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Diagnostic value of finger systolic blood pressure in the assessment of vasospastic reactions in the finger skin of vibration-exposed subjects after finger and body cooling

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KUROZAWA Y, NASU Y, NOSE T. Diagnostic value of finger systolic blood pressure in the assessment of vasospastic reactions in the finger skin of vibration-exposed subjects after finger and body cooling. *Scand J Work Environ Health* 1991;17:184–9. To assess the severity of vibration-induced white finger (VWF), finger systolic blood pressure (FSBP) after finger cooling and after combined finger and body cooling was measured by strain-gauge plethysmography for 100 vibration-exposed men and 22 healthy men. The exposed men were classified as being without VWF (EW), with mild VWF (EM), and with severe VWF (ES) according to records of blanching attacks. FSBP was significantly reduced only in the ES group after finger cooling and in the ES and EM groups after both body and finger cooling. The diagnostic sensitivity and specificity for VWF was 81.7 and 90.3 %, respectively. Skin temperature measurements before and after immersion in cold water (5°C, for 10 min) could not be used for the estimation of VWF severity.

Key words: Raynaud's phenomenon, skin temperature, strain-gauge plethysmography, vibration-induced white finger.

Long-term use of handheld vibratory tools has been implicated in the development of vibration-induced white finger (VWF). For the prevention and treatment of VWF, an objective test is sometimes needed to confirm a patient's history of its occurrence. It is difficult, however, to evoke VWF under laboratory conditions (1, 2).

Many different tests, such as the cold-water immersion test (1), the nail press test (3), and the thermography test (1), have been used, but their efficiency is unsatisfactory. For example, the method generally used for the evaluation of VWF in Japan is to measure the skin temperature of one finger of the hand immersed up to the wrist in water at 5°C for 10 min (4, 5). During the cold-water immersion test at 5°C, several unfavorable symptoms (distress in the chest, headache, nausea, pain, etc) have been elicited (6). This test was not comfortable even in the case of water at 10°C (6). Hack et al (7) showed that, although the cold-water immersion test was useful for detecting group differences, its predictive power was low for individual cases.

Nielsen (8) and Nielsen & Lassen (9) suggested that the measurement of finger systolic blood pressure (FSBP) during digital cooling is a useful method for investigating Raynaud's phenomenon. This method appears to have high sensitivity and specificity for diag-

nosing VWF (10–12). It remained unclear, however, whether this method is useful for assessing the severity of VWF. The aim of this study was to evaluate the diagnostic value and sensitivity of FSBP measurements after cold provocation as a method of assessing the severity of VWF, especially in comparison with skin temperature measurements after cold-water immersion.

Subjects and methods

Subjects

One hundred men who had received the annual compulsory examination for vibration syndrome at the San-in Rosai Hospital were examined. They consisted of 75 chain sawers, 9 rock drillers, 7 bush cleaners, 3 grinders, and 6 men in miscellaneous trades. All of them had stopped using vibrating tools more than one year before the examination. None of them suffered from metabolic or vascular disorders except for VWF. Twenty-two healthy men who had never worked with vibrating tools were subjected to the same measurements for comparison. A total of 122 men gave their informed consent and were examined. The subjects were classified according to the severity of VWF as judged in a medical interview. They were divided into the following four groups: (i) referents: 22 healthy men [mean age 51.5 (range 39–66) years, 11 smokers] without vibration exposure, (ii) exposed subjects without VWF (EW): 40 men [mean age 56.4 (range 48–70) years, 18 smokers] without VWF in the last year, (iii) exposed men with mild VWF (EM): 36 men [mean age 56.4 (range 24–71) years, 19 smokers] with several at-

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tacks of VWF in the last year, and (iv) exposed men with severe VWF (ES): 24 men [mean age 59.6 (range 49–75) years, 12 smokers) with frequent attacks of VWF in the last year. All the subjects were examined in the winter of 1986–1987.

Measurement of finger systolic blood pressure after cold provocation

No vasoactive drugs were allowed for at least a week prior to the examination. Food intake and tobacco smoking were avoided for at least 2 h before the examination. The subjects were examined in a room with the temperature and humidity controlled at 26°C and 50 %, respectively. They were lightly dressed and rested for at least 30 min in the room before the examination.

FSBP was measured with a strain-gauge plethysmograph (SP-2, Medimatic, Copenhagen) with the subject in the supine position. An occluding cuff, 2.4 × 10 cm in size, and a double-inlet cuff, 3.0 × 10 cm in size, were placed on the proximal and middle phalanges, respectively, of the most affected finger (figure 1). Only the occluding cuff was placed on the proximal phalanx of the thumb as a reference finger. For the subjects without symptoms, the middle finger and the thumb were used. Strain gauges were placed on each distal phalanx. Finger warming and cooling were performed with a double-inlet cuff for 5 min.

