VII. METHODS FOR WORKER PROTECTION

The major emphasis for worker protection from HAVS should be directed toward prevention. After the disorder has progressed beyond Stage 2 of the Stockholm classification, procedures designed to reverse the process are usually not effective. Because the development of HAVS is dose related, effective control procedures should be directed to (1) reducing the intensity (acceleration) of the vibration, (2) reducing the exposure duration, (3) identifying the early signs and symptoms, and (4) identifying vibration-sensitive individuals. Control strategies include (1) exposure monitoring, (2) engineering controls, (3) work practices, (4) ergonomic considerations, (5) protective clothing and equipment, (6) worker training, and (7) medical monitoring.

A. EXPOSURE MONITORING

Any effective control procedure requires objective data on the degree of hazard to which the worker is exposed. For the use of vibrating tools, these needed data are the vibration acceleration expressed in m/sec^2 rms measured in the three basicentric coordinates (or the coordinate with the highest acceleration), and the time in minutes per day that the tool is actually in use (scheduled or nonscheduled rest breaks are not included as exposure time). The acceleration measurements should be made as described in Chapter III, B.1 and B.2.

B. ENGINEERING CONTROLS

The major engineering approaches to the elimination or reduction of the vibration acceleration level exposure are (1) reduction at the source, (2) reduction of transmission, and (3) process modification.

1. Reduction at the Source

The acceleration level usually increases with an increase in the speed at which the tool is operated (e.g., a chain saw operating at two-thirds throttle produces significantly less vibration energy [acceleration] than one operating at full throttle). A tool designed to operate at a reduced speed while providing adequate power for the job could be beneficial. The relationship between the weight of the tool and the power needed to drive the tool will also influence the amount of vibration produced. The reciprocating gasoline engine used to power some tools is a major source of vibration. A rotary gasoline engine or an electric motor as a power source may be a successful alternative, provided it meets the operational requirements. If several tools are available that serve the same function, the tool producing the lowest acceleration should be chosen.

How well the tool is maintained will influence the level of vibration during operation. A sharp chisel or saw chain, a flat-dressed grinding wheel, and a finely tuned engine will reduce the vibration level. To maintain the optimal level of tool maintenance, the operating personnel must be adequately trained in maintenance procedures and be aware of the need for maintenance. A scheduled maintenance program should be established.

2. Reduction of Transmission

The vibration energy produced by the vibrating tool must be transmitted to the operator's hands or arms to produce a harmful effect. Any strategy that reduces the transmission from tool to hand will help prevent HAVS. Several types of energy-damping materials have been used to cover the handles of the tools or have been incorporated into the fingers and palms of hand gear with varying degrees of success. Some materials will reduce vibration transmissions at low-frequencies, and others may reduce those at higher frequencies. Damping materials in handwear are usually more effective for the higher frequencies. However, coverings on the tool handles or glove fingers and palms may interfere with the ability to control the tool during operation and thus may lead to reduced production or increased risk of accidents.

Rens et al. [1987] reported that cotton or leather gloves used for protection against trauma, chemicals, and temperature provide little or no protection against vibration and may even increase the transmission of the vibration.

Another approach to reducing vibration transmission is the use of offset handles, spring-loaded handles, and shock-adsorbing exhaust mechanisms. Again, the operating efficiency at the tool/work-surface interface would have to be considered. A decrease in the vibration transmission level must not be offset by an increase in the time needed to complete the task.

3. Process Modification

An ergonomic analysis of the entire industrial process is recommended to determine whether changes in some aspects of the process could reduce or eliminate the need for vibrating tools. For example, introducing a different casting process in a foundry might result in smoother castings and might therefore reduce or eliminate the need for grinders or power chisels. Using mechanical aids such as chucks and clamps to hold the piece being worked on can reduce the time and the intensity of the vibration exposure. Introducing automation and robots (e.g., robots used for spot welding to replace hand-held riveting guns) could reduce the need for workers to use vibrating tools. Where the size of the trees and the terrain are suitable, automated logging machines can reduce the need for chain saws to fell and debranch trees. Substituting alternative materials (e.g., plastics for cast metal) might reduce or eliminate the need for grinding or chipping operations.

