CRITERIA FOR A RECOMMENDED STANDARD

Occupational Exposure to Hand-Arm Vibration

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FOREWORD

The purpose of the Occupational Safety and Health Act of 1970 (Public Law 91-596) is to assure safe and healthful working conditions for every working person and to preserve our human resources by providing medical and other criteria that will assure, insofar as practicable, that no worker will suffer diminished health, functional capacity, or life expectancy as a result of his or her work experience. The Act authorizes the National Institute for Occupational Safety and Health (NIOSH) to develop and recommend occupational safety and health standards and to develop criteria for improving them. By this means, NIOSH communicates these criteria to regulatory agencies (including the Occupational Safety and Health Administration and the Mine Safety and Health Administration) and others in the community of occupational safety and health.

Criteria documents provide the basis for the occupational safety and health standards sought by Congress. These documents generally contain a critical review of the scientific and technical information available on the prevalence of hazards, the existence of safety and health risks, and the adequacy of control methods. NIOSH distributes these documents to health professionals in academic institutions, industry, organized labor, public interest groups, and other government agencies.

This criteria document examines the occupational health problems associated with the use of vibrating tools and provides criteria for reducing the risk of developing vibration-induced health problems. In this document, the term "vibrating tools" includes both hand-held vibrating tools and stationary tools that transmit vibration through a workpiece. The major health problems associated with the use of vibrating tools are signs and symptoms of peripheral vascular and peripheral neural disorders of the fingers and hands. These signs and symptoms include numbness, pain, and blanching of the fingers, and loss of finger dexterity. This composite of vibration-induced signs and symptoms is referred to as hand-arm vibration syndrome (HAVS).

On the basis of the 1983 National Occupational Exposure Survey, an estimated 1.45 million U.S. workers use vibrating tools. The prevalence of HAVS in workers who use such tools is reported to range from 6% to 100%, with an average of approximately 50%. Primary Raynaud's disease, whose signs and symptoms resemble those of HAVS, has been reported to occur in an estimated 5% of the general population. This percentage is consistent with the number of unexposed comparison workers who report such symptoms in studies of HAVS.

HAVS is a chronic progressive disorder with a latency period that may vary from a few months to several years. The development of HAVS in a population of workers and the length of the latency period depend on many interacting factors, including vibration level produced by the tool, hours of tool use per day, environmental conditions, type and design of the tool, manner in which the tool is held, vibration spectrum produced by the tool, vibration tolerance of the worker, and tobacco and drug use by the worker.

Because of the complex interactions among these and other factors, the general lack of epidemiologic and clinical data, and the uncertainty associated with some vibration measurements, it is not currently possible to establish meaningful dose-response relationships. Thus it is not possible to establish a specific recommended exposure limit (REL) that will protect workers against the development of HAVS in all occupational situations. However, the problem of HAVS is too serious and pervasive to delay measures for correcting it.

NIOSH has therefore recommended a standard for exposure to hand-arm vibration that includes no specific exposure limit but does include engineering controls, good work practices, use of protective clothing and equipment, worker training programs, administrative controls such as limited daily use time, and medical monitoring and surveillance. Frequency-unweighted measurements of acceleration are also recommended since they provide simpler, more appropriate means for assessing the health risk of using vibrating tools at all frequencies. A cornerstone of this standard is the requirement for medical monitoring of all vibration-exposed workers to identify the first signs and symptoms of HAVS and to remove such workers from the job until they are free of all vibration-related symptoms.

Implementation of this standard will protect users of vibrating tools from the debilitating effects of HAVS. NIOSH also anticipates that this criteria document will stimulate research and development in all areas relating to hand-arm vibration. Future research may provide new and more effective methods for reducing occupational exposure to vibration.

When appropriate data become available to develop a specific REL for vibration exposures, NIOSH will revise its recommended standard. Until then, adherence to the standard described in this criteria document should prevent or greatly reduce the potential for vibration-exposed workers to develop the painful and disabling HAVS.

NIOSH takes sole responsibility for the conclusions and recommendations presented in this document. All reviewers' comments are being sent with this document to the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) for consideration in standard setting.

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ABSTRACT

This document examines the occupational health problems associated with the use of vibrating tools (including both hand-held vibrating tools and stationary tools that transmit vibration through a workpiece), and it provides criteria for reducing the risk of developing vibration-induced health problems. The major health problems associated with the use of vibrating tools are signs and symptoms of peripheral vascular and peripheral neural disorders of the fingers and hands. These signs and symptoms include numbness, pain, and blanching of the fingers. This composite of vibration-induced signs and symptoms is referred to as hand-arm vibration syndrome (HAVS), sometimes called Raynaud's phenomenon of occupational origin, or vibration white finger disease.

In the United States, an estimated 1.45 million workers use vibrating tools. The prevalence of HAVS in a worker population that has used vibrating tools ranges from 6% to 100%, with an average of about 50%. The development of HAVS depends on many factors, including the level of acceleration (vibration energy) produced by the tool, the length of time the tool is used each day, the cumulative number of months or years the worker has used the tool, and the ergonomics of tool use. The tools most commonly associated with HAVS are powered hammers, chisels, chain saws, sanders, grinders, riveters, breakers, drills, compactors, sharpeners, and shapers.

The prevalence and severity of HAVS usually increase as the acceleration level and duration of use increase. HAVS is a chronic, progressive disorder with a latency period that may vary from a few months to several years. The early stages of HAVS are usually reversible if further exposure to vibration is reduced or eliminated; but treatment is usually ineffective for the advanced stages of HAVS, and the disorder may progress to loss of effective hand function and necrosis of the fingers. Prevention is therefore critical. Adherence to the exposure controls recommended in this document should prevent or greatly reduce the potential for vibration-exposed workers to develop HAVS.

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GLOSSARY

Acceleration: The time rate of change in velocity (ft/sec^2 or m/sec^2 or gravity). The second derivative of displacement with respect to time.

Acceleration exposure dose: The level of acceleration and years of exposure.

Acceleration, Gravity: The acceleration produced by the force of gravity (1 g = 9.81 m/sec^2 or 32.19 ft/sec^2).

Accelerometer: Transducer used to measure acceleration or time rate of change in velocity.

Amplitude: The maximum displacement in an oscillatory motion from a reference position.

Compliance, mechanical: Displacement of a structure per unit of load; the ease with which a system may be displaced.

Coupling: The linkage between the hand and a vibrating source. The integrity of the contact between the hand and the handle surface of a vibrating tool.

Damping: The process by which the amplitude of the crest of a vibration is decreased.

Displacement: A vector quantity specifying the change in the position of a body from its reference position.

Dyne: A force that gives a free mass of 1 gram an acceleration of 1 cm/sec^2.

Elasticity: The property that enables a body to resist and recover from deformation produced by a force.

ERG: A unit of work produced by a force of 1 dyne acting through a distance of 1 cm.

Force: A vector quantity that accelerates a body in the direction in which it is applied. Units of force are expressed as newtons (N).

Frequency: Rate of oscillation; number of oscillations per unit of time; the number of complete cycles per unit of time. One hertz (Hz) is one cycle per second.

Gravity (g): Acceleration resulting from gravitational force (32 ft/sec2 or 9.81 m/sec2).

Harmonic: A frequency that is an integral multiple of some fundamental or base frequency.

Hertz: A unit of frequency (cycles per second).

Impedance: The ratio of a harmonic excitation of a system to its response; ratio of applied force to resulting velocity.

Impedance, mechanical: Ratio of applied vibratory force to the resulting velocity.

Incidence: Number of new cases of a disease or condition reported in a population over a given period.

Jerk: Time rate of acceleration change.

Joule: A unit of energy equal to the amount of work done when a point is displaced 1 m by the application of a force of 1 N. A unit of energy equal to 107 ergs, or about 0.738 foot pounds.

Latency: The time interval between the application of force or stimulus and the appearance of a response.

Mass: Quantity of matter; the inertial resistance of a body to acceleration.

Mass, dynamic: Ratio of applied force to resulting acceleration.

Modulus, dynamic: Ratio of stress to strain; stress required to produce a unit of strain.

Newton: Force required to accelerate a 1-kg mass 1 m/sec2 (100,000 dynes).

Oscillation: The variation in the position of an object over time in reference to its starting point.

Oscillation, period of: Time required for an oscillation to be completed.

Power, spectral density: The mean square value of energy per unit of time passed through a given frequency range.

Prevalence: Number of current cases (old and new) of a disease or condition in a population at a given point in time (point prevalence) or during a given period (period prevalence).

Radians: The angle subtended at the center of a circle by an arc equal in length to a radius of the circle.

Resonance: The tendency of a body to act in concert with an externally generated vibration to amplify the impinging vibration; the amplification of an oscillation of a system by a force wave or oscillation of exactly equal period or frequency.

Root mean square: The square root of the arithmetic mean of the squares of a series of numbers.

Stiffness: The ratio of force or torque to the resulting change in displacement of an elastic body.

Spectrum, vibration: The distribution of frequencies that describes the frequencies that are present in a vibrating system.

Transfer function: The mathematical relation between the input into a system and the response.

Transmissibility: The ratio of vibration output divided by the input as a function of frequency.

Velocity: The first derivative of displacement with respect to time (m/sec).

Vibration: The oscillation or periodic motion of a rigid or elastic body from a position of equilibrium.

Vibration, random: An oscillatory motion in which the acceleration varies over time in a nonperiodic manner; a vibration whose magnitude is not precisely predictable for any point in time.

ABBREVIATIONS

a	acceleration
ACGIH	American Conference of Governmental Industrial Hygienists
ACTU	Australian Council of Trade Unions
ANSI	American National Standards Institute
A/V	antivibration
BSI	British Standards Institute
$^{\circ}$C	degree Celsius
CFR	Code of Federal Regulations
clo	unit of insulation value of clothing
CPT	cold provocation test
CTS	carpal tunnel syndrome
cm	centimeter
D.A.	double amplitude displacement
dB	decibel
DL	distal latency
f	frequency
F	force
$^{\circ}$F	degree Fahrenheit
FSBP	finger systolic blood pressure
ft	foot
g	gravity

H-A	hand-arm
HAVS	hand-arm vibration syndrome
hr	hour
Hz	hertz
ISO	International Standards Organization
J	joule
JAIH	Japanese Association of Industrial Health
kcal	kilocalorie
kg	kilogram
km	kilometer
M	mega
m	meter
MCV	motor nerve conduction velocity
min	minute
ml	milliliter
mm	millimeter
m/sec	meter per second
m/sec^2	meter per second squared
MSHA	Mine Safety and Health Administration
N	newton
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
REL	recommended exposure limit
rms	root mean square
SCV	sensory nerve conduction velocity

sec	second
SHE	sentinel health event
TLV®	threshold limit value
TWA	time-weighted average
USSR	Union of Soviet Socialist Republic
VTHC	Victorian Trades Hall Council
VWF	vibration white finger
v	velocity

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I. RECOMMENDATIONS FOR A STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that worker exposure to vibration from the use of vibrating tools be controlled by compliance with all recommendations given in Chapter I of this document. Adherence to these recommendations should prevent or greatly reduce the risk of incurring hand-arm vibration syndrome (HAVS) in workers who use vibrating tools. In this document, the term "vibrating tools" includes both hand-held vibrating tools and stationary tools that transmit vibration through a workpiece. An estimated 5% of the general population may develop primary Raynaud's disease (whose signs and symptoms resemble those of HAVS) without exposure to vibration. The recommendations are designed to prevent workers who use vibrating tools from developing the signs and symptoms of Stage 1* HAVS during a working lifetime.

SECTION 1. VIBRATION EXPOSURE

HAVS has been observed in workers who have used vibrating tools that transmit vibration energy to the hands and arms over a wide range of acceleration levels. The level of acceleration produced by a tool is influenced by many factors, including tool type and weight, operating speed, ergonomics of tool use, environmental conditions, antivibration materials used, etc. (see Chapter III, D and Chapter VII). Thus NIOSH cannot currently establish a specific quantitative exposure limit that will eliminate the risk of developing HAVS in all workers exposed to hand-transmitted vibration from all types of vibrating tools. NIOSH therefore recommends that exposure to hand-arm vibration be reduced to the lowest feasible acceleration levels and exposure times by adhering to the requirements presented in Section 4, Control of Vibration.

SECTION 2. EXPOSURE MONITORING

The epidemiologic and clinical evidence reviewed in Chapter IV supports the conclusion that a linear relationship exists between the acceleration exposure dose (level of acceleration and years of exposure) and the time of onset and severity of HAVS. Data on the vibration acceleration level produced by the vibrating tools are needed for the design of tools and work strategies that will help prevent and control HAVS at the earliest possible stage.

The components of the hand-transmitted vibration that shall be measured are (a) acceleration (m/sec^2 or g), (b) frequency (Hz), and (c) duration of exposure (min/day or hr/day).

*Stockholm Workshop classification. See Tables IV-4 and IV-5.

(a) Vibration acceleration shall be measured in the three orthogonal basicentric axes (Figure III-2) at the point on the tool where the vibration enters the hand or as close as possible to that point. The basicentric axis of greatest acceleration may be used to calculate acceleration levels. The magnitude of acceleration shall be measured using an accelerometer with sufficient dynamic range to cover the acceleration band of 1 to 1,000 m/sec^2. The mass of the accelerometer shall be small enough that it does not affect the vibration amplitude being measured (<5 grams if possible). The vibration measuring system shall be calibrated in accordance with appropriate standards based on National Bureau of Standards procedures. The accelerometer(s) shall be attached to the vibrating source as described in Chapter III, B, Methods of Measuring Hand-Transmitted Vibration.

(b) The frequency-unweighted acceleration shall be expressed in m/sec^2 (rms) of the 1/3-octave-band center frequencies from 6.3 to 5,000 Hz.

(c) The vibration measurement system shall have a uniform response integrated over 1/3-octave-band center frequencies of 6.3 to 5,000 Hz. All measurements and analyses of the vibration acceleration and frequency shall be performed by trained technical personnel.

(d) The vibration characteristics (acceleration and frequency spectrum) for each tool shall be measured at the time the tool is first put into use and at annual intervals thereafter. The vibration shall be measured when the tool is operating under full power and actual or simulated conditions of use.

(e) The time the tool is in use shall be determined by measuring actual operating time over a workday; these measurements can then be used to calculate average daily vibration acceleration exposures. The total daily vibration acceleration exposure shall be converted to a normalized 4-hr acceleration amplitude in m/sec^2 (frequency unweighted) (see Chapter III, Equation 13).

(f) A hand-held vibration meter may be used for screening or monitoring purposes to determine the approximate acceleration levels being produced by the vibrating system. However, proper mounting of such an acceleration measuring device onto the vibrating tool is critical (see Chapter III, B).

SECTION 3. MEDICAL MONITORING

(a) General

(1) The employer shall provide a health monitoring program for all workers occupationally exposed to hand-arm vibration from the use of vibrating tools.

(2) The employer shall ensure that all medical examinations and procedures are per-

formed by or under the direction of a licensed physician with special training and experience in occupational health problems. Board certification in occupational medicine is one way to demonstrate such training and experience.

(3) The employer or physician shall (a) counsel all workers who use tobacco about its possible role in augmenting the harmful effects of vibrating tools, and (b) encourage these workers to stop using tobacco.

(b) Preplacement Medical Examinations

At a minimum, a preplacement medical examination shall be conducted for each worker who will use vibrating tools on the job. The baseline data obtained from these examinations are for comparison with the data derived from the periodic medical examinations. The examination shall include the following:

(1) A comprehensive work history with special emphasis on present or past use of vibrating tools during work or hobby activities

(2) A medical history, including relevant information on any peripheral vascular, peripheral neural, or musculoskeletal complaints

(3) A comprehensive physical examination with special attention to peripheral vascular and peripheral neural integrity, grip strength, muscle force, and signs and symptoms of the disorders listed in Table IV-1

(4) An assessment of the use of substances that influence normal vascular and neural function, which include certain prescription drugs, alcohol, tobacco, and illicit substances.

(c) Periodic Medical Examinations

(1) Periodic medical examinations shall be made available at least annually to all workers who use vibrating tools on the job. The periodic medical examination shall include all those items specified in Chapter 1, Section 3b, and any other items considered relevant by the examining physician. If circumstances warrant (e.g., an increase in job-related vibration exposure, or a change in health status), the medical examination shall be offered at shorter intervals at the discretion of the attending physician.

(2) The peripheral neural and peripheral vascular signs and symptoms noted during the examination shall be reported in conformance with the classification presented in Tables IV-4 and IV-5.

(d) Medical Removal

Any worker occupationally exposed to hand-transmitted vibration who develops peripheral neural or peripheral vascular signs and symptoms of Stage 2 HAVS or above on the Stockholm Workshop classification described in Tables IV-4 and IV-5 shall not be exposed to further hand-arm vibration until his or her signs and symptoms have improved sufficiently that they no longer meet the criteria for Stage 1 HAVS.

If the attending physician recommends that a worker be removed from a job requiring the use of vibrating tools, the employer shall ensure that the worker retains all earnings, seniority, and other employment rights and benefits.

(e) Information for Health Care Professionals

The employer shall furnish the following information to the health care professional responsible for the medical monitoring program:

- A copy of this criteria document
- A description of the worker's duties and activities as they relate to vibration exposure
- An estimate of the worker's daily exposure to vibration and years of exposure
- A list of basic types of vibrating tools used
- A list of the acceleration levels produced by the tools
- A description of antivibration protective clothing and antivibration tool designs in use
- A list of all tasks that involve vibrating tools and workpieces and that require strong hand grip force
- Relevant information from previous work and medical histories and medical examinations
- A description of the special features of the task and the way in which this task is performed
- A description of the environmental conditions at the work site (ambient temperature, humidity, wind velocity, rain, snow, etc.)

(f) Written Report and Opinion

The employer shall receive the following information from the attending health care professional:

- An opinion as to the worker's ability to use vibrating tools
- Any recommended limitations to on-the-job exposure
- Any limitation to the worker's ability to use any required protective equipment or clothing
- With the worker's written consent, information about any condition requiring treatment or special consideration

SECTION 4. CONTROL OF VIBRATION

(a) General

Engineering and work practice controls shall be used to reduce hand-transmitted vibration exposure to the lowest feasible level. These controls shall also be supplemented by other control strategies such as the use of antivibration clothing, mittens, gloves, and equipment, and by worker training programs in the proper handling of the vibrating tools.

(b) Engineering Controls

(1) The vibration acceleration level shall be controlled by reducing the vibration energy produced by the vibrating tool to the lowest level consistent with optimal operations and/or by changing the process to reduce the requirement for using the tool.

(2) The power and weight of the tool shall be optimized to levels that minimize vibration but still permit the work to be efficiently performed.

(3) The tool manufacturers shall furnish data on the vibration acceleration and frequency characteristics of their tools as measured by a standard test protocol of simulated operation.

