 (36.8–37.2)</td>
<td>37.1 (37.0–37.2)</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Values could not be calculated in all subjects owing to poor vasoconstriction.
seen that blood flow was higher in elderly subjects throughout this period.

VC₂₀ values were marginally greater than 30 min in two young subjects, at 36.0 min and 32.6 min. In a third subject, VC₂₀ was as long as 50 min and this subject displayed large-amplitude blood flow oscillations throughout body cooling.

Diabetic patients vasoconstricted least effectively and in four of these, blood flow did not fall sufficiently to calculate a VC₂₀ value despite cooling for up to 50 min; in two of these, this VC₂₀ value could not be calculated. In all, five out of nine diabetic patients had a VC₂₀ value greater than 30 min. VC₅₀, VC₇₅ and VC₂₅ values were significantly longer than equivalent times for the young group (P<0.01, P<0.01, P<0.05, respectively) and the VC₇₅ and VC₅₀ values were significantly longer than the corresponding values for the elderly group (P<0.05 for both).

Relationship between vasoconstrictor responses to CC and to total body cooling

Seven out of nine elderly subjects with VC₂₀ greater than 30 min also had VR values for CC below 0.62 (i.e. less than the mean±1.96 sd for the young group). The two subjects with normal VR values were those who displayed marked blood flow oscillations. In the diabetic patients, poor vasoconstrictor responses to body cooling were always associated with abnormal VR values for CC [mean (sd) 0.24 (0.15)] [18].

Abnormal VR values, however, were not always associated with poor vasoconstrictor responses to body cooling. The three young subjects with VC₂₀ greater than 30 min had normal VR values. The only young subject with an abnormal VR value (0.6) responded well to body cooling and had a VC₂₀ value of 3.9 min. Likewise, six elderly subjects with abnormal VR values vasoconstricted well during body cooling.

DISCUSSION

In this study, the integrity of the skin vasoconstrictor response to IG, CC and body cooling has been examined in young and elderly subjects. The main observation is that, in comparison with young subjects, some elderly individuals do have diminished and highly variable vasoconstrictor responses to IG and CC which combined with reduced vasoconstriction in response to body cooling may impair thermoregulatory ability during cold weather. Although we did not find a difference in core temperature with body cooling for 30–60 min, longer periods may well result in a greater fall in body temperature in those subjects with poor vasoconstrictor ability. This may also be true in diabetic patients, in whom vasoconstrictor responses to IG, CC and body cooling were markedly reduced.

A reduction in the number and amplitude of vasoconstrictor bursts after equilibration in elderly subjects may be suggestive of impaired sympathetic neural function, since these fluctuations are due to skin sympathetic activity [26]. Diminished vasoconstrictor responses most likely also result from general changes in sympathetic nervous function with age [11, 16], since fingertip vasoconstriction produced by IG and CC is dependent upon sympathetic nervous activity [27], but specific details on the location or nature of the changes are not apparent. It may be that diminished vasoconstrictor responses result from impaired temperature perception, but it seems doubtful that this had a significant effect because IG and CC produced similar responses. Although core temperature after indirect heating was higher in the elderly group, there was no correlation between this and impaired VR values. The reason for the transient increase in blood flow in some elderly subjects who showed no vasoconstriction at all, i.e. negative VR values, is unclear and in preliminary studies we found no rise in blood pressure to account for this increase.

The large between-subject variability of VR values in the elderly group, therefore, may have resulted from different degrees of sympathetic neural impairment, and the within-subject variability may reflect patchy impairment which is detected on separate occasions due to spatial variations in the measurement site. Methodological problems appeared to be largely overcome, since repeated testing in young subjects showed good reproducibility which is consistent with other studies using the same methodology [19].

Diabetic patients were used as positive controls as there is substantial evidence to suggest that their drastically impaired vasoconstrictor responses result from defective sympathetic neural function [28–30], even though general assessments of autonomic function were not made. Focal abnormalities in sympathetic function, however, are not always apparent from such global assessments, and peripheral sympathetic dysfunction can occur in the absence of clinically detectable abnormalities of both peripheral and central autonomic function [31].

If, as presumed, the elderly subjects were in good health, then other factors are unlikely to have had a major influence on vasoconstrictor responses. First, they reported having had a recent medical examination by their general practitioner before attending the keep-fit class and they were free from medication. Secondly, cyclic
changes in sex hormones could not have had a modulatory effect on the peripheral vasculature in view of the age of the elderly female subjects. Thirdly, they were seemingly free from significant occlusive microvascular disease, since they had a blood flow response to indirect and direct body warming which was similar to that in the young group. In diabetic patients, however, the slightly lower blood flow values and fingertip temperatures after equilibration and after body heating may have resulted from basement membrane thickening of the microvasculature, or from a reduction in the density of perfused capillaries.

