EDITORIAL RESPONSE

The NIOSH Review of Hand-Arm Vibration Syndrome: Vigilance Is Crucial

There is strong epidemiologic evidence that high-level exposure to vibration is associated with the vascular symptoms of hand-arm vibration syndrome (HAVS), our conclusion in *Musculoskeletal Disorders and Workplace Factors.*[1] The epidemiologic literature consistently shows that one critical factor for development of HAVS is "vibration dose," which is a product of vibration level and exposure time. Also consistently seen is a strong relationship between exposure time and the severity of HAVS. The literature clearly shows that the use of antivibration devices on tools, particularly those on chain saws, have extended the time interval between exposure to vibration and development of symptoms (the latent interval). Hadler[2] admits that much has been accomplished in high-exposure occupational groups (such as quarrymen and chain-sawyers) to modify and design new tools, and to control exposure through administrative action, personal protection, and through medical monitoring to reduce the occurrence of HAVS, all of which are the crux of the recommendations found in the *NIOSH Criteria for a Recommended Standard on Occupational Exposure to Hand-Arm Vibration.*[3] The epidemiologic and clinical data support the conclusion that healthy workers who use vibrating tools can be protected from developing the disabling effects of HAVS.

Although advanced stages of HAVS are extremely rare these days, it is estimated that hand-arm vibration jeopardizes the health and future employability of two million workers in the United States and the United Kingdom alone.[4] An estimated 8% of currently employed US workers report exposure to vibrating hand tools over four hours in a workday.[5] Behrens and Pelmear [6] found high usage in the construction, shipbuilding, agriculture and forestry, and mechanical engineering industries. Behrens et al[7] noted that the prevalence of HAVS was greater among incentive workers than among workers paid by the hour in the United States. Vibration exposure continues to be a significant hazard in many contemporary work environments.

In his editorial, Dr. Hadler expressed concerns about the epidemiologic evidence that was used to support the conclusions of the National Institute of Occupational Safety and Health regarding the work-relatedness of HAVS. In this response, we will examine relevant information from the NIOSH epidemiologic reviews and discuss the issues raised by Dr. Hadler.

The 1997 NIOSH Musculoskeletal Review

In 1997, NIOSH published a critical review of the epidemiologic literature of selected musculoskeletal disorders (MSDs) of the upper extremity (including HAVS) and low back and their relationships to physical factors at work.[1] Greater focus was given to studies that had objective exposure assessment, high participation rates, a physical examination as part of the epidemiologic case definition, and a blinded assessment of either health or exposure status. Further analysis determined whether studies were likely to be substantially influenced by confounding or other epidemiologic limitations that might have major influences on the interpretation of findings. These included the absence of non-respondent bias, selection bias, and comparability of study and referent groups. The document also described information about confounders and epidemiologic pitfalls for each detailed study reviewed. After assessing the quality of individual epidemiologic studies, NIOSH investigators judged whether the evidence was strong enough to relate the exposure factor to the MSD. The framework for evaluating evidence for causality in the review included a modified Bradford-Hill[8] characterization of each study, looking at strength of association, consistency, temporality, exposure-response relationship, and coherence of evidence.

In his editorial, Dr. Hadler suggests that the HAVS chapter is limited in that it presents a review of only recent literature. It should be pointed out that in preparation of the document, HAVS presented NIOSH researchers with a charge different from that of other disorders. Unlike the other MSDs, NIOSH had already recently examined the epidemiologic literature for HAVS.[3] NIOSH concluded that there was strong evidence for a relationship between vibration and HAVS. Thus, for the 1997 document, we concentrated on studies published subsequent to the prior review.

Review of the Epidemiology of HAVS

Results of NIOSH 1989 Review

Hundreds of studies on HAVS have been published, dating back to the work of Loriga[9] (1911) and

Hamilton[10] (1918), who described Raynaud's Phenomenon (RP) in workers using pneumatic tools. Researchers[11,12] in the 1930s and 1940s showed that white finger syndrome was on the increase and that RP increased with the years exposed to vibrating hand tools.[13] In the 1960 report by Pecora et al[14] (mentioned by Hadler[2]), it was stated that among those industries approached, occupational RP from hand tools was "practically nonexistent, " since no compensation claim had been paid in the previous ten years and no case reported. However, in 1963, Williams and Reigart[15] found RP of occupational origin among uranium miners using jack-leg hammers and stoper drills. Likewise, in 1963, prevalences of RP above 70% were found among pneumatic tool users in European iron, steel, and engineering industries.[16] In 1962 and 1964, Ashe et al[17,18] found HAVS in a group of hard-rock mine drillers whose arteriographies and biopsies (in the severe cases) showed extensive pathological damage to the arteries of the fingers. Subsequent reports occurred from studying jack-leg drillers from metal mining rock drillers in Canada,[19–22] the United States,[23] Japan,[24,25] Korea,[26] and Europe,[27–29] with prevalences ranging from 12.5% to 50% and median latent intervals from 4.5 to 17 years.

