Review

Pathophysiology of Vibration-Induced White Finger and Safety Levels for Hand-Transmitted Vibration

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Abstract: Pathophysiology of Vibration-Induced White Finger and Safety Levels for Hand-Transmitted Vibration: Ryoichi INABA, et al. Department of Hygiene, Gifu University School of Medicine—This review addresses the pathogenic mechanism and vibration safety values of vibration-induced white finger (VWF). Sympathetic hyperactivity alone has long been postulated to account for VWF, but damage to vasoregulatory structures and functions in the finger skin now also seems to be involved. The physiological complexity of the response to cold is so great and the interaction between various vasoregulatory mechanisms so intricate that only a multifactorial etiology and pathogenesis is likely for VWF. These factors will be discussed in detail. Regarding vibration safety values, the prevalence of VWF and vibration magnitude (hand-transmitted vibration levels (HTVLs)) in various groups of workers which reported in our previous studies were reviewed. The prevalence rates of VWF were compared to the prevalence rates of Raynaud's phenomenon (RP) in a large group of males and females without vibration exposure. It was observed that in subjects exposed to HTVLs of between 1.1 and 2.5 m/s², the prevalence of VWF was 0.0-4.8%. The prevalence of VWF in workers exposed to HTVLs of up to 5.1 m/s² was 9.6% and significantly higher than the prevalence of RP in males in the general population (2.7%). A significant positive correlation between VWF and HTVLs values was obtained. By employing the results obtained on vibration magnitude and the prevalence of VWF, estimated vibration safety levels are discussed. (J Occup Health 1996; 38: 1-5)

Key words: Vibration-induced white finger, Vibration syndrome, Raynaud’s phenomenon, Pathophysiology. Prevention, Hand-transmitted vibration level

Prolonged exposure to hand-arm vibration may cause disturbances in the peripheral circulation, peripheral nerves, muscles, bones, and joints of the hands and arms. These disorders constitute an entity called the hand-arm vibration syndrome (HAVS). The mechanism behind the acute attacks of vibration-induced white finger (VWF) is well known as an abnormally strong contraction of skin blood vessels. The question of where the primary site of the lesion is localized, however, is controversial. The pathophysiology of VWF previously seemed to be regarded as a clear cut case of sympathetic hyperactivity, but that hypothesis is now regarded as too simple.

As VWF is known to be the most prominent component in HAVS, a number of criteria have been proposed in different countries on the basis of the relationship between the vibration magnitude and the prevalence of VWF. In Japan, HAVS has been recognized as an occupational disease for many years, but documentation for the general risk assessment of vibration exposure has not yet been established. For only one group of workers exposed to hand-arm vibration (i.e., chain saw operators in the state forests of Japan) improvement has been made in working conditions since 1978.

In this paper the publications on pathophysiology of VWF and vibration safety values, mainly our papers concerning the prize for the encouragement of research awarded by the Japan Society for Occupational Health in 1994, are reviewed. The estimated vibration-doses are also discussed.

Pathophysiology of vibration-induced white finger

The decisive role of sympathetic hyperactivity alone has long been taken more or less for granted, but it seems that vascular and vasomotor nerve structures in the finger skin are also closely involved. It is therefore more reasonable to assume that a number of factors are related to the pathophysiol-
ogy of VWF\(^2\), and these are discussed in this paper.

Three types of chronic condition indicating a chronic dysfunction of the autonomic nervous system have been observed in persons working with hand-held vibrating tools\(^3\): (1) changes in cardiac and hemodynamic functions\(^3,4\), (2) excessive hearing loss in workers with VWF\(^5,6\), and (3) reduced toe skin temperature, due to the influence of prolonged exposure to stressors, also in the absence of acute cold or vibration exposure, in persons exposed to hand-arm vibration\(^7\). The problem in reports on the first type of condition is that the confounding and effect modifying of psychological and other factors have not been clarified\(^8\). Concerning the third type of condition, Yamada and Sakakibara\(^9\) considered that workers with VWF issue cold signals to the central nervous system, hypothalamus, much more often than controls.

Sympathetic hyperactivity alone has long been postulated to account for VWF. With a microneurographic method, Ishida et al.\(^9\) observed the changes in sympathetic nerve activity in the skin following cold water immersion in patients with VWF and healthy subjects, but they failed to obtain results which support the hypothesis that increased activity of the sympathetic nervous system is of primary importance in the triggering of RP. An abnormal level of sympathetic efference is likely to be important in producing VWF, but damage to vasorregulatory structures and functions in the finger skin now also seem to be involved in the pathogenesis. Ekenval et al.\(^10\) recently showed that VWF is caused by selective damage to alpha-1 receptors, resulting in abnormally strong vasoconstrictory response to skin cooling resulting from a predominance of alpha-2 adrenoceptors.

