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PREVENTION, CLINICAL, AND PATHOPHYSIOLOGICAL RESEARCH ON VIBRATION SYNDROME

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ABSTRACT

In the 1950s, introduction of portable power tools into the production process of many industries began on a large scale around the world and resulted in many cases of occupational vibration syndrome after the 1960s. There was an urgent need to undertake preventive steps, medical assessment and therapy throughout the world.

At the end of 1964, our investigation began in Japanese national forests, and then in mining and stone quarries. Our research and efforts resulted in a comprehensive system for prevention of vibration syndrome in the Japanese national forest industry. It has presented a good model of prevention for other industries in Japan.

Clinical and pathophysiological research on vibration syndrome in the 1960s and 1970s clarified disturbances of the peripheral circulatory, nervous, and musculoskeletal systems. From the mid-1970s, neurophysiological, neurochemical, and clinical research on vibration syndrome in relation to the autonomic nervous system developed. Our studies contributed to the advancement of research in this field. More in-depth study is needed to determine the role of the autonomic nervous system in vibration syndrome.

Key Words: Vibration syndrome, Prevention, Clinical picture, Pathophysiology

INTRODUCTION

The first report of vibration syndrome caused by portable power tools appeared in Italy (Loriga: 1911),[1)] and the clinical picture was described in detail somewhat later in the USA (Hamilton: 1918).[2)] After these reports, many cases of vibration syndrome were presented in the literature of European and Asian industrialized countries.

In terms of new technical innovation in the 1950s, introduction of portable power tools into the production process of many industries began on a large scale around the world. The main kinds of portable power tools were pneumatic tools (rock drill or chipping hammer, etc.), cutting tools (engine- or electric- powered chain saw, etc.), fastening tools (impact wrench, etc.) and grinding tools. These power tools had a high vibration acceleration level and were noisy and heavy.

The huge production load and hard working conditions in those industries resulted in many cases of occupational vibration syndrome after the 1960s. The chief tools that originated these health hazards were leg-type rock drills in mining, chipping hammers in metal and stone cutting, and chain saws in tree-felling operations. This period was coincident with the rapid development of the Japanese economy, and severe cases of vibration syndrome appeared in the forestry, mining, and stone quarry sectors of Japan.

Vibration syndrome involves peripheral circulatory, nervous, and musculoskeletal disturban-

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ces. In severe cases, workers suffer from cold hand and Raynaud's phenomenon, tingling and pain of upper extremities, sleep disturbance, heavy-headed feeling, irritability, and loss of manual dexterity. This health hazard was called the "White Waxy Disease," the term used by Japanese forest workers to describe the awful feeling in relation to cold, paralyzed, and white fingers. European people called the same symptom "Dead Finger." There was an urgent need to undertake preventive steps, medical assessement, and therapy throughout the world.

The Japan Association of Industrial Health established the Research Committee of Local Vibration Hazards in October of 1965. Then, the First United Kingdom Informal Meeting on Human Response to Vibration was held in 1968, followed by The First International Meeting of Hand-arm Vibration in 1972. These health disturbances were named "Vibration Syndrome;" and Raynaud's phenomenon due to operation of vibrating power tools was named "Vibration Induced White Finger (VWIF or VWF)" at the First International Meeting.[3] Since the 1970s, researchers in many countries have conducted studies in the fields of preventive, clinical, and pathophysiological research of vibration syndrome. At the end of 1964, our investigation began in Japanese national forests, and then in mining and stone quarries.[4–6] In this report, we present a broad outline of our research work in these fields as well as many other related studies.

HISTORY OF PREVENTION OF VIBRATION SYNDROME IN JAPANESE NATIONAL FORESTS

The efforts made to prevent vibration syndrome over the last 30 years can be divided into five stages, as follows, in accordance with the introduction of preventive measurements[6]:

In stage 1, from 1965 until 1969, the introduction of chain saws with an anti-vibration handle began, and investigations for early diagnosis and hygienic work regulation were performed. Attempts were made to warm the worker's body at rest cottages, working place, and while commuting.

In stage 2-a, from 1970 until 1972, time restriction of chain-saw operation and early diagnosis were introduced. In stage 2-b, from 1973 until 1974, time restrictions were completely in place and improvement of chain saws gradually took place. A job regulation system for the workers suffering from vibration syndrome was introduced. Early treatment involving hot spa therapy was tentatively begun.

