Review

Dose-Response Relationship for Hand-Arm Vibration Syndrome

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Abstract: Dose-Response Relationship for Hand-Arm Vibration Syndrome: Makoto Futatsuka, Department of Public Health, Kumamoto University School of Medicine—Dose-effect relationships for hand-arm vibration involve relating a complex physical agent to the production of a variable and a not fully understood set of disorders. The physical agent, vibration, may be of variable magnitude, frequency, direction and duration; it is often intermittent and may contain shocks. The method of holding a tool, its physical characteristics, the ambient temperature and other factors may affect the severity of vibration exposure. The first occurrence of white finger is the effect of hand-arm vibration most usually considered in dose-response relationships. Neither the identification nor the diagnosis of this disorder is always reliable and it may not be the only significant adverse effect of exposure to hand-arm vibration. Data from cross-sectional studies show that the prevalence of white finger generally increases with increases in the vibration magnitude. The frequency weighting often employed in vibration measurement standards is loosely based on studies of subjective response to vibration and has a velocity characteristic over this frequency range. There have been few studies of the influence of vibration exposure duration on the development of relevant signs and symptoms. In a cohort of persons exposed to the same vibration, the mean latency increases with increasing duration of exposure until all persons are affected. It is becoming common for the daily exposure to vibration to be assessed on a so-called energy basis and expressed as an equivalent 8h exposure or an equivalent 4h exposure. This time-dependency is convenient because it enables exposures to be quantified by means of root-mean-square averaging. (J Occup Health 1996; 38: 47-53)

Key words: Hand-arm vibration, White finger, Dose-response relationship, Vibration exposure, Guideline

Hand-arm vibration syndrome originated with the introduction of portable power tools. The popularity of these useful tools grew apace with the advance of technology in the industrial sphere. Had those tools been introduced without safety and hygienic considerations, the risks of vibration syndrome might be greater than they are today. Recent years saw new advances in pathophysiological researches and guidelines emerged for cooperative research between the technological and medical fields in this area, but there has been not a small amount of undetailed research in this area still now, performed to seek international cooperation. The association between vibration syndrome and occupational exposure to hand-arm vibration is well recognized, but the form of the exposure-response relationship for vibration syndrome is not yet fully understood. The Scientific Committee for Vibration Syndrome of the Japan Society for Occupational Health has been discussing guideline setting for hand-arm vibration for a long time.

Quantitative evaluation of vibration exposure

Exposure to hand-arm vibration is complex and cannot be quantified simply. Vibration occurs in three translational axes, may differ in the two hands and may vary along the length of a tool handle. The magnitude of tool vibration may change from moment to moment, contain both low magnitudes of vibration and very high magnitudes of shock, and depend on the manner in which the tool is used and the condition of the tool. The vibration frequencies may extend over a wide frequency range. The exposure to vibration may comprise many periods of varying duration and defy simple measurement. The vibration received by an operator will depend on his technique and vary according to the dynamic response of his fingers, hands and arms. While recognizing the complexity of the exposure of the hand to vibration, it remains desirable to define simple means of quantifying the vibration. In particular, Japanese medical researchers tend to produce a lot of the results of health examination with-
out information on vibration exposure. In their reports, signs and symptoms of vibration syndrome have described in detail, but vibration magnitude and frequency measured by standard methods have not usually been reported. It should not be expected that the measurement of a few values can be used to accurately predict the extent of problems related to vibration. Griffin illustrated the variables

Fig. 1. Model of the factors influencing the relation between hand-transmitted vibration and the severity, prevalence and latency of adverse signs and symptoms. □, variables which current standards assume it is possible to quantify; □, other factors which may influence the accuracy of dose-effect relationships (Griffin, 1990).
which modern standards assume it is possible to quantify, as shown in Fig. 1. The other variables represent the many other factors which will limit the accuracy of such standards for predicting the effects of hand-arm vibration.