Some investigators have suggested the possibility that there is some relation between organic changes in the arteries and the occurrence of VWF\(^11,14\). Ashe and Williams\(^11\), and Takeuchi and Imanishi\(^4\) reported the results of skin biopsy in workers with VWF in whom medial and intimal thickening of the small arteries was observed. We\(^15-17\) therefore examined in an animal experiment whether the pathogenesis of VWF could be traced to organic changes in local and peripheral vessels induced by repeated exposure to vibration. For 30 days or 90 days the hind legs of rats were exposed daily to local vibration (60 Hz, 5 G) with a duration of four hours per day. In three of the five rats exposed for 90 days, several degrees of severity of thickening of the small arteries was observed. Disruption of the internal elastic lamina was observed in the small arteries. This disruption was followed by focal cell proliferation with regenerative formation of collagen and elastic fibers. This fibrocellular thickening of the intima was further augmented, and in addition complete stenosis of the lumen of small arteries was observed. Electron micrography showed that the fibrocellular thickening of the intima consisted of proliferation of arterial smooth muscle cells and numerous collagen and elastic fibers. But in this animal experiment, the thickness of the media was not observed. By applying the theory of the pathogenesis established by Ross et al.\(^18\), we hypothesized the pathogenic mechanisms for the intimal thickening induced by vibration exposure. Endothelial injury is initially caused by local vibration either directly or indirectly. The injury results in an endothelial desquamation followed by adherence and aggregation of platelets at the site of the injury. During the process, a mitogenic factor, secreted from the platelets, gains entry into the artery wall and causes a focal proliferation of intimal smooth muscle cells. If the injury is a single event, the lesions may heal and regress, with a slightly thickened intima being the result. In contrast to this, a chronically repeated injury to the endothelium develops the intimal thickening. By skin biopsy, Ashe and Williams\(^11\) found that the severity of the intimal thickening of the small arteries observed in workers using vibrating tools was relevant to the clinical condition. Taken together with other observations, our experimental study therefore indicates the involvement of the severity of the intimal thickening of the small arteries in the occurrence of VWF. It should be noted that not all workers with VWF have such intimal thickening, although the development of the thickening leads to the occurrence of VWF. It is assumed that periperal functional disorders in addition to such organic changes in local vessels act in the occurrence of VWF.

The results of our recent experiments\(^19\) with iontophoresis of sodium nitroprusside and methacholine into the finger skin of subjects with and without VWF, and laser-Doppler recording of blood flow suggested that vibration exposure may cause functional damage to endothelial vasoregulatory mechanisms. A weaker vasoconstrictor reaction to methacholine, but not to nitroprusside, was observed in the combined group of subjects with current and past white finger than in those who had never experienced white finger. This agrees with the physiological premises: metacholine induces relaxation only through endothelial-derived relaxing factor (EDRF), while nitroprusside also has direct access to the smooth muscle. The results are therefore consistent with endothelial damage and disturbance of EDRF-mediated vasoconstrictor function.

We\(^20\) measured the whole blood and plasma vis-
cosity in vibration-exposed workers with and without VWF. Our results demonstrated a significant increase in whole blood viscosity (but not in plasma viscosity) in workers with VWF as compared with those without VWF. In an animal experiment, we examined whether or not whole blood viscosity increases after repetitive exposure to local vibration. Whole blood viscosity in the vibration-exposed group (60 Hz, 5 G, 90 days) was significantly higher than that in the control group. Reduced vessel diameter drastically increases blood viscosity, but other factors related to vessel diameter and viscosity (e.g., turbulence) also strongly influence blood flow. It is a cautious contention that increased blood viscosity may be an important contributing factor in producing the vasospasms in VWF but it may occur only when there is endothelial damage with consequent platelet aggregation.

The possibility that there is an enhanced response of the vasomotor receptors (or effectors) to a cold stimulus is pathogenetically important in the development of VWF but unclarified, largely because of the complexity of vasoregulation. In addition to the adrenergic, cholinergic and purinergic receptor systems, serotonergic, mechanisms have been shown to interact with other systems, and there are several subtypes of specific receptors. Endothelium-dependent substances such as nitric oxide (NO), EDRF and prostacyclin as well as endothelin, a potent vasoconstrictor, relate to many of the other systems. Cold, like vessel wall injury, causes platelet aggregation and skin vasoconstriction as a net effect of the liberation of various vasoactive substances. Intimal damage may become a site for platelet aggregation—further enhanced by both local cooling and warming—and consequent release of vasoconstrictor substances such as thromboxane, serotonin, and thrombin.

Safety levels for hand-transmitted vibration

A number of guidelines for the assessment of exposure to and hazards of segmental vibration have been published in many countries. For instance, in the United Kingdom, a 4 m/s² safety value is supposed to result in only a 10% prevalence of VWF during 4-h exposure daily for 8 years. In Denmark, a vibration magnitude of 3.1 m/s² has been said to result in only a 10% prevalence of VWF with a daily 4-h exposure for 10 years. In France, it has been estimated that the 4-h equivalent vibration level must be less than 7.5 m/s² for an exposure duration between 0.5 and 6 h. Most of these safety values are based on criteria published by the International Organization for Standardization (ISO 5349).

