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Proceedings of an International Symposium on Vibration White Finger Disease

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PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM ON VIBRATION WHITE FINGER DISEASE

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The Etiology, Epidemiology and Symptomatology of Vibration-Induced White Finger (VWF)

by W. Taylor

1. introduction

By the end of the nineteenth century the association between intermittent attacks of white finger induced by exposure to cold and the use of hand-held vibratory tools was recognized. Pneumatic tools were used in French mines as early as 1839 and in the limestone mines of Indiana around 1890 to 1900. Loriga (1911)[1] first described "vascular spasm" in the hands of miners. In 1918, Cottingham[2] and Hamilton[3] described "spastic anaemia" of the hands of limestone miners. During the next 50 years in other industrial processes using vibratory tools outbreaks of white finger were reported — in fettling, in grinding and polishing with electrically-driven motors, and in forestry from the use of chain saws. The white finger attacks, always induced by exposure to cold, were described by Agate in 1949 as "Raynaud's Phenomenon of Occupational Origin". Colloquial terms such as "dead hand" or "white finger" were abandoned in favour of the descriptive term; "Vibration-Induced White Finger" or VWF. In 1970 a further change was made in nomenclature by the Industrial Injuries Advisory Council (Interim Report). They named the complex of symptoms associated with vibratory tools "The Vibration Syndrome", recognizing additional effects associated with the use of hand-held vibratory tools — sensory changes (damage to nerves), and bone, joint and muscle damage. It is now recognized that the intermittent pallor attacks, precipitated by exposure to cold, are the result of damage to the circulatory system of the fingers but that the sensory nerve system may also be affected by vibration either independently or in conjunction with the arterial system.

Intermittent blanching attacks of the fingers occurs in the community but is not associated with any industrial processes. The condition was recognized by Dr. Maurice Raynaud in 1862 and named **"Raynaud's Disease".** The distinguishing features are familial predisposition (up to 5-8% incidence in the population), higher incidence in females than males *(5* to 1), early onset (by the age of 30), bi-lateral distribution, cold feet in association with cold hands, and the absence of any pre-disposing disease or trauma. Primary Raynaud's Disease cases will appear therefore in industrial populations and must be distinguished from Secondary Raynaud's Phenomenon. Furthermore there are many causes of Secondary Raynaud's Phenomenon in addition to vibration and these require elimination in any VWF survey. These are trauma (lacerations and fractures), occlusive vascular disease (arterio-sclerosis, thrombosis, embolism), neurogenic lesions (poliomyelitis, hemiplegia), connective tissue disorders (scleroderma, frost-bite) and toxic agents (ergot, nicotine, acro-osteolysis). All the above medical conditions interfere with blood flow in the fingers which often occurs slowly and gradually in a similar manner to vibration.

2. Signs, Symptoms **and** Aetiology

Following exposure to vibration, the first symptoms noted by the subject are tingling and numbness of the fingers, particularly at night. Subsequently, after a variable time period dependent on the dose of vibration received (and the susceptibility of the subject), blanching of a finger tip is seen following exposure to cold or touching cold objects. The time period between first commencing work with the vibratory tool and the appearance of the first finger tip is known as the "Latent Interval". It is an indication of the vibration intensity or level — the shorter the Latent Interval, the higher the vibration level and the more hazardous the working process. During the blanching attack the affected finger is numb and in severe cases where the blanching has extended from the finger tip to the root of the finger and subsequently to all fingers on both hands, there is persistent numbness, reduced sensitivity and inability to do fine work between attacks as well as during attacks. A common story is the occurrence of attacks either handling cold objects or immersion in water. The attacks are more numerous in damp, windy conditions (chill factor) particularly in the early morning and in the evening when the subject's metabolic activity is at its lowest. A reduced body core temperature aggravates the condition. Attacks are more common in winter than in summer but eventually they will occur all year round. The blanching does not usually occur at work (except during rest periods) but in some subjects the vibration stimulus will induce blanching if the fingers are cold or if the environmental temperature is low. During attacks it is not possible to continue working especially chain saw activities. In very severe cases the thumbs are involved in the blanching process. The palms of the hands are rarely affected.

These symptoms and signs are in response to pathological and physiological changes in the tissues of the fingers. Kadlec and Pelnar[4] in 1945, on the basis of their plethysmographic studies, disagreed with the then accepted view that VWF was solely a disease of the capillaries[5] and provided evidence of the crucial role of the finger arteries. They attributed hyperactivity to the muscular layer of the arterial wall, the hypertrophy of which was later documented by Ashe[6] from biopsy and autopsy specimens. They described two stages of VWF – the first reversible, and due to exagggerated spasm and its failure to resolve into vasolidation under cold. The second, an irreversible stage, demonstrated plethysmographically to be a permanent, anatomical obstruction of the fingers' arteries.

The developmental process of VWF is not entirely clear, and several hypothesis have been proposed. It is suggested that the first response to vibration is a relaxation of the small blood vessels and an increase in permeability of the vessel wall with a resulting accumulation of exudate. Hence the odema and nerve end irritation expressed as tingling. Later, hypertertrophy of the muscle layer of the blood vessels occurs, with consequent hypersusceptibility to contraction when stimulated by cold. Eventually the lumen of the blood vessel is reduced due to the muscle hypertrophy and from secondary thrombosis consequent upon a sluggish blood flow. In well established cases, fibrotic changes occur within the hyperthrophic muscle and the intima, and this may account for the prolonged spasm with delayed relaxation on re-exposure *to* warmth which is a typical feature in such cases, as stressed by Magos et al [7]. These pathological findings, including round cell infiltration of the nerve endings, (Pacincian corpuscles) have been noted by several authors (6, 8, 9). Ultimately, with complete obliteration of blood vessels, trophic or gangrenous changes may occur at the fingertips (9, 10, 11, 12). There are many reports of bone cyst formation (13, 14, 15) but this is a common finding in manual workers and, in the series of studies by James et al [16], there was **no** statistical difference between the exposed and manual worker controls.

The symptoms and signs and the frequency of attacks may be such that eventually the subject, apart from taking immediate preventive action to keep warm and avoid cold exposure, has to curtail his activities. Socially this may mean avoiding outdoor pursuits such as gardening, fishing, swimming and watching outdoor entertainment, and ultimately it may involve a change of work to avoid further vibration exposure.

A grading index by Stage of symptoms and social/work interference has been devised by Taylor (Table I) and used to advantage by Taylor and Pelmear (17).

If the subject is young, with VWF severity no greater than Stage 2 he may completely recover if he avoids further vibration exposure. If he is subjected to further vibration he will progressively deteriorate. Older subjects, and those with severe Stage 3, on discontinuing vibration exposure, tend to remain the same, while some 50% continue to deteriorate. Treatment other than avoidance of exposure has been disappointing and therefore prevention is all important.

3. Vibration and its Measurement

The development of VWF depends on the dose of vibration and the susceptibility of the subject. The dose is a factor of time and vibration level expressed as acceleration in m/sec^2 at a given frequency.