(c) Work Practices

In addition to all possible engineering controls, work shall be modified to minimize vibration exposure. Work modification approaches include but are not limited to the following procedures:

- Reducing the number of hours a worker uses a vibrating tool during the workday
- Reducing the number of days per week the vibrating tool is used
- Arranging work tasks so that vibrating and nonvibrating tools can be used alternately, and assuring that the nonvibrating tools do not introduce other musculoskeletal stress factors
- Scheduling maintenance breaks as necessary to ensure that tools are sharp, lubricated, and tuned
- Selecting tools that produce the least amount of vibration consistent with satisfactory performance of the task
- Designing the work task and workplace to incorporate ergonomic principles to minimize vibration stress
- Reducing the grip force on the tool handle and the force applied at the tool/workpiece interface in a manner consistent with safety and performance
- Restricting the use of piecework and incentive pay

(d) Protective Clothing and Equipment

Protective clothing and equipment shall be used where feasible to reduce the level of the vibration energy transmitted to the hand and arm. Some approaches to protecting the worker with clothing and equipment are

- Incorporating vibration-damping materials into the palms and fingers of gloves and mittens
- Incorporating vibration-damping material into or on the tool handle or areas where worker-tool coupling occurs. Damping materials can be especially effective for high-frequency vibration
- Using antivibration isolators or damping techniques on tools such as the isolator used on antivibration chain saws

- Wearing adequate cold weather clothing to maintain body core temperature and prevent cold-induced peripheral vasoconstriction

- Ensuring that the antivibration equipment, clothing, and hand gear are ergonomically appropriate (e.g., glove fit, freedom of movement, and grip force required to control the tool)

(e) Worker Training

The employer shall establish a continuing training program to ensure that all workers who use vibrating tools have current knowledge of the health and safety effects of hand-transmitted vibration and of the procedures for minimizing or preventing the effects. The training program shall be conducted by persons qualified by training in and direct knowledge of the occupational safety and health implications of hand-arm vibration exposure. The program shall include adequate verbal and written information to ensure that each worker fully understands the health and safety hazards and methods for their assessment and control.

The training program shall include, at a minimum, the following topics:

- Source of vibration exposure

- Factors that adversely affect the magnitude of the vibration

- The means by which vibration is transmitted to hands and arms

- Adverse health and safety effects of vibration exposure

- Early signs and symptoms of HAVS

- Progression and reversibility of HAVS

- Exaggeration of vibration-induced health effects as a result of smoking

- Prevention of HAVS

- Use and availability of vibration protective clothing

- Antivibration devices for reducing vibration at the source

- Ergonomic approaches to reduce the effects of using vibrating tools
- The value of good tool maintenance
- The need to keep hands and body warm and dry
- Work practice procedures to minimize the effect of vibration exposure on health and safety

SECTION 5. LABELING

The following data shall be furnished by the manufacturer of vibrating tools and antivibration equipment:

(a) All hand-held tools that produce vibration shall carry a label stating the frequency-unweighted acceleration level (m/sec^2) produced by the tool during normal operation.

(b) The manufacturer of antivibration equipment, clothing, and hand gear shall provide information on the vibration-damping characteristics of each type of antivibration item produced for sale.

SECTION 6. RECORDKEEPING

(a) Maintaining Records

For all workers who are occupationally exposed to vibrating tools, the employer shall establish and maintain a record of the following:

- Type, model, and manufacturer of the vibrating tools used
- Vibration acceleration data furnished by the manufacturers on the labels of all vibrating tools used
- Daily use time of each type of vibrating tool
- Number of hours, months, and years each type of vibrating tool or workpiece was used
- Antivibration controls used and date they were first introduced

- Personnel training, including dates and content of any training courses
- Work histories and physicians' written medical reports and opinions
- Records from preplacement and periodic medical examinations
- Signs and symptoms of HAVS (if present) for each worker and date they first appeared

(b) Record Retention

In accordance with the requirements of 29 CFR* 1910.20(d), Preservation of Records, the employer shall retain the records described in Chapter I of this document for at least the following periods:

(1) Thirty years for exposure monitoring records

(2) The duration of employment plus 30 years for medical monitoring and surveillance records and other records described in Chapter I of this document

(c) Availability of Records

(1) In accordance with 29 CFR 1910.20, Access to Employee Exposure and Medical Records, the employer shall, upon request, allow examination and copying of exposure monitoring records by a worker, a former worker, or anyone having the specific written consent of the worker or former worker.

(2) Any medical records that are required by this recommended standard shall be provided, upon request, for examination and copying to the worker, the former worker, or anyone having the specific written consent of the worker or former worker.

(d) Transfer of Records

The employer shall comply with the requirements for the transfer of records as specified in 29 CFR 1910.20(h), Transfer of Records.

**Code of Federal Regulations.* See CFR in references.

II. INTRODUCTION

For more than three-quarters of a century, workers who operated vibrating tools* on the job have reported complaints resembling the signs and symptoms of primary Raynaud's disease. The major complaints were episodic numbness and tingling of the fingers, episodic blanching of the fingers, with pain occurring mainly in response to cold exposure and on return of circulation, and reduction in grip strength and finger dexterity. These signs and symptoms increased in number and severity as the exposure to vibration (acceleration intensity and duration of exposure) increased.

This composite of vibration-induced signs and symptoms is referred to as hand-arm vibration syndrome (HAVS). The syndrome has been known by a number of different names: Raynaud's phenomenon of occupational origin, secondary Raynaud's phenomenon, vibration white finger (VWF), dead finger, traumatic vasospastic disease, and vibration syndrome. The tools most commonly associated with HAVS are powered hammers, chisels, chain saws, sanders, grinders, riveters, breakers, drills, compactors, sharpeners, and shapers. Many publications on the clinical, epidemiologic, and engineering aspects of HAVS have appeared during the past 35 years.

An estimated 1.45 million workers use vibrating tools in the United States [NIOSH 1983b]. In a worker population that has used vibrating tools, the prevalence of HAVS ranges from 6% to 100%, with an average of about 50%. The development of HAVS depends on many factors such as the level of acceleration (vibration energy) produced by the tool, the length of time the tool is used each day, the cumulative number of hours, months, and years the worker has used the tool, and the ergonomics of tool use. Minimum daily exposures for several hours each day for months or years are usually required before the first signs and symptoms appear.

HAVS is a chronic disorder with a latency period of a few months to several years. The early stages of HAVS are usually reversible if further exposure to vibration is reduced or eliminated, but advanced stages are progressive. However, treatment is usually ineffective for the advanced stages of HAVS, and the disorder can progress to loss of effective hand function and necrosis of the fingers.

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This criteria document presents criteria, techniques, and procedures for the assessment, evaluation, and control of HAVS. Engineering controls, work practices, administrative procedures, medical supervision, worker training, ergonomic design of the tools and the task, and other procedures can be implemented to effectively reduce the risk of developing HAVS.

I. RECOMMENDATIONS FOR A STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that worker exposure to vibration from the use of vibrating tools be controlled by compliance with all recommendations given in Chapter I of this document. Adherence to these recommendations should prevent or greatly reduce the risk of incurring hand-arm vibration syndrome (HAVS) in workers who use vibrating tools. In this document, the term "vibrating tools" includes both hand-held vibrating tools and stationary tools that transmit vibration through a workpiece. An estimated 5% of the general population may develop primary Raynaud's disease (whose signs and symptoms resemble those of HAVS) without exposure to vibration. The recommendations are designed to prevent workers who use vibrating tools from developing the signs and symptoms of Stage 1* HAVS during a working lifetime.

SECTION 1. VIBRATION EXPOSURE

HAVS has been observed in workers who have used vibrating tools that transmit vibration energy to the hands and arms over a wide range of acceleration levels. The level of acceleration produced by a tool is influenced by many factors, including tool type and weight, operating speed, ergonomics of tool use, environmental conditions, antivibration materials used, etc. (see Chapter III, D and Chapter VII). Thus NIOSH cannot currently establish a specific quantitative exposure limit that will eliminate the risk of developing HAVS in all workers exposed to hand-transmitted vibration from all types of vibrating tools. NIOSH therefore recommends that exposure to hand-arm vibration be reduced to the lowest feasible acceleration levels and exposure times by adhering to the requirements presented in Section 4, Control of Vibration.

SECTION 2. EXPOSURE MONITORING

The epidemiologic and clinical evidence reviewed in Chapter IV supports the conclusion that a linear relationship exists between the acceleration exposure dose (level of acceleration and years of exposure) and the time of onset and severity of HAVS. Data on the vibration acceleration level produced by the vibrating tools are needed for the design of tools and work strategies that will help prevent and control HAVS at the earliest possible stage.

The components of the hand-transmitted vibration that shall be measured are (a) acceleration (m/sec^2 or g), (b) frequency (Hz), and (c) duration of exposure (min/day or hr/day).

*Stockholm Workshop classification. See Tables IV-4 and IV-5.

(a) Vibration acceleration shall be measured in the three orthogonal basicentric axes (Figure III-2) at the point on the tool where the vibration enters the hand or as close as possible to that point. The basicentric axis of greatest acceleration may be used to calculate acceleration levels. The magnitude of acceleration shall be measured using an accelerometer with sufficient dynamic range to cover the acceleration band of 1 to 1,000 m/sec^2. The mass of the accelerometer shall be small enough that it does not affect the vibration amplitude being measured (<5 grams if possible). The vibration measuring system shall be calibrated in accordance with appropriate standards based on National Bureau of Standards procedures. The accelerometer(s) shall be attached to the vibrating source as described in Chapter III, B, Methods of Measuring Hand-Transmitted Vibration.

(b) The frequency-unweighted acceleration shall be expressed in m/sec^2 (rms) of the 1/3-octave-band center frequencies from 6.3 to 5,000 Hz.

(c) The vibration measurement system shall have a uniform response integrated over 1/3-octave-band center frequencies of 6.3 to 5,000 Hz. All measurements and analyses of the vibration acceleration and frequency shall be performed by trained technical personnel.

(d) The vibration characteristics (acceleration and frequency spectrum) for each tool shall be measured at the time the tool is first put into use and at annual intervals thereafter. The vibration shall be measured when the tool is operating under full power and actual or simulated conditions of use.

(e) The time the tool is in use shall be determined by measuring actual operating time over a workday; these measurements can then be used to calculate average daily vibration acceleration exposures. The total daily vibration acceleration exposure shall be converted to a normalized 4-hr acceleration amplitude in m/sec^2 (frequency unweighted) (see Chapter III, Equation 13).

(f) A hand-held vibration meter may be used for screening or monitoring purposes to determine the approximate acceleration levels being produced by the vibrating system. However, proper mounting of such an acceleration measuring device onto the vibrating tool is critical (see Chapter III, B).

SECTION 3. MEDICAL MONITORING

(a) General

(1) The employer shall provide a health monitoring program for all workers occupationally exposed to hand-arm vibration from the use of vibrating tools.

(2) The employer shall ensure that all medical examinations and procedures are per-

formed by or under the direction of a licensed physician with special training and experience in occupational health problems. Board certification in occupational medicine is one way to demonstrate such training and experience.

(3) The employer or physician shall (a) counsel all workers who use tobacco about its possible role in augmenting the harmful effects of vibrating tools, and (b) encourage these workers to stop using tobacco.

(b) Preplacement Medical Examinations

At a minimum, a preplacement medical examination shall be conducted for each worker who will use vibrating tools on the job. The baseline data obtained from these examinations are for comparison with the data derived from the periodic medical examinations. The examination shall include the following:

(1) A comprehensive work history with special emphasis on present or past use of vibrating tools during work or hobby activities

(2) A medical history, including relevant information on any peripheral vascular, peripheral neural, or musculoskeletal complaints

(3) A comprehensive physical examination with special attention to peripheral vascular and peripheral neural integrity, grip strength, muscle force, and signs and symptoms of the disorders listed in Table IV-1

(4) An assessment of the use of substances that influence normal vascular and neural function, which include certain prescription drugs, alcohol, tobacco, and illicit substances.

(c) Periodic Medical Examinations

(1) Periodic medical examinations shall be made available at least annually to all workers who use vibrating tools on the job. The periodic medical examination shall include all those items specified in Chapter 1, Section 3b, and any other items considered relevant by the examining physician. If circumstances warrant (e.g., an increase in job-related vibration exposure, or a change in health status), the medical examination shall be offered at shorter intervals at the discretion of the attending physician.

(2) The peripheral neural and peripheral vascular signs and symptoms noted during the examination shall be reported in conformance with the classification presented in Tables IV-4 and IV-5.

(d) Medical Removal

Any worker occupationally exposed to hand-transmitted vibration who develops peripheral neural or peripheral vascular signs and symptoms of Stage 2 HAVS or above on the Stockholm Workshop classification described in Tables IV-4 and IV-5 shall not be exposed to further hand-arm vibration until his or her signs and symptoms have improved sufficiently that they no longer meet the criteria for Stage 1 HAVS.

If the attending physician recommends that a worker be removed from a job requiring the use of vibrating tools, the employer shall ensure that the worker retains all earnings, seniority, and other employment rights and benefits.

(e) Information for Health Care Professionals

The employer shall furnish the following information to the health care professional responsible for the medical monitoring program:

- A copy of this criteria document
- A description of the worker's duties and activities as they relate to vibration exposure
- An estimate of the worker's daily exposure to vibration and years of exposure
- A list of basic types of vibrating tools used
- A list of the acceleration levels produced by the tools
- A description of antivibration protective clothing and antivibration tool designs in use
- A list of all tasks that involve vibrating tools and workpieces and that require strong hand grip force
- Relevant information from previous work and medical histories and medical examinations
- A description of the special features of the task and the way in which this task is performed
- A description of the environmental conditions at the work site (ambient temperature, humidity, wind velocity, rain, snow, etc.)

(f) Written Report and Opinion

The employer shall receive the following information from the attending health care professional:

- An opinion as to the worker's ability to use vibrating tools
- Any recommended limitations to on-the-job exposure
- Any limitation to the worker's ability to use any required protective equipment or clothing
- With the worker's written consent, information about any condition requiring treatment or special consideration

SECTION 4. CONTROL OF VIBRATION

(a) General

Engineering and work practice controls shall be used to reduce hand-transmitted vibration exposure to the lowest feasible level. These controls shall also be supplemented by other control strategies such as the use of antivibration clothing, mittens, gloves, and equipment, and by worker training programs in the proper handling of the vibrating tools.

(b) Engineering Controls

(1) The vibration acceleration level shall be controlled by reducing the vibration energy produced by the vibrating tool to the lowest level consistent with optimal operations and/or by changing the process to reduce the requirement for using the tool.

(2) The power and weight of the tool shall be optimized to levels that minimize vibration but still permit the work to be efficiently performed.

(3) The tool manufacturers shall furnish data on the vibration acceleration and frequency characteristics of their tools as measured by a standard test protocol of simulated operation.

(c) Work Practices

In addition to all possible engineering controls, work shall be modified to minimize vibration exposure. Work modification approaches include but are not limited to the following procedures:

- Reducing the number of hours a worker uses a vibrating tool during the workday
- Reducing the number of days per week the vibrating tool is used
- Arranging work tasks so that vibrating and nonvibrating tools can be used alternately, and assuring that the nonvibrating tools do not introduce other musculoskeletal stress factors
- Scheduling maintenance breaks as necessary to ensure that tools are sharp, lubricated, and tuned
- Selecting tools that produce the least amount of vibration consistent with satisfactory performance of the task
- Designing the work task and workplace to incorporate ergonomic principles to minimize vibration stress
- Reducing the grip force on the tool handle and the force applied at the tool/workpiece interface in a manner consistent with safety and performance
- Restricting the use of piecework and incentive pay

(d) Protective Clothing and Equipment

Protective clothing and equipment shall be used where feasible to reduce the level of the vibration energy transmitted to the hand and arm. Some approaches to protecting the worker with clothing and equipment are

- Incorporating vibration-damping materials into the palms and fingers of gloves and mittens
- Incorporating vibration-damping material into or on the tool handle or areas where worker-tool coupling occurs. Damping materials can be especially effective for high-frequency vibration
- Using antivibration isolators or damping techniques on tools such as the isolator used on antivibration chain saws

- Wearing adequate cold weather clothing to maintain body core temperature and prevent cold-induced peripheral vasoconstriction

- Ensuring that the antivibration equipment, clothing, and hand gear are ergonomically appropriate (e.g., glove fit, freedom of movement, and grip force required to control the tool)

(e) Worker Training

The employer shall establish a continuing training program to ensure that all workers who use vibrating tools have current knowledge of the health and safety effects of hand-transmitted vibration and of the procedures for minimizing or preventing the effects. The training program shall be conducted by persons qualified by training in and direct knowledge of the occupational safety and health implications of hand-arm vibration exposure. The program shall include adequate verbal and written information to ensure that each worker fully understands the health and safety hazards and methods for their assessment and control.

The training program shall include, at a minimum, the following topics:

- Source of vibration exposure

- Factors that adversely affect the magnitude of the vibration

- The means by which vibration is transmitted to hands and arms

- Adverse health and safety effects of vibration exposure

- Early signs and symptoms of HAVS

- Progression and reversibility of HAVS

- Exaggeration of vibration-induced health effects as a result of smoking

- Prevention of HAVS

- Use and availability of vibration protective clothing

- Antivibration devices for reducing vibration at the source

- Ergonomic approaches to reduce the effects of using vibrating tools

- The value of good tool maintenance

- The need to keep hands and body warm and dry

- Work practice procedures to minimize the effect of vibration exposure on health and safety

SECTION 5. LABELING

The following data shall be furnished by the manufacturer of vibrating tools and antivibration equipment:

(a) All hand-held tools that produce vibration shall carry a label stating the frequency-unweighted acceleration level (m/sec^2) produced by the tool during normal operation.

(b) The manufacturer of antivibration equipment, clothing, and hand gear shall provide information on the vibration-damping characteristics of each type of antivibration item produced for sale.

SECTION 6. RECORDKEEPING

(a) Maintaining Records

For all workers who are occupationally exposed to vibrating tools, the employer shall establish and maintain a record of the following:

- Type, model, and manufacturer of the vibrating tools used

- Vibration acceleration data furnished by the manufacturers on the labels of all vibrating tools used

- Daily use time of each type of vibrating tool

- Number of hours, months, and years each type of vibrating tool or workpiece was used

- Antivibration controls used and date they were first introduced

- Personnel training, including dates and content of any training courses
- Work histories and physicians' written medical reports and opinions
- Records from preplacement and periodic medical examinations
- Signs and symptoms of HAVS (if present) for each worker and date they first appeared

(b) Record Retention

In accordance with the requirements of 29 CFR* 1910.20(d), Preservation of Records, the employer shall retain the records described in Chapter I of this document for at least the following periods:

(1) Thirty years for exposure monitoring records

(2) The duration of employment plus 30 years for medical monitoring and surveillance records and other records described in Chapter I of this document

(c) Availability of Records

(1) In accordance with 29 CFR 1910.20, Access to Employee Exposure and Medical Records, the employer shall, upon request, allow examination and copying of exposure monitoring records by a worker, a former worker, or anyone having the specific written consent of the worker or former worker.

(2) Any medical records that are required by this recommended standard shall be provided, upon request, for examination and copying to the worker, the former worker, or anyone having the specific written consent of the worker or former worker.

(d) Transfer of Records

The employer shall comply with the requirements for the transfer of records as specified in 29 CFR 1910.20(h), Transfer of Records.

**Code of Federal Regulations.* See CFR in references.

II. INTRODUCTION

For more than three-quarters of a century, workers who operated vibrating tools* on the job have reported complaints resembling the signs and symptoms of primary Raynaud's disease. The major complaints were episodic numbness and tingling of the fingers, episodic blanching of the fingers, with pain occurring mainly in response to cold exposure and on return of circulation, and reduction in grip strength and finger dexterity. These signs and symptoms increased in number and severity as the exposure to vibration (acceleration intensity and duration of exposure) increased.

