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Heart Rate Variability during Cold Water Immersion Test in Patients with Hand-arm Vibration Syndrome

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Abstract Autonomic nervous function during cold water immersion test in patients with hand-arm vibration syndrome (HAVS) was investigated. Fourteen patients with vibration-induced white finger and 14 healthy control subjects individually age-matched to the patients volunteered for this study. The subjects immersed the left hand into cold water at 10 ℃ for 10 min and at 15 ℃ for 3 min. These tests were conducted in summer and winter. R-R interval of electrocardiography (ECG) was analyzed with a fast Fourier transformation program and component powers of heart rate variability were calculated. In both seasons, normalized high frequency component power (HF%), which is an index of parasympathetic nervous activity during the immersion tests involving 10 ℃ water and 15 ℃ water, was lower in the patients than that in the controls. The difference between the patient and control groups was greater in winter than in summer. The findings indicate that cardiac parasympathetic activity in HAVS patients was lower than that in controls. Ratio of low frequency component power and high frequency component power (LF/HF ratio), which is an index of the sympathetic nervous activity during immersion tests with either 10 ℃ water or 15 ℃ water, was higher in the patients than that in controls in both seasons. The findings indicate the sympathetic nervous activity of HAVS patients was higher than that of controls.

Introduction

Patients with hand-arm vibration syndrome (HAVS) may have autonomic nervous dysfunction. Investigation of the autonomic nerve function is used for evaluating the disturbance of HAVS patients[1,2,3,4]. Autonomic nervous activity can be investigated by measuring changes in heartbeat[5]. The sympathetic nervous and parasympathetic nervous activities can be separately evaluated by frequency analysis of heart rate variation (HRV)[6,7].

Cold water immersion test is used for the examination of autonomic nervous system activity[8,9,10]. Currently, disturbance of the peripheral circulation of HAVS patients is evaluated with cold-stress test involving immersion of one hand in cold water at 10 ℃ for 10 min in Japan[11,12,13,14]. Different water temperatures and immersion times, such as 10 ℃ for 3 min[15], 10 ℃ for 10 min[16], 15 ℃ for 1 min[17], and 15 ℃ for 3 min[18], have been used in Europe and North America.

We used two cold water immersion test methods of 10 ℃ for 10 min and 15 ℃ for 3 min, to examine the autonomic nervous activity of HAVS patients and healthy controls individually age-matched to the patients. All subjects had these tests twice in a year, i.e. summer and winter. The differences in response of the autonomic nervous activity between two immersion test methods as well as seasons were investigated.

Subjects and methods

Subjects

Fourteen HAVS patients with vibration-induced white finger (VWF) and 14 healthy subjects (controls) volunteered for the study. Control subjects were individually age-matched with the patients. The average age (SD) of the patients was 59.2 (6.3) years and that of controls was 58.1 (5.7) years. All the subjects were men with no history of diabetes mellitus, cerebral vascular disease, or heart disease. The groups showed no statistically significant difference in average age, body height, body weight, or body mass index (BMI) (Table 1).

The patients were chain saw operators and tunnel construction workers who had been officially diagnosed with HAVS by the Japanese Ministry of Labor. The patients were under treatment for HAVS, and vibration exposure had stopped in all of them. Stage of VWF in patients' hand was classified according to the Stockholm Workshop scale[19]; for the right hands, 1 patient was at stage 0, 12 were at stage 2, and 1 was at stage 3; for the left hands, 13 were at stage 2 and 1 was at stage 3. When both hands were considered together, neurological stages of patients according to the Stockholm Workshop sensorineural scale[19] were re-evaluated as that 1 patient was at stage 0, 10 were at stage 2, and 3 were at stage 3. The job titles of the healthy controls were as follows: office worker, car driver, maintenance worker, and farmer.

Experimental protocol

All the subjects gave a written informed consent to participate in the study, after they were informed of the research purpose. Subjects sat on the armchair during the study. Each subject rested quietly for 30 minutes, and then immersed the left hand into cold water at 10 ℃ for 10 min or 15 ℃ for 3 min. After the immersion, the subject removed the hand from the water and rested for 30 min. At least 3 hours later, the subject performed the second test involving whichever condition was not used the first time. This study was conducted in August 1998 (summer) and February 1999 (winter). Therefore, all subjects underwent four tests in all. The room temperature was kept at 21±1 ℃.

