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PATHOPHYSIOLOGY AND CLINICAL PICTURE OF HAND-ARM VIBRATION SYNDROME IN JAPANESE WORKERS

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ABSTRACT

Hand-arm vibration syndrome is an occupational disease induced by long-term use of vibratory tools such as rock drills and chain saws. The three major stressors of vibration, noise and cold may produce various symptoms and signs not only with peripheral circulatory, nervous and muscle-joint disorders but also with general disorders. It is a point of controversy whether the symptoms and signs should be limited in the peripheral disorders. The question may involve differences in definition: vibration alone or work mode with vibratory tools. There are two viewpoints in the staging: peripheral and general viewpoints. The key concept in the peripheral viewpoint staging is a checkup to find disorders at the early stage and classify the peripheral disorders of the digits in detail. The general viewpoint staging seeks to grasp the general pictures of patients, and to classify from light to severe cases in the treatment. Clinical manifestations may include the general disorders in proportion to the severity of the syndrome according to our clinical experience. A differential diagnosis should be carefully made in the light of legal, medical and economic compensation. The treatments that we have used for approximately 20 years have beneficial effects on the whole-body, which include 1) physiobalneotherapy (therapeutic exercise, exercise in a pool and physiotherapy), 2) drug therapy (vasodilating drugs, autonomic stabilizers, etc.), 3) nerve blocking therapy, 4) surgical therapy for ulnar nerve paralysis or paresis, and 5) education for patients. Even with these therapies, a beneficial effect may not be observed in a short period. The recovery may be slow. It is necessary to prevent the disease and diagnose it at the earliest stage.

Key Words: Hand-arm vibration, Clinical picture, Pathophysiology, Definition, Treatment

INTDRODUCTION

Hand-arm vibration syndrome is an occupational disease induced by long-term use of vibratory tools such as rock drills and chain saws. Vibration transmitted from hand-held vibratory tools to local and distant organs leads to disorders of the peripheral circulatory and nervous systems as well as injuries of the musculoskeletal system in the early stage. In Japan, it is recognized as an occupational disease, when the syndrome deteriorates to the second half of stage 2. In this stage, the patients are found to have general symptoms and signs including disorders of the central (acoustic and labyrinthine) and autonomic nervous systems as well as the peripheral disorders.[1,2] The more severe the case is, the more symptoms and signs appear. It has been a point of controversy whether the syndrome includes general disorders or the peripheral injuries alone.[3] To resolve this question, the definition must first be clarified. The definition of the disease differs with the country because of the legal, medical and economic compensation. In the present paper, the clinical picture and pathophysiology will be described on the basis of our clinical experience with Japanese workers, and a comparison is made with the classifications of severity generally proposed in various countries.

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CLINICAL PICTURE

The diagnosis of vibration syndrome has been done by the history takings, physical and laboratory examinations. First of all, we must learn whether a patient works with hand-held vibratory tools for a long-term. The complaints in the early stage include disorders of the peripheral nervous and circulatory systems, and of the muscle-skeletal system. Numbness and cold sense in the fingers and stiff shoulders in the arm occur first. The reduction in muscle strength may also be present. In the second half of stage 2, Raynaud's phenomenon in the fingers happens even in a very hot bath (42—43°C) as well as in cold exposure. Palmar hyperhydrosis as a sign of the autonomic nerve disorders appears even when no work is performed. Ulnar nerve paralysis or paresis occurs in some cases. Headache, insomnia, forgetfulness, irritability, depressive mood, tinnitus, and impotence appear as the stage progresses.[1,2,4] These complaints should be due to the autonomic and central nervous system disorders, but actually, some of them may be considered to be "symptom-induced symptoms." For example, when muscle pain is persistent, the patient will fall into a depressive mood (Fig. 1).

The symptoms and signs in the syndrome include three major disorders: peripheral circulatory, nervous and muscular disorders, bone-joint system disorders, and the autonomic and central nervous disorders associated with hearing loss, nystagmus and vertigo. The mixed type with three major disorders is observed in 60 to 70% of the patients.

Physical examinations reveal circulatory, nervous and muscle disorders in the fingers and arms. Impairment of sensory perception and tactile discrimination are present, of which extent in the body surface must be examined. Reduction in muscle strength may also be present.

The time course of the peripheral complaints falls into two types (Fig. 2). Type A begins with muscle-joint system disorders, and type B with numbness. The period between the beginning of chain saw operation and the occurrence of Raynaud's phenomenon is not always related to the total hours of usage. However, the older the worker is at the beginning of the usage, the earlier the peripheral disorders occur.