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III. VIBRATION AS A HAZARD

A. THE PHYSICS OF VIBRATION

1. Components of a Vibrating System

Three components of a vibrating system are (1) mass, (2) elasticity, and (3) damping. The kinetic energy of the system is a function of the mass and motion of the system. The potential energy of the system is a function of the mass and elasticity of the system. When a system vibrates, the energy in the system alternately changes back and forth between kinetic and potential energy. In the absence of any mechanism to take energy out of the system, a system will theoretically vibrate forever once it begins to vibrate. Damping is the mechanism that transforms the kinetic and potential energy into heat and thereby takes energy out of a vibrating system. Thus if no energy is directed into a vibrating system to keep it in motion, the damping that is present will dissipate the initial energy in the system and all motion will stop. The human hand-arm system contains mass, elasticity, and damping and can be visualized as a series of masses connected by elastic and damping elements.

2. Parameters Associated with Vibration

Motion associated with vibration is oscillatory in nature. Such motion is called harmonic motion and is associated with motion around some equilibrium or reference position (Figure III-1). The displacement refers to the position of a vibrating object relative to its normal resting position [$X(t) = 0$ in Figure III-1]. The four primary vibration parameters—frequency, acceleration, velocity, and displacement—are interrelated. When the values for any two of the parameters are known for any single frequency, the values for the other two can be calculated. When the motion is harmonic, the displacement [$X(t)$] is

$$X(t) = X \sin(\omega t) \tag{1}$$

where

X is the peak displacement amplitude in meters,
ω is the angular frequency of oscillation in radians/sec, and
t is the time in seconds

The angular frequency can be expressed as

$$\omega = 2\pi f \qquad or \qquad f = \frac{\omega}{2\pi} \tag{2}$$

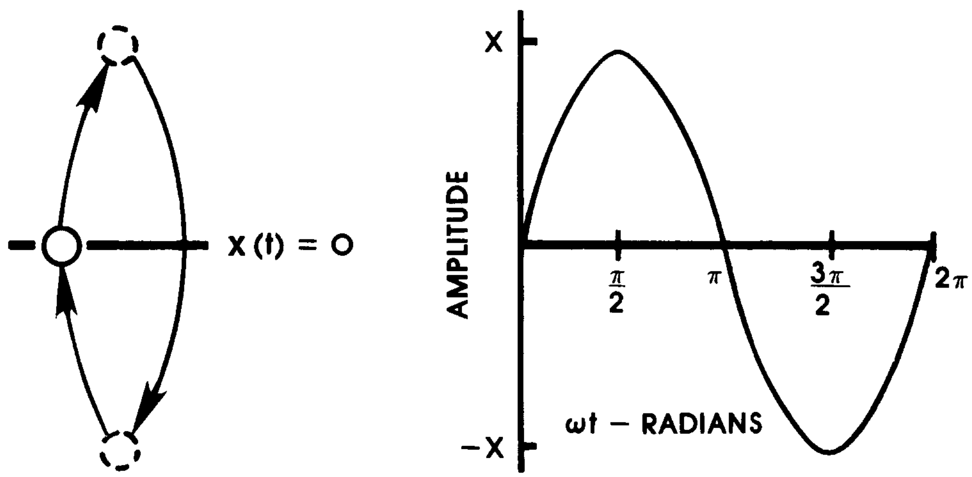

Figure III-1. Harmonic oscillation.

where

> π is a constant equal to 3.1416, and
> f is frequency (cycles/second, or hertz [Hz]).

The frequency (f) represents the number of complete cycles of oscillations an object makes in 1 sec. For example, if an object undergoes 10 complete cycles of oscillation in 1 sec, it has a frequency of 10 cycles/sec, or 10 Hz. The period of oscillation is

$$t = \frac{1}{f} \tag{3}$$

where t is seconds. The period of oscillation represents the time it takes an object to complete one cycle of oscillation.

The velocity of an object refers to the time rate of change of displacement and represents the first derivative of the displacement function given above (Equation 1). Velocity [$v(t)$] is expressed as

$$v(t) = \frac{dx(t)}{dt} = \omega X \, cos(\omega t) \tag{4}$$

where ωX is the peak velocity (m/sec). Velocity can be written as

$$v(t) = \omega X \, sin\,(\omega\, t + \frac{\pi}{2}) \tag{5}$$

indicating that velocity leads displacement by a phase of 90°.

The acceleration [$a(t)$] of an object refers to the time rate of change of velocity and represents the second derivative with respect to time of the displacement function, or

$$a(t) = \frac{d^2\,x\,(t)}{dt^2} = \frac{dv(t)}{dt} = -\omega^2 X \, sin(\omega t) \tag{6}$$

where $\omega^2 X$ is the peak acceleration amplitude (m/sec^2). Acceleration can be written

$$a(t) = \omega^2 X \, sin(\omega t + \pi) \tag{7}$$

indicating that acceleration leads velocity by a phase of 90° and displacement by a phase of 180°.

When a vibrating system acts in concert with externally applied vibration so that certain vibration frequencies impinging on the system are amplified, the frequencies at which maximum amplification occurs are referred to as resonances or natural frequencies. In the case of hand-arm vibration, a fundamental resonance is thought to occur between 100 and 200 Hz [Wasserman 1988].

3. Mechanical Impedance

When a vibrating stimulus is applied to a human, a mechanical structure, or another system, a motion results at the same frequency as the stimulus at the point of application and at other points in the system. The mechanical impedance of the system to which the stimulus is applied can be used to describe the dynamic characteristics and the motion of the vibrating system. Mechanical impedance [$Z(\omega)$] is defined as the ratio of the applied vibrating force [$F(\omega)$] divided by the resulting velocity [$v(\omega)$], or

$$Z(\omega) = \frac{F(\omega)}{v(\omega)} \tag{8}$$

Mechanical impedance is measured as a function of the frequency of the applied force. When both the applied force and resulting velocity are measured at the point of contact between the applied force and the vibrating system, the impedance is referred to as the "driving point mechanical impedance." When the resulting velocity is measured at a point on the system other than the point where the force is applied, the impedance is referred to as the "transfer mechanical impedance." Mechanical impedance measurements have been extensively used in human vibration to determine resonance, stiffness, damping, and other dynamic characteristics of the human body. Impedance is a measure of the total dynamic opposition the human body offers to the movement imparted by the vibration stimulus and can reflect body resonances without interfering with normal body function. Mechanical impedance measurements are noninvasive measurements that can be used to determine the dynamic properties of the body or different parts of the body such as the hand and arm.

Instead of velocity system dynamics in opposition (mechanical impedance) to movement, vibration can be viewed as a form of movement or dynamic compliance. The dynamic compliance [$D(\omega)$] is defined as the ratio of the displacement [$X(\omega)$] divided by the driving force [$F(\omega)$], or

$$D(\omega) = \frac{X(\omega)}{F(\omega)} \tag{9}$$

4. Vibration Related to the Hand-Arm System

Human response to vibration depends on several factors:

Frequency of vibration	Interaction between body and vibration input
Amplitude of vibration	Effect of clothing and equipment
Time history of vibration exposure	Body size (height, weight)
Direction of vibration	Body posture
Point of application of vibration	Body tension Body composition

Vibration is a vector quantity (i.e., it has a magnitude and direction). Thus nearly all of the variables above must be extended to multiple axes, depending on the nature of the vibration that is being examined.

As specified by the International Organization for Standardization (ISO) [ISO 1986], the vibration produced by the tool or the vibration transmitted to the hand should be measured in the three orthogonal basicentric or biodynamic directions specified in Figure III-2. The

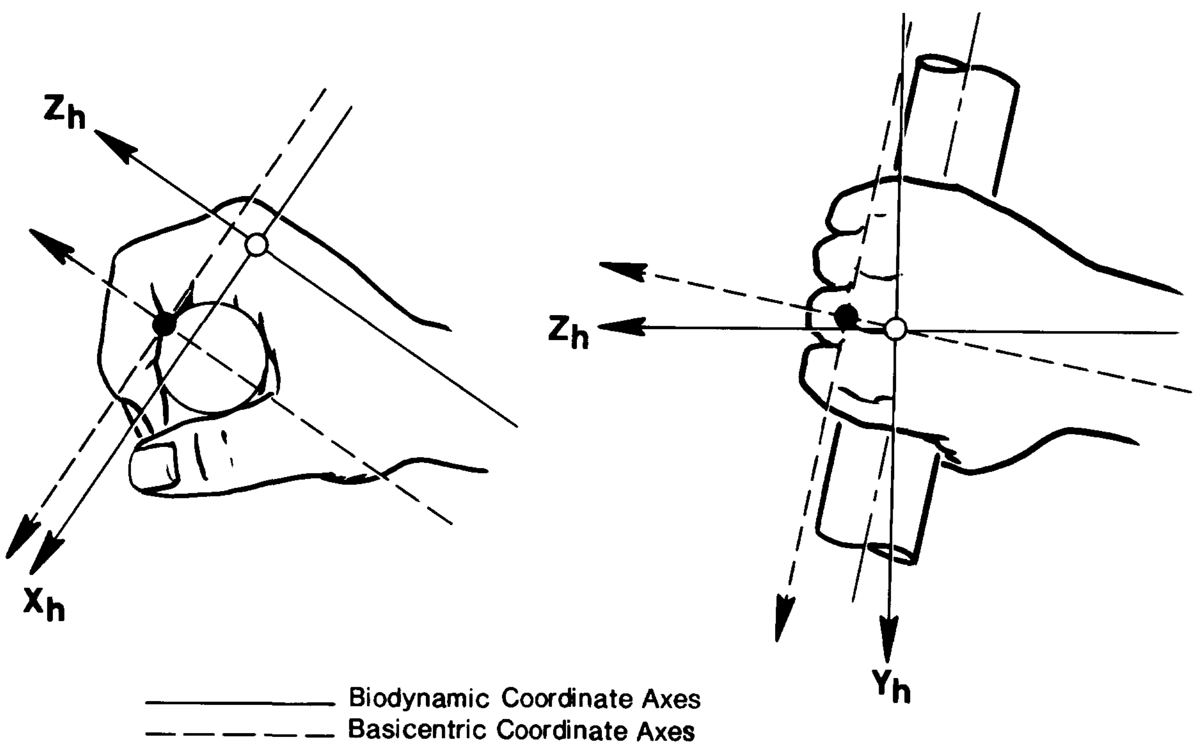

Figure III-2. Basicentric axes (x,y,z) for the hand (h).

interaction between the hands and a vibrating tool is influenced by many factors, which should be reported in detail when assessing the magnitude of the hand-transmitted vibration [Brammer and Taylor 1982; Starck and Pyykko 1986; Wasserman et al. 1977; Taylor 1974; ANSI 1986; ISO 1986]. These factors include

- The type and condition of the tool being used
- The acceleration and the frequency spectrum produced by the tool under normal operating conditions
- The magnitude and direction of sustained forces applied through the hands to the tool or the workpiece (e.g., gripping force, axial thrust force, rotational moments)
- The orientation and posture of the hands, arms, and body during work (specifically, the angles of the wrists, elbows, and shoulder joints)
- The parts of the hands that are in direct contact with vibrating surfaces
- Types and sizes of the surfaces in contact with the hands
- The work practices used
- The total number of years the worker has used vibrating tools on any job
- Climatic conditions such as the ambient temperature and humidity and the temperatures of hand-held surfaces of the tool or workpiece

The following information should be reported when assessing the duration of hand-transmitted vibration exposure [ANSI 1986; ISO 1986]:

- The duration of vibration exposure per working day and the total exposure time in hours, months, and years
- The pattern of exposure within a period of time and its association with the working method (e.g., the length and frequency of scheduled and unscheduled work and rest periods, the intermittence of vibration during the work period, whether the vibrating tool is laid aside or held during rest breaks)

B. METHODS OF MEASURING HAND-TRANSMITTED VIBRATION

1. Measurement of Acceleration

The three parameters that describe the amplitude of vibration as a function of frequency are (1) displacement, (2) velocity, and (3) acceleration. However, vibration is generally specified in terms of acceleration for the following reasons:

a. The velocity and displacement can be obtained from the measurement of acceleration.

b. A large variety of accelerometers are commercially available.

c. The amplitude of acceleration at the higher frequencies is substantially higher than either displacement or velocity and, therefore, is easier to measure.

When acceleration is measured with an accelerometer, the velocity can be obtained by electronically integrating the acceleration signal over time. The displacement can be obtained by electronically integrating the acceleration signal a second time. Electronic integration tends to reduce or minimize noise introduced into the measurements.

2. Accelerometers

Piezoelectric accelerometers are usually used to measure the amplitude of vibration associated with hand-transmitted vibration. These accelerometers can be designed to measure vibration within the frequency range of 1 to 50,000 Hz. When vibration impinges on a piezoelectric accelerometer, it moves a small mass against the face of a crystal element. The crystal element produces an electrical voltage proportional to the compression of the mass against the crystal. This voltage is proportional to the acceleration. Because the voltage produced is often very small and loss in signal can easily occur over a long cable connecting an accelerometer to a corresponding instrument, a charge amplifier is used in conjunction with the accelerometer. This amplifier overcomes signal loss problems by measuring changes in the electrical charge (or capacitance) of the crystal caused by vibration. Because the crystal charge simultaneously varies with the voltage signal, a measure of acceleration is obtained. With some accelerometers, the charge amplifier is an external device (i.e., the charge signal from the accelerometer is directed to an external amplifier that converts the charge signal to a corresponding amplified voltage signal proportional to vibration amplitude). With other accelerometers, the circuitry for converting the charge signal to a voltage signal is an integral part of the accelerometer. For these, a voltage signal from the accelerometer is directed to a voltage amplifier that generates an amplified voltage signal proportional to vibration amplitude.

When vibration is measured, it is necessary to specify whether the vibration is being measured on an impact- or nonimpact-type tool. Impact tools include chipping hammers, scalers, pneumatic riveting hammers, pneumatic nailers, jack hammers, and any other tool that generates impulse vibration signals that dominate the vibration spectrum. Nonimpact tools include chain saws, nibblers, pneumatic wrenches, grinders, routers, circular saws, reciprocating saws, and other similar tools. To measure vibration amplitudes of impact tools, specially designed shock accelerometers or ordinary accelerometers with mechanical filters must be used. These accelerometers, which are commercially available, can withstand repeated high-level, high-crest-factor acceleration pulses. If regular accelerometers are used when impact vibration is present, serious errors can be introduced into the vibration measurements [Wasserman et al. 1977; Wasserman, et al. 1981]. These errors are associated with DC shifts within the accelerometer that seriously distort the low-frequency vibration amplitudes being measured. Shock accelerometers can be used to measure both impact and nonimpact vibration, but nonshock accelerometers can be used to measure nonimpact vibration only.

Although shock accelerometers can withstand exceptionally high impulse acceleration levels, they usually have very low voltage or charge sensitivities. In the case of impact vibration, the vibration amplitudes are sufficiently high that generally no signal-to-noise problem is associated with the recording or measuring instrumentation used to record and analyze the vibration signal. In the case of nonimpulse vibration, the vibration amplitudes can be so low that the acceleration signals are near the lower sensitivity of the recording or measuring instrumentation being used. For these cases, it is necessary to use accelerometers that have substantially higher voltage or charge sensitivities.

The accelerometer should not affect the vibration amplitudes that are being measured. Large accelerometers can cause "mass-loading" on the surface to which they are mounted. That is, the mass of the accelerometer is sufficiently large compared with the mass of the object to which it is attached that the vibration signal being measured is significantly distorted. Many commercially available, light-weight accelerometers weigh 5 grams or less. The smallest accelerometer that can be used for a specific application should be chosen. The total weight of the accelerometer assembly (weight of multiple accelerometers, if more than one is used, plus accelerometer mounting block) should not exceed 20 grams in most cases. Accelerometers weighing less than 20 grams may be required for measuring vibration on small, lightweight tools.

Because vibration is a vector quantity, it is necessary to make vibration measurements in the three orthogonal axes. These axes should always be oriented in the manner specified in Figure III-2. The vibration measurements in the three axes should always be made at or as near as feasible to the surfaces of the vibrating hand-held tool or workpiece where the maximum vibration energy enters the hands. Figures III-3 through III-6 show suggested accelerometer mounting locations for chain saws, chipping hammers, and horizontal and vertical grinders [Wasserman et al. 1981]. The vibration in the three basicentric orthogonal axes may be measured with a specially designed triaxial accelerometer (a commercially

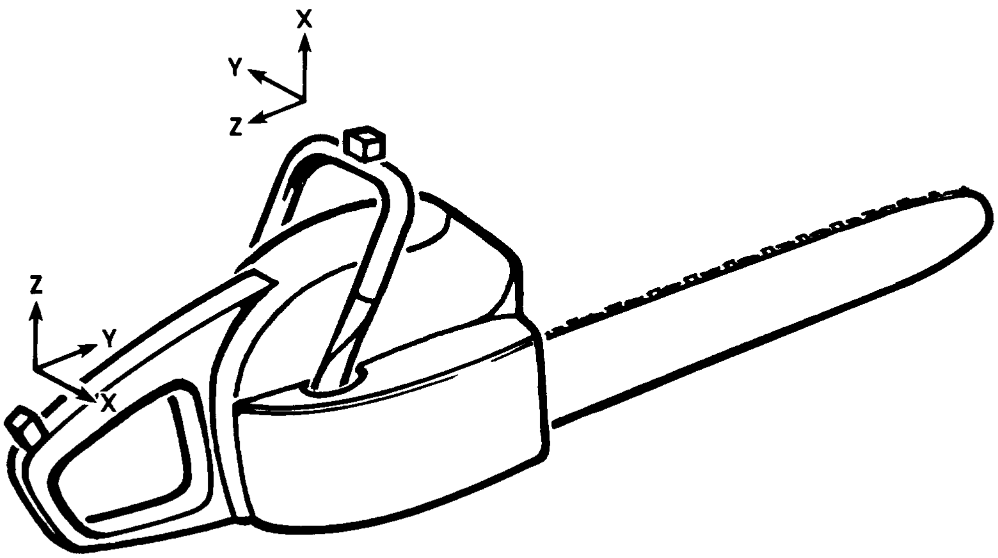

Figure III-3. Accelerometer locations and axis (x, y, z) orientations for chain saws.

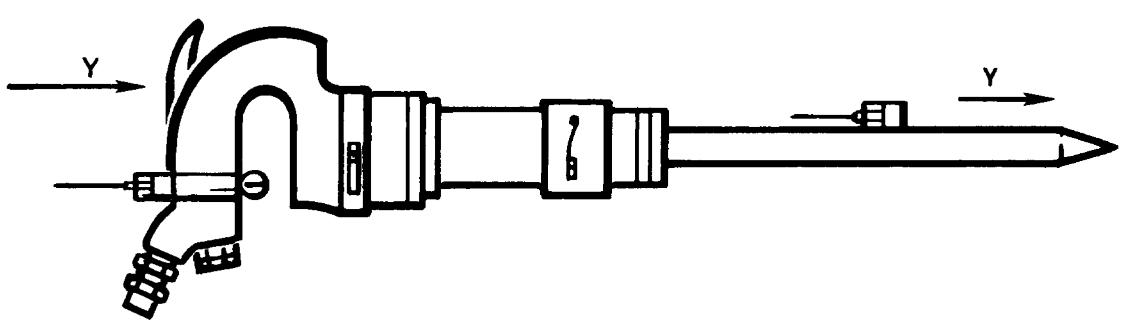

Figure III-4. Accelerometer locations and axis (x, y, z) orientations for chipping hammers.