Vibration may be measured by displacement, velocity (rate of change of displacement) or acceleration (rate of change of velocity). All are interdependent. The accepted agreed unit is acceleration but frequently the decibel scale is used.

Energy absorption is maximum at the resonant frequency of the object or tissue, and increases as the opposing force is applied, e.g. hand grip. The resonant frequency of the hand is around 30-40 Hz, the fingers 115 Hz, and the lower frequency range 30-300 Hz is considered to be the most hazardous in the production of VWF.

The International Organization for Standardization (ISO) Draft proposal for a standard ISO/TC 108/SC4 N 122 January, 1982, specifies general methods for measuring and reporting hand-transmitted vibration exposure in three orthogonal axes for 113 octave bands 6,3 - 1250 Hz, octave bands 8-1000 Hz, and a weighted measure which covers the frequency range 5-1500 Hz. The primary quantity to be measured is acceleration in the X, Y and Z axes of the hand. **A** four hour energy equivalent acceleration dose-effect relationship is provided for guidance for the assessment of exposures of different durations, and a threshold limit value corresponding to a time-weighted acceleration level of 2.9 m/sec^2 is suggested.

4. Prevention

The important steps to be taken in prevention are:

(a) Identification of VWF hazard by vibration measurement.

(b) Complete avoidance of exposure (if possible) by use of alternative work methods.

(c) Use of anti-vibration isolators on all hand-held vibratory tools.

TABLE 1

Stages of VWF

Stage	Condition of Digits	Work and Social Interference
0	No blanching of digits	No complaints
0_T	Intermittent tingling	No interference with activities
0_N	Intermittent numbness	No interference with activities
1	Blanching of one or more finger tips with or without tingling and numbness	No interference with activities
2	Blanching of one or more fingers with numbness. Usually confined to winter	Slight interference with home and social activities. No interference at work
3	Extensive blanching. Frequent episodes summer as well as winter	Definite interference at work, at home and with social activities. Restriction of hobbies
4	Extensive blanching. Most fingers; frequent episodes summer and winter	Occupation changed to avoid further vibration exposure because of severity of symptoms and signs

(d) Work rotation to limit exposure. Introduction of rest periods, e.g. 10 minutes every hour.

(e) Medical surveillance, i.e. pre-employment and periodic medical examinations.

(f) Transfer of subjects affected at an agreed Stage.

5. Conclusion

VWF is an occupational disease which requires recognition by physicians. It can be prevented. The incidence of VWF at work can only be ascertained by direct enquiry, because many workers do not complain of their symptoms and signs. They have not associated cause and effect. White finger is often associated with deteriorating blood circulation and not with vibration

Vibration White Finger has not yet been designated as a Prescribed Disease in the U.K., although the Industrial Injuries Advisory Committee has been considering this issue since 1954. In September, 1981, the latest Report (18) recommended that VWF be now added to the Prescribed Schedule. The Province of Ontario also has not yet recognized vibration as a hazardous physical agent. Therefore the onus is on occupational health services and health and safety committees to undertake enquiry and corrective action. Tool and equipment manufacturers must limit or isolate vibration from the user. There has been some progress, for example with chain saws, but much remains to be done in the area of pneumatic tools.

Prevalence of Vibration White Finger Disease (VWFD) in British Columbia Coastal Fallers

by R.L. Brubaker

The prevalence of VWFD was determined among 146 out of 147 available fallers in 7 lumber camps representing 5 major companies on Vancouver and the Queen Charlotte Islands. There are approximately 1500 coastal fallers employed in the coastal area of British Columbia. This was the first survey of VWFD to be conducted in Western Canada. Precipitation in the geographical area of the survey is very heavy (250-350 cm annually) and climate in the winter is somewhat mild (mean daily January temperature is 0" - 5°). Fallers generally operate chain saws weighing over 10 kg, 3-4 hours daily for 10 months of the year. 122 control workers not operating chain saws were included inthe survey from the same lumber camps as the fallers and 20 government employees from the Holberg Canadian Forces Base also participated. A detailed occupational and medical questionnaire including smoking and drinking history was professionally administered to all subjects. Sub-group categories were established to exclude fallers with a work history of hand-arm vibration other than the chain saw and controls with an extensive work history of all forms of exposure to hand-arm vibration, In addition, exclusions were also made for a medical history of contributing causes other than hand-arm injury which was excessive in both groups (fallers, 84%; controls, 78%). VWFD was assessed subjectively from the questionnaire according to the following criteria:

The prevalence of VWFD among the faller sub-group (n = 89) was 45% and 2% among the control sub-group (n = 85). The prevalence rates for the total groups before exclusions did not differ significantly from the sub-group. Approximately *25%* of the sub-group fallers were classified as Stage 3. The latency period for developing the first white finger tip after beginning full-time use of the chain saw was 8.6 years (SD 6.5). There was a significant positive correlation comparing individual years of saw exposure among sub-group fallers and the presence of disease. There was objective evidence of disease (suppression of cold water induced reactive hyperemia) in 31 out of 43 of the sub-group fallers (72%) with subjective symptoms, and in 13 out of 24 of the sub-group controls (18%) without symptoms. 18% of the sub-group controls without symptoms had a positive objective test (delayed rewarming in at least 1 finger). There was no association between VWFD and smoking history. There was a tendency for VWFD to be less prevalent among those fallers consuming alcoholic beverages on a routine basis.

Funded by a grant from the Workers Compensation Board of British Columbia with additional financial support from the International Woodworkers of America Details of the above study to be published separately reprints will be available upon request

Stage	Condition of Digits	Work and Social Interference
0	No symptoms	No interference
1	Blanching of one or more fingertips	No interference
2	Blanching of one or more complete fingers usually in winter months only	Interference with activities
3	Blanching in at least four complete fingers with attacks throughout the year	Interference and restriction of activities

Differential Diagnosis: Raynaud's Phenomenon

by P.L. Pelmear

1. Connective Tissue Diseases

A) SCLERODERMA

Scleroderma is characterized by deposition of fibrous connective tissue in the skin and other organ systems. Scleroderma may be accompanied by vascular lesions, especially in the skin, lungs and kidneys.

Skin

Early in the disease the skin is thickened with a diffuse non-pitting edema of mild degree. This change is often followed by a progression to atrophic skin with a concomitant loss of skin appendages, i.e., hair, sebaceous glands and sweat glands. The skin loses its pliability and appears hide-bound — tightly drawn and bound to underlying structures. This skin tightness may limit mobility, expecially in the fingers which may also develop flexion contractures. Accompanying skin abnormalities include:

a) **Telangiectasias:** red flat areas from one to several millimeters in diameter. Most prominent on the face, hands, and oral mucosa.

b) **Calcinosis:** the deposition of hydroxyapatite crystals in subcutaneous areas. They may be limited or widespread; usually located around joint capsules. They may be accompanied by skin ulceration.

c) **Melanotic pigmentation and areas of Vitiligo.**

d) **Raynaud's Phenomenon.**

The sclerodermatos skin involvement is often most prominent in the hands and fingers (sclerodactyly) but frequently the face is also involved Tightening of the facial skin results in decreased skin lines, a pursed appearance and diminution in size of the mouth In many patients, the cutaneous involvement may be more diffuse, with induration of skin throughout the body

Muscular Skeletal System

A mild inflammatory arthritis, usually symmetric in distribution and resembling a mild form of rheumatoid arthritis may occur.