Where the process produces such extreme vibration forces that they cannot be adequately controlled by any means, complete abandonment of the process may be the only feasible solution. Although such a situation may never occur, the possibility must be kept in mind.

C. WORK PRACTICES

Because the pathophysiologic effects of using vibrating tools are related to vibration intensity and use time, the total daily, weekly, and yearly exposure time and the daily exposure schedule are important factors in preventing workers from developing HAVS. The epidemiologic data and clinical experiences discussed in Chapter IV suggest some practical and acceptable work practices that can be implemented to reduce the health impact of using vibrating tools.

Saito [1987] studied the effects of limited tool use time on the presence of HAVS in 155 chain saw operators between 1978 and 1983. Each year the operators were medically examined. Skin temperature, vibratory threshold, recovery of nail bed color after compression, and pain sense were measured before a 10-min exposure of the hand to cold water (10°C) and 5 and 10 min after exposure. The results of 6 years of observation suggest that limiting chain saw use time can help prevent the occurrence of HAVS. The suggested chain saw use schedule was as follows:

One operating cycle (min)	10
Total operating time per day (hr)	2
Consecutive days of use	2
Operating hours per year	320
Upper age limit (years)	55

The daily duration of exposure can be regulated by the length of the workday or by introducing exposure/nonexposure cycles of varying lengths throughout the usual workday. Most exposures are not continuous throughout the workday but consist of actual tool operation of varying lengths of time interposed with scheduled and nonscheduled periods when the tool is not in operation. The large number of possible combinations of work/rest cycle schedules permit choosing one that will best fit the requirements of most industries.

Types of exposure schedules that are applicable include the following:

- Alternating work tasks involving a vibrating tool with some other task that does not involve exposure to vibration (on hourly or daily basis)
- Limiting daily use of vibrating tools as much as possible if acceleration is high
- Limiting use of vibrating tools to 1 or 2 days a week
- Scheduling sufficiently long rest periods each hour to reduce the time-weighted acceleration levels

D. ERGONOMIC CONSIDERATIONS

The amount of the tool-produced vibration that is transmitted to the hands and arms of the operator is influenced by (1) the grip force with which the tool is held, and (2) the force applied by the operator holding the tool against the workpiece [Sakurai and Matoba 1986, Farkkila 1978]. The tool should be held as loosely as safe tool control and operating requirements permit. The force applied to hold the tool against the workpiece should be minimal. The weight of the tool should be used to help provide the required tool/workpiece interface pressure for optimal working speed and efficiency. Moisture at the hand/tool interface (sweat or liquids) may require the worker to exert greater grip force to control the tool. A slip-resistant interface surface is desirable.

Another important ergonomic factor is the position of the body while operating the tool. The angle of the wrists, elbows, and shoulders during tool operation will influence the level of stress exerted on the joints and tendons and the incidence of such problems as tendinitis, carpal tunnel syndrome, tennis elbow, painful shoulders, and HAVS.

An ergonomic analysis of how the work is done is important. Such an analysis can determine the operating practices that may require modification to minimize health problems.

E. PROTECTIVE CLOTHING AND EQUIPMENT

Two generic types of protective clothing and equipment may be used to provide protection against the effects of vibration. These include (1) those that reduce transmission of vibration energy to the hand and (2) those that protect against exposure to cold and trauma.

Various types of vibration-damping materials have been incorporated into gloves and mittens to protect the user of vibrating tools. If these are sufficiently successful as energy dampers, this approach could be very acceptable. For most tasks involving vibrating tools, hand gear of some type is used for protection against trauma and cold. Presently, the major problem is finding energy-damping materials that (1) provide adequate damping with minimal thickness so that the dexterity required for safe and efficient tool operation will not be reduced, and (2) have adequate damping characteristics over the vibration frequency spectrum associated with HAVS. Although several materials are available, an optimal, all-purpose material is not available.