In stage 3, from 1975 until 1980, a health care system was established for early check of vibration hazards and early therapy. Improvements of reciprocal chain saws progressed, and remote control saws were introduced without time regulation. Newly designed chain saws, which had good engine balance, i.e., rotary engine chain saws and opposed twin-cylinder reciprocal engine chain saws, appeared. These had a low level of vibration. The noise and weight of chain saws gradually decreased as well.

In stage 4, from 1981 until the present, new light-weight bantam chain saws with low vibration level for limbing were introduced. Chain saws with warming handle were introduced widely in northern cold areas. This comprehensive system for prevention has proved successful. New cases of occupational vibration syndrome are now few each year.

[1] At the end of 1964, we began to investigate practical working conditions and changes in physiological function during workers' operation of chain saws in mountain forests as well as the characteristic clinical features of vibration syndrome in workers, in the national forests of Central Japan.

Conditions in working areas: The national forests in this area grow on the steep slopes of high mountains at about 1000 m above sea level. The worker's posture and load during chain saw operation were not good in many areas. The ambient conditions were cold in spring and autumn and severe cold in winter, and these promoted the incidence of vibration syndrome.

Conditions in vibrating tools: The vibration acceleration of a chain saw was more than 100 m/s^2 and the sound level was about 110 to 115 dB. These levels adversely affected the health of workers. The weight of a chain saw was about 12 to 15 kg in the class of 80 to 100 cc engine displacement. These conditions were particularly harmful for Japanese forest workers who were small in physique and ill fed.

Work conditions, employment and wages: Work was organized by piecework rate and workers were seasonally employed therefore, workers were accustomed to working long hours. These social conditions only served to cause deterioration in health.

Epidemiological findings: While the mean prevalence of VWF throughout the Japanese national forest industry was 5.6% among chain saw workers and 0.6% among workers without vibration exposure,[8,9)] the prevalence was 60.3% at the Tsukechi local forest office in the Ura-Kiso area, which reported the longest exposure time and the highest prevalence, in 1965.[11)] At the Sakashita local forest office in the Kiso area near Ura-Kiso, prevalence was 42.9%, and in the Kyushu area it was 41% in 1969.[7,8)]

In 1971, Taylor et al. reported their survey of vibration syndrome among the employees of the Forestry Commission of the UK; there was an overall 44% prevalence of vibration syndrome (numbness, pain, and blanching), compared with 69% in South England, 53% in Wales, 33% in Scotland, and 31% in North England.[10)]

Clinical picture: Characteristics of the clinical picture were as follows: lower skin temperature and coldness of hand, Raynaud's phenomenon, numbness and tingling, paresthesia in pain and vibratory sensations of hand, decreased grasping power, and difficulty in fine movements of fingers. Paresthesia in hands and feet (glove- and stocking-type polyneuropathy) was seen in severe cases. The occurrence of these symptoms was correlated with the number of years operating chain saws, and increased age was seen to promote these symptoms.[76)]

[2] Considering the results of investigations and the surrounding conditions, we concluded that the high prevalence of these symptoms in this area of Japan was due to the long daily and yearly operation of chain saws with a high level of vibration acceleration.

In March 1965, we recommended that the Japanese Government (National Forest Agency and Ministry of Labor) establish the following standards: 1) legal recognition of these health hazards as occupational vibration syndrome; 2) a health check system for early diagnosis and therapy; 3) hygienic restriction of chain saw operation time; 4) an improved chain saw design to reduce vibration, sound, and weight; and 5) a method to protect against cold.

[3] The Japan Association of Industrial Health (JAIH) organized the Research Committee of Local Vibration Hazards (Chief: T. Miura) in October 1965, and this Committee recommended that the Ministry of Labor recognize vibration hazards by chain saw operation as an occupational disease. Many research workers across Japan collaborated in the Committee's activities. Since then, they have continued their efforts to prevent vibration hazards in many areas: in the forests, mining, construction, and metal industries. The Ministry of Labor (May 1965) and the National Personnel Authority (May 1966) recognized vibration hazards from chain saw operation as an occupational disease, and they have gradually accepted our recommendations.

[4] The Research Committee disbanded after two years and the Research Organization of Local Vibration Hazards was organized within the JAIH. The first chief of this Research Organization was T. Miura from 1967 until 1979 and the second chief has been S. Yamada from 1980 until the present. This research organization was renamed the "Research Organization of Vibration Hazards" in 1975 and cooperated with the Vibration Syndrome Committee (from 1977 until

1979), recommending that the Ministry of Labor promote the prevention of vibration hazards, in 1979.