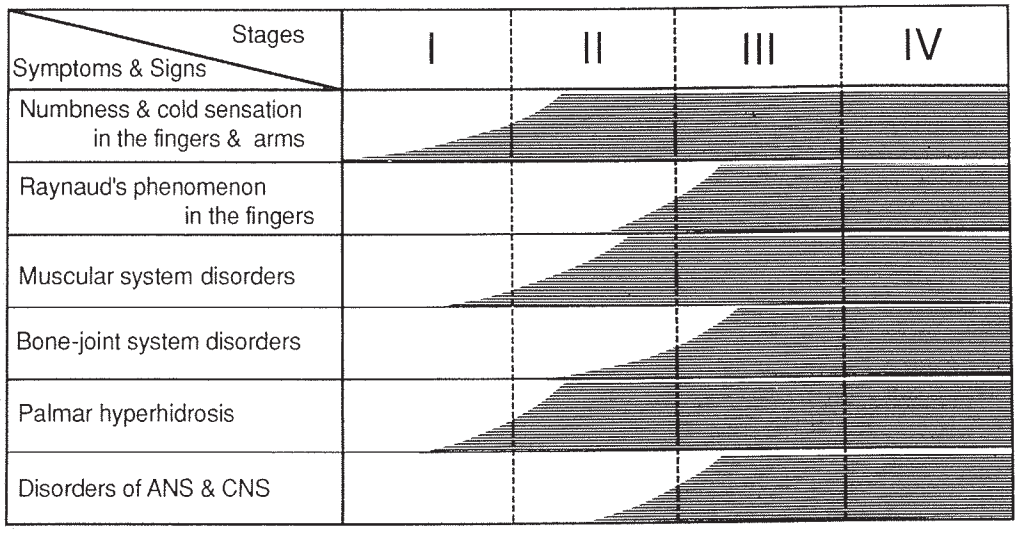

Fig. 1. Onset of symptoms and signs in each stage
In the second half of stage 2, Raynaud's phenomenon in the fingers and disorders of the central and autonomic nervous systems may appear. The severity is graded into 4 stages according to our criteria.[1]

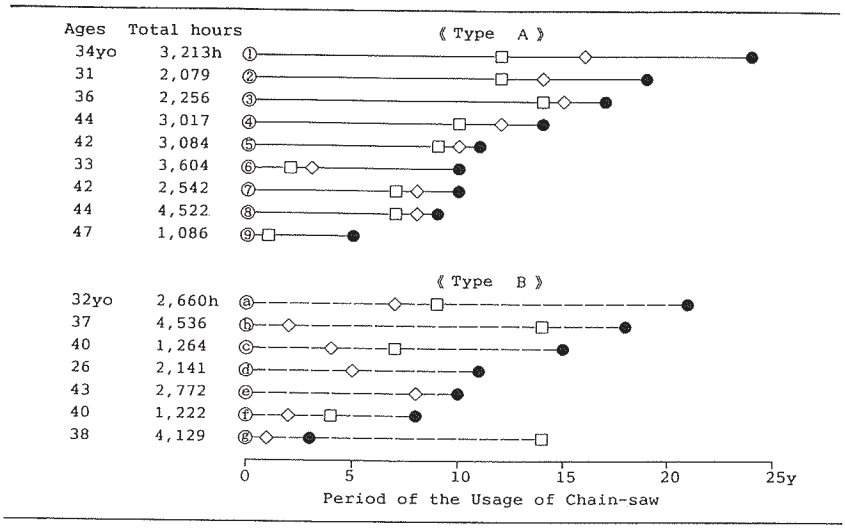

Fig. 2. Time course of peripheral symptoms and signs
The open squares show muscle-joint system disorders, the open rhombuses are numbness, and the closed circles indicate Raynaud's phenomenon. The symptoms and signs first appearing are muscle-joint system disorders. The Arabic numbers and letters surrounded by circles show case numbers. The last symptoms are Raynaud's phenomenon, of which onset is not always related to the total hours of usage and the age at the beginning of the usage. The ages at the beginning of usage in Type A and B are 39.4 ± 6.1 (mean $\pm$ SD) and 35.8 ± 4.5 years, respectively. The periods from occurrence of numbness to Raynaud's phenomenon in Type A and B are 5.2 ± 4.2 (mean $\pm$ SD) and 4.3 ± 2.4 years, respectively.