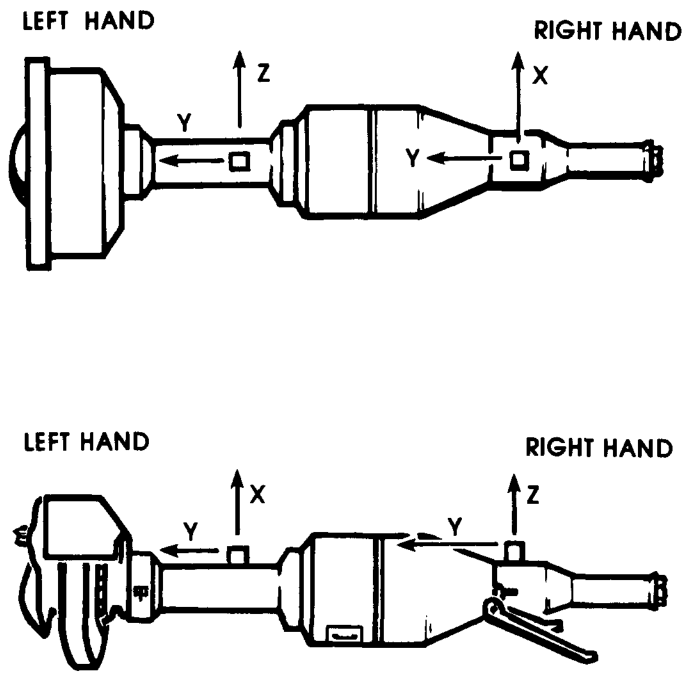

Figure III-5. Accelerometer locations and axis (x, y, z) orientations for horizontal grinders.

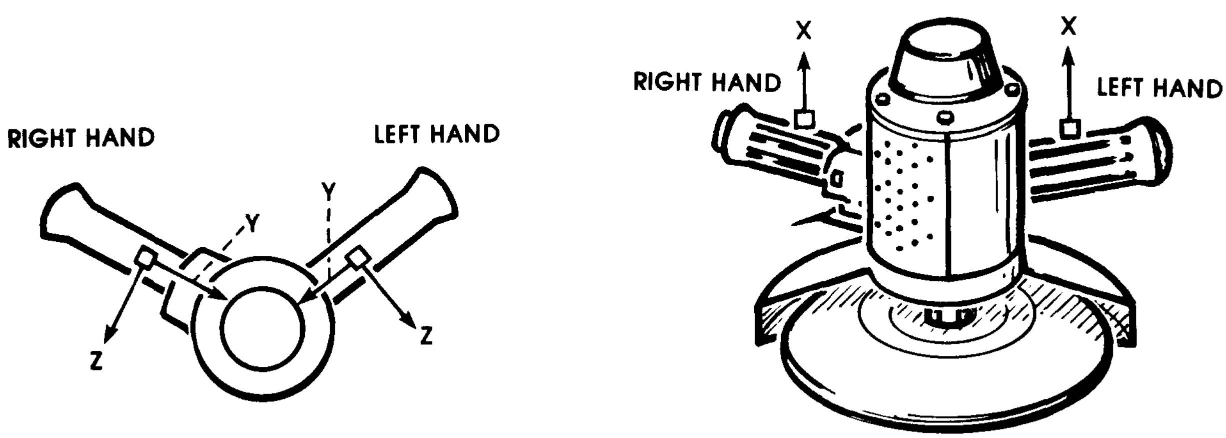

Figure III-6. Accelerometer locations and axis (x, y, z) orientations for vertical grinders.

available multiple accelerometer block that measures vibration in three axes) or by three regular accelerometers that are oriented along the three orthogonal basicentric axes (Figure III-3) that are attached to a small metal cubic block. The accelerometers should be attached directly to the vibrating surface, and the accelerometer and accelerometer-mounting configuration should be selected so that they do not distort the vibration measurements. More detailed information on procedures associated with the mounting of accelerometers can be found in Hempstock and O'Connor [1977], Reynolds et al. [1984], Wasserman et al. [1981], and Wasserman [1987].

3. Vibration Frequencies

Many vibration frequencies found in the workplace and other environments contribute to the total vibration measured. In the case of hand-transmitted vibration, the frequency range of importance designated by the International Organization for Standardization (ISO) is 5.6 to about 1,400 Hz [ISO 1986]. However, many types of tools produce vibration up to 5,000 to 10,000 Hz. Measured vibration data can be separated into its constituent parts by using a Fourier spectrum analysis. Mathematically, this can be expressed as

$$\begin{aligned} f(t) &= a_o + a_1 \, sin(\omega t) + a_2 \, sin(2\omega t) + \ldots + a_n \, sin(n_\omega t) \\ &\quad + b_1 \, cos(\omega_1 t) + b_2 \, cos(\omega_2 t) + \ldots + b_n \, cos(\omega_n t) \end{aligned} \tag{10}$$

where a_1 through a_n and b_1 through b_n define the amplitude of each of the corresponding vibration frequencies ω_1 through ω_n present in a given frequency spectrum. The combined sine and cosine terms give the actual vibration frequency components comprising the spectrum in the frequency range of interest and in their corresponding phases. The vibration spectrum is the frequency "finger print" of the vibration present in a given situation. Spectra are usually derived by means of computer analysis and graphically displayed as follows:

a. The horizontal axis represents frequency (Hz).

b. The vertical axis represents one of the following: acceleration (m/sec^2), velocity (m/sec), displacement (m or cm), or energy (joules).

c. The total number of vertical lines in the spectrum indicates all of the vibration frequencies present in the frequency range measured.

d. The height of each of the vertical lines indicates the amplitude of a parameter given in item b above. Each respective frequency element contributes to the total spectrum.

The Fourier spectra give the specific frequencies at which the vibration energy exists. Often when a vibration analysis is made, only the general vibration amplitudes are sought and it is not necessary to determine specific vibration frequencies at which these amplitudes exist. When this is the case, vibration amplitudes are measured using 1/3-octave-band filters.

In many cases when measurements are made to determine whether a particular level of vibration is within acceptable limits specified by a standard or regulation, using a single number to express the vibration stress is desirable. With respect to hand-transmitted vibration, the frequency-weighted acceleration level in m/sec^2 is the single-number variable used by the American National Standards Institute (ANSI) [ANSI 1986], the ISO [ISO 1986], the American Conference of Governmental Industrial Hygienists (ACGIH) [ACGIH 1988], and the British Standards Institution (BSI) [BSI 1987]. The frequency-weighted acceleration may be obtained by passing the signal through a frequency-weighting filter.

4. General Considerations Associated with Vibration Measurements

The duration of vibration signals associated with many vibrating hand-held tools or workpieces is relatively short. Thus to measure the vibration spectra or the 1/3-octave-band center frequency vibration acceleration associated with these signals, real-time analyzers must be used. These analyzers measure or compute the vibration amplitudes at all frequencies simultaneously. The dynamic range of these analyzers should be as large as possible over the frequency range of 5 to 5,000 Hz.

To analyze vibration signals, the signals must first be recorded and then played back through the recording device to an analyzer. This procedure is usually necessary when multiaxis acceleration measurements are being made relative to both hands at the same time. The recording device is usually a multichannel FM tape recorder or a multichannel analog-to-digital board that directs the recorded signals into a computer.

When high-peak acceleration signals associated with percussive tools are being analyzed, precautions must be taken to ensure that no part of the measuring, recording, or analyzing system is overloaded. To avoid overload, one of the following may be used:

- A commercially available shock accelerometer with a low voltage or charge sensitivity

- An electronic low-pass filter with an upper cut-off frequency above 5,000 Hz placed between the accelerometer voltage or charge amplifier and the recording device or analyzer

- A mechanical low-pass filter with a linear transfer function between 5 and 5,000 Hz placed between the accelerometer and the tool or workpiece

The acceleration signals associated with hand-transmitted vibration vary with time. Thus when measuring acceleration, it is always necessary to obtain values that are averaged over time. The acceleration is measured and reported as the root mean square (*rms*) value of acceleration [$a_{(rms)}$] in m/sec^2. The rms value of acceleration is

$$a_{(rms)} = \left[\frac{1}{T}\int_0^T a^2(t)\ dt\right]^{1/2} \tag{11}$$

where

$a(t)$ is the instantaneous amplitude of acceleration, and

T is the period of time over which a(t) is averaged.

The value of T in Equation 11 must be long enough to be representative of the task associated with the use of the tool being investigated. Also, T should be sufficiently long to ensure reasonable statistical accuracy of the data [Hempstock and O'Connor 1977; ANSI 1986; ISO 1986].

During a vibration measurement, the tool or workpiece should be operated in a manner that is representative of its everyday use. The measured vibration signals in each of the three basicentric orthogonal axes of vibration should be reported as rms acceleration in each of the 1/3-octave-band center frequencies.

C. GUIDELINES FOR ASSESSING VIBRATION AMPLITUDES

Most assessments of vibration amplitudes are based on vibration measurements of the dominant, single-axis vibration directed into the hand [ISO 1986; ANSI 1986; BSI 1987]. That is, the largest of the rms acceleration amplitudes along the three orthogonal basicentric axes shown in Figure III-2 may be used for assessing exposure to hand-transmitted vibration. Recommendations of the ISO, ANSI, and BSI are derived from studies associated with such tools as chain saws, pneumatic chipping hammers, and hand-held grinders. The level of vibration exposure associated with these tools is characterized not only by the vibration of the tool, but also by the type of coupling that exists between the tool and the hands of the tool operator (e.g., tight grip or axial thrust force), and the length of time the tool is used without interruption. Most studies assume good coupling exists between the tool and hands. Many of the assessment guidelines are based on time-averaged, frequency-weighted rms acceleration levels. Most of the studies indicate that regular daily vibration exposures do not exceed 4 hr per regular 8-hr workday [Brammer and Taylor 1982; Starck and Pyykko 1986; ANSI 1986; ISO 1986].

The overall time-averaged intensity of exposure to hand-transmitted vibration varies with such factors as the tool operator's work assignments, work practices, intermittence of exposure to vibration, and length of rest periods between vibration exposures. Thus when measuring vibration to assess the effects of exposure to hand-transmitted vibration, the estimates of total daily exposure should be based on representative vibration measurements for all of the different operating conditions (e.g., using more than one type of tool) associated with the operator's total work assignments over an 8-hr workday. This approach will usually result in several different sets of 1/3-octave-band center frequencies with different rms acceleration amplitudes for each of the different operating conditions. The total daily time-averaged rms acceleration [$a_{t(rms)}$] for each 1/3-octave-band can be obtained from

$$a_{t(rms)} = \left[\frac{1}{T_t} \sum_{i=1}^{n} \left[a^2_{(rms)\,i} \times T_i \right] \right]^{1/2} \tag{12}$$

where

$a_{(rms)i}$ is the component of rms acceleration with a time duration of T_i for the i_{th} operating condition

$$T_t = \sum_{i=1}^{n} T_i$$

Many of the assessments and recommendations are based on an actual tool use of 4 hr over an 8-hr workday. If the value of T_t in Equation 12 is other than 4 hr, the total daily rms acceleration amplitude can be converted to an equivalent 4-hr acceleration amplitude [$a_{t(rms)}(4\ h)$] by Equation 13 [ANSI 1986; ISO 1986; Wasserman 1987]:

$$a_{t(rms)}\ (4\ hrs) = \left[\frac{T_t}{4} \right]^{1/2} \times a_{(rms)}\ (T_t\ hrs) \tag{13}$$

where

$a_{t(rms)}\ (T_t h)$is the *rms* value of acceleration given by Equation 12, and T_t is the total daily exposure time.

The acceleration $a_{xyz(rms)}$ associated with vibration in the three basicentric orthogonal directions in Figure III-2 can be obtained from the following equation:

$$a_{xyz\,(rms)} = \left[a^2_{x(rms)} + a^2_{y(rms)} + a^2_{z(rms)}\right]^{1/2} \tag{14}$$

where

$a_{x(rms)}$ is the *rms* value of acceleration in the x direction,
$a_{y(rms)}$ is the *rms* value of acceleration in the y direction, and
$a_{z(rms)}$ is the *rms* value of acceleration in the z direction.

When comparing measured tool vibration acceleration levels with recommended limits, the comparison should be made using the acceleration level measured in the dominant basicentric axis.

D. FACTORS THAT INFLUENCE VIBRATION AMPLITUDES

1. Effects of Tool Type

Several factors influence the vibration levels produced by vibrating tools. The first is whether or not it is an impact tool. Vibration acceleration levels related to impact tools are generally higher than vibration levels associated with nonimpact tools. When appropriate elastomer or similar materials isolate the vibration-generating parts of tools from contact with the hands, the vibration acceleration levels are usually reduced.

2. Effects of Tool Operation

Other factors that affect the vibration acceleration levels of tools are associated with the ergonomics of operating the tool and related tool design. For example, a chipping hammer works by means of a reciprocating piston actuated by fluctuating pressure pulses. The vibration is generated by the repeated impact of the piston on the end of the chisel inserted into the hammer and the subsequent impact of the chisel on the workpiece. The fundamental vibration frequency is associated with the repetition rate at which the piston strikes the chisel. There is a vibration frequency at multiple harmonics of the primary repetition rate of the tool. The weight of the hammer also influences the vibration acceleration amplitudes directed into the hand. For similar operations, the heavier hammers appear to direct lower vibration levels into the hand at the tool handle. More of the vibration energy generated by the heavier tools goes into moving the tool mass, leaving less energy directed into the hand at the handle. However, increasing the tool weight may increase the grip force required to use the tool and thus increase vibration transmission to the hand. Increased tool weight could also increase stress on the wrist, elbow, and/or shoulder, which in turn could result in musculoskeletal disorders such as carpal tunnel syndrome (CTS).

Imbalance and repetitive impulses are the primary causes of vibration in chain saws and other tools using gasoline engines as the driving mechanism. Imbalance is associated with the rotating and reciprocating masses of the engine. The primary vibration frequency is directly related to the operating speed of the engine. Repetitive impulses are associated with the motion of the chain on the guide bar and the explosions of the gas-air mixture in the engine. The hand-transmitted vibration associated with these vibration mechanisms can be significantly reduced by properly designing and placing elastomer vibration-isolation pads between the engine and the chain saw handles.

The vibration associated with grinders and similar tools is related to the unbalanced rotating mass of the grinder and to the interaction between the grinder wheel, cup or pad, and the workpiece. If the grinder is well maintained, the vibration associated with the unbalanced rotating mass of the grinder is usually not a problem. The condition of the grinder wheel or cup, however, has a very significant effect on the vibration amplitudes produced. If the wheel or cup is well dressed and kept "in round," the vibration associated with the interaction of the wheel or cup with the workpiece will be at a minimum. If the wheel or cup is not periodically "dressed" during use, it can become "out-of-round" and very rough. This substantially increases the vibration acceleration of a poorly maintained grinder compared with a new grinder [NIOSH 1984].

3. Effects of Tool Maintenance

Poor maintenance of vibrating tools significantly influences the vibration acceleration amplitudes that are generated. For example, the vibration acceleration of poorly maintained grinders may be many times higher than the corresponding vibration acceleration of new grinders. Part of the difference can be associated with poorly dressed grinding wheels. As was mentioned above, the use of elastomer vibration-isolation pads in chain saws can be very effective in reducing chain saw vibration directed into the hand. However, these pads must be inspected and replaced periodically.

4. Effects of Work Cycle and Work Conditions

The work cycles, work conditions, and work incentives significantly affect the time-averaged vibration acceleration level associated with many tools. For example, a major use of chipping hammers is for cleaning castings in foundries. In some foundries, the workers clean castings on a piecework basis—the more castings cleaned, the more wages earned. For these situations, the chipping hammers are generally operated at full throttle for periods of up to 4 hr or more in an 8-hr workday [Brammer and Taylor 1982].

Another use of chipping hammers is to form propeller blades. For this situation, the chipping hammers are operated at 1/2 to 3/4 throttle for periods of up to 3 hr over an 8-hr workday [Brammer and Taylor 1982]. Typically, grinders are used for an additional 2.5 to 3 hr during the workday. The time-averaged vibration acceleration at the handle of the chipping hammer was 10 to 14 m/sec^2 for the hammer operated at 1/2 to 3/4 throttle versus 50 to 190 m/sec^2 for the hammer operated at full throttle [NIOSH 1981]. The total time-averaged rms acceleration amplitudes depend on the duration of use and corresponding acceleration associated with the chipping hammer and the grinder.

5. Effects of Coupling between Hand and Tool

Another factor that can influence the transmission of vibration energy produced by vibrating tools is the coupling that exists between the tool and the hands of the operator. Even though the degree of coupling between the hand and a vibrating tool affects the amount of vibration energy transmitted to the hand from the tool, it will not have much effect on the measured vibration acceleration amplitudes produced by the tool. The reason is that the vibrating mass of the tool in contact with the hand is usually much greater than the total effective mass of the hand that is coupled to the tool. In some situations (e.g., electrically driven engraving tools, small riveting guns, and the light-weight handles of small, antivibration hobby chain saws), the mass of the hand may be of the same order of magnitude as the mass of the vibrating tool. For these situations, the degree of coupling between the hand and the tool will have an effect on the vibration acceleration amplitudes measured on the tool.

E. VIBRATION RESPONSE CHARACTERISTICS OF THE HAND

1. Factors Influencing the Vibration Response Characteristics of the Hand

Several factors influence the vibration response characteristics of the hand. These include the following:

- Grip force exerted by the hand around the tool handle
- Axial or static force exerted by the hand on the tool
- Size of vibrating surface in contact with the hand
- Body position associated with using the hand tool
- Clothing and gloves worn

Of these factors, the effects of grip and axial force are the most important, followed by body position and gloves [Griffin et al. 1982; Goel and Rim 1987].

Although it has been demonstrated that the presence of vibration-related disorders affect an individual's subjective response to and perception of vibration directed into the hand, these disorders do not have a measurable effect on the vibration-response characteristics of the hand [Wasserman et al. 1981]. Radwin et al. [1987] reported that vibration can affect the way operators hold and use tools, which is then reflected in altered work performance and injury risk. With increased vibration, grip force on the tool handle is increased, and tactile sensitivity is decreased.

2. Energy Directed Into the Hands

Many vibration assessment guidelines are based on 1/3-octave-band, center-frequency-weighted rms acceleration levels. However, acceleration levels alone do not necessarily represent a true measure of the energy that is directed into the hand. To obtain this information, the coupling between the tool handle must be considered along with the acceleration levels. This can be accomplished by attaching a specially designed fixture to the handle of a vibration tool to measure grip force (coupling) as well as acceleration. A second method is to use the results of acceleration measurements on a tool handle in conjunction with dynamic compliance [Brammer and Taylor 1982; Reynolds et al. 1984; Wasserman et al. 1981].