We are not certain why there were inconsistencies in core temperature responses between young and elderly subjects during the two experimental protocols. Perhaps the shorter equilibration time during protocol II (i.e. 20 min as opposed to 30 min) was insufficient for some elderly subjects to raise core temperature to a value similar to that during protocol I, especially so if resting metabolic rate was reduced [2]. The higher core temperature in elderly subjects after indirect body heating may have resulted from more rapid arm vasodilatation, thereby increasing heat input into the body. This effect was not observed during protocol II, perhaps because elderly subjects had a lower starting core temperature. The transient elevation of core temperature during body cooling resulted from reduced heat loss, due to vasoconstriction, and the observation that diabetic patients showed the smallest rise was consistent with their attenuated finger vasoconstrictor responses and also with poor lower extremity vascular control [28].

We did not measure blood pressure during our experiments but presume that changes observed in the laser Doppler recordings reflected vasoconstriction or vasodilatation. We have shown previously that blood pressure is similar during equilibration, after indirect body warming and after IG or CC [27]; the latter finding has also been reported by Marshall et al. [32]. The same is also probably true for body cooling, which lasted no longer than 60 min in any individual [33, 34]. Furthermore, it is unlikely that finger blood pressure changed significantly, since it follows brachial blood pressure quite well during vasoconstriction (35, 36). Thus, although the vascular resistance may have been higher throughout in the elderly group, owing to a higher blood pressure, the change in vascular resistance during CC and body cooling is much less. Consistent with an elevated blood pressure was the finding that elderly subjects had a larger pulse amplitude, which probably results from a decrease in arterial compliance with age.

This study has shown that the ability of the cutaneous vasculature to make thermoregulatory adjustments to cold is impaired in the elderly because nine subjects had reduced vasoconstrictor responses to body cooling and, in addition, seven of these also had reduced VR values for CC. The relationship between impaired vasoconstrictor responses to body cooling and to CC is highlighted in the diabetic group, who had severely reduced VR values and also the poorest vasoconstrictor responses to body cooling. It is noteworthy that the nine elderly subjects with reduced vasoconstrictor responses to body cooling had poorer blood flow responses than the diabetic patients (Fig. 4). Thermoregulatory impairment appeared to be more common in elderly males than in the females because vasoconstrictor responses were poor in a larger proportion of males. It is known that elderly males tend to have less body fat and a relatively reduced metabolic response to cold stress than elderly females [2], which make them more vulnerable to the effects of cold environments.

Poor responses to body cooling and poor VR values were not always related. Some subjects had a slow response to body cooling and a good VR value. In subjects with long VC25 values but marked blood flow oscillations and normal VR values, thermal homeostasis during cold exposure may be maintained adequately by cyclical adjustments to peripheral blood flow. In such situations, therefore, the relatively long VC25 may not necessarily reflect an impaired thermoregulatory response. Some elderly subjects had a reduced VR value but a good vasoconstrictor response to body cooling, which, as explained earlier, may reflect patchy sympathetic dysfunction or spatial variations in microvascular architecture, since the two tests were performed on separate occasions. Alternatively, total body cooling may elicit a much larger afferent input than CC because total body thermosensitivity is greater than local thermosensitivity, particularly if the spine was cooled significantly. This explanation may be valid because, in this study, body cooling in the environmental chamber was produced by blowing cold air over the back. The association between impaired vasoconstrictor responses to total body cooling and to CC may be much better though if sympathetic impairment is more drastic, as it may well have been in diabetic patients. The disparity between the two evoked responses suggests that elderly individuals who are susceptible to the effects of cold stress may be identified by a combination of tests.

Since thermal equilibrium is protected by reflex adjustments of cutaneous blood flow in the extremities, diminished vasoconstrictor responses would promote significant heat loss in the elderly during cold exposure, particularly since shivering was not observed. The reduced vasoconstrictor response most probably occurs in the thermoregulatory shunts because a major proportion of the laser Doppler finger blood flow signal arises from flow through arteriovenous anastomoses [37]. Our assessments were made at the fingertip only, but since there is no similar intense vasoconstriction in forearm skin [26], the change in impedance offered by the opening and closing of acral shunts could modify whole body thermal heat loss. It could be argued that the transient nature of the vasoconstrictor response to IG and CC bears no relation to overall body thermoregulation, but it should be remembered that all subjects were ‘forced’ into a vasodilated state by elevating core temperature before stimuli. In a more thermoneutral state and with no indirect body heating, vasoconstriction after CC is more sustained in young than in elderly subjects [F. Khan, unpublished work]. Additionally, small changes in blood
flow which are hardly noticeable by plethysmography can represent potentially large adjustments in thermal balance [38].

In summary, this study provides evidence that vasoconstrictor responses to IG, CC and body cooling are significantly reduced in some otherwise healthy elderly individuals. Vasoconstrictor responses to IG and CC varied from poor to good both within and between elderly subjects, and the sensitivity of the test procedure is enhanced by repeated assessments. Importantly, elderly subjects who had reduced vasoconstrictor responses to body cooling, without spontaneous sympathetic vasoconstrictor bursts, also had impaired responses to CC. The above relationship may be even more obvious in older and less healthy individuals, as demonstrated in diabetic patients probably as a result of sympathetic dysfunction and may be of particular importance in elderly males. Thus, a diminished reflex vasoconstrictor response might have important consequences for thermoregulation in the elderly and may increase their susceptibility to the harmful effects of cold weather.

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