During the provocation, digital blood circulation was stopped with suprasystolic pressure by the occluding cuff. First, we measured FSBP by slowly deflating the occlusion cuff and recording the first increase in fingertip volume with a strain gauge after local heating of the finger at 35°C for 5 min. The test was repeated after only local cooling of the finger at 10°C for 5 min. After an interval of more than 30 min, the FSBP was again measured after finger and body cooling at 10°C for 10 min. Downs et al (13) reported that an FSBP of less than 70 mm Hg (9.3 kPa) indicated arterial obstruction. An FSBP of less than 60 mm Hg (8.0 kPa), which is here strictly defined, may be due to a potent vasospasm. The subjects who showed an FSBP value below 60 mm Hg (8.0 kPa) after finger cooling only were excluded from the test of finger and body cooling. Body cooling was performed by cooling the back of the body with a water pad perfused with cold water at 10°C. Arm systolic blood pressure (ASBP) was measured by means of the auscultatory method on the upper arm of the side opposite to that on which the FSBP was measured. The change in FSBP during cooling at 10°C was expressed as the percentage of FSBP at 35°C according to the following formula from Nielsen & Lassen (9).

$$\text{FSBP } \% = \frac{\text{FSBP}_x}{\text{FSBP}_{35^\circ\text{C}} - (\text{FSBP}_{\text{pref}, 35^\circ\text{C}} - \text{FSBP}_{\text{pref}, x})} \times 100,$$

where FSBP_x is the pressure measured on the cooled finger and FSBP_{pref} is the pressure measured simulta-

neously on a noncooled reference finger of the same hand.

Second, in order to investigate the relationship between each finger's symptom and its FSBP % value, we selected 14 exposed men with VWF at random, and measured the FSBP after finger and body cooling of the bilateral index, middle and ring fingers of each person. A total of 82 fingers (2 defect ones) from 14 men were tested.

Cold-water immersion test

After more than 2 h after the FSBP measurement, the 100 men of the EW, EM, and ES groups were examined in the same room. They were relaxed in a sitting position, and the cold-water immersion test was performed. For each hand, the thermosensitive part of a thermometer was attached to the volar surface of the distal phalanx of the experiment finger. The finger skin temperatures were measured every minute before, during, and after the immersion. The average of the skin temperatures during the 5 min prior to the immersion was regarded as the initial finger skin temperature. The hand was then immersed up to the wrist for 10 min into well-stirred cold water at 5°C. After 10 min of immersion, the immersed hand was removed from the

Figure 1. Blood pressure cuffs on each proximal phalanx of the first and third fingers with strain gauges on the distal phalanges. The double-inlet cuff on the third finger was used for flowing with water at a preset temperature.

water and wiped dry with a towel. Recordings were continued for 10 min after the immersion. The re-warming response after 10 min of immersion was expressed as the recovery rate as follows:

$$\text{Recovery rate (\%)} = \frac{T_x - T_e}{T_i - T_e} \times 100,$$

where T_i is the initial skin temperature, T_e is the skin temperature at the end of the immersion, and T_x is the skin temperature of the immersed finger x minutes after removal of the hand from the water. Recovery rates at 5 and 10 min were calculated.

Statistical methods

The populations from which the samples were drawn were not normally distributed in some of the groups. The existence of a difference among the groups was therefore checked with the Kruskal-Wallis rank test. If the difference was found to be significant, Tukey's method was used to make a two-group comparison. A P -value of 0.05 was considered the minimum level of statistical significance.

Results

Finger systolic blood pressure and percentage of change in the finger systolic blood pressure as a diagnostic method for the severity of vibration-induced white finger

The results of the ASBP and FSBP measurements are shown in table 1. There were no significant differences among the groups with respect to the ASBP, the FSBP of the warmed finger and the FSBP of the reference finger. The differences in FSBP after finger cooling

were found to be significant between the ES group and the other groups according to Tukey's method. However, there were no significant differences in FSBP between any of the other groups.

Furthermore, for the men who had an FSBP value above 60 mm Hg (≈ 8.0 kPa) after finger cooling only, the FSBP was measured after finger and body cooling. All of the referents and the members of the EW group, 34 men in the EM group, and 14 men in the ES group were subjected to the combined cooling test, in which the FSBP of the EM group, as well as the FSBP of the ES group, differed significantly from that of the other two groups.