If the vibration directed into the hand is harmonic in nature or can be broken down into harmonic components, it can be shown that the amplitude of the energy dissipated (E_D) in the hand and arm as a result of damping or other dissipative mechanisms is

$$E_D = \frac{\ddot{X}^2 \, sin(\Phi)}{2\omega^4 \; X/F} \tag{15}$$

where

ω is the frequency in units of radians/second,
X is the measured amplitude of acceleration (m/sec^2) at ω,
X/F is the dynamic compliance (m/N), and
Φ is the radians.

Similarly, the energy (E_S) that is stored in the hand as kinetic and potential energy, and is consequently transferred back and forth between the hand and vibrating tool handle, is presented by Brammer and Taylor [1982], Reynolds et al. [1984], and Wasserman et al. [1981] as follows:

$$E_S = \frac{\ddot{X}^2 \cos(\Phi)}{2\omega^4 \; X/F} \tag{16}$$

Also of interest is the time rate of change of energy or power transmitted to the hand. The power (W) is

$$W = \frac{\ddot{X}^2 \sin(\Phi)}{2\omega^3 \; X/F} \quad \text{or} \quad W = \omega E_D \tag{17}$$

The power transmitted to the hand and arm is related to the energy that is dissipated in the hand and arm.

3. Mathematical Models of the Hand and Arm

The hand-arm system is a very complicated, continuous, nonhomogeneous system that consists of skin, muscle, bone, etc. An accurate model must take all of these components into account. Many investigators have developed models of the hand and arm [Brammer and Taylor 1982; Meltzer et al. 1980; Mishoe and Suggs 1977; Miwa 1968a; Reynolds and Keith 1977; Wassennan et al. 1977; Reynolds and Falkenberg 1984; Starck and Pyykko 1986]. Mechanical impedance or dynamic compliance data or both were used as the basis for developing many of these vibration models. The parameters of many of the models can be related to the physiology of the hand and arm. However, there is no general agreement about which parts of the hand and arm should be described by a model. For example, work reported by Suggs and Mishoe [1977] and Wood and Suggs [1977] supports the idea that the mass elements of a model should represent the respective masses of the fingers, hand, arm, etc. However, the work reported by Reynolds and Keith [1977], Reynolds and Falkenburg [1984], and Wasserman et al. [1977] supports the idea that the mass elements of a model should represent the components of dermis and epidermis of the skin, subcutaneous tissue, and muscle tissue in the area of the hand that is in direct contact with a vibrating surface. Most models imply that (1) vibration energy directed into the hand at frequencies below 80 Hz is transmitted to and can be perceived in the arm, and (2) vibration energy directed into the hand at frequencies above 100 Hz is generally local to the area of the hand in contact with a vibrating surface. These implications are confirmed by vibration transmissibility tests in the hand and arm.

IV. BIOLOGIC EFFECTS

A. HAND-ARM VIBRATION SYNDROME (HAVS)

HAVS comprises a composite of pathophysiologic signs and symptoms that develop over time in workers who use hand-held vibrating tools. Many of the signs and symptoms of HAVS are also seen in other clinical entities such as primary Raynaud's disease, occlusive vascular disease, traumatic injury of hands, proximal vasculature compression, peripheral neuropathies, carpal tunnel syndrome, etc. [Taylor 1989; Taylor and Pelmear 1975; Taylor and Brammer 1982; Pyykko and Starck 1986; Wasserman 1987]. The factors listed in Table IV-1 [NIOSH 1983a] must be considered in differential diagnoses for HAVS.

B. PATHOPHYSIOLOGY OF HAVS

The development of HAVS is a gradual progressive process that may involve years of exposure to hand-arm vibration [NIOSH 1983a]. Some of the etiologic aspects of HAVS have been reviewed by Pyykko and Starck [1986], and Taylor [1988]. A requisite for diagnosis of occupational HAVS is a history of occupational use of vibrating tools such as drills, chipping hammers, grinders, concrete vibrators and levelers, polishers, swagging tools, shoe pound-up tools, caulking tools, fettling tools, clinching and flanging tools, burring tools, rock drills, chain saws, jackhammers, riveting hammers, bucking bars, and jackleg hammers.

In primary Raynaud's disease, the signs, symptoms, and involvements are usually symmetrical (same areas of both hands involved), whereas in secondary Raynaud's disorders, including HAVS, the involvement is usually asymmetrical [NIOSH 1983a]. Presently, however, no single test is available that will reliably distinguish HAVS from other secondary Raynaud's disorders [NIOSH 1983a; NIOSH 1984; Gemne 1982; Brammer et al. 1986; Pyykko 1986].

The classification of the clinical stages of signs and symptoms of HAVS most widely used in the past is the one suggested by Taylor and Pelmear [1975]. This classification assumes two major pathophysiologic consequences of using vibrating tools: peripheral neural and peripheral vascular involvements. This classification does not specifically distinguish the peripheral neural and peripheral vascular progressive changes as separate entities (Table IV-2).

A revision of the Taylor-Pelmear classification of the stages of HAVS has been proposed by Taylor [Brammer et al. 1986]. This revised classification takes into account the concept

Table IV-1.—Relationships considered in differential diagnoses for HAVS*

Medical condition	Signs or symptoms
Primary Raynaud's phenomenon	Constitutional white finger
Trauma direct to extremities	Injuries or fractures; vibration of occupational origin (HAVS); frostbite and immersion syndrome
Nerve compression	Carpal tunnel syndrome
Trauma to proximal vessels by compression	Thoracic outlet syndrome (cervical rib, scalenus anterior muscle), costoclavicular and hyperabduction syndromes
Occlusive vascular disease	Thromboangiitis obliterans, arteriosclerosis, embolism, thrombosis, Burger's disease
Dysglobulinemia	Cold hemagglutination syndrome, cryoglobulinemia, macroglobulinemia
Intoxication	Acroosteolysis; reactions to ergot, nicotine, and vinyl chloride
Neurogenic dysfunction	Poliomyelitis, syringomyelia, hemiplegia, polyneuropathy
Secondary connective tissue disease	Scleroderma, systemic lupus erythematosus, rheumatoid arthritis, dermatomyositis, polyarteritis nodosa, mixed connective tissue disease

*Adapted from NIOSH [1983a].

Table IV-2.—Taylor-Pelmear classification of vibration-induced white finger by stages*

Stage	Signs and symptoms	Interference with activities
0	None	None
0T	Intermittent tingling	None
0N	Intermittent numbness	None
0TN	Tingling and numbness	None
1	Blanching of one or more finger-tips with or without tingling and numbness	None
2	Blanching of one or more fingers with numbness, usually during winter only	Slight interference with home and social activities; no interference with work
3	Extensive blanching with frequent episodes during both summer and winter	Definite interference with work, home, and social activities; restricted hobbies
4	Extensive blanching of most fingers; frequent episodes during summer and winter; finger ulceration	Occupation change required to avoid further vibration exposure

*Adapted from Taylor and Pelmear [1975].

that the peripheral neural and the peripheral vascular involvements in HAVS may be distinct entities and that the disabilities related to each may progress independently of the other. The revision also recognizes that the tactile sensory deficits can and should be measured and considered independently of the vasospastic episodes (Table IV-3).

At the 1986 Stockholm Workshop, a new staging classification of vibration-induced signs and symptoms was introduced [Brammer et al. 1987; Gemne et al. 1987; Taylor 1987; Taylor 1989]. The Stockholm Workshop staging classification of the peripheral-neural and the peripheral-vascular pathophysiologic effects of hand-arm vibration exposure are considered

Table IV-3.—Brammer et al. revisions of the Taylor-Pelmear clinical stages of vibration-induced white finger*

Stage	Signs and symptoms	Interference with activities
0N†, 0V†	No signs or symptoms	None
1N	Intermittent tingling and/or numbness	None
1V	Episodic blanching of one or more finger tips	None
2N	Intermittent numbness; reduced tactile perception	Possible interference with activities involving fine manipulative tasks
2V	Episodic blanching of one or more fingers, usually during winter only	Some interference with work and/or social activities
3N	Degraded tactile resolution; intermittent numbness	Interference with activities involving fine tasks at work and at home
3V	Extensive finger blanching, frequent episodes during both summer and winter; tissue changes (finger ulceration)	Restricted hobbies and social activities to avoid vasospasms; interference with work

*Adapted from Brammer et al. [1986].
†N = neural; V = vascular.

separately, thus reflecting the concept that they are two clinical entities. In addition, a system is provided for a semiquantitative expression of the extent of the involvement of each finger on each hand. This system provides a mechanism for a quantitative clinical estimate and description of the involvement. The stagings as presented at the Stockholm Workshop are shown in Tables IV-4 and IV-5. It was suggested at the Workshop that this staging classification be used in all future hand-arm vibration studies. A standard staging classification will enhance the comparability of the data.

The signs and symptoms and their time sequence in appearance indicate that vibration affects several components of hand and arm function [Taylor and Brammer 1982; Farkkila et al. 1982; Pyykko et al. 1982a, 1982b; Futatsuka and Ueno 1985; Farkkila 1986]. HAVS may involve, separately or in combination, the (1) peripheral neural system, (2) peripheral vascular system, (3) muscles of the hands and arms, (4) bones and joints of the hands and arms, and (5) central nervous system.

The Russian and Japanese [Griffin 1980; Habu 1984] classifications of the relative degree of the disorder in patients with HAVS include subjective symptoms, objective responses to tests, and clinical evaluations. The degree of impairment ranges from Stage 1 with minimal impairment to Stage 4 with extensive impairment. The systems impaired are considered separately as (1) vascular, (2) sensory, (3) musculoskeletal, and (4) brain stem and neuropsychiatric. The degree of impairment ranges from no change (–), to minimal change (+), to extensive involvement (++++). The possible involvement of the central autonomic nervous system in HAVS was the subject for an international symposium in 1983 [Gemne and Taylor 1983].

A classification for staging the severity of vibration-induced HAVS, including some functional changes, has been proposed in Japan [Okada 1983; Okada and Suzuki 1982]. The major features of the classification are summarized in Table IV-6.

The biological effects of vibration exposure may be influenced by many nonvibration factors [ACTU-VTHC 1982; see also Chapter III], including the following:

- Exposure pattern
- Length and frequency of work and rest periods
- Magnitude and direction of forces applied to the workpiece by the operator
- Body posture and orientation of the wrists, elbows, and shoulders
- Area of hand exposed to vibration
- Climatic conditions

Table IV-4.—The Stockholm Workshop classification scale for cold-induced peripheral vascular symptoms in the hand-arm vibration syndrome*,†

Stage	Description
0	No attacks
1	Occasional attacks that affect only the tips of one or more fingers
2	Occasional attacks that affect the distal and middle (rarely also proximal) phalanges of one or more fingers
3	Frequent attacks affecting all phalanges of most fingers
4	As in stage 3, with trophic skin changes in the finger tips

*Adapted from Gemne et al. [1987].
†The Stage is determined separately for each hand.

Table IV-5.—The Stockholm Workshop classification scale for sensorineural stages of the hand-arm vibration syndrome*,†

Stage†	Symptoms
0SN	Exposed to vibration but no symptoms
1SN	Intermittent numbness, with or without tingling
2SN	Intermittent or persistent numbness, reduced sensory perception
3SN	Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity

*Adapted from Brammer et al. [1987].
†The sensorineural stage is determined separately for each hand.

Table IV-6.—Japanese staging classification for hand-arm vibration syndrome*

Classification	Signs and symptoms
Stage 1	Episodic blanching of distal phalanges Borderline decrease in motor and sensory conduction velocities Minimal changes in hand radiographs Periodic numbness and pain in fingers Paresthesia may be present
Stage 2	Extended episodic blanching Further decrease in motor and sensory conduction velocities Slight EMG abnormalities Moderate changes in hand and arm radiographs Pain and numbness lasting longer at rest and at night More pronounced hyperesthesia
Stage 3	Blanching extended to all fingers but not the thumbs Greater decreases in motor and sensory conduction velocities Pronounced EMG changes Pronounced changes in hand and arm radiographs Some restriction of hand and arm movement Atrophy of hand/arm muscles Exaggerated subjective symptoms
Stage 4	Frequent blanching of all fingers but not thumbs Pronounced decrease in motor and sensory nerve conduction velocities Very pronounced EMG changes Pronounced changes in radiograph Increased motility restriction and muscle atrophy Further exaggerated subjective symptoms

*Adapted from Okada [1983].

- Worker's skill and work practices
- Hand covering
- Maintenance of equipment
- Noise (possible synergistic effect)
- Use of tobacco, some drugs, and some chemicals

Taylor and Brammer [1982] and Brammer [1984] have categorized the factors as physical, biodynamic, and individual (Table IV-7). These factors may vary extensively in amount and combinations from one exposure situation to another and from day to day when using the same tool [Brammer 1984].

Knowledge of HAVS is based mainly on retrospective epidemiologic studies or clinical examinations and comparisons between workers who use and do not use vibrating tools, and who do or do not have symptoms of HAVS. Lack of objective data from controlled laboratory investigations limits the accuracy of any dose-response or risk factor predictions.

Taylor [1988, 1989], in reviewing the biological effects of hand-arm vibration, pointed out some of the information gaps in the understanding of the mechanisms involved in the neurological, vascular, and musculoskeletal damage.

1. Peripheral Neural Effects

The early symptoms frequently experienced by workers exposed to hand-arm vibration include intermittent attacks of tingling and/or numbness of the fingers with or without pain [Brammer 1984; Taylor and Brammer 1982; Brammer and Taylor 1982; Taylor 1982a; Taylor 1982b; Vines 1984; Pyykko 1986]. On continued exposure, the attacks may become more frequent and the symptoms more severe with decreased tactile sensitivity, decreased temperature sensitivity, and decreased manual dexterity and grip strength [Taylor and Brammer 1982; Brammer et al. 1986; NIOSH 1983a; Farkkila et al. 1982; Brammer 1984].

The mechanisms involved in the observed peripheral neural changes have not been fully described. In workers who have been exposed to hand-arm vibration on the job and who have developed intermittent peripheral neural symptoms (numbness, tingling, pain, loss of sensitivity), the increased vibration perception threshold may reflect the functional disturbance of the peripheral nerves, of the sensory nerve endings, or of the mechanoreceptors, including the Pacinian corpuscles [Lundstrom 1986]. Harada and Matsumota [1982] suggested that the peripheral neural effects are a pathophysiologic entity separate from and independent of the circulatory disturbances. This suggestion was based on neural and

Table IV-7.—Categories of factors that may modify the biologic effects of hand-arm vibration exposure*

Factor categories	Modifying factors
Physical	Dominant vibration amplitudes entering the hand Dominant vibration axis relative to the hand Years of employment involving vibration exposure Total duration of exposure each workday Pattern of work/rest exposure each workday Nonoccupational exposure to vibration
Biodynamic	Hand grip forces (compressive and push or pull forces) Surface area, location, and mass of parts of the hand in contact with the source of vibration Posture (position of the hand and arm relative to the body) Other factors influencing the coupling of vibration source to the hand (e.g., texture of handle—soft, complaint vs. rigid material)
Individual	Factors influencing source, intensity, and exposure duration (e.g., state of tool maintenance, operator control of tool, work rate, skill, and productivity) Biological susceptibility to vibration Vasoconstrictive agents affecting the peripheral circulation (e.g., tobacco, drugs, etc.) Predisposing disease or prior injury to the fingers or hands (e.g., trauma, lacerations, diabetes, connective tissue disorders)

*Adapted from Taylor and Brammer [1982] and Brammer [1984].

vascular tests of workers not exposed to vibration, workers who used vibrating tools but had no symptoms, and workers who used vibrating tools and had symptoms of HAVS. Workers with neurophysiologic symptoms compatible with hand-arm vibration syndrome have a decreased sensory nerve conduction velocity from the fingers to the wrist [Alaranta and Seppalainen 1977; Sakurai and Matoba 1986]. These findings are consistent with the concept of a direct pathophysiologic effect of vibration on the peripheral nerves and nerve endings.

On the basis of a study of 245 vibration-exposed subjects with a history of nerve symptoms or evidence of neural injury, Lukas [1982] and Lukas and Kuzel [1971] concluded that the peripheral neural lesions may result from causes other than the direct effect of vibration. Nerve conduction velocity measurements of the fast motor and sensory fibers of the median and ulnar nerves frequently indicated that only one of the nerves tested was involved. In individuals using hand-held vibrating tools, both nerves would be expected to be affected. The authors also observed that conduction velocities in the distal portion of the sensory and motor fibers of the median and ulnar nerves were significantly reduced in the patients with symptoms of vasoneurosis as compared with the patients without vasospastic symptoms. The author concluded that the peripheral neural damage was secondary to the complex damage to the vascular, joint, and muscular systems of the arms and hands (multifactorial). Juntunen et al. [1983] found that nerve conduction velocity was slower and motor nerve latency longer in the patients with vibration syndrome who had neurologic signs of polyneuropathy. The authors stated that these findings provided evidence of a wider neural involvement than just the peripheral nerves.

On the basis of an analysis of data from forest workers, Farkkila et al. [1988] suggested that a large part of the previously diagnosed vibration neuropathies belong to the category of carpal tunnel syndrome (CTS), which is the most common entrapment neuropathy among forest workers.

Brammer et al. [1986] evaluated the degradation of vibrotactile and spatial-tactile perception in workers who used hand-held vibrating tools. The vibrotactile perception threshold values in workers with HAVS Stage 1, 2, or 3 of the Taylor and Pelmear classification exceeded the values of workers with no vibration exposure by more than 2 standard deviations. On the spatial-tactile resolution test [Carlson et al. 1984], the workers with vibration syndrome had values exceeding the controls by 2 to 4 standard deviations. Brammer et al. [1986] concluded that the neurological signs and symptoms in workers with chronic hand-arm vibration exposure involve both the peripheral nerve fibers and the mechanoreceptors.

Several types of neurophysiologic structures in the skin of the fingers are involved in the sense of touch [Vallbo and Johansson 1984]. The different structures function (fire) in response to different mechanical stimuli. The Pacinian corpuscles, the quick-adapting receptors, and the two types of slow-adapting receptors are the most important mechanoreceptors in the skin that are involved in the sense of touch [Lundstrom 1986]. For the sense of touch as measured by the sharp edges of the aesthesiometer (tactospatial), the slow-acting Type I receptors were more sensitive than the Pacinian corpuscles, the quick-acting receptors, or the slow-acting Type II receptors. Brammer et al. [1986] reported a decrease in the vibrotactile sensitivity that reflected the threshold of the Pacinian corpuscles.

In a biopsy study of 60 fingers with HAVS, Takeuchi et al. [1986] reported a decreased number of axon cylinders and a destruction of the myelin sheath in 90% of the cases. Such histopathologic deterioration could provide the basis for the sensory changes.

Researchers in this field agree that exposure to hand-arm vibration will eventually result in peripheral neural impairment with sensory loss, numbness, and decreased sensory and motor nerve conduction velocities but that the cause-effect mechanisms are not clear [Brammer 1986; Taylor and Brammer 1982; Brammer and Taylor 1982; Pyykko 1986; Ekenvall et al. 1986; Lundstrom 1986; Saraki et al. 1988; Radwin et al. 1987]. Taylor [1982a] summarized the state of knowledge as follows: "It is not known whether vibration directly injures the peripheral nerves thereby causing numbness and subsequently sensory loss, or whether the para-anesthesia of the hands is secondary to the vascular constriction of the blood vessels causing ischemia . . . in the nerve-end organs."