In NIOSH's 1989 review[3] of 52 cross-sectional studies from 1969 to 1986, the prevalence of vascular symptoms of HAVS ranged from 6% to 100%. More than half the studies found HAVS prevalence rates greater than 40%. Nineteen of the studies reported that the prevalence of vascular symptoms among workers at the same sites without vibration exposure ranged from 0% to 14%, with a mean of 5%. Forty-four studies included some information about the latency of vascular symptoms among exposed workers. Thirty-three of these reported that the mean latency of vascular symptoms ranged from 0.7 to 17 years, with a mean of 6.3 years. A statistically significant relationship for linearity ($r^2 = 0.67$, $P < 0.01$) was found between the HAV acceleration level and the prevalence of vascular symptoms in the 23 studies that reported vibration measurements. Thus the prevalence of vascular symptoms tended to increase as the HAV acceleration level increased. Of the three longitudinal studies reviewed by NIOSH in 1989,[3] all were able to demonstrate an appreciable decrease in the prevalence of vascular symptoms after the introduction of the antivibration chain saw. The 5-year cohort study by Brubaker et al,[30] issued after the NIOSH review, concluded that antivibration saws were not effective at preventing RP, but the study had a poor follow-up participation rate (53%), so interpretation of results must be viewed with caution. Saito,[31] on the other hand, attributed prevention of HAVS to improvement in chain saw design, age restriction of employees, and a decrease in operating time.

Results of NIOSH 1997 Review

The studies from the 1997 review[1] by NIOSH researchers were those of workers with high levels of exposure, such as forestry workers, stone drillers, stone cutters or carvers, shipyard workers, and platers, and included 18 studies conducted between 1988 and 1995 (two studies[32,33] were conducted prior to 1988). Thirteen of the studies found prevalence rates greater than 20% for HAVS vascular symptoms among workers exposed long term to HAV. Significant results (odds ratios or relative risks) could be derived in 13 studies when comparing exposed workers with referents; four studies reported only prevalence of symptoms among exposed workers. One study[32] did not find significant differences, most likely because it evaluated male construction machine operators who used heavy vibrating equipment (bulldozers and forklifts) but not hand tools.

Specific Methodologic Issues

In his editorial, Hadler[2] questions whether specific abnormalities were found in the studies described above. Severity scales for VWF have been established by consensus groups composed of international researchers in the field. The clinical picture and the epidemiologic case definition of HAVS were defined in 1983.[33] Prior to this, Taylor and Pelmear[34] derived a grading index by stage of symptoms and social/work interference. In Table 2 of his article, Hadler[2] outlined for us the 1986 Stockholm revision, which supported separate staging systems for the vascular and sensorineural phenomena. At the Stockholm Workshop on Hand-Arm Vibration Syndrome in 1994,[35] the consensus from the Working Group on Clinical and Laboratory Diagnostics of Vascular Symptoms Induced by Hand-Arm Vibration was that screening methods for the anamnestic diagnosis of VWF, such as questionnaires, should be based on the proposed minimal requisites for the diagnosis of VWF in a medical interview. Furthermore, they stated that the advantages of the Stockholm Workshop Scale[36] are far greater than any limitations. They recommended that the scale be used in clinical work and epidemiological studies. Four of the studies we reviewed used the Stockholm Scale for symptom classification. Four studies used the Taylor and Pelmear scale, and 10 mentioned using unspecified questionnaires or interviews and some of these used additional tests, such as cold provocation. There were two articles that did not use questionnaires or interviews (McKenna et al, 1993, and Shinev et al, 1992).[37,38] Of those seven studies[30,39–44] that reported the separate classification stages of RP, all reported greater than 30% to 40% of the vibration-exposed workers to be in either stage 2 (moderate grade) or stage 3 (severe grade). None of the studies reported any unexposed referents in stage 3; the range in stage 2 was 0% to 6%.