Individual values for the FSBP % after local cooling of the finger is shown in figure 2. Six of the 24 men in the ES group showed complete arterial closure. No subjects in the reference group or the EW group and only one subject in the EM group showed a zero pressure. If 90 % is considered tentatively as the lower limit of the normal value of the FSBP %, 16 (66.7 %) of the 24 men in the ES group, 12 (33.3 %) of the 36 men in the EM group, and 5 (12.5 %) of the 40 men in the EW group had abnormal FSBP % values. Only one (4.5 %) of the 22 men in the reference group had an FSBP % value below the defined limit. Severe cases were distinguished from the others by their FSBP % values, although there were large overlaps among the reference, EW, and EM groups.

The individual FSBP % values after combined finger and body cooling are shown in figure 3. In finger and body cooling, the ES and EM groups differed in their FSBP % significantly from the reference and EW groups. If 90 % is used as the lower limit for the normal FSBP % value, for either local cooling or combined finger and body cooling, 49 of the 60 cases with VWF and 6 of the 62 cases without VWF had values

Table 1. Systolic blood pressure of the upper arm (ASBP), finger systolic blood pressure (FSBP), and reference finger systolic blood pressure (FSBPref) of the reference group and the three groups exposed to vibration after warm and cold provocation. (EW = exposed group without vibration-induced white finger, EM = exposed group with mild vibration-induced white finger, ES = exposed group with severe vibration-induced white finger, 1 mm Hg $\approx$ 133.333 Pa)

	Reference group (N = 22)		EW group (N = 40)		EM group (N = 36)		ES group (N = 24)	
	Median	Range	Median	Range	Median	Range	Median	Range
Finger warming								
ASBP (mm Hg)	129	96–158	120	100–140	119	100–160	125	100–170
FSBP (mm Hg)	125	96–150	110	80–140	108	82–140	109	40–170
FSBPref (mm Hg)	123	96–150	110	80–142	102	82–140	109	68–170
Finger cooling								
ASBP (mm Hg)	123	100–160	120	103–151	120	100–140	126	100–170
FSBP (mm Hg)	117	96–147	106	86–138	101	0–130	76 ^b	0–146
FSBPref (mm Hg)	116	96–142	108	90–140	105	78–132	110	68–170
Finger and body cooling^a								
ASBP (mm Hg)	134	103–170	128	90–166	115	100–152	126	109–180
FSBP (mm Hg)	124	96–156	112	86–142	84 ^c	0–126	89 ^c	0–134
FSBPref (mm Hg)	128	100–150	113	88–140	106	90–130	130	90–170

^a Subjects who had a low FSBP (<60 mm Hg) after finger cooling only were excluded from the test. All of the reference group and the EW group, 34 of 36 men in the EM group, and 14 of the 24 men in the ES group were examined.

^b Significantly different from the other groups ($P < 0.05$).

^c Significantly different from the reference and EW groups ($P < 0.05$).

FSBP%.

Figure 2. Percentage of change in finger systolic blood pressure (FSBP %) after local cooling of the finger for the individual subjects in the reference (control) group and the three groups with different severities of vibration-induced white finger (VWF). (EW = exposed subjects without VWF, EM = exposed subjects with mild VWF, ES = exposed subjects with severe VWF)

FSBP%.

Figure 3. Percentage of change in finger systolic blood pressure (FSBP %) after combined finger and body cooling for the individual subjects in the reference (control) group and the three groups with different severities of vibration-induced white finger (VWF). Subjects with a marked reduction in FSBP after only local cooling of the finger were excluded from this test. (EW = exposed subjects without VWF, EM = exposed subjects with mild VWF, ES = exposed subjects with severe VWF)

Table 2. Percentage of change in the finger systolic blood pressure (FSBP%) after finger and body cooling and the severity of blanching (SB) in the bilateral index, middle, and ring fingers of 14 patients.

Subject	Age (years)	Right fingers						Left fingers					
		Index		Middle		Ring		Index		Middle		Ring	
		FSBP%	SB ^a	FSBP%	SB ^a	FSBP%	SB ^a	FSBP%	SB ^a	FSBP%	SB ^a	FSBP%	SB ^a
1	64	78.4	++	86.8	-	89.6	+	94.5	-	59.3	+	0	++
2	60	80.4	+	80.3	+	107.4	+	109.8	+	102.3	++	0	++
3	65	60.3	+	68.4	+	69.2	+	115.4	-	96.3	-	65.0	+
4	60	75.0	+	74.6	+	73.8	+	75.0	+	83.7	+	79.0	+
5	65	97.1	++	7.1	++	100.0	+	100.0	+	14.6	+	68.5	+
6	74	85.2	-	83.0	-	84.6	-	84.7	-	79.1	+	66.1	+
7	61	83.3	+	97.2	+	57.5	+	74.4	++	76.3	+	70.0	++
8	61	0	++	32.8	++	43.5	++	0	++	56.0	++	90.9	++
9	61	Defect		103.8	+	88.3	+	90.4	-	94.3	-	76.4	-
10	65	98.4	+	81.8	+	70.6	+	0	+	115.4	+	26.7	+
11	61	64.0	-	60.0	++	0	++	27.9	++	51.9	++	109.1	-
12	61	91.7	-	92.3	-	55.2	+	66.0	+	31.9	+	109.8	+
13	61	100.0	-	89.2	+	96.2	+	91.8	-	94.8	+	72.8	+
14	57	73.5	+	90.6	+	86.9	+	0	+	90.6	+	Defect	