Lundborg et al. [1987] investigated the value of the vibrotactile sense test in assessing vibration-related neuropathies. The vibration sensation threshold for individuals who had not used vibrating tools was constant at vibration frequencies from 8 to 250 Hz. At 500 Hz, the sensation threshold was higher. For workers who used vibrating tools and had symptoms ranging from intermittent numbness to constant numbness and pain, the vibration sensation threshold increased progressively with higher vibration frequencies. The abnormalities in the vibrogram (sensation threshold) correlated not only with numbness and pain, but also with the occurrence of white finger. The authors concluded that the numbness resulted from a change in the intraneural vascular function. The finger blanching and pain and the numbness all reflect a common peripheral vascular disorder.

2. Peripheral Vascular Effects

The earliest signs of peripheral vascular changes in HAVS are the episodic attacks of fingertip blanching. These initial attacks of ischemia usually occur during cold exposure [Taylor and Brammer 1982; Brammer 1984; Pyykko 1986; Wasserman 1987]. With the continued exposure to vibration, the frequency and severity of the episodes of white finger increase until the blanching extends to the base of the fingers and may occur even in warm weather. The time between the first use of vibrating tools and the first appearance of episodic finger blanching (vasospasms) is designated as the latent interval. The latent interval appears to vary with the vibration intensity, as well as with other factors such as the type, model, unique individual characteristics of the tool, material on which the tool is used, tool maintenance, operating speed, operating technique, user characteristics, hand-grip force, push force, hand and arm posture, work/rest regimen, air temperature and moisture, protective hand gear, and clothing [Taylor and Brammer 1982; Brammer 1984].

In one of the early reports, the peripheral vascular symptoms of HAVS were considered to be only a nuisance [Pecora et al. 1960]. However, for the individual worker, the effects may seriously interfere with work [Taylor et al. 1977; Pyykko 1986]. Laroche [1976] reported that 10 out of 13 patients with HAVS had to change jobs because of the disabling effects of the disorder.

Although the phenomenon of the vasospastic episodes (sequence of events) has been described and accepted, basic underlying pathophysiologic mechanisms are not understood.

Nonetheless several have been proposed. The present concepts are built on data derived mainly from epidemiologic and clinical studies.

The sequence of events in the progression of the episodes of blanching appear to involve (1) bouts of digital arterial spasms that become progressively more frequent and prolonged, (2) arterial hypertrophy with an increase in the medial muscular layer of the arterial wall, (3) perivascular fibrosis with increased collagen formation, and (4) increased vasoconstrictor sensitivity. The hypertrophy of the arterial smooth muscle may progress until the arterial lumen is partially or completely obliterated [Ashe et al. 1962, 1964; Pyykko et al. 1982a; Brammer and Taylor 1982; Brammer 1984; Wegelius 1972; Takeuchi et al. 1986]. Biopsies on 60 fingers from 30 patients with HAVS revealed increased thickening of the muscular layer that was severe in 82% and moderate in 15% when compared with 7 biopsies on 3 control subjects. Perivascular fibrosis was found frequently and was severe in 55% and moderate in 37%. Intimal thickening was minimal in 35% and moderate in 7% of the HAVS workers [Takeuchi et al. 1986]. Okada et al. [1987a] in animal experiments observed that vibration resulted in intimal changes in the small arterioles with minimal medial changes. Similar findings were reported by Inaba et al. [1988].

Several etiologic theories have been postulated to account for the observed pathophysiologic changes in the digital arteries, but no single theory can account for all the changes. The mechanisms that could help explain the events seen in HAVS include (1) direct effects of vibration on the digital arteries, (2) effects on the peripheral sensory aspects of the sympathetic nervous control of the peripheral circulation, (3) central neural control, (4) hypersensitivity to chemical mediators (prostaglandins, serotonin, and noradrenalin), and (5) some combination of the above [Brammer 1984; Taylor and Brammer 1982; Azuma and Ohhashi 1982; Gemne et al. 1986]. The use of tobacco has been reported to be an additional risk factor in the development of HAVS in workers who operate noise-producing, hand-held vibrating tools [Miyakita et al. 1987; Bovenzi 1986; Ekenvall and Lindblad 1989].

Ekenvall and Lindblad [1989] measured the levels of nicotine and cotinine in the blood of 111 tobacco users and nontobacco users who did or did not have HAVS as determined by the digital systolic blood pressure after finger cooling. Blood nicotine concentrations in ng/ml were 0.8 in nontobacco users, 14.5 in cigarette smokers, 10.8 in snuff users, and 16.3 in users of other tobacco products; the cotinine levels were 0.7, 196, 252, and 210 ng/ml, respectively. When the 111 workers were grouped according to the Taylor-Pelmear stages of HAVS, the blood levels of cotinine in ng/ml were 5.7 for stages 0T and 0V, 8.7 for Stages 1 and 2, and 11.8 for Stages 3 and 4; the cotinine levels were 124, 117, and 171, respectively. The digital systolic blood pressure (as a percent of the arm systolic pressure during finger cooling at 15°C) was significantly lower in the tobacco users: 52% for nonusers, 29% for smokers, and 45% for snuff users. On the basis of their study results and a survey of the relevant literature, the authors concluded that "habitual use of tobacco aggravates the symptoms of VWF disease and has a direct effect on the results of a cold provocation test in this disease" [Ekenvall and Lindblad 1989].

Obliterative histopathologic changes reported in biopsies and arteriograms of the peripheral arterioles in some workers with HAVS appear convincing. But whether these changes are relevant histopathologic factors concerned with episodic finger blanching has been questioned on the basis of physiologic blood flow studies [Ekenvall et al. 1987]. Using venous occlusion plethysmography before and after induced vasodilation, these authors observed that the maximum blood flow after vasodilation was similar in the control subjects who were not exposed to hand-arm vibration and in vibration-exposed workers with advanced symptoms of HAVS. They reasoned that if the vessel lumen were narrowed by occlusive muscle hypertrophy, then blood flow would not be normal when maximum vasodilation was induced. Arteriograms were not taken; consequently, evidence of whether these subjects actually had arterial occlusion was lacking.

Regardless of the mechanisms involved in episodic finger blanching, the primary response concerns the digital arteries. During ischemic attacks, arterial blood flow to the affected segments of the fingers is reduced or completely shut off by contraction of the smooth muscles in the medial arterial wall. The episodic arterial muscle contractions could reflect an increased sympathetic nervous activity or an increased sensitivity of the arterial musculature (vasomotor tone) to local factors (chemical mediators including prostaglandins, serotonin, and noradrenalin) [Brammer 1984; Azuma and Ohhashi 1982; Bovenzi 1986]. Repeated contractions of the arterial muscles could lead to muscle hypertrophy. Gradual occlusion of the arterial lumen could result from intimal thickening. Stimulation of the vascular smooth muscle by adrenergic nerves constricts the digital artery lumen. Vasodilation occurs passively in the absence of vasoconstrictive action [Taylor and Brammer 1982].

The episodic ischemic attacks could be inappropriate pathophysiologic vascular responses to the vibration forces transmitted to the hands of the workers using vibrating tools. The medial muscle hypertrophy could be a histopathologic response to the sustained contraction of the vascular muscles. Any intimal changes could be a direct response to the vibration or a response to some changes in the blood chemistry [Taylor and Brammer 1982; Brammer 1984]. If the sympathetic nerve supply to the digital arteries is cut at the stellate ganglion, episodic blanching of the fingers induced by cold will return after an initial dilation of the digital arteries, which could last 3 to 4 months. This would imply that local chemical mediators may be at least partially involved.

A series of studies on workers with or without exposure to vibration and vibration-exposed workers with or without HAVS indicated that the finger vasospasm in the vibration-exposed group is the result of chronic stimulation of the mechanoreceptors in the fingers by the vibration. The receptors then serve as the sensory receptor link to the sympathetic nervous system with the effectors being the smooth muscle of the medial layer of the finger arterioles [Hyvarinen et al. 1973; Pyykko 1974b; Farkkila et al. 1985; Farkkila and Pyykko 1979; Pyykko et al. 1982a; Koradecka 1977].

Although the findings in these studies support the concept that the vibration sensory receptors contribute to HAVS by initiating excessive afferent impulses in the sympathetic reflex involving the peripheral vascular musculature, the exact etiologic (pathophysiologic) mechanisms are not fully known [Pyykko et al. 1982a]. Generally, in experimental studies when the hand is stimulated by vibration, a vasoconstriction occurs in the fingers. In workers who have not used vibrating tools, the vasoconstriction response to vibration stimuli was mild (about 10% have a strong response). Among workers who have used vibrating tools occupationally, about 40% exhibited a strong vasoconstrictive response, and 40% had a mild response similar to that of the controls [Pyykko et al. 1982a]. This suggests that chronic vibration stimulation increases the sensitivity of the mechanoreceptors to the vibration stimuli and increases the level of afferent impulses to the central nervous system with resulting increased reflex-sympathetic vasoconstriction. The prolonged contraction of the vascular muscles could result in the hypertrophy of the medial musculature and increased narrowing of the vessel lumen [Ashe et al. 1962; Ashe and Williams 1964; Takeuchi et al. 1986].

3. Skeletal Muscle Force and Muscle Fatigue

The subjective complaints of deterioration of hand grip force and muscle strength in workers using vibrating tools have been mentioned in many of the studies of HAVS. This aspect of HAVS has received specific emphasis in studies in Japan [Miyashita et al. 1983] and in Finland [Farkkila et al. 1982; Farkkila et al. 1980; Farkkila et al. 1979; Farkkila 1978]. Among Japanese chain saw operators with more than 2,000 hr of chain saw use, about 28% reported symptoms of decreased grip force and muscle strength. These symptoms were reported by 20% of Finnish chain saw operators with more than 5,000 hr of chain saw use.

The Finnish group measured maximum grip strength and rate of development of muscle fatigue with or without acute vibration exposure under controlled laboratory conditions. Lumberjacks with or without symptoms of diminished grip force and with or without symptoms of HAVS were compared with a control group who had no occupational vibration exposure. In the group of lumberjacks with HAVS, some experienced only episodes of white finger without ever experiencing decreased grip force; some reported finger numbness without decreased grip force; and some experienced decreased grip force and white finger and/or finger numbness.

The data indicated the following relationships:

- Grip force was reduced in lumberjacks throughout the entire muscle fatigue curve when the hand was exposed to vibration.
- Grip force was reduced more in workers who reported numbness, reduced muscle strength, or muscle pains.
- Acute vibration exposures reduced grip force more in those with symptoms than in those without symptoms of white finger.

- Reduced muscle strength was present in lumberjacks with 5,000 or more hours of total chain saw operating time.
- Muscle force was reduced and the prevalence of symptoms increased when total exposure times exceeded 5,000 hr.
- Lumberjacks with white finger used a stronger grip force when using the chain saws than did those who did not have white finger.
- A dose-response relationship seemed to exist between diminished muscle force and vibration exposure.
- Grip strength decreased as a function of age in vibration-exposed and unexposed groups.
- Muscle strength fatigue curve for the chain saw operators was similar to that of unexposed workers.
- Muscle strength for controls and for chain saw operators was the same when the hand was not exposed to vibration.
- Muscle strength of the controls was similar to that of the lumberjacks who had no symptoms of white finger.

The pathophysiologic mechanisms involved in the reduced muscle strength aspect of HAVS are not clear. Some of the possibilities include neurogenic muscle dysfunctions, direct mechanical effect on the muscle fibers, biochemical alterations in the muscle intracellular substances, and neuropathies. Whatever the mechanism(s) involved, diminished grip force can progress to the point of significant occupational disability [Farkkila et al. 1982].

4. Bone Cysts

Degenerative changes in the bones of the fingers and wrists of workers using vibrating hand-held tools have been reported [McLaren and Camb 1937; Wilson et al. 1967]. The changes observed were mainly cysts, vacuoles, and areas of decalcification. It is clear, however, that bone cysts were not observed as being specific to HAVS [Casciu et al. 1968; Kumlin et al. 1971]. Kumlin et al. [1973] found that 7 of 35 lumberjacks (20%) studied showed radiographic presence of cysts and vacuoles in the metacarpal bones or the phalanges or both. These seven lumberjacks had used chain saws for 10 years or more and had one or more subjective symptoms typical of HAVS.

Radiographs of the hands were specifically included in a British health survey of occupational chain saw operators [James et al. 1975]. The objective of this investigation was the association, if any, between the presence of wrist and hand bone cysts and the occupational exposure to hand-arm vibration. X-rays of the hands were taken of 165 lumberjacks and

162 controls (manual laborers in the same environment as the lumberjacks). Each X-ray was read independently by three radiologists. Based on positive findings by two or more of the three readers, the incidence of vacuoles was 44% in the lumberjacks versus 33% in the controls. The difference between the incidence of vacuoles in lumberjacks and in other workers who did not use vibrating tools was not statistically significant.

In a 1977-78 study of Italian shipyard workers, 169 caulkers who worked with vibrating tools were compared with 60 welders and electricians who were not exposed to hand-arm vibration [Bovenzi et al. 1980]. Only the workers who used hand-held vibrating tools were X-rayed. In the caulkers, 51% exhibited HAVS in Stages 1 and 2 of the Taylor and Pelmear classification. Only 7% of the control group showed similar signs and symptoms. Bone cysts, vacuoles, or both were reported in the hand/wrist bones of 31% of the caulkers. No X-ray data from controls were available for comparison. This is similar to the incidence of bone cysts-vacuoles that James et al. [1975] reported in lumberjacks and controls not exposed to vibration.

A NIOSH study compared 205 foundry and shipyard chipping and grinding workers with 63 manual workers in the same industries who did not use vibrating tools [NIOSH 1984]. The frequency, location, and size of cysts and vacuoles in the hand and wrist bones as inicated on X-rays were compared. The films were read independently by two radiologists. The vibration-exposed and the control workers showed no statistical differences in frequency, location, or size of cysts and vacuoles. This study, with its adequate control group, supports the concept of James et al. [1975] that cysts and vacuoles occur in the hand and wrist bones of workers performing manual work but that these changes are not necessarily vibration related. The presence of bone cysts in workers exposed to vibration is therefore not a useful, objective diagnostic criterion for HAVS.

Gemne and Saraste [1987] surveyed the literature (125 published articles) to evaluate the evidence for and against radiological demonstrable effects of vibration on the bones and joints of the arm and hand. The authors concluded that the evidence does not support a "causal relationship between vibration exposure and the formation of bone cysts and vacuoles."

5. Central Nervous System

The inclusion of the central nervous system in the hand-arm vibration syndrome has been postulated by USSR and Japanese researchers [Griffin 1980; Matoba et al. 1975a, 1975b; Habu 1984]. The etiology of the "systemic effects" involves the concept that hand-arm vibration can impair central nervous system function through damage to the autonomic centers in the brain [Matoba et al. 1975a, 1975b].

The symptomatology alleged to be associated with vibration-induced central nervous system disturbances includes anxiety, depression, insomnia, headache, palmar sweating, vertigo, irritability, emotional instability, etc. [Habu 1984]. These signs and symptoms, derived from statements made by the subjects being examined, usually have not been objectively assessed and are not specific to a single stressor such as vibration. Gemne and Taylor [1983], in summarizing the conclusions from an international symposium on hand-arm vibration and the central nervous system, stated that the present data do not support the hypothesis that exposure to hand-arm vibration may cause damage to the autonomic centers in the brain. In a study of 78 HAVS patients, Taylor et al. [1986] found no evidence to support an involvement of the central nervous system in HAVS.

6. Other Responses

Several other responses, whose significance in the identification and description of HAVS is unclear at present, may have some diagnostic value. These include the following:

a. In comparing the grip strength of nonvibration- and vibration-exposed workers, Miyashita et al. [1983] observed that grip strength progressively decreased as the total vibration exposure time increased: 52.5 kg grip strength in controls; 46.5 kg (–11.5%) in workers with up to 2,500 hr of total vibration exposure time; 40.1 kg (–24%) in wokers with more than 7,500 hr. Because of the wide differences in grip strengths among people, individual previbration-exposure values would be needed for grip strength to be a reliable diagnostic tool.

b. In the same control and exposure groups, sarcoplasmic enzyme levels (aldolase [ALD], creatinine phosphokinase [CPK], and lactic dehydrogenase [LDH]) in the exposure group increased over controls: 6% and 30% for ALD, 23% and 20% for CPK, 15% and 13% for LDH for <2,500 and >7,500 hr of vibrating tool use, respectively [Miyashita et al. 1983]. Adrenaline and noradrenalin in the urine of the exposed group were also measured and, when expressed as ng/mg creatinine, increased over control values by 260% and 269% for adrenaline, and 12% and 11% for noradrenalin for vibration exposures up to 4,000 hr and longer than 12,000 hr, respectively. Whether these changes are a general stress response or are specific to vibration stress remains to be proved.

c. It has been suggested that whole blood viscosity may play a role in HAVS and might be a useful tool in diagnosing HAVS between attacks. Whole blood viscosity in workers with HAVS was reported to be statistically significantly higher than in workers without HAVS ($p<0.01$) [Okada et al. 1982; Okada et al. 1987b]. However, Inaba et al. [1988] found no change in blood viscosity, hematocrit, cholesterol, and high density lipoproteins in vibration-exposed animals.

d. Okada et al. [1983] postulated a possible role of enhanced peripheral vasoconstriction caused by the exaggerated response of alpha adrenergic receptors in the arterial smooth muscles during attacks of white finger in workers with HAVS. These authors reported that during the cold provocation test (CPT), the plasma level of cyclic guanosine 3′, 5′-monophosphate (cyclic GMP) was increased to 170% over pretest levels in workers with

HAVS. The cyclic GMP levels did not increase in control subjects during the CPT. Without the CPT, the control and HAVS subjects had similar levels of cyclic GMP.

Phentolamine administered before and during the CPT and atropine injected subcutaneously immediately before the CPT inhibited the plasma rise in cyclic GMP during the CPT. The authors suggested that in individuals with HAVS, the increase in endogenous noradrenalin was enough to cause a significant increase in cyclic GMP in response to cold exposure (the CPT). This increased cyclic GMP response could result in an enhanced alpha-adrenergic response and a peripheral vasoconstriction.

e. An increased digital blood vessel reactivity to cold was reported by Bovenzi [1986]. Brown et al. [1988] measured radial digital artery blood flow in workers with and without HAVS before and after 20 min of chipping hammer use. Blood flow was measured by a 20-MHz, pulsed, ultrasonic Doppler velocimeter. Digital artery blood flow rate following the 20-min use of the chipping hammer increased substantially in the HAVS group, but there was little change in the control group. Pre-exposure flow rates were approximately equal in the control group and those with Stage 2 HAVS. The authors suggest that the 20-MHz Doppler velocimeter might be a valuable indicator tool for studying HAVS pathology.

