

Diagnosics of hand-arm system disorders in workers who use vibrating tools

Gösta Gemne

Abstract

A hand-arm vibration syndrome occurs in some workers who use hand held vibrating tools. It is recognised to consist of white fingers, diffusely distributed finger neuropathy, pain in the arm and hand, and a small excess risk of osteoarthritis from percussion to the wrist and elbow. Carpal tunnel syndrome is mainly due to ergonomic factors other than vibration, but certain factors related to vibration may contribute to its development. A decrease in muscle power induced by vibration, and excessive hearing deficit have been postulated. The assessment of a disorder suspected of being induced by vibration includes deciding whether there is a disorder and, if so, whether the symptoms can be caused by vibration. To decide whether the symptoms can be caused by vibration epidemiological documentation and pathogenically reasonable theories must exist. A causal diagnosis finally requires an epidemiological decision whether or not the factual exposure has elicited the patient's symptoms. Epidemiological data on the quantitative association between vibration and excessive risks of white fingers and diffusely distributed neuropathy are incomplete. The symptomatic diagnosis of white fingers is still mainly based on anamnestic information. Available laboratory tests are incapable of grading the severity of individual cases. Recording the finger systolic blood pressure during cold provocation is a method of symptomatic diagnosis with reasonable levels of specificity, sensitivity, and predictive value. For diffusely distributed neuropathy these levels are lower than desired. Electrodiagnostic tests for carpal tunnel syndrome have sufficient validity. Proper exposure evaluation must be based on an appreciation of the character of the vibration as well as effective duration and intermittency. If this is not taken into account, the number of hours of exposure and intensity of vibration are likely to be non-commensurable variables, and the simple product of them is a questionable dose measure. Separate models for risk evaluation of vascular and neurological disorders related to work with different tools and processes will have to be established. Ongoing research to obtain fur-

ther data on exposure-response relations for neurological disturbances begins to yield encouraging results.

(*Occup Environ Med* 1997;54:90-95)

Keywords: carpal tunnel syndrome; epidemiology; hand-arm vibration syndrome; risk evaluation models; vibration white fingers

Disorders suspected of being induced by vibration need to be assessed in three ways. Firstly, it must be found whether there is indeed a disorder. This is done on the basis of clinical and laboratory findings compared with epidemiological knowledge about the normal variation of the variables studied. Secondly, it must be decided whether the symptoms could be caused by vibration. For this, there must be reasonable theories on the pathogenic mechanisms. Again, epidemiological documentation is necessary, which can be found in studies on the occupational group to which the patient belongs, concerning not only vibration but also other factors in the work environment that may cause the symptoms.

Thirdly (only if the first two types of assessment are positive) it must be decided whether the factual exposure has been harmful enough to elicit the patient's symptoms. This requires an evaluation of the intensity and other characteristics of the vibration in a way that is meaningful for the disorder in question. Unfortunately, the methods available for these tasks have several shortcomings.

What disorders may be caused by vibration?

There is no complete agreement as to what disorders may be caused by vibration from hand held tools (hand-arm vibration). However, current opinion favours the following general picture.^{1,2}

HAND-ARM VIBRATION SYNDROME

The symptoms that are possibly related to vibration are collectively referred to as the hand-arm vibration syndrome.³

Disturbance of finger skin circulation

Disturbance of the circulation in the skin of fingers (elicited by exposure to cooling of the hand or general body) in the form of reduced blood flow occurs in the most exposed parts of

74 Rådmansgatan,
S-113 60 Stockholm,
Sweden
G Gemne

Correspondence to:
Professor Gösta Gemne,
74 Rådmansgatan, S-113 60
Stockholm, Sweden.

Accepted 1 August 1996

the hand (vibration white finger (VWF); secondary Raynaud's phenomenon due to vibration). This disorder may be due to a combination of sympathetic hyperactivity and a lesion to structures and functions in the walls of blood vessels in the skin.

Diffusely distributed finger neuropathy

This disorder may be caused by damage to nerve fibres and receptors by direct mechanical influence of vibration or impeded blood circulation or both.

Pain in the arm and hand developing during work with low frequency tools

Pain in and around joints and the often concomitant restriction of movements may be due to excessive strain caused by the loading of muscles and tendons, or by osteoarthritis of the joints caused by shocks from percussive tools. Vibration may contribute to this disorder by increasing muscle and joint load.