Cherniak et al[44] found that 25% to 33% of those subjects reporting vascular symptoms had abnormal clinical responses to either light touch, pinprick, 30-Hz tuning fork extinction, or two-point discrimination. Thus many of the reviewed studies used standardized scales to classify symptoms; the stages defined by these scales clearly identify level of severity and sensorineural abnormalities.

Our review clearly demonstrates that an increase in symptom severity is found in workers exposed to high levels of vibration, compared with unexposed workers. In studies that included further evaluation, severe symptoms have been correlated with objective evidence of dysfunction, as demonstrated by abnormal physiologic responses. In recent[45,46] and older[17,18,47] studies, physiologic abnormalities in subjects with VWF have been documented by anatomical changes. We believe, therefore, that the studies we reviewed do present real abnormality with regards to VWF. And it is prudent and scientifically reasonable, until further epidemiologic studies have been completed to demonstrate specific quantitative exposure limits, to focus our recommendations on preventing workers who use vibrating tools from developing the signs and symptoms of Stockholm Stage 1 during a working lifetime.

Hadler[2] indicates that "specialized testing" was used to try to discern abnormality and define RP in many of the epidemiologic studies reviewed in the NIOSH document.[1] We disagree. Our review showed that overall, the epidemiologic studies used fairly standard case definitions of VWF using the Stockholm Scale[38] or combination of the scale and medical examination. The "specialized testing" (eg, Allen's test or vibrometry) to which Hadler[2] refers was supplemental and not for clinical diagnostics. These tests were for the epidemiologic purpose of determining differences between vibration-exposed and unexposed groups, or between cases and controls.

Regarding Hadler's[2] statement that cold provocation is controversial, we believe he is ignoring the final summary recommendations of the 1994 Stockholm Workshop,[45] the source of the majority of his references. Olsen et al[48] state "that a positive cooling test supports the diagnosis of RP which has been made during a medical interview. Cooling tests using visual inspection of finger colours and cooling tests measuring finger systolic blood pressure and using a recorded zero blood pressure as a detection limit, are the most supportive objective tests of the diagnosis of RP when the tests are positive." Other investigators concluded that the bulk of reliable clinical data from 4500[49] patients in the international literature suggests that such cooling tests have reproducible, diagnostic, and prognostic value and provide significant data for grading the severity and assessing the reversibility.[50–52]

As to the interobserver reliability of a timed Allen's test, we believe Hadler[2] may have been misguided by focusing on the conclusions of the study by Haines et al,[53] without examining whether the methods were comparable to those used by Nilsson et al.[39] One cannot use a reliability measure calculated for a 3-second timed Allen's test (which is used to detect problems with arterial line placement in intensive care units) and apply this measure to a 35-second timed Allen's test used in vibration-exposed workers. These are not the same test, as Haines et al admit, and the predictive value, sensitivity, specificity, and interobserver reliability, derived for a 3-second test and a 35-second test will be quite different. Also, Haines et al[53] used the test in a population of sheet metal workers with low use of vibrating tools as compared with platers with high use in the study by Nilsson et al,[39] a difference that would further invalidate the comparison.

We would refer Hadler[2] back to Olsen et al[48] for answers to his questions concerning consensus as to the reliability of recall, the fashion in which it is to be elicited, and the basis for quantification. These issues are addressed, and the recommendations from the Working Group are as follows: "A medical interview is accepted as the best available method of diagnosing RP and VWF." We recognize that symptom reports by patients may be open to bias, but, in view of the large number of populations studied, the use of both questionnaire and medical interview, based on an international symptom scale, seems appropriate to investigate the occurrence of VWF among worker groups at risk. With regard to validity of self-reported exposures, Nilsson et al[39] reported evidence for good concordance between estimated and measured exposure time among vibration-exposed workers.

Permissible Exposure Levels

Hadler[2] criticizes several professional organizations that put forth recommendations and guidelines for permissible worker exposure to HAV. Currently there are three human-exposure guidelines to HAV used in the United States: the American Conference of Government Industrial Hygienists Threshold Limit Value for Hand Arm Vibration,[54] the American National Standards Institute S3.34 standard,[55] and the NIOSH HAV Criteria.[3] There is one UK standard (British Standards Institution BS 6842[56]), one international standard (International Standards Organization [ISO] 5349.5[57]), and several standards in other countries. We will focus on the ISO 5349[57] and NIOSH guidelines.[3]