Laboratory examinations are performed in the peripheral nervous function tests for pain and vibration senses, and in the peripheral circulatory function test for the recovery function of skin temperature reduced by immersion in 4°C water. Other examinations include roentogenography of finger joints and elbows, audiometery, electrocardiography, electroencephalography and others.[2)]

STAGINGS

There are two typical stagings with different viewpoints, either peripheral or general (Fig. 3). Each viewpoint has a clear principle. The peripheral viewpoint staging is for a checkup to find disorders at the early stage and classify the peripheral disorders of the digits in detail. The general viewpoint staging is for the purpose of treatment to determine the general picture of patients and classify the severity from light to severe cases. In all stagings, the severity is graded by 4 or 5 stages.

First, we attempted to apply Taylor-Pelmear's scale to our patients.[6)] However, we found it impossible because the patients had various symptoms and signs besides blanching, tingling and numbness of the fingers. In particular, Japanese patients had serious disorders in the bone-joint system. Therefore, we proposed a new staging on the basis of bedside observation of patients.[1)] In comparisons of Taylor-Pelmear's staging and ours, the grades of severity in vascular and nervous disorders in the fingers are almost the same. However, our staging includes symptoms other than blanching, tingling and numbness of the fingers.

The Stockholm classification is now internationally adopted. It is graded by Raynaud's phe-

Comparisons of STAGINGS

Viewpoint	Peripheral Viewpoint			General Viewpoint
Principle	* To find disorders in the early stage under the established checkup system. * To classify the peripheral disorders of digits in detail.			* To grasp the general pictures of patients. * To classify from light to severe cases.
Scale	A Taylor & Pelmear (1974)	B Stockholm (1987)	C Ministry of Labor (1986)	Matoba (1975) Forestry Agency (1975) Ministry of Labor (1976)
Stage	0 V/N	0 R / 0 N	0 V, R/N	I V, R/N G
	0_T 0_N V/N	0 R / 1 N	0 V, R/N	I V, R/N G
	1 V/N	1 R / 2 N	1 V, R/N	II V, R/N G
	2 V/N	2 R / 3 N	2 V, R/N	III V, R/N G
	3 V/N	3 R / 3 N	2 V, R/N	III V, R/N G
	4 V/N	4 R / 3 N	3 V, R/N	IV V, R/N G

V=vascular disorders; N=nervous disorders; R=Raynaud's phenomenon; G=general disorders

Fig. 3. Comparison of staging in vibration syndrome
There are two viewpoints in the staging, peripheral and general. The former is for a checkup, and the latter for treatment.

nomenon (RP) and neuropathy of the median and ulnar nerves. However, the severity of both disorders is not the same. Why does the peripheral viewpoint staging focus on RP? The prevalence of RP in the population survey differs with sex and race.[7] The prevalence rate is 2 to 8% in males and 5 to 18% in females. It is 0.5 to 4.0% in Japanese, 2% in Chinese, and 4 to 18% in Western Europeans. Rates are higher in the West than the East; if skin color turns to white, Japanese people are very fearful of the change.

Our classification consists of 4 stages.[1] Figure 1 shows the onset of some of the symptoms and signs in each stage. The complaints in the early stage include disorders of the peripheral circulatory and nervous systems, and musculoskeletal disorders. Numbness and cold sense in the fingers and muscle pain in the arm occur first. In the second half of stage 2, Raynaud's phenomenon in the fingers appears. It is recognized as an occupational disease in Japan, when the syndrome deteriorates to the second half of stage 2. Fortunately, we no longer encounter severe cases of stage 4. It is difficult to practically discriminate the prevalence of symptoms and signs between stage 3 and 4.[2] According to our classification, instead of being not able to see the wood for the trees like a proverb, we could see "the wood," i.e. patients as a whole.

PATHOPHYSIOLOGY

Workers using hand-held vibratory tools are exposed to 3 major stressors: vibration, noise generated from the machines, and environmental cold. In general, typical levels of tool vibration are more than 0.316 m/s^2, while tool noise levels are generally more than 95 dB (air). Chronically repeated action of the stressors on the human body may overload and impair not only the peripheral systems but also the central nervous system, including the higher center of the auton-

omic nervous system, in addition to the acoustic nerves.[4] In the input overloading state, excitation of the hypothalamus and the limbic lobe in the cortex, where the higher center of the autonomic nervous system exists, results in an increase in circulating catecholamines from the adrenal medulla. This process may result in a very large increase in vasoconstriction and stimulation of the heart, leading to hypoxia and lack of nutrition in the target tissues. The peripheral circulatory and nervous disorders reveal, in particular, Raynaud's phenomenon in the fingers.