In Japan, the ISO 5349 guidelines have usually been used for the assessment of risk due to hand-arm vibration, but because of differences in climatic conditions, workers' physical and biological abilities, tolerance of working with hand-held vibrating tools, and the prevalence rates of RP in the general population, a vibration-dose limit for Japanese workers should be estimated. In the design of our studies, we therefore paid particular attention to the prevalence of finger blanching in workers exposed to vibration and in the Japanese general population not using vibrating tools.

The hand-held transmitted vibration levels (HTVLs) and prevalence rates of VWF were investigated in eight groups of subjects operating various hand-held vibrating tools and aged 30–59 years (164 male dental technicians, 54 male orthopaedists, 256 male technicians in the aircraft industry, 79 male digging laborers, 27 male workers using hand-held grinders in a precision industry, 46 female sewing machine operators, 23 male workers using tea harvesting machines, and 272 male chain saw operators). HTVLs were measured on the back of the hand, by means of unidirectional (x-axis) vibration dosimeters (Type VB-03, Rion Co., Tokyo). The VWF prevalence rates were compared to the RP prevalence rates in the hands of 1027 males and 1301 females not occupationally exposed to vibration (age range: 30–59 years).

It was observed that in subjects exposed to HTVLs of between 1.1 and 2.5 m/s², the prevalence of VWF was between 0.0% and 4.8%. The prevalence of VWF reached 9.6% in chain saw operators exposed to HTVLs of 2.7–5.1 m/s². The latter group showed a significant difference in the prevalence of VWF compared to the 2.7% prevalence of RP in male subjects in the general population. The prevalence of VWF in female sewing machine operators (4.3%) was not significantly different from the prevalence of RP in female subjects in the general population (3.4%). It should be mentioned that the HTVL values were obtained on the x axis (on the back of the hand), which in some cases may be lower than that for combined components (x, y and z). Regarding the result of a study by Thiede et al., however, we speculate that if the HTLs are about 2.5 ± 1.2 m/s², the risk of developing VWF in the exposed subjects may be decreased to some extent.

As in some Japanese industrial sectors the maximum daily vibration exposure has been reduced to 2 h/day (in the state forest companies); so that it is also necessary to establish a safety limit for 2-h daily vibration exposure. The prevalence of RP in
Japanese male subjects in the general population did not differ significantly from that reported in 256 male Chinese workers not exposed to vibration (1.6%)\textsuperscript{35}. That is, the prevalence of RP in the Japanese and Chinese general population is the same. A literature review was therefore conducted on publications from Japan and China which contain useful information on the relationship between exposure and response, i.e., between vibration magnitude and duration of exposure and the occurrence of VWF. Among numerous reports, only publications in which the daily exposure time of workers had been cited as <6 h/day were selected. By plotting the prevalence of VWF against the frequency-weighted vibration acceleration, it was observed that there was a significant correlation between the prevalence of VWF and the vibration magnitude ($R^2=0.8$). By using the results obtained, it was reported that the prevalence of VWF in workers using vibrating tools may be restricted to the prevalence of RP in the Japanese general population if the vibration magnitude is about $4.5\pm1.2$ m/s$^2$, but the application of this value should be further evaluated.

Griffin\textsuperscript{36} stated that many factors should be taken into consideration to evaluate the exposure to hand-transmitted vibration. 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 (e.g. grip), its physical characteristics (e.g. weight), the ambient temperature and other factors may affect the severity of vibration exposure. In Stockholm Workshop 94, this topic was discussed. One of the topics for ISO in 1994 was the evaluation of 8-h energy-equivalent frequency-weighted acceleration [A (8) in m/s$^2$]. In these conditions, Bovenzi\textsuperscript{37} investigated the relationship between vibration exposure and VWF among stone workers in Italy. Hand-transmitted vibration was measured on the handles according to ISO 5349. Daily vibration exposure was assessed in terms of 8-h energy-equivalent frequency-weighted acceleration. On the basis of the estimated regular vibration exposure time per year and the frequency-weighted acceleration measured on the tools, he calculated the individual vibration exposure index as acceleration-weighted exposure time (m/s$^2 \cdot$ hours/year). This report should be very helpful for our future studies\textsuperscript{38}.

We should mention that so far no firm guidelines have been established regarding maximum no-effect vibration exposure levels, but, following a general opinion, we suggest that extensive vibration exposure tasks should be minimized. Redesigning of tools and jobs may be required in many situations. To establish preventive measures, in addition to achieving appropriate reductions in risk factors, medical surveillance (e.g., periodic medical examination) is required and will make possible greater appreciation of the extent of the vibration syndrome, as well as assessment of the efficacy of preventive intervention.

References

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