Gastro-Intestinal Tract

Many areas of the alimentary tract may be involved in scleroderma. Dryness of the oral mucosa and excessive dental cavities is not uncommon. The lower two-thirds of the esophagus frequently exhibits hypomotility. In advanced stages this sometimes causes dysphagia owing to the absence of a coordinated paristaltic wave. In addition the integrity of the lower esophagial sphincter may be lost leading to gastric reflux and peptic esophagitis. These effects may be complicated by haemorrhage, stricture or both.

Hypomotility, atony and dilatation may also involve the small intestine. Atrophy and fibrous replacement of the muscularis of the large intestine results in wide mouth diverticula or sacculations.

Lungs

A high incidence of pulmonary hypertension is associated with scleroderma. Intimal fibrosis occurs in the walls of the pulmonary arteries, and there is diffuse interstitial pulmonary fibrosis. These changes may progress to pulmonary insufficiency and cor-pulmonale. The pulmonary manifestations are usually chronic.

Heart

The classic scleroderma heart is characterized by extensive replacement of the cardiace muscle with fibrous tissue leading to arrhythmias, conduction disturbances and congestive heart failure.

Kidney

Chronic mild proteinuria and mild hypertension are common effects of scleroderma. The most significant renal complication is malignant hypertension.

B) SYSTEMIC LUPUS ERYTHEMATOSIS (SLE)

SLE shows great variability in its clinical manifestations, its mode of presentation and its course. This chronic multi-systemic inflammatory disease ranges in severity from a benign illness to a fatal one. Although no curative therapy is available, medical measures frequently ameliorate its course.

The incidence of SLE is not known with any certainty. Ninety percent of SLE occurs in females; black females are affected more frequently than white females. The first symptoms most commonly appear between 15 and 25 years of age.

C) MIXED CONNECTIVE TISSUE DISEASE

A class of patients have been described who exhibit clinical features suggesting several of the rheumatic diseases, yet such patients do not easily fit into the diagnostic categories discussed above. Patients in this group have features suggestive of systemic lupus, scleroderma, and polymyositis, justifying a separate category of rheumatic disease, mixed connective tissue disease (MCTD). These patients also possess high titers of antibodies to extractable nuclear antigens, differentiating them from patients with other rheumatic diseases. The clinical features are diverse.

D) POLYARTERITIS NODOSA

Polyarteritis Nodosa is a multi-system disease characterized by acute inflammation and fibrinoid necrosis of medium and small arteries. Although of unknown etiology pathogenic associations of polyarteritis nodosa include hepatitis-B antigenaemia, serum sickness, allergic reactions to drugs and other toxins, and amphetamine abuse.

E) DERMATOMYOSITIS/POLYMYOSITIS

The etiology of polymyositis, a disease that primarily affects skeletal muscle, has not been established. Although it is a potentially serious disorder, the majority of affected patients respond to therapy. In dermatomyositis, a common form of the disease, skin eruptions accompany the myopathy. Polymyositis may be linked with other rheumatic diseases and with malignancy. It is twice as common in females as in males.

F) RHEUMATOID ARTHRITIS

Rheumatoid Arthritis is a chronic flammatory disorder that is systemic in nature but is characterized by the manner in which it involves joints. Its onset is usually in the third or fourth decades but it may occur at any age. Many joints, particularly those of the extremities, are usually affected at the same time, often in a symmetric fashion. The course of rheumatoid arthritis is variable, commonly involving remissions and exacerbations, and the spectrum of clinical manifestations is broadranging from barely recognizable forms to debilitating and mutilating ones. To diagnose the disorder, other causes of chronic arthritis should be excluded. This is usually not difficult if the clinical condition is viewed over a period of time. Rheumatoid arthritis has no specific biologic marker; although rheumatoid factor is present in the serum of most affected individuals, there are some patients with typical disease who are persistently seronegative. Diagnosis is primarily dependent on observation of the patient and fulfillment of a sufficient number of established criteria. One percent of the adult population is probably affected and females predominate, usually by a margin of about three to one.

2. Occlusive Vascular Disease

A) ACUTE

Acute arterial occlusion of the extremities may be separated into three principal categories: embolism that originates in the heart; embolism that originates in an atheromatous lesion in the abdominal aorta or ileo-femoral artery; and acute thrombosis. Emboli that originate in the heart are found most frequently in two particular classes of patients. The first consists of patients who have coronary artery disease with a history of old or recent myocardial infarction and mural thrombi in the left ventricle. The second is composed of patients who have rheumatic mitral valvular disease with mural thrombi in the enlarged, usually fibrillating left atrium. Thrombi on prosthetic heart valves, left ventricular mural thrombi present in congestive cardio-myopathy, vegetations of infective endocarditis, and left atrial myxomas are other important sources of emboli in the peripheral arteries.

B) CHRONIC

Chronic arterial occlusion in the extremities is nearly always arterio-sclerotic in nature. About half of the patients with symptomatic chronic occlusive disease of the extremities have clinically evident coronary or cerebral arterio-sclerotic disease as well.

3. Dysglobulinaemia

The blood's viscosity is related to the concentration of abnormal protein such as in IgG Myeloma and this may produce a Raynaud's phenomenon as may cryoglobulins where the pathogenetic mechanisms relate to systemic immune complex deposition.

4. Neurogenic

Such conditions as poliomyelitis, syringomyelia and hemiplegias are various mechanisms which may also produce Raynaud's phenomenon.

5. Vinyl Chloride Intoxication

Vinyl Chloride is an increasingly important compound in industry and cases of Raynaud's phenomenon caused by the polymerization process have been described.

6. Obstructive and Traumatic Cases

A variety of physical abnormalities have been recognized which constrict or compress the brachial plexus, the subclavian artery or vein. This is generally considered under the title Thoracic Outlet Syndrome.

Objective Tests for the Vibration White Finger

by P V. Pelnar

Attacks of Raynaud Phenomenon of the Vibration White Finger (VWF) typically occur in response to exposure to cold, particularly when larger parts of the body are exposed. Thus they are almost never observed in the doctor's office, neither spontaneous or provoked by various cooling procedures. Yet a positive objective diagnosis is important for clinical evaluation of individual cases, for epidemiological studies, and it is indispensable for dealing with disability claims with all their social and legal consequences. It is therefore most desirable to find ways to demonstrate the existence of VWF by objective clinical tests.