Among the cardiovascular manifestations are sinus bradycardia, enlarged heart and increased left ventricular ejection fraction at rest. Blood pressure runs on the low side.[7,8] These symptoms and signs of the cardiovascular system are similar to those frequently observed in endurance athletes.[9] Well-trained athletes are adapted to physical training and possess, at rest, sinus bradycardia, cardiomegaly, comparatively lower blood pressure, increased stroke volume and left ventricular ejection fraction, increased cardiac output, and electrocardiographic abnormalities. Thus, it is emphasized that the clinical features of the vibration syndrome can include adaptive responses to the stressors, in addition to direct injuries induced by vibration.

The pathophysiological mechanism of Raynaud's phenomenon in the fingers, one of the typical symptoms and signs of the disease, has not yet been clarified. Raynaud suggested in 1862 that the vasospasm was mediated through central sympathetic nervous impulses.[10] Contradictory to this, Lewis advanced a theory in 1929 that an attack of Raynaud's phenomenon was produced only by defects in the nerve endings with no role of central sympathetic nervous impulses.[11] From this controversy, many experimental and clinical data have been presented.

According to our results, we have proposed the pathogenesis of Raynaud's phenomenon due to the habitual use of hand-held vibratory tools[12]: first, three major stressors, vibration, noise and cold, may repeatedly act on the human body, producing histological injuries and ischemia in the vessels. And also these stressors may decrease the modulatory action of the sympathetic nervous system. Under these conditions, the chemical substances for vasoconstriction such as endothelin and thromboxan A_2 could readily be released from the intima of the affected vessels. In the second step, vasospasm of the affected vessels may be provoked by cold exposure, enhancing release of chemical substances from the endothelium. No regulation from the central and local autonomic nervous systems was noted. It is concluded that the vasospasm in vibration syndrome can occur as a result of disorders of the central and local autonomic nervous systems in addition to the histological injuries of the local vessels and nerves.

Although there is a limit to our clinical experience, the autonomic nervous disorders must be functional (Fig. 4). The autonomic nerve tones are functionally increasing in proportion to the stage. In stage 4, however, the tones change to be hyporeactive. However, it will remain a question whether or not there is pathological damage.

According to our bedside observation, patients often complain of palmar hyperhidrosis even when not working. Two weeks after treatment with sulpiride, a dopamine-2 receptor inhibitor in the hypothalamus, sweating reduces or disappears.[4] Secondly, observing changes of skin temperature in response to auditory stimuli using a thermography, auditory stimuli result in a decrease in skin temperature. The premedication of sulpiride increases blood flows due to inhibition of the hypothalamus. On the contrary, the excitation of the brain by L-DOPA leads to hyperreactivity to the stimuli.[13] Thirdly, vibration to one hand evokes the reaction of the other hand. Pretreatment with sulpiride, however, suppresses the response. These findings suggest normalization of the hyperreactive state in the hypothalamus. Fourthly, the prevalence of Raynaud's phenomenon (RP) correlates with the level of autonomic nerve activity. The highest incidence of RP is observed in the hyporeactive state, and the lowest in the normal reactive state.[12] Fifth, changes of blood flow to mechanically and thermally induced pain are markedly different in patients with vibration-induced white finger and the controls. These patients have no

or weak vasoconstriction in response to the stimuli.[14] Thus, sympathetic vasoconstriction nerves or receptors are affected in vibration syndrome. It is natural to include central and local sympathetic nervous dysfunction.