Acute episodes of white finger, especially in the early stages of HAVS, are frequently triggered by exposure of the hands or body to cold. Thermal protection by adequate body clothing and handgear to prevent hand or central body cooling might reduce the frequency of the attacks. However, protecting the hands and body in cold weather is a complex problem that depends on many interacting factors such as

- Air temperature
- Wind speed
- Presence of rain or snow
- Sunshine or other radiant heat source
- Water permeability of clothing and handwear
- Vapor permeability of clothing and handwear
- Air permeability of clothing and handwear
- Insulation value of clothing and handwear
- Metabolic heat production
- Exposure time
- Fit of clothing
- Dryness of the handgear
- Compression of insulation (hand grip force)

The insulation value of clothing is expressed in clo units (1 clo = 5.55 kcal/m^2 per hr per °C). A clothing ensemble that will keep a sedentary individual in thermal balance at a calm air temperature of 23.9°C (75°F) has about 1 clo of insulation value. Clothing that is 1/4-in. thick provides about 1 clo of insulation. The insulation value of clothing under minimal airflow conditions is not a function of fiber or fabric type but depends on the amount of air trapped between the fabric layers or between the fibers.

If the clothing is not adequate to prevent a negative body heat balance, the circulatory system will respond with a peripheral vasoconstriction, particularly of the fingers and toes. Thus exposure to cold air may precipitate an attack of white finger, especially in susceptible individuals with HAVS. For a discussion of cold weather clothing, see Horvath [1985], Goldman [1973], Belding [1973], Newburgh [1949], ACGIH [1988], and NIOSH [1986].

Besides the insulation value of the clothing and handwear, the following other factors should be considered for cold weather operations:

- In the presence of rain or snow, a water-repellent outer clothing layer should be used.
- Handgear should be kept dry. If the handgear becomes wet, a change to dry gear should be made and the wet articles should be dried before being used again.
- In cold conditions (<0°C or 32°F) when wind velocities are greater than 0.5 mile/hr (0.8 km/hr), air-impermeable coverings for hands and torso should be provided. Wind barriers to reduce airflow over the body surface can effectively change the rate of heat loss.
- Warm-up breaks may be required even when the air temperature is above freezing. A work/warm-up schedule for a 4-hr shift is presented in the TLV on cold stress proposed by the ACGIH [1988]. Because the blood circulation of the fingers is especially sensitive to even short exposures to cold, responding by acute vasoconstriction and reduced blood flow, constant vigilance must be exercised to protect the fingers from cold exposure when using vibrating tools. Exposing the hands to cold can cause a vasoconstriction even though the body as a whole is in thermal balance and the torso skin temperature is normal. Warm-up facilities may range from portable handwarmers to whole-body warming shelters.
- Battery-powered, electrically heated handgear is, in some situations, a viable solution to cold-induced vasoconstriction of the fingers.

F. WORKER TRAINING

Because of the wide range in tolerance to vibration within a group of workers, it is imperative that each worker be instructed in the recognition of early symptoms of HAVS and in the cause and prevention of HAVS. A worker training program is vital to prevention and control of HAVS and should emphasize the following, at a minimum:

- Recognition of the early signs and symptoms of HAVS, including finger tingling, numbness, and episodes of finger blanching
- Reporting of all signs and symptoms
- Role of medical supervision in prevention and control of HAVS
- Possible health effects of continued operation of vibrating tools
- Reversibility of early signs and symptoms
- Role of tool maintenance and vibration production
- Ergonomic aspects of tool use, including the influence of handgrip force, pressure exerted at the tool/workpiece interface, manner in which the tool is held, body posture, etc.
- Need and procedures for keeping the body and hands warm and dry
- Use of protective clothing and equipment
- Work/rest schedules to control exposure duration
- Informing supervisor about any abnormal functioning of the tools
- Possible aggravation of HAVS from smoking and use of some drugs

The training should be provided to each new worker and repeated at intervals for each worker using vibrating tools to ensure continued worker awareness of the potential problems. Because the earliest signs and symptoms of HAVS are periodic numbness or tingling of the fingers, or episodic blanching of the fingertips, the worker will be the first to recognize that something unusual is occurring. A trained worker can recognize the disorder at the early stages, when further progression can be prevented or reversed.