C. EPIDEMIOLOGIC STUDIES

Epidemiologic studies of workers using hand-held vibrating tools have been conducted in Europe, North America, and Asia. Workers using gasoline-powered chain saws in forestry have been studied most frequently, followed by studies of workers using pneumatic chipping hammers in foundries, shipyards, and quarries, and pneumatic jack-leg drills in mining. These have been cross-sectional studies except for a few longitudinal studies of chain sawyers in the United Kingdom, Finland, and Japan. Cross-sectional studies examine a group of workers using hand-held vibrating tools in an industry at one particular time to determine the proportion of workers with HAVS (i.e., the prevalence of HAVS). Longitudinal studies of HAVS examine a group of workers at more than one point in time. The prevalence of HAVS is usually expressed as the prevalence of specific symptoms of HAVS such as vascular or neurologic symptoms. Sometimes studies report the latency of HAVS symptoms, the years of exposure to hand-arm vibration from the tool, and the hand-arm vibration acceleration level of the tool. The latency of a HAVS symptom is defined as the time from first use of a tool to the first appearance of the symptom.

1. Cross-Sectional Studies of HAVS

Table IV-8 summarizes pertinent information from cross-sectional studies of HAVS. The prevalence of vascular symptoms of HAVS is shown in the table because these symptoms were reported more consistently among epidemiologic studies of HAVS than the prevalence of other symptoms. If reported, the mean latency and mean years of exposure for the group of exposed workers is presented in Table IV-8; otherwise, the median is presented. If the mean or median latency or years of exposure are not reported, these variables are presented

Table IV-8.—Summary of epidemiologic studies of hand-arm vibration syndrome (HAVS)

Tool types	Industry	Number of workers exposed to H-A vibration	Prevalence of vascular symptoms* of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A vibration	H-A vibration acceleration level† (m/sec^2)	Author and date of publication	Country where study was conducted
Chain saw	Forestry	76	39	1-10 (range)	6.3 (mean) for workers with symptoms	N.A.§	Barnes et al. 1969	Australia
Chain saw	Forestry	82	47	4.5 (median)	7.5 (median)	N.A.	Allingham and Firth 1972	New Zealand
Chain saw	Forestry	296	47	8 (mean)	N.A.	N.A.	Hellstrom and Andersen 1972	Norway
Chain saw	Forestry	550	41	3-5 for 42% of workers with symptoms	≥5 for 84% of exposed workers	N.A.	Laitinen et al. 1974	Finland
Chain saw	Forestry	728	25	1-13 (range)	5 (mean)	N.A.	Wakisaka et al. 1975	Japan
Chain saw	Forestry	24	54	5 (mean)	N.A.	N.A.	Miura 1975	Japan
Chain saw	Forestry	87	38	4 (median)	7.8 (mean)	75	Matsumoto et al.1979	Japan
Chain saw	Forestry	402	36	13 (median)	12 (median)	N.A.	Suzuki 1979	Japan
Chain saw	Forestry	52	8	N.A.	< for 75% of exposed workers	N.A.	Iwata et al. 1980	Japan

(continued)

*Stages 1V, 2V, and 3V as defined by the revised Taylor-Pelmear staging system (Table IV-3).
†Frequency unweighted unless otherwise noted.
§Denotes data not available from articles cited.

Table IV-8 (Continued).–Summary of epidemiologic studies of hand-arm vibration syndrome (HAVS)

Tool types	Industry	Number of workers exposed to H-A vibration	Prevalence of vascular symptoms* of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A vibration	H-A vibration acceleration level† (m/sec^2)	Author and date of publication	Country where study was conducted
Chain saw	Forestry	365	29	5.6 (mean)	8.5 (mean)	N.A.	Olsen et al. 1981	Denmark
Chain saw	Forestry	107	62	7.9 (mean)	17.5 (mean)	N.A.	Patri et al. 1982	France
Chain saw	Forestry	323	28	7 (mean)	N.A.	68	Pelnar et al. 1982	Canada
Chain saw	Forestry	1,055	30	7.8 (mean)	N.A.	N.A.	Theriault et al. 1982	Canada
Chain saw	Forestry	89	54	7.3 (mean)	≥6 for 90% of exposed workers	N.A.	Brubaker et al. 1983	Canada
Chain saw	Forestry	279	18	N.A.	10.4 (mean)	N.A.	Harkonen et al. 1984	Finland
Brush saw	Forestry	506	6	6.4 (mean)	7 (mean)	59	Futatsuka 1984	Japan
Riveter	Boiler repair	78	61	≤10 for 87% of workers with symptoms	>10 for 58% of exposed workers	N.A.	Hunter et al. 1945	United Kingdom
Riveter, drill, shaver, bar	Aircraft manufacturer	340	25	≥20 for 50% of workers with symptoms	≤5 for 50% of exposed workers	10 (weighted)	Engstrom and Dandanell 1986	Sweden

(continued)

Table IV-8 (Continued).--Summary of epidemiologic studies of hand-arm vibration syndrome (HAVS)

Tool types	Industry	Number of workers exposed to H-A vibration	Prevalence of vascular symptoms* of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A vibration	H-A vibration acceleration level† (m/sec^2)	Author and date of publication	Country where study was conducted
Riveter, caulker, chipping hammer	Shipyard	195	75	N.A.	≥20 for >80% of exposed workers	1,183 (caulker and riveter only)	Oliver et al. 1979	United Kingdom
Chipping hammer	Pressed steel	31	93	1.7 (mean)	N.A.	N.A.	Marshall et al. 1954	United Kingdom
Chipping hammer	N.A.	49	41	8 (mean)	N.A.	N.A.	Lidstrom 1977	Sweden
Chipping hammer	Steel foundry	21	24	3.8 (mean)	>5 for 52% of exposed workers	N.A.	Suzuki 1978	Japan
Chipping hammer	Granite quarry	18	72	13 (mean)	20 (mean)	N.A.	Olsen and Nielsen 1979	Denmark
Chipping hammer, grinder	Shipyard	169	31	N.A.	7.3 (mean)	205	Bovenzi et al. 1980	Italy
Chipping hammer, grinder, scaler	Foundry	49	45	2.2 (mean)	3.8 (mean)	424	Taylor et al. 1981	United States
Chipping hammer	Iron foundry	25	64	≤10 for 96% of workers with symptoms	>10 for 52% of exposed workers	378	Matsumoto et al. 1979, 1981	Japan

(continued)

Table IV-8 (Continued).--Summary of epidemiologic studies of hand-arm vibration syndrome (HAVS)

Tool types	Industry	Number of workers exposed to H-A vibration	Prevalence of vascular symptoms* of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A vibration	H-A vibration acceleration level† (m/sec^2)	Author and date of publication	Country where study was conducted
Chipping hammer, grinder	Foundry	147	47	2 (mean)	2-3 (mean)	251	Behrens et al. 1982, 1984, Wasserman et al. 1984	United States
Chipping hammer, grinder	Shipyard	58	19	17 (mean)	12 (mean)	29	Behrens et al. 1982, 1984, Wasserman et al. 1984	United States
Chipping hammer	Quarry	69	36	N.A.	>15 for 72% of exposed workers	N.A.	Sakakibara et al. 1984	Japan
Chipping hammer	Limestone quarry	15	80	7.7 (mean)	37 (mean)	2,014	Taylor et al. 1984	United States
Hand grinder	Aircraft manufacture	112	21	0.7 (mean)	N.A.	N.A.	Dart 1946	United States
Hand grinder	Foundry	233	70	2 (mean)	N.A.	N.A.	Agate 1949	United Kingdom
Hand grinder	Foundry	54	35	15.3 (mean)	19 (mean)	20	Pelmear et al. 1975, Taylor et al. 1975c	United Kingdom
Hand grinder	N.A.	44	20	9 (mean)	N.A.	N.A.	Lidstrom 1977	Sweden

(continued)

Table IV-8 (Continued).--Summary of epidemiologic studies of hand-arm vibration syndrome (HAVS)

Tool types	Industry	Number of workers exposed to H-A vibration	Prevalence of vascular symptoms* of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A vibration	H-A vibration acceleration level† (m/sec^2)	Author and date of publication	Country where study was conducted
Hand grinder	Steel foundry	30	23	2 (mean)	>5 for 34% of exposed workers	N.A.	Suzuki 1978	Japan
Pedestal grinder	Foundry	37	86	1.8 (mean)	N.A.	382	Agate et al. 1946, Agate 1949	United Kingdom
Pedestal grinder	Foundry	34	94	4.5 (mean)	12.5 (mean)	N.A.	Pelmear et al. 1975	United Kingdom
Pedestal grinder	Foundry	26	96	1.8 (mean)	4.1 (mean)	125	Pelmear et al. 1975, Taylor et al. 1975c	United Kingdom
Pedestal grinder	Foundry	74	11	14 (mean)	N.A.	60	Taylor et al. 1975a, Taylor et al. 1975c	United Kingdom
Pedestal grinder	Foundry	12	100	0.9 (mean)	1.1 (mean)	122	Starck et al. 1983	Finland
Jack-leg drill	Metal mine	185	72	N.A.	N.A.	121	Iwata 1968	Japan
Jack-leg drill	Copper mine	68	22	5 (mean)	N.A.	N.A.	Miura 1975	Japan

(continued)

Table IV-8 (Continued).—Summary of epidemiologic studies of hand-arm vibration syndrome (HAVS)

Tool types	Industry	Number of workers exposed to H-A vibration	Prevalence of vascular symptoms* of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A vibration	H-A vibration acceleration level⁺ (m/sec²)	Author and date of publication	Country where study was conducted
Jack-leg drill	Zinc mine	45	80	N.A.	>10 for 64% of exposed workers	335	Matsumoto et al. 1977, 1979	Japan
Jack-leg drill	Uranium mine	96	70	>10 for 91% of workers with symptoms	>10 for 78% of exposed workers	339	Robert et al. 1977	France
Jack-leg drill	Fluorspar mine	42	50	5.7 (mean)	9.9 (mean)	362	Chatterjee et al. 1978	United Kingdom
Jack-leg drill	Hard rock mine	58	45	7.2 (mean)	N.A.	20 (weighted)	Brubaker et al. 1986	Canada
Rock drill	Stone quarry	70	37	4 (mean)	N.A.	N.A.	Miura 1975	Japan
Rock drill	Construction	40	55	8 (mean)	N.A.	N.A.	Lidstrom 1977	Sweden
Rock drill	Anthracite coal mine	208	13	N.A.	>8 for 28% of exposed workers	N.A.	Moon et al. 1982	Korea
Pavement breaker	Gas supply	851	10	N.A.	N.A.	195	Walker et al. 1985	United Kingdom
Motorcycle	Speedway racing	32	94	5 (mean)	N.A.	416	Bentley et al. 1982	United Kingdom
Riveter, chipping hammer, grinder	Railroad	1,028	13	9.2 (mean)	>10 for 32% of exposed workers	N.A.	Zeng-Shun et al. 1986	China

in the form given in the cited article. A method of standardization (presented in Appendix A) was applied to the acceleration measurements of hand-arm vibration if they were reported in a study. This method of standardization makes the measurements comparable with each other.

The prevalence of vascular symptoms of HAVS in Table IV-8 ranged from 6% to 100%. To evaluate the relative significance of these prevalence values, they must be compared with the background rate of vascular symptoms among worker populations that have not been exposed to hand-arm vibration. Nineteen of the studies reported the prevalence of vascular symptoms among a group of control workers who had not been exposed to hand-arm vibration and had worked at the same site as the exposed workers [Allingham and Firth 1972; Hellstrom and Andersen 1972; Taylor et al. 1974; Pelmear et al. 1975; Taylor et al. 1975a; Matsumoto et al. 1977; Chatterjee et al. 1978; Bovenzi et al. 1980; Matsumoto et al. 1981; Moon et al. 1982; Patri et al. 1982; Pelnar et al. 1982; Theriault et al. 1982; Brubaker et al. 1983; Behrens et al. 1984; Harkonen et al. 1984; Walker et al. 1985; Brubaker et al. 1986; Zeng-Shun et al. 1986]. The prevalence of vascular symptoms among these 19 groups of control workers ranged from 0% to 14% with a mean prevalence of 5.4% and a median of 4%.

Most of the studies listed in Table IV-8 had prevalence rates of vascular symptoms that were well above background rates. More than half of the studies had HAVS prevalence rates that were greater than 40%. Epidemiologic studies of HAVS clearly confirm an association between vascular symptoms and exposure to hand-arm vibration from hand-held vibrating tools and workpieces. These studies also provide clues to HAVS prevention. A study showing a relatively low prevalence of vascular symptoms or a relatively long latency of vascular symptoms may provide such clues. In addition, some of the studies in Table IV-8 had tool vibration measurements taken at the time of the cross-sectional medical evaluations, and these studies indicate the exposure-response relationship between HAVS and hand-arm vibration.

Nine of the studies in Table IV-8 [Taylor et al. 1975a; Iwata et al. 1980; Behrens et al. 1982, 1984; Moon et al. 1982; Futatsuka 1984; Harkonen et al. 1984; Walker et al. 1985; Zeng-Shun et al. 1986] reported prevalence rates of vascular symptoms among the exposed workers that were nearly within range of the prevalence rates for the control group (i.e., from 0% to 14%). The study by Iwata et al. [1980] found an 8% prevalence of vascular symptoms among chain saw operators. A control group was not included in this study. The low prevalence rate may have been due to the high proportion (75%) of chain saw operators in this study who had less than 10 years of exposure to hand-arm vibration from chain saws, or it may have been that the use of antivibration chain saws by 1980 reduced exposure. Although the authors did not report the latency of vascular symptoms for this group of chain saw operators, the average latency for other studies of chain saw operators in Table IV-8 ranged from 4 to 13 years. Thus the group of chain saw operators in the study by Iwata et al. [1980] probably had not experienced sufficient exposure for all cases of HAVS (with vascular symptoms) to manifest themselves.

Harkonen et al. [1984] observed the relatively low 18% prevalence of vascular symptoms of among a group of chain saw operators. A control or reference group of peat bog workers were examined and were found to have a 3% prevalence of vascular symptoms. The authors reported that the difference in prevalence between the exposed and control groups was statistically significant ($p<0.001$).

In the study of workers using gasoline-powered brush saws, Futatsuka [1984] reported a 6% prevalence of vascular symptoms, the lowest reported prevalence in Table IV-8. No control group was examined in this study. Among the exposed group, the mean duration of exposure to brush sawing was 7 years and the mean latency of vascular symptoms was 6.4 years. Because the mean exposure time was greater than the mean latency, the prevalence of vascular symptoms in this group of brush saw operators would not be likely to increase appreciably with further exposure. The author reported some factors that probably contributed to the low prevalence of vascular symptoms in these brush saw operators. Workers used the brush saws for 4 to 5 months a year, during the warmer season of May to September. Also, since 1970, the use of the brush saw was limited to 2 to 3 hr/day. Before that date, workers were using the brush saws up to 6 hr/day. The effect of limiting the number of hours of brush saw use per day was revealed in the difference between the prevalence of vascular symptoms in workers who started using the brush saws in 1961 and 1962 (12% peak prevalence from 1961 to 1980) and workers who started in 1969 and 1970 (0% prevalence from 1969 to 1980).

A relatively low prevalence of vascular symptoms among chipping and grinding workers was reported by Behrens et al. [1982, 1984]. In this study of workers using pneumatic chipping hammers and grinders at a shipyard, the prevalence of vascular symptoms was 19%. A control group working at the shipyard was included in this study, and the prevalence of vascular symptoms in the control group was 0%. The difference in prevalence rates between the exposed and control groups was statistically significant ($p<0.0001$) [Wasserman et al. 1982]. In this group of chipping hammer and grinder operators, the prevalence would probably increase over time because the mean exposure time (12 years) was less than the mean latency for vascular symptoms (17 years).

Four other studies in Table IV-8 showed relatively low prevalence rates of vascular symptoms [Taylor et al. 1975a; Moon et al. 1982; Walker et al. 1985; Zeng-Shun et al. 1986]. All of these studies reported the prevalence of vascular symptoms in a control group of workers. The study of pedestal grinders by Taylor et al. [1975a] found an 11% prevalence in the exposed group and 4% in the control group. The authors did not compare the prevalence statistically. Also, the authors did not report a mean exposure time for this group of pedestal grinders, although the mean latency of vascular symptoms was reported as 14 years. In the study by Moon et al. [1982], the prevalence of vascular symptoms among anthracite miners using pneumatic rock drills was 13%, whereas the prevalence in the control group was 0.9%. The statistical comparison of prevalence rates was significant ($p<0.05$). Similarly, Zeng-Shun et al. [1986] reported that the prevalence of vascular symptoms among railroad workers using riveters, chipping hammers, and grinders was 13%, whereas the control group prevalence was 1.6% ($p<0.001$).

The Walker et al. [1985] study of workers in the gas industry who used pavement breakers is the only study in Table IV-8 in which the difference in prevalence between the exposed and control groups was not statistically significant. The prevalence rates of vascular symptoms in the workers using pavement breakers and the workers not exposed to hand-arm vibration were both 10%. After adjustment for differences in the ages of the exposed and control groups, the age-adjusted prevalence was 12% in the exposed group and 10% in the control group. This comparison was not statistically significant. The authors did not report the latency of vascular symptoms, but the prevalence of vascular symptoms among workers using the pavement breakers for 1 to 5 years was 9%, whereas the prevalence in workers using the pavement breakers more than 20 years was 18%. Two factors may have contributed to the nonsignificant and relatively low prevalence of vascular symptoms in this group of pavement breaker operators. First, the average latency of vascular symptoms may have been longer than latencies recorded for exposures to other tool types because the prevalence among the exposed workers did not increase much above that of the control group until the exposed workers had more than 20 years of exposure. Second, the prevalence of vascular symptoms in the control group was relatively high (10% prevalence in this control group compared with a mean prevalence of 5.4% in 19 control groups from Table IV-8).

A recent survey of workers who used impact power tools indicated a prevalence rate of 29% for numbness and tingling of the fingers and 17% for white finger. The workers used the impact tools for an average of 23% of the workday. Frequency-weighted acceleration levels exceeded 12 m/sec^2 for all measurements, and they averaged approximately 24 m/sec^2 for chipping hammers and rammers. The mean cumulative exposure for each worker over a working lifetime was nearly 4,000 hr. The 17%- to 29%-prevalence of signs and symptoms of HAVS occurred even though the daily tool use time was only about 2 hr [Musson et al. 1989].

Forty-four studies listed in Table IV-8 included some information about the latency of vascular symptoms among exposed workers. Thirty-three of these 44 studies reported the mean latency of vascular symptoms. These 33 mean latencies ranged from 0.7 to 17 years, with a mean value of 6.3 years. When compared with the range and mean values of the 33 mean latencies, four studies [Pelmear et al. 1975; Taylor et al. 1975a; Olsen and Nielsen 1979; Behrens et al. 1982, 1984] reported relatively long mean latencies. A relatively long latency of vascular symptoms suggests the possibility that some workers may never show vascular symptoms.

Olsen and Nielsen [1979] found a 13-year mean latency for vascular symptoms among 18 (out of 20 total) workers using pneumatic chipping hammers at a granite quarry. Despite the relatively long latency, the prevalence of vascular symptoms was 72% (13/18). The high prevalence is expected because the mean duration of exposure (20 years) for the workers was greater than the mean latency. For the 18 quarry workers, the individual latencies varied from 0 to 27 years. A latency of 0 years may indicate that this quarry worker had vascular symptoms before starting to use the chipping hammer at this quarry. The next four lowest latencies for individual workers were 2, 4, 7, and 7 years. Thus the individual variation in onset of vascular symptoms shows that all workers in this group could not be protected by limiting the years of exposure.