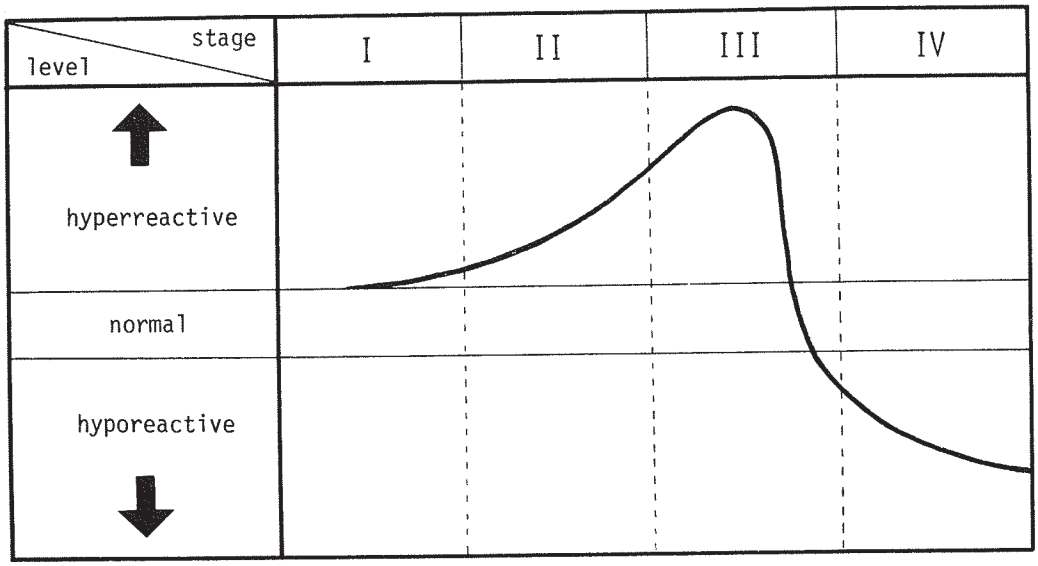

Fig. 4. Schematic representation of the level of autonomic nerve tone in each stage
The level of the autonomic nerve tones tends to become hyperreactive in proportion to the stage. In the second half of stage 3, however, the level declines so as to be hyporeactive in stage 4.

DEFINITION

The definition of the syndrome is different in terms of varying conditions of the countries because of the legal, medical and economic compensation. The Ministry of Labor in Japan defined the disease entity in 1977.

Vibration syndrome is an occupational disease in workers who are exposed to vibration due to the usage of vibratory tools such as jack hammers, pneumatic hammers, and chain saws. The following items must be satisfied for requirement of treatment:

1. The disease is caused by habitual use of vibratory tools for one year or more.
2. The disease includes at least one of the following items (2.1 or 2.2):
   - 2.1 Subjective symptoms such as numbness, pain, cold, stiffness, etc. occur intermittently or continuously in the upper extremity such as fingers and arms. One marked finding or all in the following items should be included.
     - 2.1.1 Peripheral circulatory disorders in the upper extremity such as fingers and arms.
     - 2.1.2 Peripheral nervous disorders in the upper extremity such as fingers and arms.
     - 2.1.3 Motor function disturbances due to the disorders of bones, joints, muscles, tendons, etc. in the upper extremity such as fingers and arms.
   - 2.2 Raynaud's phenomenon appears in the fingers.

Thinking of the outcomes of our bedside observation, this definition of the disease entity is reasonable for an occupational disease. According to this definition, the syndrome entity as an occupational disease must be defined as a disorder elicited by the mode of work with hand-held

vibratory tools, although some investigators have emphasized the vibration alone.[3] Thus, the genesis includes vibration, noise, cold, ergonomic and biodynamic conditions, and emotional stress in work.[4] It should not be restricted to vibration alone.

TREATMENT AND PROGNOSIS

Treatments for vibration syndrome that we have used for approximately 20 years are as follows.[15]

Physiobalneotherapy is the key treatment for the syndrome. It affects the whole body and leads to an improvement of the circulatory, nervous, and motor disorders due to an enhancement of blood flow in the injured tissues. When the therapeutic exercise and exercise in a pool (water temperature 38 to 40°C) are done in a group, the therapy exerts a psychologically favorable influence on the patients. During physiobalneotherapy, therapeutic exercises and exercises in a pool are provided for all patients. The efficacy of the treatment in a double blind controlled trial for six weeks showed the improvement rates for the subjective symptoms and the laboratory examinations were 40 and 33%, respectively, for the group receiving physiobalneotherapy and 83 and 63%, respectively, for the group undergoing physiobalneotherapy and drug therapy.[16]

The other therapies, drug therapy (vasodilating drugs, autonomic stabilizers, anti-inflammatory analgesic drugs, etc.), nerve blocking therapy for tinnitus and surgical therapy for ulnar nerve paralysis or paresis, are selected according to the patients' symptoms and signs. Drug therapy may accelerate the effects of physiobalneotherapy. The improvement rate with drug therapy ranged between 50 and 80%. As the disease becomes more severe, the drug therapy increases. When such therapy is continued for long periods, patients and their wives take an education program providing information on the pathophysiology of the syndrome, the importance of therapy, and the general management of daily life.