Carpal tunnel syndrome

There is less agreement on the causal relation between exposure to hand-arm vibration and carpal tunnel syndrome. This disorder consists of a typically nocturnal paraesthesia in the three radial fingers and the radial half of the fourth finger with numbness and sometimes pain. The symptoms arise from compression of the median nerve as it passes to the hand through the wrist. As the syndrome has also been found among people who are not exposed to vibration but perform repetitive, forceful movements with or without a hand held tool, it is not specific to vibration. These ergonomic factors, in most cases, seem to be the main cause of carpal tunnel syndrome.⁴ Some work with vibrating tools, however, requires stressful postures of the wrist and a hard grip on the tool handle. This may contribute to the development of carpal tunnel syndrome by prolonging static work, increasing nerve compression, and eliciting harmful ischaemia of the nerve.

Other possible effects of vibration

A direct effect of vibration on muscles has also been postulated to result in decreased muscle power.^{5,6} Finally, a hearing deficit that cannot be ascribed to exposure to noise alone has been described in workers exposed to vibration of the hands or arms.⁷⁻¹⁰ It may be an effect of enhanced sympathetic hyperactivity, perhaps particularly associated with impulse vibration, that harms cochlear cells.

METHODS OF ASSESSMENT

White fingers

The assessment of the presence of white fingers is mainly based on the anamnestic information received from the patient. The typical symptom of vibration white finger is a cold induced, patchy blanching of the skin of the fingers (Raynaud's phenomenon) due to obstruction of blood flow (vasospasm) to the skin of the fingers that have been most exposed to vibration.¹ The attack is commonly triggered by cooling of the fingers or, espe-

cially, the whole body in a way that is experienced as disagreeable. The blanching is connected with a reduction of skin sensitivity in the affected fingers and usually lasts until the body is properly warmed. It is sometimes followed, upon the return of the blood flow, by a sensation of throbbing in the fingers.

The available tests to ascertain whether there is a Raynaud's phenomenon, unfortunately, are not entirely objective. Straightforward immersion of the hand in cold water in the laboratory to see if the phenomenon can be provoked often fails in patients who indisputably have a history of white fingers. This, presumably, is due to the absence in the experimental conditions of some decisive factor or factors. The results of temperature measurements made in this way often do not permit an unequivocal interpretation of the presence or absence of obstruction to blood flow. With a negative test result—that is, if the most exposed fingers do not blanch in the typical patchy way, or if the temperature of the skin of the finger is not abnormally reduced—the existence of white finger cannot be excluded.

As the results of skin temperature measurements during simple cold water provocation seem to depend on unknown and partly uncontrollable factors, this method has serious limitations for screening purposes. An attempt to reduce the shortcomings of cold provocation tests has been made^{11,12} by automating and standardising the recording of so called chronothermograms and by the collection of large quantities of data from population samples that may pass as normal values. Further promising results can be expected from this project, when some epidemiological uncertainties have been resolved.

So far, the best way of making objective a cold induced reduction of blood flow in the skin of the finger is the method of critical opening pressure. It consists of recording the finger systolic blood pressure during cold provocation.¹³⁻¹⁵ A positive outcome in the form of a reduction of the blood pressure in the skin of the finger (at 15°C finger cooling temperature) by more than 40% of its original value after correction for changes in the blood pressure of the arm has been considered suitable for the differentiation between absence or presence of vasospasm.^{16,17} The critical opening pressure method has been found to have levels of specificity, sensitivity, and predictive value high enough to be of use for diagnosis of symptoms in individual people.^{17,18} The limit for abnormal reduction in blood pressure in the skin of the fingers, however, depends on whether general body cooling is used as well as finger cooling, and on room temperature.¹⁹ This rather time consuming method requires well established laboratory procedures and skilled personnel, which makes it less suitable for the purpose of screening large occupational groups.

The clinical and laboratory diagnostics of vascular symptoms suspected of being induced by hand-arm vibration^{20,21} have been recently evaluated by an international panel.²² The screening methods available were scrutinised.

It was concluded that a medical interview is still the best method for diagnosing white fingers triggered by cold. None of the existing cooling tests are capable of grading the severity of VWF in individual cases.

Neurological disturbances

Diffusely distributed neuropathy—Neurological disturbances in the fingers may be demonstrated in many workers exposed to vibration with methods for assessing vibration and temperature perception thresholds.²³⁻²⁵ The sensitivity, specificity, and predictive values of tests for diffusely distributed neuropathy, however, are all lower than required for use in screening or for aetiological diagnosis,²⁶⁻²⁷ and further research is urgently needed.

The pathogenesis of diffusely distributed neuropathy remains unclear. Direct mechanical influence of vibration may result in structural and functional damage. Anatomical changes have been reported in animal nerves after exposure to vibration, among them epineural oedema²⁸ and certain reversible alterations of unmyelinated fibres.²⁹ In the work on unmyelinated fibres, a nerve more proximal to the site of vibration, however, showed no changes. Loss of myelinated nerve fibres and, among other changes, Schwann cell proliferation have also been shown in biopsies of skin of the fingers directly exposed to vibration from hand held tools.³⁰⁻³¹ However, epidemiological data on the prevalence of all these lesions in people exposed to vibration are lacking.