The ISO 5349 standard. In the 1960s, the ISO developed the HAV standard based primarily on laboratory-response data (not epidemiologic data). Subjects were asked to respond (as functions of exposure time) to vibration intensity and frequency they experienced in their hands from grasping handles attached to small vibrating shakers. A series of "elbow-shaped," time-dependent, daily vibration dose curves were formulated from these studies. These weighted curve shapes, together with some early vibrating-tool data, became a critical part of the ISO 5349. Brammer's[58] review of HAV studies became the basis of the current ISO 5349 dose-response section. For the ISO 5349, the daily weighted vibration exposure is determined for three perpendicular hand directions; each result is then separately normalized to a 4-hour equivalent exposure for each axis. These results are then sequentially applied to a dose-response graph to determine the onset of HAVS peripheral vascular symptoms as a percentage of the exposed population. The ISO chose *not* to recommend acceptable human vibration intensity (acceleration) values for various exposure times throughout the workday. The ISO deferred to each country the choice of selecting their own acceptable weighted acceleration levels. Wasserman[59] outlined that the ISO 5349 provided what the ISO Committee believed to be the "weighted" shape (or envelope) of the human hand-arm response to HAV exposure (analogous to "A" weighting of the ear's response to sound). These weighted curve shapes are important since they determine the magnitudes and frequencies at which the instrumentation records the vibration intensity impinging on the worker's hands. Virtually all HAV standards, NIOSH's excepted, use this weighted measurement concept.

The NIOSH criteria document[3] discussed several issues raised by the ISO standard. The first issue was whether the ISO human hand-arm response curves are valid for the newer, faster tools with high-frequency vibration components above 16 Hz. The current ISO standard doesn't address these higher frequencies. Second, the ISO standard does not account for unweighted vibration levels. Frequency-weighted acceleration assumes that the harmful effects of vibration are independent of frequencies between 6.3 and 16 Hz but progressively decrease with higher frequencies between 16 and 1,500 Hz. NIOSH concludes that this measurement grossly underestimates the total energy produced by the vibrating tool and may then grossly underestimate the HAVS-producing effect of the high-frequency vibration exposure.

NIOSH criteria. In 1989, NIOSH[3] recommended a standard for exposure to HAV that included engineering controls, good work practices, use of protective clothing and equipment, worker training programs, administrative controls such as limited daily use time, medical monitoring and surveillance—many of the things for which Hadler[2] is calling. NIOSH chose not to issue any *recommended exposure level* (REL) because the data on the pathogenesis of HAVS were not sufficient to establish a level that would ensure that healthy workers who use vibrating tools would not develop signs and symptoms of HAVS. NIOSH required medical monitoring of all vibration-exposed workers in order to identify the signs and symptoms of HAVS and to remove (at the stage 2 level) such workers from vibration exposure until they are free of all vibration-related symptoms. The NIOSH criteria document[3] specifies (a) weighted and unweighted triaxial acceleration measurements, (b) an extended frequency bandwidth from 5.6 Hz to 5,000 Hz, not the 1,400 Hz in existing standards, thus encompassing the high-speed tool spectra, and (c) labeling of vibrating tools with their overall acceleration levels. The document voiced concern over the shape of the weighted curves used in the ISO standard and their sufficiency to protect workers principally exposed to high-speed tools. NIOSH recommended that worker exposure be controlled by reducing exposure to HAV to the lowest feasible levels and exposure times by adhering to its control strategies, such as the use of antivibration clothing, mittens, gloves, and equipment, and by worker training programs.

Conclusion

From epidemiologic studies of groups highly exposed to HAV, evidence supports a monotonic relationship between the acceleration exposure dose (level of acceleration and years of exposure) and the latency and severity of HAVS. HAVS has been observed in workers who have used vibrating tools that transmit energy to the hands and arms over a wide range of acceleration levels. We disagree with Hadler[2] that NIOSH has singled out archaic work practices—the problem of physiologically significant exposure to vibrating tools is still widespread.

We share Hadler's[2] concern that workers are not only exposed to hazardous vibration but have an even greater risk day to day of acute injury. Lacerations, amputations, fractures, and other work-related musculoskeletal injuries—which lead to disability and some degree of incapacity to which Hadler[2] refers—are being addressed both at NIOSH and in the larger research community. But just because greater problems may deserve more resources, other problems need not be ignored. The challenge that we all have is eliminating all of those risk factors—including risks from HAV—which prevent workers from experiencing fulfilling lifelong pursuits of labor.

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