Data recording and analysis

Electrocardiography (ECG) data was recorded in a sitting position from 2 min

Table 1 Subjects characteristics

	Patients (n=14)	Controls (n=14)
Age (years)	59.2 (6.3)	58.1 (5.7)
Height (cm)	162.5 (5.5)	163.7 (5.0)
Weight (kg)	60.5 (8.2)	59.8 (5.7)
BMI (kg/m^2)	22.9 (3.2)	22.3 (2.2)
Years exposure to vibration	21.4 (9.0)	———
Years under treatment	4.9 (3.0)	———

before cold exposure to 10 min after cease of cold exposure, and data was stored on tape (Digital Cassette Recorder PC 208 AX, SONY). The ECG data were played back and digitized into a microcomputer with an analog to digital converter at a sampling frequency of 250 Hz and then processed further on a microcomputer to calculate the power related to frequencies up to 1.25 Hz. Continuous successive 256-point time series of R-R intervals after exclusion of extra-systole or abnormal arrhythmia were re-sampled and analyzed with a fast Fourier transformation (FFT) program. The normalized percentages of very low frequency (0.01-0.04 Hz) component power (VLF%, index of both the sympathetic and parasympathetic nervous activity which, was influenced with the renin-angiotensin system), normalized low frequency (0.04-0.15 Hz) component power (LF%, index of both the sympathetic and parasympathetic nervous activity), normalized high frequency (0.15-0.40 Hz) component power (HF%, index of the parasympathetic nervous activity), and the LF/HF ratio (index of the sympathovagal balance) were calculated from 2 min of ECG data during study.

Statistical analysis

Age, height, weight, and BMI for the HAVS patients and healthy controls were examined with a paired t-test. The three-way analysis of variance was used to analyze the factors of exposure, group, and season, and the interaction of these factors in cold immersion test of 10 ℃ for 10 min and that of 15 ℃ for 3 min. Differences were considered statistically significant at $P < 0.05$.

Results

Table 2 shows results of three-way analysis of variance for each immersion test. Figures 1 and 2 show data on changes of frequency components of HAVS patients and of healthy controls for immersion tests involving cold water at 10 ℃ for 10 min and cold water at 15 ℃ for 3 min, respectively.

Cold immersion test involving 10 ℃ water for 10 min

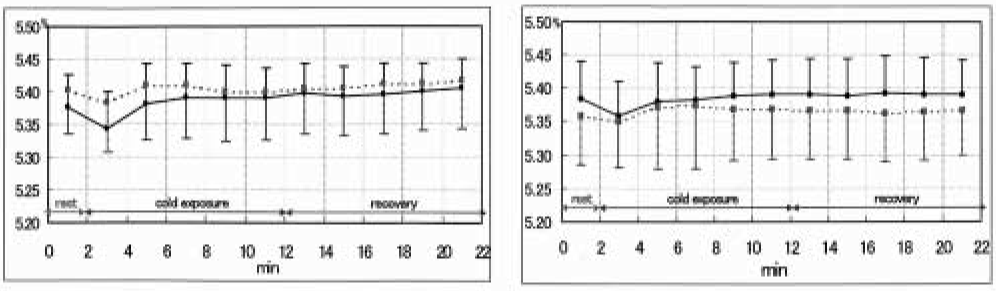
The exposure condition of cold water was statistically significant only for HF%. Group factor (i.e., HAVS patients or healthy controls) was statistically significant for all frequency components of HRV. The season factor (summer or winter) was also statistically significant for all frequency component of HRV. The interactions of these three factors were not statis-

Table 2 Results of three-way analysis of variance each for immersion test.