G. MEDICAL MONITORING

Medical monitoring of workers using vibrating tools should be a primary approach to HAVS prevention and control, but it presents some difficulties because there is no specific clinical or medical test to objectively diagnose or assess the presence of HAVS. HAVS, as the name suggests, is a composite of signs and symptoms. The medical monitoring program should consist of (1) a preplacement medical examination with special attention to peripheral vascular and neural factors, (2) yearly or more frequent examinations designed to elicit responses that may be related to early HAVS, and (3) continued communication with the workers to ensure that early signs and symptoms are reported. Regardless of the signs and symptoms present, a diagnosis of HAVS is not justified without an occupational history of the use of vibrating tools.

1. Preplacement Baseline Medical Examinations

The primary purpose of the preplacement medical examination is to identify (1) any worker who has HAVS from previous vibration exposures, (2) workers who have primary Raynaud's disease, (3) workers who have other disorders with signs and symptoms similar to HAVS (e.g., peripheral vascular or neural disease), (4) workers who are on medications or drugs that may have peripheral vascular or neural effects and (5) baseline data for comparison with subsequent examinations. The preplacement medical examination should be structured to elicit information pertinent to these points.

Specific screening tests considered useful in the diagnosis of HAVS are listed in Chapter IV, D (Screening and Diagnostic Tests). At a minimum, the preplacement medical examination should include tests or questions to identify the following:

- Peripheral neural status--light touch, pain, temperature, two-point discrimination, depth perception, vibrotactile sensitivity level

- Peripheral vascular status--finger blood flow response to the cold and cold provocation test with before, during, and after plethysmography conducted under standardized conditions

- Presence of carpal tunnel syndrome, tennis elbow, or other work-related cumulative trauma disorders of the hand or arm

- Old injuries that could have peripheral vascular or neural effects (cold injury, burns, trauma, etc.)

- Primary Raynaud's disease, and its history

- Other disorders that may have similar peripheral vascular or neural signs and symptoms (polyneuritis, occlusive vascular disease, thromboangiitis, chemical intoxication)

- Use of therapeutic and/or other drugs that have peripheral vascular or neural effects (including alcohol and tobacco)

- Anatomical abnormalities that may interfere with the safe use of the vibrating tools
- Presence of cold sensitivity and previous cold injuries
- History of past use of vibrating tools (including type of tool and duration of use)
- Age, sex, race, body weight, and other demographic data that may be relevant to differences in peripheral neural and vascular function and cold sensitivity
- Baseline measurements of vibrotactile threshold, grip force, muscle strength, etc.

2. Periodic Medical Examinations

Periodic medical examinations for workers exposed to vibration from vibrating tools should be offered on a yearly basis or more frequently for affected workers on the recommendation of the responsible physician. The periodic medical examination should emphasize tests and questions that will elicit information on the early signs and symptoms of HAVS or the progress of its severity.

The periodic medical examination should include

- Review of worker health complaints
- Review and updating of the data derived from the preplacement examination
- Repetition of tests and procedures directed to peripheral vascular and neural functions and symptoms
- Assessment of peripheral vascular and neurological signs and symptoms, aesthesiometric and vibrotactile test results, grip strength, and presence of musculoskeletal symptomatology to establish whether HAVS has developed to Stage 1 or has progressed further

3. Medical Surveillance

To ensure that the control practices provide adequate protection to workers exposed to hand-transmitted vibration, the responsible health professional can use the workplace exposure data, periodic medical data, and the interview history to determine any significant changes within a worker or group of workers since the previous examination. These events may include complaints of episodic numbness, tingling, or cold-induced white fingers; changes in grip strength and muscle force; and pain in the hands, arms, and shoulders. The events may lead the physician to suspect overexposure of the work population or a change in an individual's health status or susceptibility. The occurrence of these sentinel health events (SHEs) could signal a breakdown of or inadequacy of the vibration exposure control systems established at the workplace.