Carpal tunnel syndrome—The median nerve, together with the nine finger flexor tendons, pass through the carpal tunnel in the wrist.² Compression of this nerve produces carpal tunnel syndrome, which typically presents as nocturnal paraesthesia with numbness and, sometimes, pain. The main pathogenesis of this disorder may be repeated mechanical insult from the flexor tendons. In certain hand postures, the tendon movements reduce the tunnel width causing nerve compression, perhaps aggravated by flexor tendon synovitis.³²⁻³³ It has been suggested³⁴ that exposure to vibration may produce anatomical changes which make the nerve more susceptible to additional trauma from compression, the so called conditioning lesion phenomenon.

With these possible mechanisms it is not surprising that the occurrence of carpal tunnel syndrome is increased in occupations that involve manual labour with or without hand held tools, especially work involving repetitive wrist movements and strenuous work.⁴⁻³⁵ A meta-analysis of occupational groups with increased prevalence of carpal tunnel syndrome has indicated that physical work load, not vibration, is the main risk factor.⁴

Electrodiagnostic tests of sensory and motor nerve conduction can identify carpal tunnel syndrome reasonably well,²⁷ but so far no studies have been able to make an aetiological distinction between exposure to vibration and work with hand held tools.

Musculoskeletal disturbances

Work with hand held vibrating tools involves

several factors that may influence the muscles, tendons, and joints of the hand-arm system. Painful conditions in the wrist and elbow region are therefore common in several occupational groups with considerable load on the hand-arm system. Percussive vibration from chisel hammers also causes repeated shocks to the wrist and elbow joints. In the long run, this may damage the joint surfaces and cause degeneration, the sequelae of which are known as osteoarthritis. Accordingly, as described in a review of bone and joint disorders in workers who use hand held vibrating tools,³⁶ a small but detectable excessive occurrence of osteoarthritis of the elbow has been convincingly shown among coal miners in the Ruhr district who use chisel hammers.

Vibration from percussive tools may contribute in other ways to locomotor disturbances: the contraction that automatically occurs in a muscle exposed to vibration, the tonic vibration reflex,³⁷⁻³⁸ as well as a harmful feedback through several neural pathways,³⁹ increased muscle tension, and joint load.

The diagnosis of osteoarthrotic conditions rests upon radiography, but the causal connection with vibration in individual cases can seldom be established. Among other things, this is because these changes are fairly common in middle aged men. Restrictions of movements can be objectively assessed, but pain (an aetiological multifactorial condition) cannot.

THE QUESTION OF CAUSALITY

The causal connection in a person between a disorder and exposure to vibration rests on the basis of a probability evaluation. The probability is increased if epidemiological studies have been able to show an excessive risk for that particular disorder in the occupational group to which the patient belongs (compared with pertinent subgroups of the general population). This, unfortunately, applies only to white fingers and, partly, to diffusely distributed neuropathy in the hands, and even so the magnitude of the causal relation is incompletely documented. An important reason for this deficiency is the fact already mentioned that the pathogenic mechanisms are largely unknown.

If it is pathogenically and epidemiologically reasonable that the symptoms of a particular patient may have been caused by vibration, one further decisive step is required to establish causality. It consists of assessing in a quantitative way how and to what extent this patient has been exposed to vibration, which is essentially a question of evaluating the dose of exposure. No aetiological diagnosis is possible without a reasonably certain knowledge about the quantitative relation between the dose (or whatever measure is used) and the response to vibration in terms of presence and severity of the symptoms in question. Although results of epidemiological studies on some occupational groups have prompted attempts to establish dose-response relations,⁴⁰⁻⁴³ these have largely failed or have had limited validity.⁴⁴⁻⁴⁶ It is especially troublesome that different tools and work processes definitely seem to require separ-

rate models for risk evaluation. Also, in all likelihood, there are different relations for vascular and neurological disorders.

If the concept of dose is used to evaluate exposure, attention must be paid to the following questions.

Effective exposure—Ideally, this is only that part of the vibration which actually reaches the target organ. However, it is often difficult to identify the tissue within the hand-arm system where the lesion is producing the symptoms. In any case, only that time each day should be considered when the tool is in close enough contact with the hand for substantial vibration to be absorbed. This is most often considerably less than the estimation by the worker, and careful time studies are therefore a prerequisite for a meaningful dose measure.

Duration—For how many days a week, weeks a year, and for how many years has effective exposure to vibration occurred?

Intermittency—Did the work contain breaks significantly long enough to allow recovery from the harmful influence of vibration to take place?