Bovenzi reported the relationship between vibration exposure and the occurrence of vibration-induced white finger among stone workers in Italy. In his study, the professional use of vibrating tools was expressed in terms of operating hours per day, days per year, and total exposure duration in years. Hand-arm vibration was measured on the handles of a representative sample of tools according to ISO 5349. Daily vibration exposure was assessed in terms of eight hours energy-equivalent frequency-weighted acceleration $[A(8) \text{ in ms}^{-2}]$. On the basis of the estimated regular vibration exposure time per year and the frequency-weighted acceleration measured on the tools, an individual vibration exposure index was calculated as acceleration-weighted exposure time $(\text{ms}^{-2} \cdot \text{hours/year})$. This trial seems to be useful as a basis for quantifying vibration exposure in cases of stable vibration exposure over time.

In Stockholm Workshop 1994, the following questions were discussed in connection with exposure evaluation: (1) Over what frequency range should hand-transmitted vibration be evaluated? (2) Is it advisable to collect both weighted and unweighted vibration measurement? (3) How should the time-dependent characteristics of vibration effects be allowed for in evaluation of exposure (duration and intermittency)? (4) How should transient vibration (e.g., repetitive shocks) be evaluated? (5) Does high-frequency vibration $(>1,000\text{HZ})$ require special consideration? (6) Should grip and push forces be taken into account when evaluating the severity of vibration exposure?

### Table 1. Prevalence rate of VWF due to vibratory tools in Japan (1980–)

<table>
<thead>
<tr>
<th>Vibratory tools</th>
<th>Job</th>
<th>Time of investigation</th>
<th>Prevalence</th>
<th>Raynard's Phenomenon (%)</th>
<th>Number of finger (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Bush cutters</td>
<td>Private forestry bush cutting</td>
<td>1989–1990</td>
<td>1.7</td>
<td>3 (3–13)</td>
<td>3.4 (10–43)</td>
</tr>
<tr>
<td>(2) Chain saws</td>
<td>Public officer maintenance of roads</td>
<td>1985</td>
<td>0</td>
<td>1 (1–12)</td>
<td>22.1 (13–55)</td>
</tr>
<tr>
<td>(3) Rock drills</td>
<td>Private forestry wood sawing</td>
<td>1985–1990</td>
<td>2.8-5.3</td>
<td>8 (8–43)</td>
<td>7.8–15.6 (15–66)</td>
</tr>
<tr>
<td>(4) Chipping hammers</td>
<td>Mine pneumatic drilling</td>
<td>1984</td>
<td>23.1</td>
<td>8 (8–44)</td>
<td>39.4 (49–67)</td>
</tr>
<tr>
<td>(5) Pick hammers</td>
<td>Stone cutting</td>
<td>1982</td>
<td>36.2</td>
<td>20 (20–45)</td>
<td>53.6 (7–67)</td>
</tr>
<tr>
<td>(7) Air hammers</td>
<td>Steel &amp; Refinery</td>
<td>1989</td>
<td>4.4 (9.9)</td>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td>(9) Handy vibratory tools</td>
<td>Engineering &amp; Machinery</td>
<td>1992</td>
<td>3.4 (0.6–3)</td>
<td></td>
<td>10.7 (3–41)</td>
</tr>
</tbody>
</table>

( ) reported in 1970 (Futatsuka, 1994).

### Importance of field research in Japan

Table 1 shows the prevalence rates for white finger and numbness of finger reported in the 1980s compared with those in the 1970s. The amount of epidemiological data available has decreased remarkably in recent years, because of general improvements in the conditions concerning vibration problems. The number of vibration tool operators is estimated to be over 1,300,000: 880,000 workers in manufacturing, 260,000 in construction, 150,000 in forestry and less than 10,000 in mining. Out of this large number, 170,000 workers are subject to an annual compulsory health examination for vibration syndrome. Only 40% of this subjective population, 70,000 workers were examined. This can show only the tip of the iceberg. In the results only twenty to thirty verified vibration syndrome patients were recorded. The main reasons for such a discrepancy between the exposed population and the examined population are the following: (1) these workers belong to a variety of small enterprises: machinery, foundry, and steel factories, (2) these workers belong to various employment groups, for example, the self-employed, contractors and informal sectors in forestry, quarrying, and construction.