[5] The National Forest Agency and the Workers Union of the National Forest reached agreements from 1970 until 1977 through our recommendations. The agreements consisted of time restrictions on chain saw and bush cutter operation (1970), an early therapy system (1973), improvements of chain saws and bush cutters (1973), and a health care system (1975).

To realize these preventive measurements, the Committee for Occupational Accidents and Disease in the National Forest was established in 1976. S. Yamada was a member of this Committee, and from 1977 until the present, under the auspices of this Committee, the Annual Research Congress of Vibration Syndrome in National Forests has been regularly held. This Congress plays an important role in integrating much information about vibration syndrome patients in the national forests.

[6] The Ministry of Labor organized the Committee of Special Medical Examination for Diagnosis of Vibration Syndrome (Chief: T. Miura) in the private forest industry in 1976. This Committee had a subcommittee (Chief: S. Yamada) for examinations throughout the six areas selected from across Japan. At this Committee's recommendation, the Ministry of Labor ordered the legal introduction of the preventive system for vibration syndrome of the national forest as a model for other industries in 1976. The Ministry of Labor ordered chain saw makers to keep the vibration acceleration level of chain saws below three G by recommendation of the Technological Committee in 1977, and this order accelerated improvements of portable vibratory power tools in Japan. We evaluated the characteristics of improved chain saws and bush cutters before their introduction on the job. In the 1980s, preventive measurements were introduced into many industries, and the prevalence of vibration syndrome decreased gradually.

[7] The mean prevalence of abnormal findings in physical examinations for early diagnosis of vibration hazards was at maximum level (18.4%) in 1976 and decreased to 6.9% in 1985 in all industries using vibrating tools. The number of new cases recognized as resulting from occupational vibration hazards per year in all industries increased from 361 in 1965 to 2,595 in 1978, and then gradually decreased to 941 in 1986, 655 in 1988, and 361 in 1990. The total number of patients under treatment was 13,282 in 1986, 13,301 in 1988, and 11,683 in 1990 in all industries.[13)]

In the national forest industry, which made continual efforts to prevent vibration hazards, the number of workers recognized as suffering from vibration hazards was highest in 1969 at 558 of 12,000 operation workers, decreased to 31 in 1980, and then to only 7 in 1985. Now, there are only a few new cases each year (two cases in 1990).[14)] Our comprehensive prevention system has succeeded after twenty-five years, through the cooperation among researchers, workers, and government. But in private forestry, which has had many difficult problems due to social conditions, the number was highest in 1978 at 1,431 of 50,000 operation workers and decreased to 821 in 1980, 307 in 1985, and 98 in 1990.[13)] In the construction industry, which had 151 new cases in 1990, the improvement of the pneumatic hammer for prevention, as well as work regulation were recommended by the Ministry of Labor.

[8] Ecological conditions

Rapid and large-area cutting of trees has changed the face of nature (trees and animals living in forests, and water and living things in mountain streams) in Japan. Changes in the health of workers suffering from vibration syndrome form a part of these ecological changes. Work regulation of chain saw operation has served to encourage prevention and recovery in the forests as well as in the workers. The period of our prevention of vibration syndrome has corresponded to the period of ecological development in Japan.

[9] In Europe, the development of a prevention system has taken place in various ways in ac-

cordance with each country's conditions. In Czechoslovakia, the "Directives on Health Protection against Adverse Effects of Vibration" were issued by the Chief Hygiene Office in 1967. Combination of the maximum permissible vibration levels with improvements of chain saws, hygienic regulation, and protection against cold and moisture obtained good results in the early stage.[15] In Finland, from 1972 until 1990, the decreased vibration acceleration and the lighter weight of chain saws were considered the main reasons for the decrease in prevalence of vibration-induced symptoms (VWF: from 40% to 5%; numbness at night: from 78% to 28%; muscle weakness: from 19% to 9%).[16] In the USA, in spite of the long history from the days of Alice Hamilton, conditions have not been good, and prevention is still insufficient.[17]

COMPREHENSIVE SYSTEM FOR PREVENTION OF VIBRATION SYNDROME IN NATIONAL FORESTS AND OTHER INDUSTRIES

The comprehensive prevention system used in Japanese national forests consists of the following five systems: 1) health care system: for early diagnosis, early treatment, and consideration of worker aging; 2) work regulation system: restriction of operation time of chain saws and bush cutters with an alternative job system; 3) improvement system of mechanized tools: new design of chain saws and bush cutters and hygienic evaluation before their actual introduction; 4) warming system to protect against cold in the workplace and while commuting; and 5) education and training system: education and training for hygiene and safety.