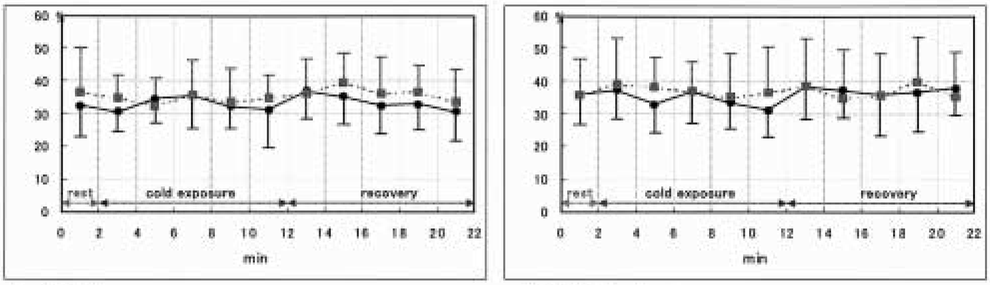
	10 ℃ for 10 min				15 ℃ for 3 min			
Factors	VLF%	LF%	HF%	LF/HF	VLF%	LF%	HF%	LF/HF
Exposure	1.50	0.89	2.07	0.96	0.49	0.61	0.64	0.33
(A)	0.137	0.541	0.025	0.474	0.841	0.746	0.723	0.940
Group	4.93	4.10	28.98	23.13	20.96	2.42	53.00	29.46
(B)	0.027	0.043	0.001	0.001	0.001	0.121	0.001	0.001
Season	4.93	5.91	17.51	11.91	7.34	0.02	10.74	2.65
(C)	0.027	0.015	0.001	0.001	0.007	0.886	0.001	0.104
A*B	0.19	0.29	0.19	0.22	0.02	0.37	0.44	0.38
	0.997	0.983	0.997	0.995	1.000	0.919	0.879	0.911
B*C	3.25	0.50	4.85	0.87	11.31	0.01	1.30	1.04
	0.072	0.479	0.028	0.352	0.001	0.905	0.254	0.308
A*C	0.19	0.47	0.47	0.54	0.13	0.30	1.26	0.71
	0.997	0.908	0.907	0.862	0.996	0.953	0.266	0.660
A*B*C	0.09	0.50	0.52	0.42	0.03	0.24	0.46	0.29
	0.999	0.893	0.874	0.938	1.000	0.975	0.864	0.958

Upper and Lower rows of each factor show F and P values, respectively tically significant except for HF% of group and season factors (Table 2).

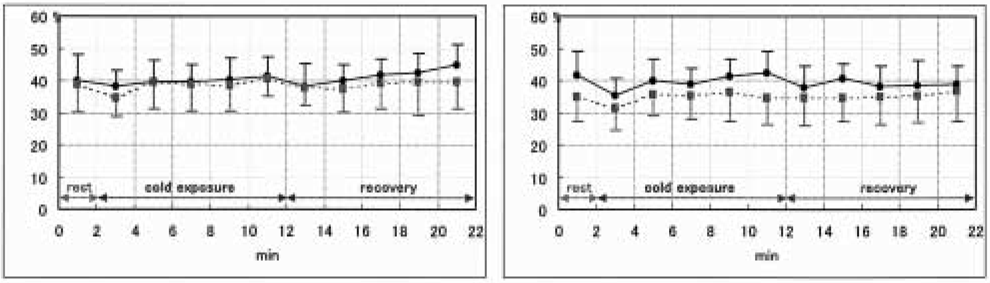
We plotted the mean changes in frequency components during the test (Figure 1). VLF% of the HAVS patients was higher than that of the healthy controls in summer; however, VLF% of the patients was lower than that of the controls in winter. LF% was higher for HAVS patients than for healthy controls in both summer and winter, whereas HF% was lower for patients than for controls in both seasons. The difference between the HF% of HAVS patients and healthy controls was greater in winter than in summer. The HF% of HAVS patients and healthy controls was lower during the first 2 min of cold exposure than during the rest of the exposure time, but the difference was unremarkable. LF/HF ratio of HAVS