The Japanese Labour Ministry developed the “Vibration acceleration $>3G$ and time regulation $>2$ hours” hygienic standards. This newly administrative system had a true rule for the prevention of the vibration syndrome. But it is difficult to improve pneumatic vibrating tools technologically all over the world, and also it is very difficult to regulate operation time for piece work and wage system workers. It is unclear from data issued by the Japanese government whether there is a decrease or not in the risk of vibration syndrome such levels as the numbers of verified patients with vibration syndrome. I must emphasize that the importance of
field research on actual working conditions and health status has changed from those in the 1970s \cite{12,16} from the point of view of reconstruction of dose-response relationship for hand-arm vibration syndrome based on actual present conditions.

**Quantifying effects of hand-arm vibration**

Annex A to ISO5349 offers a dose-response relationship between the 4 hours energy-equivalent frequency-weighted acceleration in the dominant axis of vibration, and the exposure period before the onset of white finger. The proposed relation between these parameters is illustrated in Fig. 2. For the percentage of the population affected by white finger and the frequency-weighted acceleration magnitude from 2–50 ms$^{-2}$ r.m.s., the exposure periods are shown in this figure. It states that the dose-response relationship can be approximated by the following equation.

$$\text{percentage affected} = \left[ \frac{\text{ahw} (\text{eq} \cdot 4h) \cdot E}{95} \right]^2 \cdot 100$$

Where ahw is the vibration acceleration frequency-weighted and E is the exposure time (in years) before white finger occurs.

It seems to be difficult to evaluate white finger as effect model of vibration exposure and validity of diagnosis of vascular disorders, but pathophysical research is progressing gradually.

As to the Stockholm Workshop scale (1986) available for the diagnosis of white finger, the following items were discussed in Stockholm Workshop in 1994. The questions considered were the following. (1-a) Minimal requisites for the anamnestic diagnosis of vibration-induced white finger (VWF) (1-b) Screening methods for suspected VWF. (2) Advantages and limitations of the Stockholm Workshop scale for the classification of VWF. (3) Advantages and limitations of diagnostic cooling tests in subjects with VWF. (4) Arterial obliteration in fingers exposed to vibration: diagnostics and possible white finger sequence. Definition and estimation of white finger developed clearly in this Workshop as shown in the proceedings.

A wide range of disorders could occur as a result of vibration exposure: vascular disorders, peripheral neurological disorders, bone and joint disorders, muscle disorders and others. Each type may be a complex combination of several disorders and it is possible that disorders of one type arise as a consequence of disorders of another type. The model illustrated in Fig. 3 shows complex interactions between some of the many relevant variables and should warn against any expectation that cause-effect relationships for hand-arm vibration will be simple. As to peripheral neurological disorders which are important indicators of the exposure effect, the definition and disease model name, such as white finger is still not clear. The validity of normative values is based on the quality of epidemiologic data, which are particularly influenced by the selection of the study group. The cut-off point between normal and abnormal will depend on the relative occurrence of all determinants for the disorder, including both vibration and other ergonomic factors; for example grip force, working posture, as well as various medical conditions such as clinical disorders and physical factors. Studies performed to date on occupational groups using vibrating tools have not been able to distinguish between vibration and the several ergonomic factors which may cause neurological disturbances by evoking load on the locomotor apparatus and stress on neurological structures.

It is recognized that hand-arm vibration may cause or contribute to a variety of neurological disorders. The following further research is needed: (1) type of effect, (2) mechanisms and etiopathologic factors responsible for the effects, (3) models for the development of the effects, and (4) any reversibility of the effects. In order to allow a comparison between studies and pooling of results of studies, it is necessary to standardise testing techniques and evaluate their reliability.

**Guideline setting for hand-arm vibration in Japan**

There are many complex variables influencing the cause-effect relationships associated with hand arm
vibration: vibration variables, exposure variables and worker variables. It should not be expected that the measurement of a few values can be used to accurately predict the extent of vibration problems.