[1] Health care system

This system is for early diagnosis, early therapy, and consideration of aging. Early examinations are performed twice (autumn and spring) a year. They consist of the following items[6,18–20]: 1) physical examination: peripheral circulation (skin temperature, nail press test, plethysmography, etc.), peripheral nervous function (touch, pain, and vibratory sensation threshold, reflex, radiation of pain, nerve-conduction velocity, etc.), muscular function (grasping and pinch power, tapping facility, stiffness and pain of muscle, electromyogram), skeletal function (pain and limitation in motion of joints, roentgenogram of joints, etc.), and hearing level; 2) subjective symptoms; 3) history of chain saw or bush cutter operation; and 4) differential diagnosis.

If the chain saw operator is more than 55 years of age, he must stop using chain saws. Initial use is not allowed after age 50 as a rule. In 1972, a system of hospital treatment with hot spa therapy was organized in Kyushu by Takamatsu et al. and was soon adopted in other areas. If a worker is recognized as suffering from occupational vibration exposure, he is sent to a hot spa for early therapy, and treatment is controlled by the health care system. This early therapy system has been very effective.

[2] Work regulation system[6]

This system is for regulation of operation time of chain saws and bush cutters in relation to an alternative work system. In the 1960s and 70s, because of the high vibration acceleration level of chain saws and the difficulty of their improvement, there was great need for hygienic regulation of operation time. From the results of physiological study in chain saw operation, and of epidemiological study concerning operation hours and days, the following conditions were established in 1970 at our recommendation: Continuous operation, which involves static muscular strain and decrease of local circulation, was limited to ten minutes. The next ten minutes was for hand work, promoting dynamic muscular movement and circulation. Total operation time (total engine driving time) was limited to two hours a day. Other working hours in the day were for other manual work. After two days' operation, the following day was to be devoted to other hand work. The number of days for operation was limited to 150 days per year.

These conditions, however, made it difficult for forest workers to obtain sufficient income on a piecework rate. Workers had mixed feelings about this control method, but they eventually preferred the control of operation time for the health benefits to the long-time operation for money, thanks to long and hard discussion, education by researchers, and the assistance of the workers' union. They succeeded in stopping seasonal employment five years after the introduction of time restrictions, and the piecework rate was halted five years later.

In 1973, three years after introduction of time restrictions, we evaluated the effects of these restrictions. The prevalence of complaints of the group with and without complete restriction was 28.7% and 51.1%, respectively. Incidence of complaints among workers who began to use chain saws after the introduction of time restrictions was 12.1% and 25.6%, respectively. New patients decreased in number, but in 1974 the number increased again because of the high vibration acceleration level of chain saws and still incomplete time restrictions. The National Forest Agency then decided to enforce complete time restrictions. This enforcement remarkably reduced the number of new vibration syndrome cases. Thus, time restriction played a key role in the early stages of prevention when chain saws had not yet been improved.

In 1977, another control condition was added. Workers more than 55 years old had to stop chain saw use to avoid bone and joint aging. Now, new controls on operation time in terms of the total operation hours over one's lifetime are being considered.

[3] System for improvement of chain saws and bush cutters.[6)]

This system is to encourage both fresh design of chain saws and bush cutters and hygienic evaluation before their introduction on the job. Improvements were made to decrease vibration, sound, and weight. The first design improvement began with the equipping of a new anti-vibration handle in 1965. In 1977, from the viewpoint of isolation from vibration, remote-control chain saws were designed with stands that fasten to the tree trunks for felling. A carrier-mounted, remote-control chain saw for cutting trunks was designed. The amount of tree felling per hour by remote-control chain saws for felling decreased 30%, but vibration exposure also diminished. Some engineers considered this kind of chain saw to be a step backward because of the resulting lower production levels. This view overlooks the hygienic viewpoint, of course. In reality, workers suffering from vibration syndrome can use this type of chain saw without time restrictions and can continue their work, i.e., tree felling in forests. Remote-control chain saws worked well during the period characterized by insufficient chain saw engine balance.

In 1973, rotary engine chain saws were put into practical use at a low vibration level (3.5 m/s^2 rms). This encouraged better engine balance in the engineering of reciprocal engine chain saws. In 1983, opposed two-cylinder reciprocal engine chain saws appeared with the same low vibration level as the rotary engine chain saw. And in the 1980s, bantam chain saws (35 to 40 cc engine displacement) with low vibration were developed for artificial forests. More recently, electric bush cutters with low vibration have been developed. Now, workers can select appropriate chain saws in terms of the tree diameter.