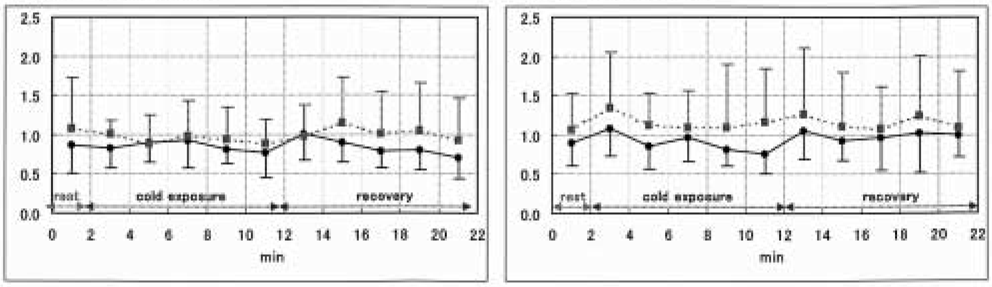
a. VLF% in summer
e. VLF% in winter



b. LF% in summer
f. LF% in winter



c. HF% in summer
g. HF% in winter



d. LF/HF in summer
h. LF/HF in winter

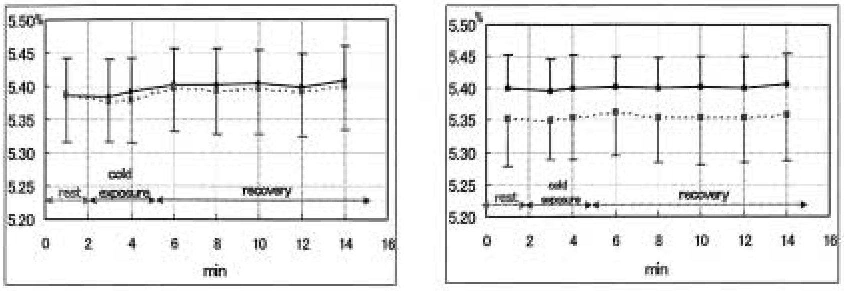
Fig. 1 Frequency components of heart rate variability during immersion tests involving cold water at 10 °C for 10 min in summer (a, b, c, d) and in winter (e, f, g, h), Mean ± SD. Dotted line represents patients and solid line represents controls.

patients was higher than that of healthy controls in both summer and winter. The difference between LF/HF ratio of HAVS patients and that of healthy controls was greater in winter than summer.

Cold immersion test involving 15 ℃ for 3 min

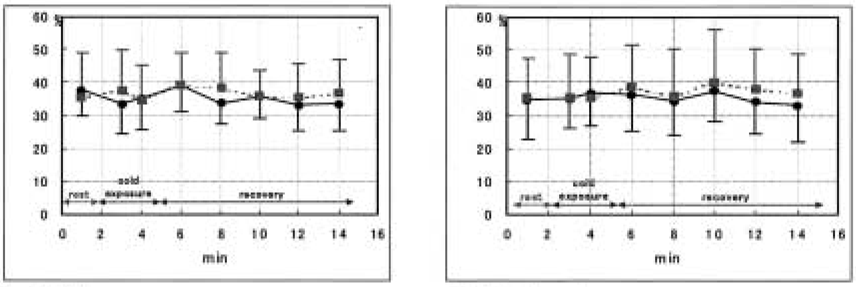
The exposure condition was not statistically significant for any frequency component of HRV. The group factor was statistically significant for VLF%, HF%, and LF/HF ratio but not for LF%. The season factor was also statistically significant for VLF%, HF%, and LF/HF ratio but not for LF%. The interactions of group and season factors were statistically significant only for VLF% (Table 2).