Vibration character—What was the character of the vibration (frequency, percussive, or non-percussive, etc)?

A seemingly straightforward way of evaluating dose is to multiply the total number of hours of effective exposure by a figure that tells something about vibration intensity—for instance, 12 000 hours times the acceleration of, say, 10 m/s². However, if intermittency is not taken into account, these two variables are likely to be non-commensurable and a dose measure determined in this way is therefore likely to be misleading.

The time factor may influence exposure-response relations in different ways. In a comparison between predicted and observed occurrence of white fingers among dockyard workers,⁴⁷ no particular model for time dependency was found to yield a good explanation for the relation. The results did not confirm that the frequency weighting or the time dependency as given in the current standard for the measurement of vibration exposure, ISO 5349,⁴⁹ are appropriate.

The methods recommended in the current standard are only partly supported by scientific observation,^{40-43,49} and no warning is given that the methods may require change with improved knowledge⁴⁹; amendments such as changes in time dependency and frequency weighting seem necessary.

There is as yet only sparse epidemiological evidence of the beneficial effect of intermittency in the vibration exposure, but simple physiological deliberations tell us that there should be such an effect because of the chance for recovery of organ function before permanent damage has been done. The ISO 5349, however, does not consider this idea.

A disadvantage has been pointed out⁴⁹ with the use of energy equivalent magnitude, recommended with the tacit assumption that variations in exposure to vibration during the working day are unimportant. Without any change in vibration magnitude, the same four

hour energy equivalent exposure may come from one continuous exposure or from a cumulative exposure of the same total duration produced by individual exposures that each last a few seconds and are separated by rest periods. It is concluded that the potential harmfulness may not be the same in the two exposures.

Some of the deficiencies of the risk prediction model in the annex A of ISO 5349, are epidemiological and statistical.⁴⁴ They concern overestimation of risk caused by the use of latency as an effect variable, underestimation because a possible healthy worker effect was ignored, and diagnostic uncertainties. As well as the fact that the effects of different axes of vibration and contact forces have not been taken into account in the construction of the standard itself,⁵¹ the accuracy and scientific background of the model can be questioned on several other grounds.^{44,46} Many factors contribute to the effects of vibration on the hand, and it has been pointed out⁵⁰ that the individual or combined effects of these factors are not easily discernible from a reanalysis of average values contained in published data. The statistical techniques needed to identify the relations require access to the raw data for each exposed person. Predictions, furthermore, should not be expected to be accurate because of the wide variation between subjects within the many variables, and the absence of standardised means for combining (or averaging) the different exposure patterns of individual people within a group.

In summary, it is clear that it is not possible to specify the accuracy of the risk prediction model discussed here,⁵¹ and that separate models will have to be established⁵² for vascular and neurological disorders in work with different tools and work processes.

Ongoing studies on exposure-response relations—There are encouraging studies going on that may advance our knowledge of the all important relation between occurrence or severity of neurological symptoms and the exposure to vibration.

In a study on neurological disturbances in the hands of workers who use grinders and chipping hammers,⁵³ the frequency of people without symptoms was found to decrease with increasing cumulative exposure to vibration. In the group with the strongest exposure, 12% of the workers had severe symptoms of diffusely distributed neuropathy with an odds ratio of 6.4 (95% confidence interval 1.9 to 21) when non-exposed workers were used as reference.

In a follow up study on the same cohort,⁵⁴ vibrotactile perception thresholds at frequencies between 8 and 500 Hz were measured. The result did not show a clear relation between exposure to vibration and individual vibrotactile deficiency, and it was not possible to establish an exposure-response relation on the basis of the present results alone. However, a fourfold increase in the relative risk for deteriorated vibrotactile sensitivity was found at frequencies above 40 Hz, when

the group with greatest exposure was compared with non-exposed workers.

In an epidemiological study of stoneworkers,⁵⁵ symptoms of VWF were found to be strongly related to exposure to vibration, and a monotonic exposure-response relation could be shown. Although caution was expressed that the findings were based on a cross sectional study, a relatively simple relation was suggested. Its time dependency is such that, if vibration magnitude were doubled, a halving of the years of exposure would be required to produce the same prevalence.

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Occupational and Environmental Medicine and the electronic age

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We are moving towards electronic publishing and for some months now we have been asking authors to send us their revised papers on disk as well as a hard copy. I am delighted to report that nearly all our

authors are managing to comply with this request. Oddly enough, the few authors who have not sent us a disk version of their revised papers have been almost exclusively from the United Kingdom. I would be interested in suggestions for why this might be. Perhaps United Kingdom based authors read our correspondence and instructions less assiduously? Watch for revised Instructions to Authors.

The Editor