We have sought to evaluate all of these new chain saws and bush cutters from the viewpoint of hygiene for long-term, practical tree felling and limbing in mountain forests. From our test results, we often recommended improvements on newly designed chain saws and bush cutters.

[4] Warming system[6)]

This system is for protection against cold. Cold in the workplace and while commuting plays an important role in the occurrence and advance of vibration syndrome. We investigated the effect of cold and methods of keeping warm on physiological function of workers in chain saw operation and while commuting by motorcycle or bus, from 1965 until 1970. These results showed warming to be very effective in preventing decrease of blood flow, loss of hand work facility, and occurrence of VWF. We recommended that the National Forest Agency introduce warm cottages in working places and commuter buses, encourage workers to keep warm at an atmospheric temperature of less than 10°C, and to travel by bus or car rather than by motorcycle. Fishing or hunting in cold conditions was also to be discouraged.

Keeping the chain saw handle warm is effective in preventing reduction of blood flow in the fingers and in warming the body. We tested and proved its effectiveness, then recommended that chain saws with handle warming be used in the middle and northern areas of Japan. In these areas, 70% of chain saws now have warming handles.

[5] Cooperation

Our principles in prevention have been medical and technological cooperation in research work, and cooperation among specialists, workers, and administrators in practice. We have made a consistent effort based on these principles as the way to assure effective prevention in Japan.

CLINICAL PICTURE OF VIBRATION SYNDROME

[1] Clinical picture

The clinical picture has been well described both in European countries and Japan. Japanese descriptions are similar to the European descriptions for many items, but the evaluation of subjective symptoms is different. Research on vibration syndrome in relation to the autonomic nervous system has been reported in Japan as well as in Finland, Denmark, Sweden, and Italy.[21,22] The characteristics of the clinical picture obtained from observation of many patients in Japan since 1964 may be summarized as follows:

Clinical symptoms reflect disturbances of vascular, neurological, and musculoskeletal components, which develop independently in the early stage. The main symptoms are cold hand, hypersensitivity to cold, Raynaud's phenomenon, numbness and tingling of fingers, loss of finger coordination and dexterity, and difficulty of joint movement. In severe cases, workers suffer from numbness, tingling and pain of upper extremities and joints at night, and sleep disturbance. Numbness and coldness of lower extremities also appear.[23] In some cases, Rynaud's phenomenon in the toes occurs.[24,25] Patients often complain of a heavy feeling in the head, tinnitus, and irritability.[5,75,78] Then they lose manual dexterity, especially in cold conditions. If there is good protection against cold, VWF attacks are infrequent and other disorders are slight in many cases.

The vascular component is controlled by the autonomic nervous system as well as by functional and histological changes in the smooth muscles of blood vessels. If circulation of blood and tissue fluid in perineural and neural tissues is disturbed, neurologic disturbances may increase. Nocturnal pain and tingling of hands and arms may be due to increase of inner pressure from stagnation of tissue fluids at night. Neurologic changes appear alone without blood circulatory disturbances in the early stage. In severe cases these take the form of polyneuropathy of glove and stocking type.[62] Repeated decrease of blood flow for a long time promotes this change. Decreased muscle power of the hand may be due to neurogenic changes of motor nerves.[62] Change in the elbow joint may appear; it is characterized by limited stretching of joints, and is sometimes painful.[27]

[2] Dose-effect relation

In the study of the dose-effect relation between exposure to vibration and the results of examination or clinical symptoms, the indices of exposure are total exposure hours or operation years.[76] In cases with few total vibration exposure hours in a year or with only a slight vibration acceleration level of vibrating tools, it is useful to know the number of years of operation, which involves the number of winters. We analyzed the dose-effect relation between the number of exposure years (or exposure hours) and clinical findings (subjective symptoms and functional changes in vascular, neurological, and musculoskeletal system) in the same age groups, from long-term observation of workers using vibrating tools,[5] with the following results: 1) The dose-effect relation was clear in the 1960s and 1970s. At advanced ages, the relation was more remarkable than at younger ages. But it became obscure with ongoing improvements in vibrating tools and operation time restriction after the 1980s. 2) The relation was clearer in the functional changes of the nervous and musculoskeletal systems (i.e., sensory threshold and muscle power) than in those of the vascular system (i.e., skin temperature and VWF). 3) Subjective symptoms (easily tired, hypersensitivity to cold, heavy-headed feeling, irritability, etc.) had a close relation with VWF, numbness, and years of exposure.