The prognosis following comprehensive therapy in the hospital was "good" for 13%, "good with therapy" for 63%, "fair with therapy" for 15%, and "poor despite therapy" for 9% of the patients during the five to seven years of follow-up.[17]

CONCLUSION

Hand-arm vibration syndrome should be diagnosed as the disease entity with general disorders induced by the mode of work using vibratory tools. Therefore, the genesis involves vibration, noise, cold, ergonomic and biodynamic conditions, and emotional stress in work. The symptoms and signs include disorders of the central and autonomic nervous systems as well as of the peripheral circulatory, nervous and muscular systems. Treatments persisted for a long-term are for the whole body. The protracted course of treatments for the disease suggests the need for early diagnosis and treatment.

REFERENCES

1) Matoba, T., Kusumoto, H. and Takamatsu, M.: A new criterion of the severity of the vibration disease. *Jpn. J. Ind. Health,* 17, 211–214 (1975).
2) Matoba, T., Kusumoto, H., Mizuki, Y., Kuwahara, H., Inanaga, K. and Takamatsu, M.: Clinical features and laboratory findings of vibration disease: a review of 300 cases. *Tohoku J. exp. Med.,* 123, 57–65 (1977).
3) Dupuis, H. and Gemne, G.: Hand-arm vibration and the central nervous system. Report for an international symposium. *Int. Arch. Occup. Environ. Health,* 55, 185–199 (1985).

4) Matoba, T., Chiba, M. and Inutsuka, S.: Autonomic nervous system disorders in subjects exposed to hand-arm vibration – a review of clinical investigations in Japan. *J. Low Fre. Noise & Vib.*, 1, S74–S83 (1983).
5) Taylor, W., Pelmear, P.L. and Pearson, J.: Raynaud's phenomenon in forestry chain saw operators. In *The Vibration Syndrome,* edited by Taylor, W., pp 121–139 (1974), Academic Press, London.
6) Matoba, T.: The pathophysiology and prevalence of Raynaud's phenomenon in vibration disease. *Jpn. J. Traumatol. Occup. Med.*, 37, 149–256 (1989).
7) Matoba, T., Chiba, M. and Toshima, H.: Cardiovascular features of the vibration syndrome: an adaptive response. In *Vibration Effects of the Hand and Arm in Industry,* edited by Brammer, A.J. and Taylor, W., pp.25–30 (1982), John Wiley & Sons, New York.
8) Matobe, T., Chiba, M. and Sakurai, T.: Body reactions during chain saw work. *Br. J. Ind. Med.*, 42, 667–671 (1985).
9) Scheuer, J. and Tipton, C.M.: Cardiovascular adaptations to physical training. *Annu. Rev. Physiol.*, 39, 221–251 (1977).
10) Raynaud, M.: De l'asphyxie locale et de la gangrene symmetrique des extremities. Ringnoux, Paris, 1862. Barlow T: translation: On local asphyxia and symmetrical gangrene of the extremities. In: *Selected Monographs, The New Syndenham Society,* 121, pp. 1–99, (1988), London.
11) Lewis, T.: Experiments relating to the peripheral mechanism involved in spasmodic arrest of the circulation in the fingers. A variety of Raynaud's disease. *Heart,* 15, 7–101 (1929).
12) Matoba, T. and Ishitake, T.: Cardiovascular reflexes during vibration stress. *Kurume Med. J.*, 37, S61–S71 (1990).
13) Matoba, T., Kusumoto, H., Mae, H., Toshima, H., Kuwahara, H. and Kimura, N.: The role of the higher center of the autonomic nervous system in Raynaud's phenomenon in vibration disease. *A.N.(Tokyo),* 14, 76–80 (1977).
14) Ekenvall, L., Lindblad, L.E., Carlsson, A. and Etzell, B.M.: Afferent and efferent nerve injury in vibration white fingers. *J. Auton. Nerv. Syst.*, 24, 261–226 (1988).
15) Matoba, T. and Kuwahara, H.: Treatments for hand-arm vibration disease in Japan. *Kurume Med. J.*, 37, S123–S126 (1990).
16) Matoba, T., Kusumoto, H., Mizuki, Y. and Yamada, K.: Comparative double-blind trial of dl-α-tocopheryl nicotinate on vibration disease. *Tohoku J. exp. Med.*, 123, 67–75 (1977).
17) Matoba, T.: A follow-up study of treatment of vibration disease. *Jpn. J. Traumatol. Occup. Med.*, 25, 447–453 (1977).