As the symptomatology of VWF belongs to three main categories of systems: the vascular system, the neuromuscular system and the bone-joint system, the objective tests explored and used are vascular, neurological and radiological.

1. Vascular Tests

PLETHYSMOGRAPHY

Finger-plethysmography was introduced into the study of vibration disease by K Kadleç and P V Pelnar in 1944 and has been a useful tool since It records and measures the "pulse-wave'' representing changes of volume of a finger, which normally occur with every pulse of the finger arteries When there is complete arterial obstruction, either anatomical or caused by a spasm, there is no pulse, no volume changes and no pulse-wave on the plethysmogram In lesser degrees of obstruction, various modifications of the pulse-wave can be observed

The Kadlec-Pelnar technique of **finger-plethsmography** in **three trials and tracings** helps not only to discover the **presence** of an arterial obstruction, but also to study its **nature** and its probable **site of origin.** The first tracing is obtained under normal conditions at room temperature. The second tracing is obtained with the contralateral hand submerged in cold water (approximately 10°C), and the third tracing immediately following cooling of the examined hand.

A definite pattern is seen in the varying stages of Vibration White Finger Disease. Another practical indirect method of measuring blood supply is to measure the skin temperature of the fingers under various thermal conditions. Sophisticated electronic instrumentation such as thermocouples or infra-red thermography are two types of techniques used to measure these skin temperatures.

A very simple test of peripheral vascular disease is to measure the time needed for return to normal colour to the nailbed after compression for five seconds. In Vibration White Finger Disease the time for returning to normal colour is usually two to three times the normal reaction.

Arteriography of the arteries of the hands and fingers has been performed in a limited number of persons but ethical considerations as well as expense made this an unacceptable test.

2. Neurological Tests

Neurological symptoms are often present in vibration exposed workers but linking the symptoms to VWF is seriously complicated by the fact that work with vibration is invariably heavy, muscular work engaging large masses of muscles, most joints and ligaments. Impairment of the peripheral neurone can be caused by other disease processes apart from vibration as well as by toxic influences such as tobacco, alcohol and drugs.

The most frequently reported symptom is numbness and loss of sensitivity and the test used for this is two point discrimination. More complex, subjective testing can be carried out with electromyography and nerve conduction measurement. Mobile equipment is available for non-invasive measurements by means of skin-electrodes. Clinical neurological assessment can be made but standardization of this is extremely difficult.

3. Radiological Examination

Radiology of the hands in persons with vibration disease will reveal small, largely symptomless bone cysts. However, these have been found in considerable numbers of control subjects and in both cases and controls the cysts can be combined with Osteoporosis,

In summary, for an objective test of Vibration White Finger the most consistent is doubtless the finger-plethysmography The neurological and radiological examinations are also useful in assessment of possible disability of a person with Vibration White Finger Disease

The Role and Function of the Vascular Diagnostic Laboratory

by P.D. Fry

Vibration White Finger Syndrome is a variant of Raynaud's Phenomenon and is essentially investigated along the same lines.

Unfortunately, the industrially exposed individual who is most likely to present with this syndrome usually falls into the age and area where other common denominators such as smoking, trauma, arthritis, etc., may also produce the same classical Raynaud's appearance so that the differential diagnosis becomes extremely important in isolating Raynaud's due to vibration injuries.

The discussion will center around the following areas:

1. The importance of good history taking and physical examination.

2. The mechanism of thoracic outlet syndrome and the production of Raynaud's Phenomenon.

3. The role of the Non-Invasive Diagnostic Vascular Laboratory at the Vancouver General Hospital and both the assessment of these patients and the investigation of patients with neurological or vascular disease.

4. Specifically the cold water immersion test in reproducing the classical syndrome of vibration white finger.

Hand-Arm Vibration Measurements

by Gunnar Rasmussen

The measurement of Hand-Arm Vibration presents some special problems both regarding instrumentation and transducer technique.

Basically 113 octave or 1/1 octave filtered signal levels are quoted. However it is also common practice to use overall weighting filters for single number readings.

The overall weighting method has become the primary method of quoting hand-arm vibration levels for regulatory purposes, industrial hygiene applications and single number readings for labelling of hand tools. (See fig. 1)

The 1/3 octave analysis method is still to be preferred for gathering data in research and practical engineering hand-arm vibration control work. The most common error in quoting 113 or 1/1 octave levels is introduced using results obtained from FFT analyzers. Harmonic signals or well defined random noise may very well be treated by the calculation of a block sample with good approximation to the continuous sampling technique, and the measurement of one single transient like a hammer blow is also well suited for FFT calculation. But series of transients or time varying signals like those most often dealt with on percussive tools – chain saws – pedestal grinders etc. are very difficult to assess without error even using averaging over many samples. Errors in the power spectrum at high frequencies may easily be introduced through limited block sample length.

Gathering data in the field for research purposes is most conveniently carried out using portable instrumentation with instrumentation tape recorders for subsequent laboratory examination. (See fig. 2)

The introduction of errors due to the very high acceleration levels experienced in idling percussive tools may cause transducer problems like zero-shift or breakdown. These errors may be eliminated using proper transducer adaptation techniques.

On transducer application the following is quoted from the draft proposal ISO/DIS 5349:

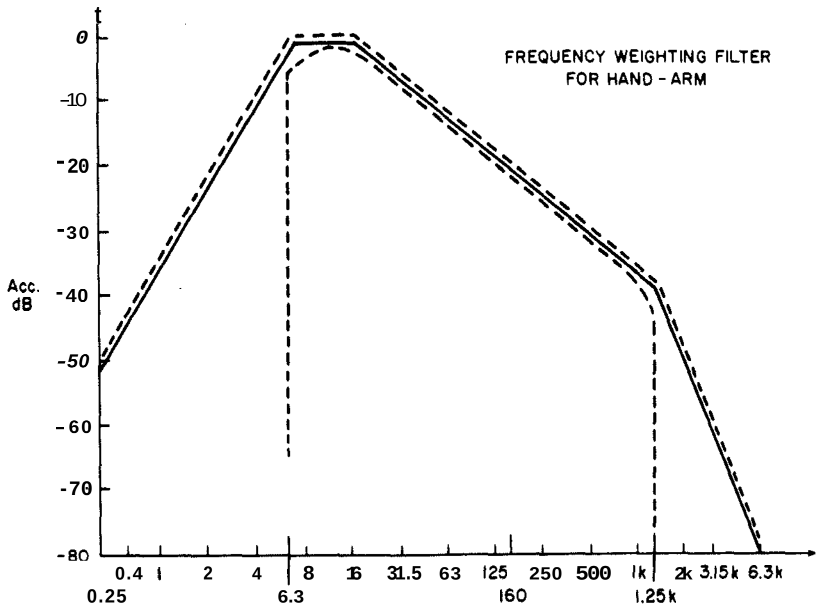


Fig. 1

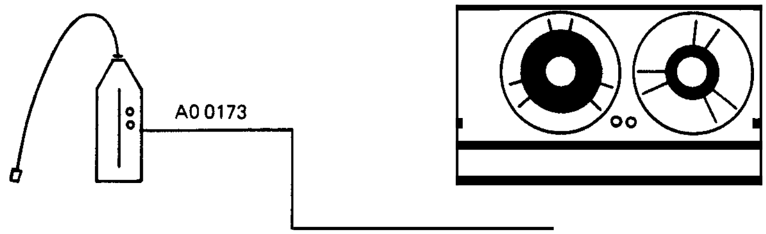


Fig. 2

"The vibration pick-up must be small and light enough for specific application. Its cross-axis sensitivity must be at least 20 dB below the sensitivity in the axis to be measured.