[3] Pathological picture

In the first report by Ashe, the main histologic change was medial muscular hypertrophy.[29] From a recent study of biopsies in 60 fingers of patients, the pathologic picture of finger skin in vibration syndrome has been reported as follows[30]:

The main characteristic changes lie in three tissues: the blood vessels, nerves, and connective tissues. First, muscular layers of the arteries revealed intense thickening with hypertrophy of individual muscle cells without intimal fibrosis. Periarterial fibrosis was also noted. Arteriosclerosis with foamy cells, lipid deposition, and fibrous sclerosis were occasionally observed. The second main feature was demyelinated neuropathy in the peripheral nerves in which a marked loss of nerve fibers had occurred. There was also an increase in the number of Schwann cells and fibroblasts with strong collagen formation. Severe loss of myelin sheath frequently occurred, and relatively smaller axons without myelin, which appeared to have regenerated, were observed. Perineural fibrosis was also noted, forming an onion-layer shape. The third main change was increased connective tissues with collagen, not only in the perivascular and perineural lesions, but especially in the corium of the skin. The elastic fibers there were often destroyed.

The combination of these three principal pathologic changes is useful for the histopathologic diagnosis of vibration syndrome. These changes explain well why the skin temperature is lower even in warm weather and why the skin sensation threshold is higher for a long period in the recovery stage.

[4] Classification of combinations of symptoms and clinical stages.[5]

From long-term observation, we clarified that the vascular component (VWF) and neurologic component (N: numbness and tingling) are excellent indices of the grade of vibration syndrome severity. And combinations of grades of VWF and N serve to establish the stage of vibration syndrome. We divided subjects into five groups in accordance with the grade of VWF (+) or VWF (−) and N (+) or N (−). The categories of combination of VWF and N correspond well to the results of physical examinations and subjective symptoms, as follows:

VWF(−)N(−): After beginning operation of vibrating tools, many workers do not complain of any symptoms for a few months or years.

VWF(−)N(+): In the course of vibration syndrome development, numbness and tingling are the first subjective signs of vibration syndrome. Peripheral sensation, especially vibratory and tactile sensation, is affected. These neurologic changes appear in the form of polyneuropathy. Peripheral circulation disorder follows and skin temperature decreases gradually, but VWF does not appear at this stage.

VWF(+)N(−): In this category, peripheral circulation disorder becomes severe, but nervous disturbances are slight or none. Coldness of hand becomes evident. VWF occurs early in this stage in some cases and late in others. This is due to a difference in sensitivity to vibration and cold. The presence of VWF plays an important role in the progress of vibration syndrome.

VWF(+)N(+): In the fourth category, disorders of peripheral sensation and circulation become severe and sensitivity to cold is remarkable. Numbness and tingling appear at night and sleep is disturbed. Disorder of muscle function appears. Fine finger movements become difficult. In some cases, muscle power decreases. Some cases complain of heavy-headed feeling and irritability.

VWF(++)N(++): In the fifth category, the frequency of VWF attack and the number of fingers with VWF increase. VWF appears even in summer. Coldness and polyneuropathy appear in the lower extremities. In some cases, Raynaud's phenomenon appears in toes. Hypersensitivity to cold, sleep disturbance, heavy feeling in the head, and tinnitus become severe. Hyper-perspiration of palm appears. Muscle power decreases. Difficulty of finger movements at work and in cold conditions increases.

The clinical stages nearly correspond to these above categories.

In Europe, Taylor and Pelmear's Classification of Stage of vibration syndrome appeared in 1968, and the Stockholm Classification revised the Taylor-Pelmear Classification in 1986. The former took notice of the "Condition of Digits" (VWF, numbness and tingling) and "Work and Social Interference." The latter separated the vascular and neurologic components of Taylor and Pelmear's Classification "Condition of Digits" and described "The Classifications of Cold-Induced Raynaud's Phenomenon" and "Classification of Sensorineural Affects." "Work and Social Interference" was deleted.[23] Our description is characteristic in its combination of the grade of VWF and numbness and tingling.

Recovery Process: In the recovery course after stopping vibration exposure, the frequency of attacks of Raynaud's phenomenon decreased gradually, especially in patients who kept their body warm in daily life and work. But, in severe cases, recovery of skin temperature in cold conditions, peripheral sensation, and numbness of hand and arm was very slow.[31,32] In the cases with irreversible severe histologic changes of peripheral tissues, recovery has been impossible, especially in those in the category VWF(++)N(++).[5]

PATHOPHYSIOLOGY AND AUTONOMIC NERVOUS SYSTEM

The vibration effects on health from the use of vibratory tools may be divided into two types. The first is the direct effect of vibration upon the peripheral tissues exerted by conductance of the vibration. The second is the effect exerted through the nervous system by the impulse generated from a peripheral neuroreceptor under vibration stimulus.[23] Certain factors in tool usage (weight, drive noise, and cold) reinforce both of these effects.