H. RECORDS AND RECORDKEEPING

Records of the data obtained from the following measurements are required to establish adequate control procedures: (1) updated acceleration and frequency characteristics of the vibrating tools used, (2) hours per day the worker operates the tool, (3) intraday exposure pattern, (4) years of operating the tool, (5) nonoccupational exposure to hand-arm vibration, (6) exposure year in which HAVS symptoms first appeared, (7) stage assessment of HAVS, (8) environmental conditions at the workplace, including air temperature, wind speed, and humidity, (9) type of personal protective clothing and equipment used, (10) results of preplacement and periodic medical examinations, (11) change in medical status between medical examinations, and (12) worker training programs.

The records on vibration exposure levels and times and medical status should be retained in accordance with the requirements of 29 CFR 1910.20(d). HAVS should be considered a reportable occupation-related disorder.

VIII. RESEARCH NEEDS

Guidelines and recommendations for the control and prevention of HAVS are based mainly on clinical experiences and retrospective epidemiologic studies. These experiences and studies are limited, however, because no two industrial situations are exactly alike. Measuring methods and results may vary greatly from one work site to another. In addition, no controlled laboratory studies on the production of HAVS in human subjects have been, or ethically should be, conducted. Progress in knowledge about HAVS control will depend on epidemiologic and clinical data carefully collected under standardized situations of industrial use.

A. DOSE-RESPONSE

To make the data from different epidemiological studies comparable, a minimum list of factors required from all investigators would include all those factors known to have a significant influence on the development of HAVS. If data on those factors were collected in every study, data from several studies could be grouped to increase the number of observations and increase the reliability of the risk predictions. Some of the factors that are known to have a dose-response effect and that must be routinely included are (1) vibration measurement techniques and instruments (for acceleration, frequency, and exposure time), (2) work history of previous use of vibrating tools, (3) medical signs and symptoms of peripheral neural, vascular, and muscular complaints, (4) environmental conditions such as temperature, wind, and moisture, and (5) ergonomics of how the task is performed (tool/workpiece force interface, grip force on tool, arm and body posture, manner in which the tool is held and used, tool maintenance, and type of tool). Other factors that may influence the development of HAVS must be searched for and included.

B. CLINICAL TESTS AND STOCKHOLM STAGES

All clinicians and researchers should now use the Stockholm classification to determine the stage of vascular and neurological symptoms from the patient's history so that studies may be compared. In addition, internationally accepted objective tests should be conducted and the results should be correlated with the Stockholm stages to assist parties involved in litigation and compensation.

Objective methods for evaluating and determining the stage are also needed to correctly estimate improvement or deterioration with and without (a) further hand-arm vibration exposure, (b) therapy or surgical intervention, and (c) a combination of these factors.

C. IDENTIFICATION OF VIBRATION-INTOLERANT WORKERS

Identifying vibration-intolerant workers and strictly limiting their exposure before signs and symptoms of HAVS develop would be an effective preventive procedure. Presently, complaints and symptoms of peripheral neural, vascular, and/or muscular involvement must first appear before vibration intervention procedures are indicated. No currently available set of medical or pathophysiologic measures can be used alone to predict, with an acceptable degree of reliability, those workers who are especially sensitive to the effects of tool-produced vibration and who are at high risk of developing HAVS as a result of using vibrating tools.

D. ENGINEERING MODIFICATION OF TOOLS

During the past decade, considerable success has been achieved with the engineering approach to reducing the vibration level of some powered tools and workpieces. Greater improvement is needed, however, to make the various types of vibrating tools acceptable for routine use. Engineering modification may be directed to the design of the tool or to the design of the task. Reducing tool vibration to acceptable levels during optimum operating conditions will lower the worker's risk of developing HAVS.