Change of frequency components during cold immersion test involving 15 ℃ for



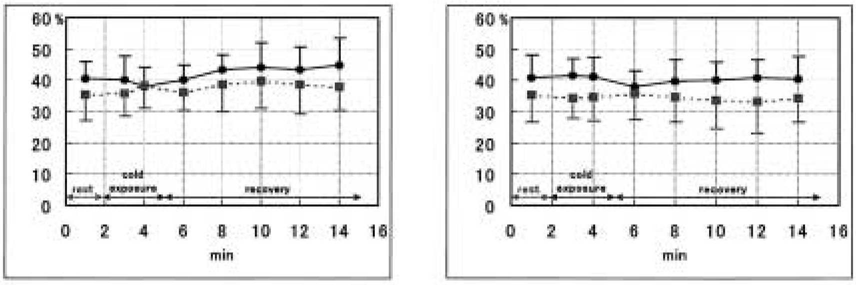
a. VLF% in summer

e. VLF% in winter



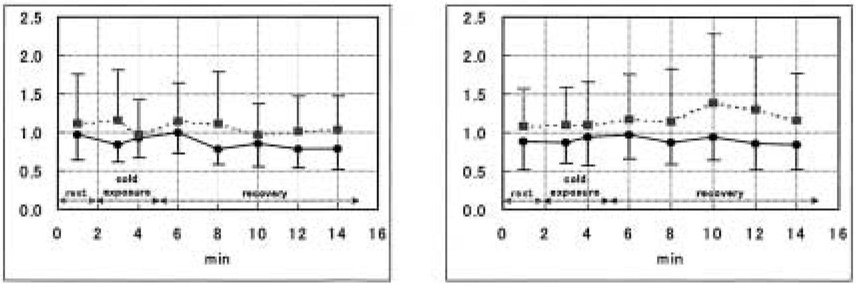
b. LF% in summer

f. LF% in winter



c. HF% in summer

g. HF% in winter



d. LF/HF in summer

h. LF/HF in winter

Fig. 2 Frequency components of heart rate variability during immersion tests involving cold water at 15 °C for 3 min in summer (a, b, c, d) and in winter (e, f, g, h), Mean ± SD. Dotted line represents patients and solid line represents controls.

3 min are shown in Figure 2. Although VLF% of HAVS patients was almost equivalent to that of healthy controls in summer, VLF% of HAVS patients was lower than that of healthy controls in winter. LF% of HAVS patients was also almost equivalent to that of healthy controls in both summer and winter. HF% of HAVS patients was lower than that of healthy controls in both summer and winter. The difference between HF% of HAVS patients and that of healthy controls was greater in winter than in summer. LF/HF ratio of HAVS patients was higher than that of healthy controls in both summer and winter. The difference between LF/HF ratio of HAVS patients and that of healthy controls was similar in both seasons.

Discussion

LF/HF ratio of HAVS patients was higher than that of healthy controls during the cold immersion tests involving 10 ℃ for 10 min and 15 ℃ for 3 min. This finding indicates that activity of the sympathetic nervous system of the HAVS patients increased during the test. Many reports have described greater sympathetic nervous system activity in HAVS patients than in healthy controls[2,4,20,21]. They observed that the difference was greater in winter than in summer. HF% is an index of the parasympathetic nervous activity; HF% of our HAVS patients was lower than that of healthy controls before and during the cold immersion tests involving 10 ℃ for 10 min and 15 ℃ for 3 min. Previous reports[3,5,7,9,20] indicated that activity of the parasympathetic nervous system of HAVS patients and workers exposed to hand-arm vibration decline, and our data agree with them.

In regard to seasonal differences of frequency components of R-R intervals, LF/HF ratio of our HAVS patients was higher than that of healthy controls in both summer and winter, and the difference was clearly greater in winter. Leppert et al[22]. investigated seasonal response of the sympathetic nervous system to cold exposure in women with primary Raynaud's phenomenon, and they found that patients with Raynaud's phenomenon showed a greater response in summer than in winter. Harada et al[12]. reported similar result of seasonal response in healthy men. They reported that finger skin temperature of healthy men was lower in winter than in summer. We considered that decrease of skin temperature was induced by peripheral vasoconstriction as a result of increased sympathetic nervous system activity in a cold atmosphere. Our results showed increased sympathetic nervous system activity of the HAVS patients during winter. HF% of HAVS patients was lower than that of healthy controls in both seasons. The difference between HF% of the HAVS patients and that of controls was greater in winter than in summer for both immersion methods. This finding of seasonal effects on HF% may coincide with that on LF/HF ratio.