An ongoing, significant theme at present with regard to the etiology of vibration syndrome is whether or not the second effect has an influence on the function of the sympathetic nervous system. Research on the postsynaptic effects has made it clear that the direct effect of vibration on blood vessel walls serves to enhance the noradrenaline (NA) reactivity in the peripheral vessel smooth muscle.[34]

The key focus in study on the presynaptic effect is confirmation of the existence of the influence mediated by the sympathetic nerve centers.

[Effects of acute vibration exposure in non-exposed location]

Temporary threshold shift of hearing (TTS) is cuased by noise exposure. In experimental study on the combined effect of noise and vibration, it has been suggested that noise may play a part in inducing changes in the peripheral circulation after local exposure to vibration, and that hand-arm vibration affects the temporary threshold shift additively with noise. This suggests the role of the autonomic nervous system in these results.[35,36]

The sympathetic nervous system regulates skin perspiration and skin vessel constriction. We investigated physiologically the perspiration, skin temperature, and skin nerve sympathetic activity (SSA) in non-exposed locations when vibration was loaded on one hand. In our first experiment, a vibration load to one hand resulted in the decrease of skin temperature in the fingers of the contralateral hand and toes.[37] In the second experiment, the combined effect of vibration loading to one hand and noise, promoted palmar perspiration in both locations.[38] In the third experiment, an increase of SSA in the lower extremities, a concomitant decrease in skin blood flow, and an increase of perspiration were noted.[39]

Findings by other researchers: A plethysmographic study found that fluctuation of the pulsation volume in the fingertip was closely connected to that in the toes.[40] Upper and lower extremity SSA was demonstrated to increase concurrently in a cold environment.[41] A vibration load to one hand resulted in an increase in the skin sympathetic activity (SSA) in the contralateral hand.[42]

On the basis of this line of study and after a reading of the relevant literature, we confirmed that the exposure of one hand to vibration physiologically causes the tonus of the sympathetic nerves in the contralateral hand and foot and the sympathetic nervous system centers to play a role in these reactions.

When these physiologic reactions are repeated over a long period, do they result in the pathophysiologic findings of vibration syndrome in relation to the sympathetic nervous system center?

[Effects of chronic vibration exposure]

To answer the above question, peripheral circulation and Raynaud's phenomenon in vibration syndrome patients have been investigated by many researchers, with the following results:

1) The occurrences of VWF were found to be controlled by local vascular factors and central nervous factors.[43–48]

2) Hearing loss and VWF: From the fact that the hearing level in the high frequency range of sound in vibration syndrome patients with VWF is higher than in those without VWF, it was assumed that the combined influence of tool noise and tool vibration played a contributory role in the sympathetic vasoconstriction of auditory tissue.[50–52]

3) Cardiovascular response: From the studies of the R-R interval variation in electrocardiograms taken during deep breathing, a noticeable reduction in heart rate variation was indicated that suggested a depressive effect on parasympathetic activity, which was accompanied by an increase in the activity of the sytmpathetic component.[53,54,64] The effect of exposure to cold on the level of sympathetic activity, as assessed by measurements of systolic time interval, was studied. The left ventricular ejection time index was found to be shorter in the vibration-exposed workers with and without Raynaud's phenomenon than in the controls, both at rest and during cold exposure and recovery. This suggested that "excessive sympathetic reflex activity plays a dominant role in the pathogenesis of VWF.[56]

In digital plethysmography, healthy workers showed rapid recovery from decrease in the amplitude of the pulse wave by auditory stimuli. But patients with vibration disease showed delayed recovery, and this delay had a positive correlation with the left ventricular ejection fraction, which was significantly higher in patients than in controls. Research in this area suggested an autonomic nervous dysfunction.[47,48]

4) Postural response: The relative capillary blood flow rate in the skin of the finger was measured by the local ^{133}Xenon washout technique during three different postural stimuli before, during, and after vibration of hands. Three postures — 1) elevation of finger 20 cm, 2) lowering of finger 40 cm, and 3) changing the body posture from supine to sitting upright — re-

flect, respectively, 1) vasomuscular, non-neurogenic autoregulation, 2) local veno-arteriolar vasoconstrictor axon reflex, and 3) central sympathetic vasoconstrictor reflex. In patients with Raynaud's phenomenon, the central sympathetic vasoconstrictor reflex was significantly increased.[59,60]