The measurements in the three axes shall be made at, or clearly related to, the surface of the hand where the energy enters the body. If the hand of the person is in direct contact with the vibrating surface of the hand grip, the transducer should be fastened to the vibrating structure. If **a** resilient element is being used between the hand and the vibrating structure (for example, a cushioned handle), it is permissible to use a suitable mount for *the* transducer (for example, a thin, suitably formed metal sheet) placed between the hand and the surface of the resilient material. In either case, care must be taken that the size, shape and mounting of the transducer **or** of the special transducer support do not significantly influence the transfer of vibration to the hand. Care must be taken when mounting the transducer that the transfer function is flat up to 1500 Hz for all three directions.

Notes:

1 For signals with a very high crest factor, for example those obtained from percussive tools, special precautions must be taken to avoid overloading any part of the system. Correct choice of the transducer is essential in this case. It may be possible to use a mechanical filter with a suitable calibrated linear transfer function to reduce the crest factor of these signals.

2 The proposed method for the case of a resilient element between the hand and the vibrating structure is not satisfactory for all conditions, particularly in the case of thin cushions mainly affecting the transfer of higher frequencies. In such cases it might be preferable to make the measurements with the transducer rigidly attached to thehandle or structure and to report separately the type, thickness, physical properties and estimated attenuation achieved by the cushioning material.

Although characterization of the vibration exposure currently uses the acceleration (velocity) transmitted to the hand as the primary quantity, it is reasonable to assume that the biological effects might depend to a large extent on the energy transmitted. This energy depends on the coupling of the hand-arm system to the vibration source and consequently on the grip pressure applied and the magnitude and direction of the static force. Measurement of the energy transmitted to the hand and of the tool application force is feasible and desirable for research purposes and for future application to special tools but is not yet proposed in this International Standard. For the purpose of this International Standard, the vibration exposures shall be reported for a grip pressure and static force representative of the operational application of the tool or coupling of the hand to the vibrating machinery. It must be realized that changes in coupling can affect considerably the vibration exposure measured."

In order to meet the requirements a special handle has been developed. It has been important to consider the following points:

a) The frequency response of the adaptor should be linear from 5 Hz to above 1200 Hz.
b) The adaptor must represent a minimum load to the hand.
c) It should be easily adaptable and measure as close as possible to the standardized reference point on both right and left hand.
d) It should realistically reflect the used grip strength.
e) It shall never underestimate the energy transmitted to the hand from the handle.

An adaptor has been developed which covers these requirements and has been tested in various practical situations. The adaptor represents a compromise between close coupling to the handle of the work piece and close coupling to the hand;

To be on the safe side in protecting the hand, the adaptor is designed to measure more closely the vibration of

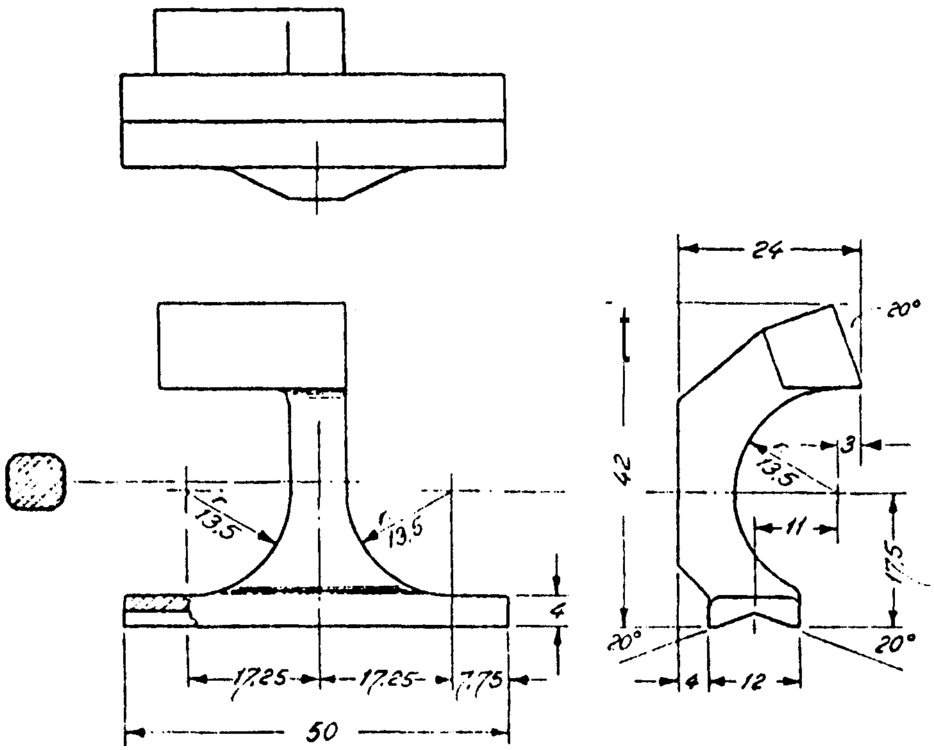


Fig. 3: Handle adaptor manufactured in lightweight metal, magnesium or aluminum alloy

the handle than that experienced on the hand itself, if any difference exists.

A drawing giving main dimensions is shown in fig. 3

In fig. 4 the response of a special vibrator with a test handle with built-in accelerometer is shown. The spectrum is equalized between 12 and 1200 Hz for a flat pink noise spectrum. The output from the adaptor applied by normal hand pressure shown for the x direction. The transfer function handle to adaptor can thus be measured. The increase in level at 500 to 1000 Hz is caused by the compliance of the hand combined with the stiffness of the adaptor and the application force. The adaptor seems thus to overestimate the vibration level fed to the hand around 1000 Hz. However a practical test on a pneumatic tool indicates an underestimation in reference to the usual reference point for pneumatic tools. In this case it is safe to assume that the adaptor gives a more realistic value than the reference accelerometer mounted on a mechanical filter on a welded stud in front *of* the handle.

For comparison is shown the transfer function to the head of the third metacarpal, which is the standardized coordination system reference for the hand. (See fig, 5)

The transfer function to the wrist (fig. 5) and to the elbow is also shown.

It is thus believed to be very safe, convenient and reproducible to use the proposed adaptor for hand-arm measurements.

Fig. 6 shows the actual test set-up for obtaining the hand-arm vibration response shown in fig. 4 and 5.