^a - = without blanching, + = mild blanching, and ++ = severe blanching.

below the limit. Therefore the diagnostic sensitivity is 81.7 % and the specificity is 90.3 % for VWF.

The results of the FSBP measurements on the bilateral index, middle, and ring fingers of 14 randomly selected men with VWF are shown in table 2. We investigated 82 fingers of eight patients of the EM group and six men of the ES group. The FSBP % values varied among the fingers of each person. Five of the 18 fingers with severe blanching and two of the 47 fin-

gers with mild blanching showed a zero pressure. Statistical differences for the FSBP % value after finger and body cooling were disclosed for the fingers without blanching and the respective ones with mild and severe blanching in the 14 patients (figure 4).

Cold-water immersion test for assessing the severity of vibration-induced white fingers

The results of the cold-water immersion test (10 min at 5°C) are shown in table 3. There were no significant differences in the skin temperatures and recovery rates of the three groups of exposed workers.

Discussion

A significant decrease in FSBP was observed only in the severe VWF group after finger cooling only. FSBP was significantly reduced in the EM and ES groups after combined finger and body cooling. Additional body cooling promoted vasospastic reaction. When the critical value of the FSBP % was defined to be 90 %, the diagnostic sensitivity for VWF was 81.3 %, and the corresponding specificity was 90.3 %. This sensitivity is not as high as reported earlier (11, 12). One explanation for the higher sensitivity in the earlier studies may be that the patients had been in more advanced stages of the disease. Another possible explanation is that the cited studies were performed at room temperatures (9–19°C) lower than in the present work (26°C). The lowest air temperature at which a human can maintain its body temperature at a resting level of metabolic rate is approximately 26°C (14); below this point heat production increases in proportion to the body-to-air temperature gradient. At room temperatures of 18 to 25°C, the skin temperature in normal subjects has been shown to fall continuously (15).

All digits on both hands were not equally affected with blanching attacks. The number of fingers with blanching varied among the patients. The amounts of decreases in the FSBP % after finger and body cooling relatively correlated with the severity of blanching. Furthermore, the differences in the FSBP %

Figure 4. Percentage of change in the finger systolic blood pressure (FSBP %) without blanching and with mild and severe blanching of the bilateral index, middle, and ring fingers of 14 patients after finger and body cooling.

Table 3. Skin temperature and recovery rate after a cold water immersion test (5°C for 10 min) of the three groups of vibration-exposed workers. (EW = exposed group without vibration-induced white finger, EM = exposed group with mild vibration-induced white finger, ES = exposed group with severe vibration-induced white finger)

	EW (N = 40)		EM (N = 36)		ES (N = 24)	
	Median	Range	Median	Range	Median	Range
Skin temperature (°C)						
Before	31.8	21.6–34.6	31.7	26.2–34.8	32.1	23.0–34.1
During	5.0	5.0–8.6	5.6	5.0–7.6	5.7	5.0–7.2
5 min after	20.8	12.8–30.0	17.4	11.9–29.5	17.6	13.0–30.0
10 min after	26.3	16.6–33.9	21.3	14.0–34.0	24.3	15.6–33.4
Recovery rate (%)						
5 min after	55.7	18.9–87.9	47.6	17.2–93.0	48.2	31.8–88.8
10 min after	77.9	43.0–114.3	70.7	31.2–115.3	74.6	50.0–100.8

among the index, middle, and ring fingers on the same hand mean that a central fault may be a necessary but not sufficient factor.

Pelmear et al (1) reported that cooling (cold-water immersion for 3 min at 0°C) and heating (hot water immersion for 3 min at 45°C) with the thermocouple technique failed to be an objective test for assessing the severity of VWF. In Japan, skin temperature measurements after cold-water immersion have been used for assessing peripheral circulatory disturbances in vibration syndrome. Kurumatani et al (16) used skin temperature measurements after cold-water immersion for 10 min at 5°C as a screening test with high sensitivity for VWF. However, they did not mention whether skin temperature measurements are useful for evaluating the severity of VWF. In the present study, measurements of skin temperature after cold-water immersion were found not to be feasible for discriminating among exposed men without VWF, those with mild VWF, and those with severe VWF.

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