5) Polyneuropathy and coldness of lower extremities: Peripheral nervous system disturbances indicate polyneuropathy. Polyneuropathy is observed in lower extremities in severe cases as well as in upper extremities, and the findings are suggested to be due to ischemic effect through the sympathetic vasoconstriction reflex.[53,62,63]

Vibration syndrome patients with a great frequency of VWF manifestation often complained of coldness in hands and feet.[23] Their blood flow to the upper and lower extremities decreased at normal temperatures. And skin temperature of the fingers and toes dropped; this decrease in temperature was reinforced under cold loading.[65,66]

Close observations have recently been made of Raynaud's phenomenon in the toes of vibration syndrome patients without complications.[24,25]

6) Chills and VWF: Vibration syndrome patients feel chills in their body sooner than the controls, in cold conditions.[68] Their complaint of hypersensitivity to cold has a close relation with the number of vibration exposure years.[5,77] When they ride a motor bicycle on a road in cold conditions, their finger skin temperatures fall to the same level when wearing either light or heavy clothing. But the VWF occurs only when wearing light clothing and feeling chills.[69] Lowering of skin temperature and chills throughout the body are both fundamental conditions of VWF.[68]

In the recovery process of vibration syndrome after stopping vibration exposure, the warm feelings of body and hands gradually return, and the frequency of VWF attacks decreases over a long time.[5,31] If there is good protection against cold, these recover even sooner. These facts suggest that hypervasoconstriction and hypersensitivity to cold in vibration syndrome may be due to the repeated, combined effect of vibration exposure and cold over a long time. In the recovery process, this combined effect diminishes and hypersensitivity gradually decreases. Thus, autonomic nervous function may be involved. More study is necessary to clarify the role of the autonomic nervous system in these conditions.

7) Noradrenaline (NA) concentration level in plasma under cold conditions: The few studies on the subject to date indicate that the urine adrenaline and plasma NA are higher in vibration syndrome patients,[71,72] that plasma NA definitely rises during cold exposure,[56] and that the high NA concentration in vibration syndrome cases can be brought down by spa therapy.[74]

To obtain a direct perspective on the sympathetic nervous system, we examined the occurrence of chills and change of NA concentration in plasma during whole-body cooling at a room temperature of 7°C.[75]

At 25°C there was no obvious mean difference among patients with and without VWF and the control groups in terms of NA level and finger skin temperature, and no one felt the cold. By cooling, an increase in the NA level caused a decrease in the finger skin temperature. The rate of NA increase was considerable. This tendency was marked in the vibration-exposed groups, especially in those with VWF. The NA increase was especially great in those who experienced severe body chills. This study shows that patients with VWF tend to have higher sympathetic nervous system tonus in cold environments and this relates to their hypersensitivity to cold. Changes in the levels of plasma cyclic AMP, cyclic GMP, and thyroid hormones after whole-body cooling were measured and their significance was discussed in relation to the autonomic nervous system.[54]

6) Subjective symptoms: Japanese researchers reported subjective symptoms, involving headache or heavy feeling in the head, irritability, etc.[11,75,78]

In Europe, researchers have taken little notice of such subjective symptoms in their surveys of vibration-exposed workers. Some researchers discussed such findings in the Japanese research in relation to the Soviet theory,[22] which involves diencephalic syndromes. But these subjective symptoms were analyzed on the basis of the exact observations and inquiries by physicians, and were not conducted by Soviet theory. Lately, these symptoms have also been analyzed in new surveys in relation to total operating time in the same-age groups,[76,77] and to the severity of VWF and numbness in the same-age and operation-years groups.[5] More study is necessary to determine why longterm vibration exposure causes these subjective symptoms in vibration syndrome patients.

CONCLUSION

Our research and efforts resulted in a comprehensive system for prevention of vibration syndrome in the Japanese national forest industry. This system has presented a good model of prevention for other industries in Japan.

Clinical and pathophysiologic research on vibration syndrome in the 1960s and 1970s clarified disturbances of the peripheral circulatory, nervous, and musculoskeletal systems. From the mid-1970s, neuro-physiologic, neurochemical, and clinical research on vibration syndrome in relation to the autonomic nervous system developed. Our studies contributed to the advancement of research in this field; however, more in-depth study is needed to determine the role of the autonomic nervous system in vibration syndrome.

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