E. ERGONOMICS OF THE WORK TASK

Several important ergonomic factors that affect the impact of the vibrating tool on normal hand-arm function are (1) the grip force exerted on the tool handle to hold and control the tool, (2) the muscular force required at the tool/workpiece interface to do the work, and (3) the amount of flexion, abduction, and rotation at the wrist, elbow, and shoulder joints required to guide the tool properly. A change in bench height, workpiece orientation, and muscular forces required to do the job may reduce the pathophysiologic consequences of the vibration exposure task. This aspect of the HAVS problem has not received much research attention, even though it has a vast potential for significantly reducing HAVS.

F. EXPOSURE SCHEDULE

Adhering to an optimum exposure/nonexposure schedule during the workday can be a successful approach to hazard control. This concept is known from studying other hazards and is recognized in the ISO Guide 5349, ACGIH TLV, ANSI Standard S3.34, BSI Standard 6842, and other guidelines for HAVS control [ISO 1986; ACGIH 1988; ANSI 1986; BSI 1987]. The vibration exposure data on which the concept is based, however, are mainly extrapolations and best estimates. The common denominator in these guidelines and recommendations is usually "minutes of exposure per day." The question is whether the health effects of exposure to a constant level of vibration are the same for 120 continuous minutes of exposure in an 8-hr day as they are for 120 minutes of noncontinuous exposure (that is, eight 15-minute periods of exposure, each followed by 45 minutes of nonexposure).

G. PROTECTIVE DEVICES

Protective devices can be inserted between the tool producing the vibration and the tissue of the hand where the transmitted vibration energy is absorbed. The protection may be applied to the handles of the tool, or it may be incorporated into handgear worn by the tool operator. The amount of vibration that will be absorbed will be influenced by the vibration force (acceleration) or the vibration frequency (hertz). Data are available on the transmission and damping characteristics of some materials. However, for a large number of materials, there are no available data on which to base a choice of vibration-reducing material suited to the vibration characteristics of a particular vibrating tool or class of tools. New concepts for antivibration and damping devices and materials need to be explored. Until such data are available, specific recommendations for the type and amount of protective material cannot be made.

H. ETIOLOGY AND PATHOGENESIS OF HAVS

Although it is well established that the use of vibrating tools is associated with the development of HAVS, it has not been fully explained how the vibration energy causes organ, tissue, and cellular changes and damage. A rational approach to the prevention and treatment of HAVS will require fundamental data on the mechanisms involved in changes in the arteries, muscles, nerves, connective tissue, and tendons associated with HAVS. New therapeutic or prophylactic drugs need to be explored.

I. EXPOSURE MONITORING

With the instrumentation available today, measurement of the acceleration and frequency of the vibration produced by a tool is not a simple task. A dosimeter-type instrument that could be attached to the worker or the tool and that could provide an integrated acceleration level over time would do much to ease the burden of conducting vibration testing. Because vibration frequencies above 1,400 Hz are produced by some vibrating tools (up to 10,000 Hz), accelerometers need a window wide enough to capture these high frequencies.

A pressing need exists for investigators to evaluate the health effects from both frequency-weighted and -unweighted acceleration measurements over the extended frequency range. Particular attention should be paid to the high-frequency component for the possible pathophysiological effects on the hand structure components.

J. HAVS RECOGNITION TRAINING PROGRAM

HAVS differs from many other occupationally-induced health disorders in that an acceptable risk/exposure factor cannot be set. This dictates a secondary prevention approach requiring that early signs and symptoms be recognized by the attending health professional and by the exposed worker to prevent progression of the disorder and to minimize morbidity. Most health professionals are not adequately trained or experienced to detect the early signs and symptoms of HAVS. To ensure that HAVS will be recognized and diagnosed at an early, reversible stage, a refresher course and self-instruction aids should be developed for interested physicians.

K. OBJECTIVE TESTS

A pressing research need is the development of laboratory and clinical tests for objectively identifying the signs and symptoms of the early stages of HAVS. The tests must be both sensitive and specific. To be clinically practical, they must be easy to perform and noninvasive, and they must not require esoteric equipment.