Until recently, many of the standards of the former U.S.S.R., former Czechoslovakia, Sweden, the U.K. and France were biased towards the simple specification of limits rather than the standardization of the measurement of vibration exposure. The Draft International Standard 5349.1 (International Organization for Standardization, 1979a) specified vibration limits for various exposure periods but was revised so as to define a more convenient means of quantifying complex exposures without specifying a limit. The revised document was published as International Standard 5349 in 1986. The measurement procedure, as in some national standards, involves the determination of the 'energy-equivalent' frequency-weighted acceleration received during a full day of vibration exposure. An Annex offers a means of calculating the period of exposure (in the range 1–25 years) required before the occurrence of various incidences (10–50%) of finger blanching as a consequence of exposure to 4h energy-equivalent vibration magnitudes in the range 2–50 ms$^{-2}$ r.m.s.

Annex to the current standard for measurement and evaluation of hand-arm vibration, ISO5349 presents a model for the relationship between white finger latency and vibration exposure expressed as 4 hour-equivalent daily acceleration in a small number of selected occupational groups including Japanese data having worked regularly with one type of tool or in one industrial process during most of the day. This exposure-response relationship was constructed with the help of a statistical and mathematical treatment of epidemiological data on white finger prevalence and latency in a number of studies carried out from 1946 to 1978. This ISO5349 has been used for the planning and implementation of prevention in several countries and has undoubtedly contributed to a general reduction in vibration exposure to the tools most used in industry. Because of the major importance of a reliable exposure-response relationship for adequate preventive work, the quality and accuracy of the studies on which the ISO5349 is based have been scrutinised from the view of technical aspects, occupational medicine and epidemiology.

On the other hand the Comité Européen de Normalisation (CEN) commenced work on the produc-
tion of harmonized standards concerned with human response to vibration. The machine-directive 89/392/EEC contains the obligation to inform the user about the hand-arm vibration emission of hand-held and hand-guided tools and of steering wheels etc. at mobile equipment if the weighted acceleration value exceeds 2.5ms\(^{-2}\).

Mirbod et al. reported that in eight groups of subjects operating various hand-held vibrating tools, the prevalence rates of VWF were investigated\(^{20}\). Hand-transmitted vibration levels (HTVLs) were measured on the back of the hand, by means of uni-directional (x-axis) vibration dosimeters, and the frequency-weighted acceleration levels were determined as the vibration levels. The prevalence rates of VWF in these subjects compared to those in more than 1,000 controls not occupationally exposed to vibration. It was observed that in subjects exposed to HTLVs of between 1.1 and 2.5ms\(^{-2}\), the prevalence of VWF was between 0 and 4.8%. The prevalence rate of primary Raynaud's phenomenon was 2.7% in male controls. They concluded that the prevalence of VWF should be employed in decisions concerning quantitative recommendations for vibration exposure.

Because of a lack of guidelines on hand-arm vibration in Japan, the Scientific Committee for Vibration Syndrome of the Japan Society for Occupational Health has discussed guideline setting for hand-arm vibration for a long time. Guideline setting must be a valuable preventive measure, but it is true that evaluation of the dose-response relationship has had some limitations as I mentioned above. I must add a reference to the following problems in evaluating dose and response. As to dose, 'single-value' measures of tool vibration attempt to indicate vibration severity without describing in detail the characteristics of the exposure: the frequency-weighted root-mean-square (r.m.s.) acceleration provides an average indication assuming a simple frequency dependence and a convenient duration dependence of vibration effects. An 8h (or 4h) energy-equivalent magnitude employs the same frequency weighting and time dependency to express the overall severity of a 1-day exposure to vibration. As to response, what is the most convenient single measure of human effects? Psychological response (temporal threshold shift in vibration sensation), cross-sectional exposure point prevalence of white finger and latency periods of white finger from the beginning of exposure have been discussed for a long time. And what about peripheral neuropathy as an independent human effect?

At present, a draft of guidelines has been open for discussion for several months. Fig. 4 shows the frequency weighted vibration acceleration (ahweq \cdot 8\text{hour}: 2.2\text{ms}^2) and exposure time in this draft. This new draft for hand-arm vibration will recommend as a guideline to the Committee of Threshold Limit Values of the Japan Society of Occupational Health in the near future. The procedures defined in current standards imply that effects depend on vibration frequency, direction and duration, but they are greatly influenced by practical convenience and the desire for uniformity between countries. Substantial scientific evidence of the relative effect potential of different frequencies, directions and durations is not available. Consequently the accuracy of the guidelines given in the standards cannot yet be quantified.

References