Except for HF%, cold water exposure did not induce statistically significant changes of the frequency components of R-R intervals during the immersion test involving 10 ℃ for 10 min. Sakakibara et al[23]. reported that LF/HF ratio of HAVS patients was higher than that of healthy controls during cold immersion test involving 10 ℃ for 10 min. Although we have no clear explanation for this discrepancy between their finding and ours, the sitting position and lower room temperature in our study may be factors in the difference. These conditions cause increased sympathetic nervous system activity. In the Sakakibara study[23], test position was supine and room temperature was higher than that of our study, and they reported a clear change in LF/HF ratio of HAVS patients after cold water immersion. Because sympathetic nervous system activity was already increased before cold water immersion test in our study, no clear change of frequency components of R-R intervals could be observed.

VLF% of our HAVS patients during immersion test involving cold water at 10 ℃ for 10 min in summer was higher than that of healthy controls. However, VLF% of HAVS patients was lower than that of healthy controls during immersion test involving cold water at 15 ℃ for 3 min in summer and during both tests in winter. LF% of HAVS patients was significantly higher than that of healthy controls during immersion test involving cold water at 10 ℃ for 10 min, whereas there was no significant difference of the LF% at 15 ℃ for 3 min. The VLF% and the LF% of R-R intervals reflect both sympathetic nervous function and parasympathetic nervous function, and the renin-angiotensin system in the case of VLF%[6,24]. Therefore, we can not differentiate the findings of VLF% and LF% according to which systems are influencing them.

Difference of frequency components of R-R intervals between HAVS patients and healthy controls in winter was greater than that in summer. Especially, HF% was lower and LF/HF ratio was higher for patients than for healthy controls in winter. These findings confirm that both sympathetic and parasympathetic nervous systems are prone to be affected by change in season. Our results agree with those of previous reports indicating that sympathetic nervous system activity is higher and parasympathetic nervous system activity is lower in HAVS patients with VWF than in healthy persons in daily life, and that the sympathetic nervous system tends to show a greater increase in activity when the temperature is lower and in winter [4,7,10,16,22].

Conclusions

HF% is the index of the activities of parasympathetic nervous system. The findings of the present study indicate that cardiac parasympathetic activity is lower in HAVS patients than in healthy controls. LF/HF ratio is the index of the sympathovagal balance. Because LF/HF ratio of HAVS patients was higher than that of healthy controls, the increase in cardiac sympathetic activity during the tests was greater in patients than in controls. These phenomena were particularly apparent in winter. The sympathetic nervous system of HAVS patients is stressed by long-term exposure to vibration, and the parasympathetic nervous system is also affected. Furthermore, the strain on these systems is worse during exposure to low air temperature as in winter.

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References

1) Bovenzi, M.: Cardiovascular responses to autonomic stimuli in workers with vibration induced white finger. *Eur J Appl Physiol* **59**: 199-208, 1989.
2) Bovenzi, M.: Autonomic stimulation and cardiovascular reflex activity in the hand-arm vibration syndrome. *Kurume Med J* **37**[Suppl]: 85-94, 1990.
3) Harada, N., Kondo, H. and Kimura, K.: Assessment of autonomic nervous function in patients with vibration syndrome using heart rate vibration and plasma cyclic nucleotides. *Br J Ind Med* **47**: 263-268, 1990.
4) Sakakibara, H. and Yamada, S.: Vibration syndrome and autonomic nervous system. *Cent Eur J Public Health* **3**[Suppl]: 11-14, 1995.
5) Murata, K., Araki, S. and Maeda, K.: Autonomic and peripheral nervous system dysfunction in workers exposed to hand-arm vibration: a study of R-R interval variability and distribution of nerve conduction velocities. *Int Arch Occup Environ Health* **63**: 205-211, 1991.
6) Akselrod, S., Gordon, D., Ubel, FA., Shannon, DC., Barger, AC. and Cohen, RJ.: Power spectrum analysis of heart rate fluctuation: A quantitative probe of beat-to-beat cardiovascular control. *Science* **213**: 220-222, 1981.
7) Laskar, MS. and Harada, N.: Assessment of autonomic nervous activity in hand-arm vibration syndrome patients using time- and frequency- domain analyses of heart rate vibration. *Int Arch Occup Environ Health* **72**: 462-468, 1999.