Fig. 7 shows the performance of the adaptor under standardized response test conditions for acceleration pick-ups mounted on 180 gr. of stainless steel.

In fig. 8 *is* shown a comparison between measured levels on a PNEUROP round robin chip hammer shaving a 2 mm chip measured on a welded stud as shown in fig. 9 using a mechanical filter B&K UA 0559 and an accelerometer B&K 4369 to the measuring handle. The increase in level at low frequencies 8-31, 5 Hz for the stud mounted accelerometer is caused by noise.

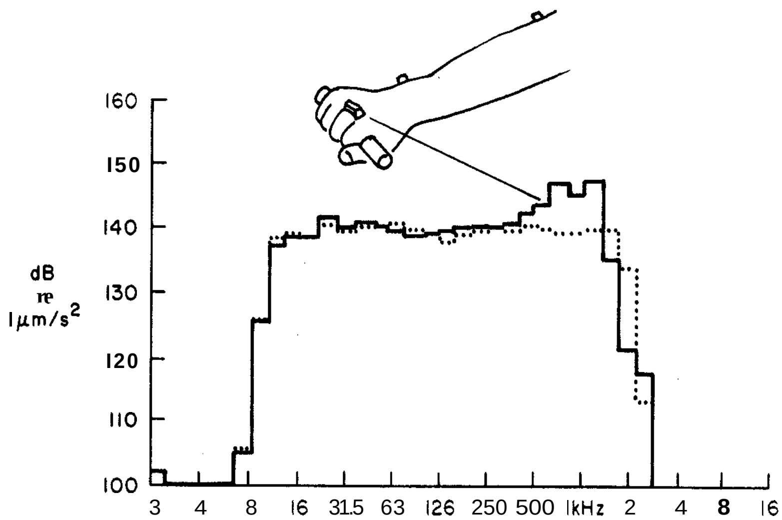
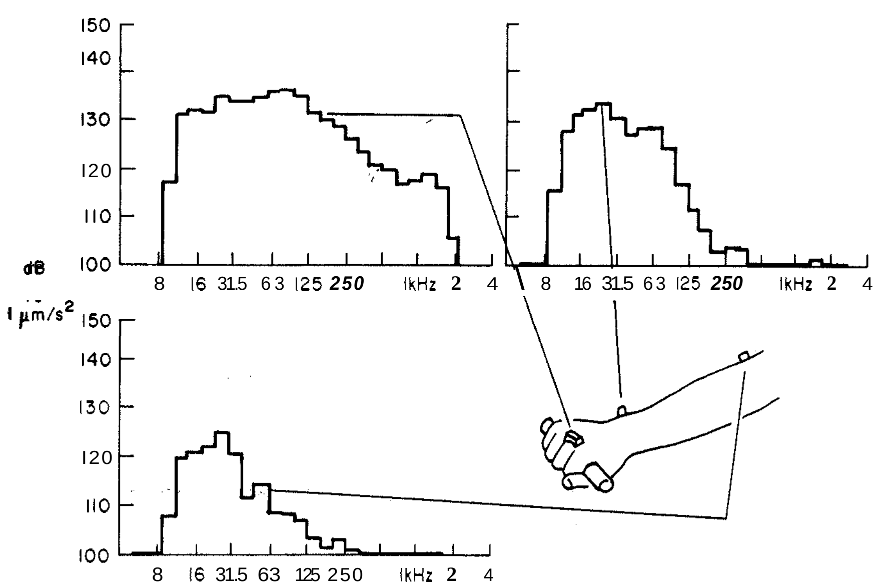


Fig. **4:** Transfer function from handle to hand adaptor
.... vibration level of handle
—— vibration level of hand



Fib. 5: vibration level on third metacarpal, on wrist and elbow for flat pink noise spectrum on handle as shown in fig. 4.

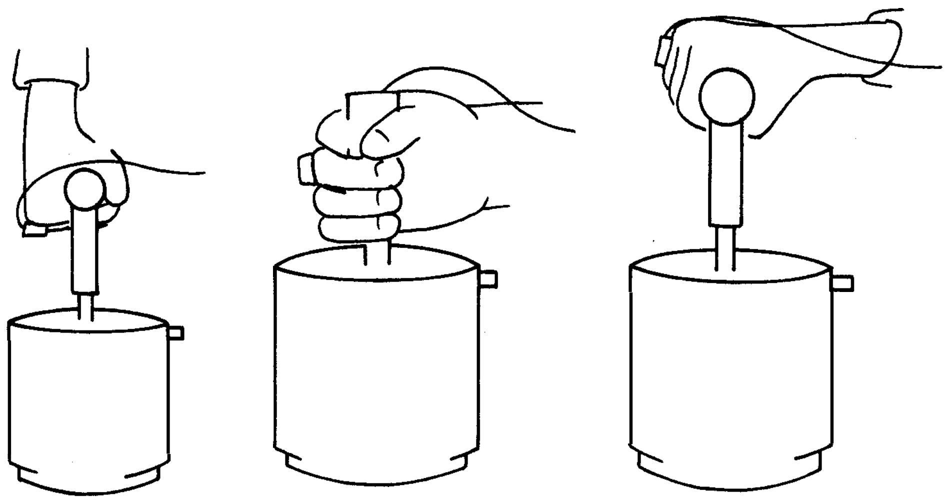


Fig. 6: Test set-up for transfer function measurements.