8) Bovenzi, M.: Cardiovascular responses of vibration exposed workers to a cold provocation test. *Scand J Work Environ Health* **12**: 378-381, 1986.

9) Harada, N., Nakamoto, M., Kohno, H., Kondo, H. and Tanaka, M.: Hormonal responses to cold exposure in subjects with vibration syndrome. *Kurume Med J* **37**[suppl] : 45-52, 1990.

10) Nakamoto, M.: Responses of sympathetic nervous system to cold exposure in vibration syndrome subjects and age-matched healthy controls. *Int Arch Occup Environ Health* **62**: 177-181, 1990.

11) Harada, N., Hirosawa. I., Fujii, M. and Dodo, H.: Seasonal vibration of circulatory and sensory functions during immersion test in cold water for vibration syndrome (in Japanese, with English abstract). *Jpn J Ind Health* **25**: 422-431, 1983.

12) Harada, N., Iwamoto, M., Laskar, MS., Hirosawa, I., Nakamoto, M., Shirono, S. and Wakui, T.: Effects of room temperature, seasonal condition and food intake on finger skin temperature during cold exposure test for diagnosing hand-arm vibration syndrome. *Ind Health* **36**: 166-170, 1998.

13) Harada, N., Yoshimura, M. and Laskar, MS.: A minireview of studies conducted in Japan using finger-skin temperature during cold-stress tests for the diagnosis of hand-arm vibration syndrome. *Int Arch Occup Environ Health* **72**: 330-334, 1999.

14) Mirbod, SM., Akbar-Khanzadeh, F., Onozuka, M., Watanabe, K., Inaba, R. and Iwata, H.: A four-year follow-up study on subjective symptoms and functional capacities in workers using hand-held grinders. *Ind Health* **37**: 415-425, 1999.

15) Welsh, CL.: Digital rewarming time in the assessment of vibration-induced white finger. *Scand J Work Environ Health* **13**: 249-250, 1987.

16) Virokannas, H. and Rintamäki, H.: Finger blood pressure and rewarming rate for screening and diagnosis of Raynaud's phenomenon in workers exposed to vibration. *Br J Ind Med* **48**: 480-484, 1991.

17) Dupuis, H.: Thermographic assessment of skin temperature during a cold provocation test. *Scand J Work Environ Health* **13**: 352-355, 1987.

18) Gautherie, M.: Clinical studies of the vibration syndrome using a cold stress test measuring finger temperature. *Cent Eur J Public Health* **3**[Suppl]: 5-10, 1995.

19) Stockholm Workshop 86: Symptomatology and diagnostic methods in the hand-arm vibration syndrome. *Scand J Work Environ Health* **13**: 271-388, 1987.

20) Laskar, MS., Iwamoto, M., Toibana, N., Morie, T., Wakui, T. and Harada, N.: Heart rate variability in response to psychological test in hand-arm vibration syndrome patients assessed by frequency domain analysis. *Ind Health* **37**: 382-389, 1999.

21) Olsen, N.: Hyperreactivity of the central sympathetic nervous system in vibration induced white finger. *Kurume Med J* **37**[Suppl]: 109-116, 1990.

22) Leppert, J., Ringqvist, Å., Ahlner, J., Myrdal, U., Walker-Engström, ML., Wennmalm, Å. and Ringqvist, I.: Seasonal variation in cyclic GMP response on whole-body cooling in women with primary Raynaud's phenomenon. *Clinical Science* **93**: 175-179, 1997.

23) Sakakibara, H., Jin, L., Zhu, S., Hirata, M. and Abe, M.: Cardiac autonomic nervous activity in response to cold in VWF patients. *Proceeding* 8*th International Conference on Hand-Arm Vibration* : 95-97, 1998.

24) Niederberger, M., Aubert, JF., Nussberger, J., Brunner, HR. and Waeber, B.: Sympathetic nerve activity in conscious renal hypertensive rats treated with an angiotensin converting enzyme inhibitor or an angiotensin Ⅱ antagonist. *Journal of Hypertension* **13**: 439-445, 1995.