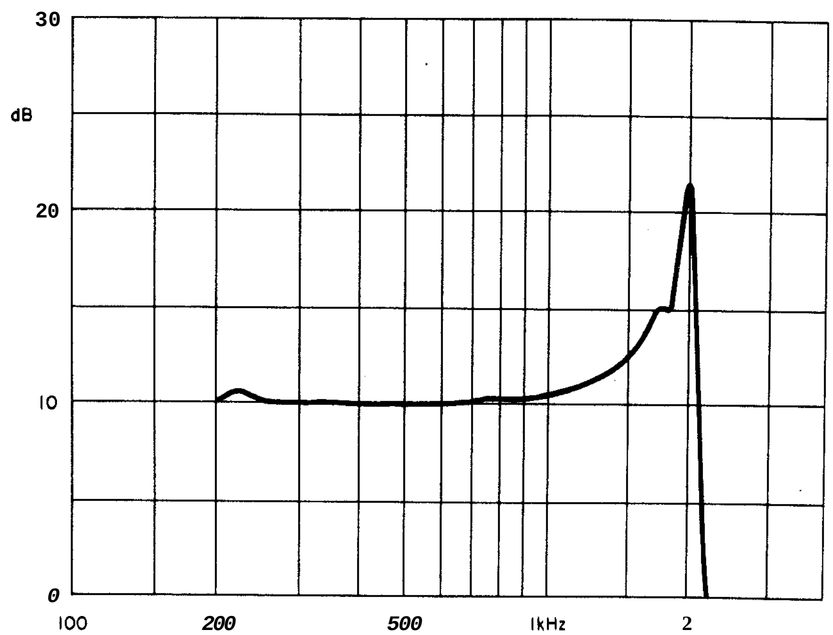


Fig. 7: Adaptor No. 6 with 4375 accelerometer in z direction

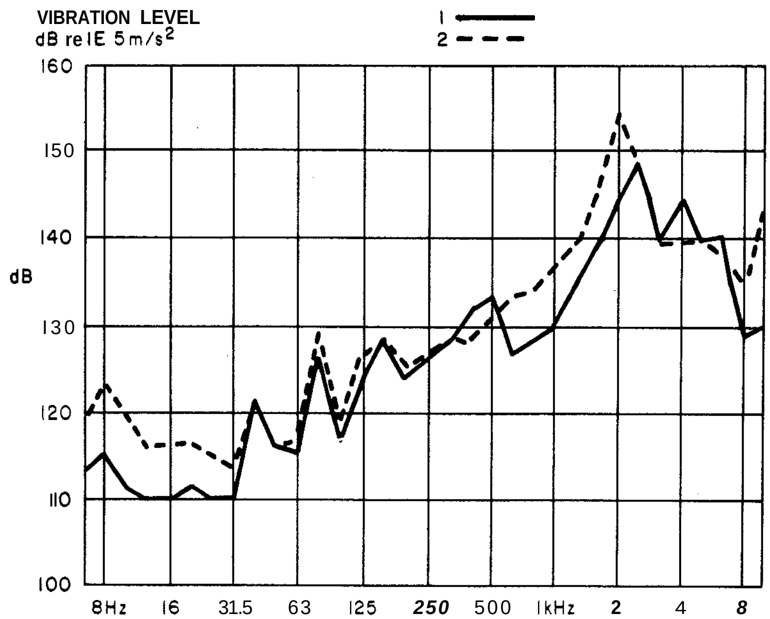


Fig. 8: PNEUROP chip hammer measurements
comparing - - welded stud mounting versus
—— hand adaptor measurements

Relating Exposure to Symptoms

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The parameters controlling the development of the early stages of the Vibration Syndrome (usually known as vibration-induced white finger - VWF) have been derived from retrospective studies of workers occupationally exposed to the vibration. The desire to interrelate all published epidemiological data, the few studies linking vibation exposure to symptoms, and the lack of a universally accepted, objective measure of the severity of VWF suggested the following analysis.

To establish that some symptom or symptoms reported by individuals can be collectively related to some measure of vibration exposure, all published studies of population groups using a particular tool (chain saws) were compared. It is found that the average duration of employment primarily determines the average time for the first white finger tip to appear (i.e. the latent interval), rather than the detailed nature of the operation and epidemiological factors, such as ethnic group, age and climate. In addition, the time of exposure before symptoms appear in individual members of a group appears to follow a normal distribution. Symptoms representative of the progression of the disorders can thus be determined by applying a traditional statistical tests to all studies using the Taylor-Pelmear Classification of VWF. It is then possible to derive broadly-based dose-effect relations applicable to persons who nominally work all day with a particular vibrating tool, by systematically imposing constraints on the minimum size of population groups, the prevalence of symptoms, and procedures for measuring vibration. The strict application of selection rules is believed to eliminate unrepresentative data.

For population groups maintaining a given vibration exposure (e.g. continuing their occupation) it appears that:

(i) the time for 20% of a group to develop Stage 3 is 3.2 times the average latent interval, irrespective of the occupation, and
(ii) the range of times for individuals with differing "susceptibility" (here taken to include differences between individuals' exposures) to develop VWF is directly proportional to the duration of the average latent interval reported by the group.

To derive a quantitative relation between the vibration level of a power tool and the average rate of development of symptoms, a single numerical measure of the vibration amplitude is first formed, by frequency-weighting the available acceleration spectra according to the equinoxious contour implied in the Draft International Standard ISO/DIS 5349. A simple power law results between the average latent interval and the weighted acceleration, a_K, experienced by the population group.

By combining these three relations, it is possible to predict the time for workers to develop VWF, including those susceptible to the disorders, and the time for a significant fraction to develop the potentially severe symptoms associated with Stage 3, from the vibration entering the hand.

(Adapted from Paper L1 "Relations between exposure to vibration and the development of the Vibration Syndrome" presented at the Third International Symposium on Hand-Arm Vibration, Ottawa, May 1981.)

Biological Monitoring of Vibration White Finger

by P L. Pelmear

Introduction

Raynaud's Phenomenon, so-named after Maurice Raynaud (1834-1881) may be defined as intermittent constriction of the peripheral vessels — arteriols and veins — with consequent colour change of the skin of the extremities such as pallor, cyanosis, or both. The phenomenon commonly precipitated by exposure to cold may occur primarily as in Raynaud's disease or in association with a number of conditions or diseases.

The primary condition of Raynaud's disease or constitutional white finger must be distinguished from the secondary causes. The distinguishing features are the familial pre-disposition (up to 10% incidence in the population); higher incidence in females than in males (511); early onset with over 60% of those pre-disposed experiencing the phenomenon by the age of 30; bilateral appearance of the phenomenon in response to stress as well as cold; and the absence of any predisposing disease or trauma.

The more important secondary causes include the connective tissue disease, vascular disease and trauma. Trauma to the extremities may arise from acute injury causing immediate blood flow interference, or the trauma may be accumulative as with vibration and the vascular changes occur gradually.

Vibration as a cause of Raynaud's Phenomenon was first reported in 1911. Compressed air tools were the cause and this was confirmed by other authors in 1918, who reported on stone cutters using pneumatic hammers in the limestone quarries of Indiana.

Dr. Hamilton's description of the symptoms and signs have not been surpassed in the literature since.

The recognized hazardous work situations now include all situations where compressed air tools are used for example, fettling, hand-grinding, polishing, as well as pedestal grinding, swaging and chain saw operating.

Symptoms and Signs

Following exposure to vibration the first symptoms are tingling and numbness of the fingers when at rest, particularly at night. Swelling of the fingers, especially over the knuckles, is often noticed as well. Subsequently, after a variable period of time, depending on the dose of vibration received and the sensitivity of the subject, blanching of a finger tip occurs following exposure to cold. The affected finger is numb when blanched and, in severe cases, there may be some persistent numbness or reduced sensitivity between attacks.

With continued exposure to vibration the blanching attacks become more frequent. They are precipitated by exposure to cold, damp conditions, particularly in the morning and at night, when the subject's metabolic activity is low with a reduced central body temperature. Blanching, following the handling of cold objects or immersion in water, is a common story. Attacks are more common in winter than in summer, but eventually they will occur all year round.

Initially the blanching is localized to the tips of the fingers most exposed to the vibration source, but eventually it spreads to involve all fingers as far as the interphalangeal joints and the tips of the thumbs. The palms of the hands are rarely affected. The blanching does not usually occur at work except during rest periods, but in some subjects the vibration stimulus itself will induce blanching if the fingers are cold.

These symptoms and signs are in response to pathological and physiological changes in the tissues of the fingers. Kadlec and Pelnar in 1945, on the basis of their plethysmographic studies, disagreed with the then accepted view that VWF was solely a disease of the capillaries and provided evidence of the crucial role of the finger arteries. They attributed hyperactivity to the muscular layer of the arterial wall, the hypertrophy of which was later documented by Ashe from biopsy and autopsy specimens. They described two stages of VWF — the first reversible and presumably due to exaggerated spasm and its failure to resolve into vasolidation under cold. The second, an irreversible stage, demonstrated plethysmographically to be a permanent, anotomical obstruction of the fingers' arteries.

The development process is not entirely clear, and several hypotheses have been proposed. It is suggested that the first response to vibration is a relaxation of the small blood vessels and an increase in permeability of the vessel wall with a resulting accumulation of exudate. Hence the oedema and nerve and irritation expressed as tingling. Later, hypertrophy of the muscle layer of the blood vessels occurs, with consequent hypersusceptibility to contraction when stimulated by cold. Eventually the lumen of the blood vessel is reduced due to the muscle hypertrophy and from secondary thrombosis consequent upon a sluggish blood flow. In well established cases, fibrotic changes occur within the hypertrophic muscle, and this may account for the prolonged spasm with delayed relaxation on re-exposure to warmth which is a typical feature in such cases, as stressed by Magos et al. These pathological and physiological findings, including round cell infiltration of the nerve endings have been noted by several authors.

Ultimately, with complete obliteration of blood vessels, trophic or gangrenous changes may occur and these have been reported There are many reports of cyst formation in bones but this is a common finding in manual workers and in the series of studies by James et al There was no statistical difference between the exposed and manual worker controls Bone cysts occur because of synovial fluid extrusion from joints and not from reduced blood flow

The symptoms and signs and the frequency of attacks may be such that eventually the subject, apart from taking immediate preventive action to keep warm and avoid cold exposure, has to curtail his activities. Socially this may mean avoiding outdoor pursuits such as gardening, fishing, swimming and watching outdoor entertainment, and ultimately it may involve a change of work to avoid further vibration exposure.

A grading index by stage of symptoms and sociallwork interference has been described and used to advantage by Taylor and Palmear

If the subject is young, with VWF severity no greater than stage 2 he may well completely recover if he avoids further vibration exposure. If he does not, he will progressively deteriorate. Older subjects and those with severity grade *3* on discontinuing vibration exposure tend to remain the same, while some continue to deteriorate.

Treatment other than avoidance of exposure is ineffective so prevention is all important.

Vibration

The development of VWF depends on the dose of vibration and the sensitivity of the subject The dose is a factor of time and vibration intensity expressed as acceleration in m/sec² over the critical low frequencies

Vibration may be measured by displacement, velocity (rate of change of displacement) or acceleration (rate of change of velocity). All are interdependent.

Energy absorption is maximum at the resonant frequency of the object or tissue, and increases as the opposing force is applied, e.g. hand grip. The resonant frequency of the hand is 30-40 Hz, the fingers 115 Hz, and the lower frequencies 4-2000 Hz are now considered to be the most hazardous.

The International Organization for Standardization (ISO) Draft proposal for a standard ISO/TC 108/SC4 N 122 January, 1982 specifies general methods for measuring and reporting hand-transmitted vibration exposure in three orthogonal axes for 113 octave bands 6, *3* .1250 Hz, octave bands 8-1000 Hz, and a weighted measure which covers the frequency range 5-1500 Hz. The primary quantity to be measured shall be acceleration in the X, Y and Z axes of the hand. A four hour energy equivalent acceleration dose-effect relationship is provided for guidance for the assessment of exposures of different durations, and a threshold limit value corresponding to a time-weighted acceleration level of 2,9 m/sec² is suggested

Prevention

The important steps to be taken in prevention are:

(a) Identification of hazard by vibration measurement.
(b) Complete avoidance of exposure (if possible) by use of alternative work methods.
(c) Use of anti-vibration pads on tools and chain saws.
(d) Work rotation to limit exposure.
(e) Medical surveillance, i.e., pre-employment and periodic.
(f) Transfer of subjects severely affected.

Conclusion

VWF is an occupational disease which needs to be recognized and prevented. The incidence at work can only be ascertained by direct enquiry, because many workers do not complain of their symptoms and signs. They have not associated cause and effect.

Vibration has not yet been designated in Ontario as a hazardous physical agent, so the onus is on occupational health services and health and safety committees to undertake enquiry and corrective action. The onus is also on tool and equipment manufacturers to limit or isolate vibration from the user. There has been some progress but much remains to be done.

If workers are not protected from exposure, the development of VWF and claims for compensation are inevitable. In Ontario the Workmen's Compensation Board has been receiving claims since 1944, and have been allowing them since the early 50's.

Establishing Tolerable Levels of Exposure to Vibration

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Establishing tolerable limits for habitual exposure of the hands to vibration is an essential prerequisite to the formulation of meaningful occupational health standards, and the specification of design goals for the manufacture of vibrating power tools. The evidence on which to base exposure limits consists of epidemiological studies of population groups exposed to vibration, individual case histories, experience with the application of current or past occupational health standards, and laboratory experiments on man or animals.

This lecture considers the establishment of tolerable exposure levels from two types of epidemiological studies:

(i) prospective studies of selected cohorts of workers, who perform a well-defined task using tools with known vibration characteristics, and
(ii) cross-sectional, retrospective studies, in which the onset of disorders has been related to the vibration exposure of a population group whose members perform identical work

Few prospective studies satisfy this requirement, and the retrospective studies present a confusing picture unless analysed by a consistent procedure.

The dose-effect relations discussed in an earlier lecture have been extended to lower vibration levels by introducing data with a low prevalence of VWF, and then compared with the Threshold Limit Values proposed by Miura (Miura T, Morioka M, Kimura K, Akutu A. J. Science of Labour 1959; 35: 760-767). It is found that the maximum component acceleration at the hands of persons whose full-time occupation involved operation of a power tool or industrial process should be in the range $1 < a_K < 3$ m/s², to prevent the onset of disorders during a working lifetime.

(Adapted from Paper L5 "Tolerable limits for exposure to vibration" presented at the Third International Symposium on Hand-Arm Vibration, Ottawa, May 1981.)

Compensation Aspects of Vibration White Finger Disease

by Craig Paterson

A brief review was given of the schedules for industrial diseases and compensation eligibility procedures of the various Workmen's Compensation Boards in Canada but with particular emphasis on those of British Columbia. The presentation emphasized the medico-legal aspects of compensation claims for Vibration White Finger Disease including actual and projected loss of earnings, disability entitlement, time periods, diagnostic criteria and future employability and rehabilitation. A strong case for supplementary payments for workers needing to change jobs was made.

The paper urged the importance of having a comprehensive and adequate compensation scheme for V.W.F. in order to stimulate preventive measures and proper treatment.