In a study of shipyard workers using chipping and grinding tools [Behrens et al. 1982, 1984], the mean latency of vascular symptoms was 17 years, with a range of 4 to 35 years. Eleven shipyard workers had vascular symptoms, and 5 of these 11 workers had latencies of less than 10 years. At the high end of the range, 2 of the 11 workers had latencies greater than 30 years. Therefore, the mean latency was relatively long among these shipyard workers because of the wide variation in individual latencies, as was also shown in the study by Olsen and Nielsen [1979].

The Pelmear et al. [1975] study of hand grinders found a 13.7-year mean latency of vascular symptoms, and the Taylor et al. [1975a] study of pedestal grinders found a 14-year mean latency. Neither of these studies reported the range of latencies or individual latency values. The mean exposure time (19 years) for workers using hand grinders in a foundry [Pelmear et al. 1975] was greater than the mean latency (13.7 years), which resulted in a substantial 35% prevalence of vascular symptoms. Workers using pedestal grinders in a foundry [Taylor et al. 1975a] had an 11% prevalence (and a 14-year mean latency), but the authors did not report the average years of exposure. As a result, the relationship between the latency, the years of exposure, and prevalence in this group of workers is not known.

Vibration measurements were reported for 23 of the studies listed in Table IV-8. These 23 studies are ranked in Table IV-9, in descending order, from highest to lowest hand-arm vibration acceleration level. The prevalence of vascular symptoms, the tool type, and the publication reference are also repeated in Table IV-9. The 23 hand-arm vibration acceleration levels in Table IV-9 range from 10 to 2,014 m/sec^2, and the mean and median values were, respectively, 312 and 195 m/sec^2. The relationship between the hand-arm vibration acceleration level and the prevalence of vascular symptoms for these 23 studies was tested for linearity by calculating a correlation coefficient. The correlation coefficient was 0.67 and was statistically significant at the 1% level ($p<0.01$). Thus the prevalence of vascular symptoms tends to increase as the hand-arm vibration acceleration level increases for these 23 studies.

In general, the studies in Table IV-9 that showed hand-arm vibration acceleration levels greater than the median acceleration level for these 23 studies (195 m/sec^2) also showed prevalence rates of vascular symptoms greater than 40%. Only the Bovenzi et al. [1980] study deviated from this trend. Also, in general, the studies in Table IV-9 with acceleration levels less than or equal to the median acceleration level had prevalence rates of less than

Table IV-9.—Hand-arm vibration acceleration levels ranked from highest to lowest for studies listed in Table IV-8.

Hand-arm vibration acceleration level (m/sec^2)*	Prevalence of vascular symptoms of HAVS (%)	Tool type	Author and date of publication
2,014	80	Chipping hammer	Taylor et al. 1984
1,183†	75	Riveter, caulker, chipping hammer	Oliver et al. 1979
424	45	Chipping hammer, grinder, scaler	Taylor et al. 1981
416	94	Motorcycle	Bentley et al. 1982
382	86	Pedestal grinder	Agate et al. 1946 Agate 1949
378	64	Chipping hammer, grinder	Matsumoto et al. 1979, 1981
362	50	Jack-leg drill	Chatterjee et al. 1978
339	70	Jack-leg drill	Robert et al. 1977
335	80	Jack-leg drill	Matsumoto et al. 1977, 1979
251	47	Chipping hammer, grinder	Behrens et al. 1984 Wasserman et al. 1984
205	31	Chipping hammer, grinder	Bovenzi et al. 1980
195	10	Pavement breaker	Walker et al. 1985
125	96	Pedestal grinder	Pelmear et al. 1975 Taylor et al. 1975c
122	100	Pedestal grinder	Starck et al. 1983
121	72	Jack-leg drill	Iwata 1968

(continued)

See footnotes at end of table.

Table IV-9 (Continued).—Hand-arm vibration acceleration levels ranked from highest to lowest for studies listed in Table IV-8.

Hand-arm vibration acceleration level (m/sec^2)*	Prevalence of vascular symptoms of HAVS (%)	Tool type	Author and date of publication
75	38	Chain saw	Matsumoto et al. 1979
68	28	Chain saw	Pelnar et al. 1982
60	11	Pedestal grinder	Taylor et al. 1975a Taylor et al. 1975c
59	6	Brush saw	Futatsuka 1984
29	19	Chipping hammer, grinder	Behrens et al. 1984 Wasserman et al. 1984
20[§]	45	Jack-leg drill	Brubaker et al. 1986
20	35	Hand grinder	Pelmear et al. 1975 Taylor et al. 1975c
10[§]	25	Riveter, drill, shaver, bar	Engstrom and Dandanell 1986

*Frequency unweighted except as noted.
†Measured riveter and caulker only.
§4-hr ISO weighted value.

40%. Four studies (Iwata [1968]; Pelmear et al. [1975]; Starck et al. [1983]; and Brubaker et al. [1986]) did not follow this trend.

In the Bovenzi et al. [1980] study of shipyard workers using chipping hammers and grinders, the hand-arm vibration acceleration level was 205 m/sec^2 and the prevalence of vascular symptoms was 31%. The authors did not report the latency of vascular symptoms for those shipyard workers with symptoms. They did report that the mean duration of exposure to hand-arm vibration was 7.3 years for the 169 shipyard workers studied, and that 46% had been exposed for 5 years or less and 44% for 6 to 10 years. Also, in this study, the mean duration years of exposure for shipyard workers with vascular symptoms was 10.2 years, whereas the mean duration of exposure for shipyard workers without vascular symptoms was 6.1 years. Thus at least 46% of the shipyard workers studied had been exposed for fewer years (i.e., <6) than the mean years of exposure for workers with vascular symptoms (approximately 10 years). These results indirectly indicate that the prevalence of vascular symptoms in the group of shipyard workers studied by Bovenzi et al. [1980] would probably increase over time and with further exposure.

Two other studies in Table IV-9 that deviate from the trend of a linear relationship between hand-arm vibration acceleration levels and prevalence of vascular symptoms are the pedestal grinder studies of Pelmear et al. [1975] and Starck et al. [1983]. For both of these studies, the prevalence of vascular symptoms was exceptionally high (96% for Pelmear et al. [1975] and 100% for Starck et al. [1983]). The authors for both of these studies attributed the high prevalence rates to the use of zirconium wheels on the pedestal grinding machines because the prevalence of vascular symptoms increased markedly in their study groups when wheels of "softer" material were replaced by "harder" zirconium wheels. The Taylor et al. [1975a] study of pedestal grinders in Table IV-9 reported a relatively low prevalence (11%), an average acceleration level of 100 m/sec^2, and the use of "soft" wheels on the pedestal grinding machines. The only other study of pedestal grinders in Table IV-9 (by Agate et al. [1946]) did not specify the type of wheels used.

Brubaker et al. [1986] found that 45% of hard rock miners using jack-leg drills had vascular symptoms but that the hand-arm vibration acceleration level for the jack-leg drills was frequency weighted at 20 m/sec^2, a relatively low acceleration level. Acceleration levels for jack-leg drills were reported for four other studies in Table IV-9; the levels were all greater than 100 m/sec^2, and for three of these studies, the levels were greater than 300 m/sec^2. Brubaker et al. [1986] measured the jack-leg drills "under actual drilling conditions at the mine sites according to guidelines specified in ISO 5349." The authors pointed out that ISO 5349 [ISO 1986] suggests that 50% of the workers exposed to a frequency-weighted vibration level of 20 m/sec^2 will develop vascular symptoms after a 3- to 5-year exposure. Therefore, a 45% prevalence of vascular symptoms may not be unexpected for this group of workers. Brubaker et al. [1986] did not compare their measurements of jack-leg drills to those of other investigators and thereby offered no explanation for the relatively low acceleration levels they reported.

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The study by Iwata [1968] shows a similar result to that of Brubaker et al. [1986]. For workers using jack-leg drills, Iwata [1968] found a relatively high prevalence of vascular symptoms (72%) but a below-average hand-arm acceleration level (121 m/sec^2). Iwata's study [1968] was reported earlier than the other studies of jack-leg drills in Table IV-9. He could not compare his hand-arm vibration measurements with other studies of jack-leg drills, and he did not perform the measurements according to international standards recommended during the late 1960s.

2. Longitudinal Studies of HAVS

Longitudinal studies of workers exposed to hand-arm vibration demonstrate the effect that lowering the acceleration level of a hand-held vibrating tool has on the prevalence of HAVS. Three longitudinal studies have been conducted; all of them concern forestry workers using gasoline-powered chain saws. Tables IV-10, IV-11, and IV-12 summarize the longitudinal studies of chain saw operators in the United Kingdom, Finland, and Japan, respectively. Neither a longitudinal nor a cross-sectional study of chain saw operators has been done in the United States.

Gasoline-powered chain saws in the 1950s were large and difficult to maneuver, and their use was limited to 1 to 2 hr per day. In the 1960s, technical improvements in the design of chain saws allowed their use to be extended to 4 to 6 hr per day. By the early 1970s, initial reports of HAVS among chain saw operators were made public. In the early 1970s, chain saws were redesigned to lower the vibration acceleration levels. These saws are called antivibration chain saws. By the 1980s, the prevalence of HAVS among chain saw operators had been reduced.

Table IV-10 presents a summary of the longitudinal studies of antivibration chain saw operators in the United Kingdom reported by Taylor and co-workers [Taylor et al. 1974, 1975a, 1975b, 1975c, 1977; Riddle and Taylor 1982]. An original group of 46 forestry workers using gasoline-engine-powered chain saws was followed from 1970 to at least 1981. In 1970, the prevalence of vascular symptoms in this group was 85%. Antivibration chain saws were introduced in 1973, and by 1975, 73% of the 44 remaining chain saw operators had vascular symptoms. In 1981, 28 of the original 46 chain saw operators were still working in forestry, and 46% of these workers had vascular symptoms. Taylor and co-workers [Riddle and Taylor 1982] noted that some workers had recovered and no longer had vascular symptoms after the introduction of antivibration chain saws. Also in 1981, 18 chain saw operators who had worked exclusively with antivibration chain saws

Table IV-10.—Summary of epidemiologic studies of forestry workers using chain saws in the United Kingdom*

Number of forestry workers	Prevalence of vascular symptoms of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A[†] vibration	H-A vibration acceleration level (m/sec^2)
46 in 1970 (non A-V[§] chain saw users only)	85	N.A.**	6 (mean)	150-350 for non A-V chain saws
44 in 1975 (non A-V and A-V chain saw users)	73	3 (mean)	11 (mean)	150-350 for non A-V and 15-50 for A-V chain saws
18 in 1981 (A-V chain saw users only)	17	N.A.	5 (mean)	15-50 for A-V chain saws

*Sources: Taylor et al. [1974, 1975a, 1975b, 1975c, 1977], Riddle and Taylor [1982].
[†]Hand-arm.
[§]Antivibration.
**Denotes data not available from articles cited.

Table IV-11.—Summary of epidemiologic studies of forestry workers using chain saws in Finland*

Number of forestry workers	Prevalence of vascular symptoms of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A† vibration	H-A vibration acceleration level (m/sec²)
66 in 1972	34	5 (mean)	N.A.§	162
66 in 1977	10	5 (mean)	N.A.	17
66 in 1983	5	5 (mean)	N.A.	16

*Sources: Pyykko [1974a] and Pyykko et al. [1978, 1982b, 1986b].
†Hand-arm.
§Denotes data not available from articles cited.

Table IV-12.—Summary of epidemiologic studies of forestry workers using chain saws in Japan*

Number of of forestry workers	Years workers began using chain saws	Prevalence of vascular symptoms of HAVS (%)	Latency of vascular symptoms of HAVS (years)	Years of exposure to H-A† vibration	H-A vibration acceleration level (m/sec^2)
123	1958 and 1959	63	N.A.§	14 (mean)	111-304 for chain saws made in 1966
114	1968 and 1969	22	N.A.	7 (mean)	49-105 for chain saws made in 1970
103	1974 and 1975	2	N.A.	5 (mean)	10-33 for chain saws made in 1975
1,330	1956 to 1979 (includes workers given above)	28	6.4 (mean)	10 (mean)	(same as above)

*Source: Futatsuka and Ueno [1985, 1986].
†Hand-arm.
§Denotes data not available from articles cited.

were examined and were found to have a 17% prevalence of vascular symptoms. Hand-arm vibration acceleration levels for chain saws measured before the introduction of antivibration designs ranged from 150 to 350 m/sec^2, whereas antivibration chain saws ranged from 15 to 50 m/sec^2.

Pyykko and co-workers [Pyykko 1974a and Pyykko et al. 1978, 1982b, 1986b] in Finland followed 66 forestry workers using gasoline-powered chain saws from 1972 until 1983 (see Table IV-11). The prevalence of vascular symptoms in this group was 34% in 1972 and reached a peak of 38% in 1975. Antivibration chain saws were introduced in the mid-1970s, and the prevalence of vascular symptoms in the study group of 66 chain saw operators had decreased to 5% by 1983. Hand-arm vibration acceleration levels on chain saws measured in 1972 were 162 m/sec^2. Antivibration chain saws were measured at 17 m/sec^2 in 1977 and at 16 m/sec^2 in 1983.

A longitudinal study of forestry workers using gasoline-engine-powered chain saws in Japan was conducted by Futatsuka and Ueno [1985, 1986]. Forestry workers employed by the Japanese government in national forests have been examined on a regular basis since 1965, and results of these examinations have been reported through 1980. Chain saw operators in this study were grouped according to the year when they first began using a chain saw (see Table IV-12). The peak prevalence of vascular symptoms for chain saw operators who began chain saw use in 1958 and 1959 was 63%. For chain saws measured in 1966 (the earliest year measurements were available), the vibration acceleration level ranged from 111 to 304 m/sec^2. The peak prevalence for chain saw operators who began chain saw use in 1968 and 1969 was 22%. For nonantivibration chain saws measured in 1970, acceleration levels ranged from 49 to 105 m/sec^2. The peak prevalence for chain saw operators who began working in 1974 and 1975, after the introduction of antivibration chain saws, was only 2%. For antivibration chain saws measured in 1975, acceleration levels ranged from 10 to 33 m/sec^2.

The Japanese government in the early 1970s began restricting the number of hours per day that chain saws could be operated. Between 1970 and 1975, chain saw use was limited to 2 hr/day for the national forestry operations. Futatsuka and Ueno [1985, 1986] reported that of the 185 chain saw operators who began using chain saws in 1972 and 1973, only 3 (2%) had vascular symptoms as of 1980 (not shown in Table IV-12). These chain saw operators had been exposed for at least 7 years, a period of time greater than the 6.4-year mean latency of vascular symptoms for the entire study population (see Table IV-12).

3. Summary of Epidemiologic Studies of HAVS

Epidemiologic studies of workers using hand-held vibrating tools show a strong association between exposure to hand-arm vibration and vascular symptoms of HAVS or Raynaud's phenomenon. Only 9 of the cross-sectional studies presented in Table IV-8 had relatively low prevalence rates of vascular symptoms (i.e., less than 20%) compared with prevalence rates of vascular symptoms in 19 control groups. In five of these nine studies, the prevalence of vascular symptoms in the exposed group of workers was compared with the prevalence in a control group. In four of these five studies, the prevalence was significantly higher in the exposed group than in the control group even though the prevalence of vascular symptoms in the exposed group was relatively low.

The study [Futatsuka 1984] with the lowest prevalence of vascular symptoms (6%) in Table IV-8 was the only one of the eight studies with relatively low prevalence rates that offered a plausible reason for the low prevalence. In this study of brush saw workers, the use of the brush saw was restricted to 4 to 5 months/year during the summer season and to 2 to 3 hr/day. The conditions of using the brush saw in this study [Futatsuka 1984] seemed to produce a very low prevalence despite a hand-arm vibration acceleration level of 59 m/sec^2. The study in Table IV-9 with the lowest frequency-weighted acceleration level (10 m/sec^2) [Engstrom and Dandanell 1986] reported a prevalence of vascular symptoms (25%) among workers using pneumatic drills, riveters, shavers, and bucking bars that was four times greater than that reported by Futatsuka [1984] although the frequency-weighted acceleration level (10 m/sec^2) was less. The vibration frequencies produced by the tools used in the Engstrom and Dandanell [1986] study were much higher (up to 10,000 Hz) than those reported by Futatsuka [1984].

Twenty-three studies from Table IV-8 included measurements of hand-arm vibration acceleration levels. These studies showed a statistically significant linear relationship between increasing exposure to hand-arm vibration and increasing prevalence of vascular symptoms of HAVS. Even though this relationship could be demonstrated statistically, only 3 of the 6 studies reporting the lowest acceleration levels (i.e., less than or equal to 60 m/sec^2) among these 23 studies (see Table IV-9) also reported relatively low prevalence of vascular symptoms (i.e., less than 20%). The relationship between hand-arm vibration exposure and the prevalence of vascular symptoms of HAVS among these 23 studies was more consistent for those with higher acceleration levels than for those with lower levels.

The longitudinal studies of chain saw operators were able to demonstrate an appreciable decrease in the prevalence of vascular symptoms after the introduction of the antivibration chain saw. The lower acceleration level of the antivibration chain saw apparently contributed to the decrease, although the amount of decrease varied from study to study. Riddle and Taylor [1982] reported a 17% prevalence among 18 workers exclusively using antivibration chain saws; Pyykko et al. [1986b] reported a 5% prevalence for 66 workers in 1983 who had used antivibration chain saws since the mid-1970s; and Futatsuka and Ueno [1985] reported a 2% prevalence in 185 workers who started using chain saws in the mid-1970s when antivibration chain saws were introduced. The exceptionally low prevalence in Japanese chain saw operators [Futatsuka and Ueno 1985] could reflect the requirement that they do not operate chain saws for more than 2 hr/day [Saito 1987].

4. Conclusions from Epidemiologic Studies of HAVS

HAVS was found among workers exposed to hand-arm vibration in all of the epidemiologic studies cited, regardless of the level of vibration exposure. These studies therefore provide no basis for determining an exposure level at which no cases of HAVS would occur. However, the studies do provide ample evidence that the use of vibration-producing, hand-held tools is associated with the development of HAVS.

D. SCREENING AND DIAGNOSTIC TESTS

The signs and symptoms characteristic of HAVS are also observed individually or in various combinations in some other disorders. No single sign or symptom is specific to HAVS alone. This introduces uncertainties and difficulties in the classification and diagnosis of HAVS. Regardless of the complaints and symptoms presented by an individual, a diagnosis of HAVS is not justified unless a history of using vibrating tools is present [Taylor 1982a, 1982b; Gemne 1982; NIOSH 1984; Pyykko and Starck 1986; Matoba and Sakurai 1987; Farkkila 1987]. Several tests can be used to help substantiate a clinical diagnosis of HAVS.

- **Screening Tests**

  Vascular Assessment

  Adson's test (neck rotation and deep inspiration)
  Allen's test (compression of vessels at wrist)
  Lewis-Prusik test (nailbed compression)
  Doppler test (segmental arm and digital blood flow and pressure)
  Cold provocation test (immersion of digits and hands)

  Neurologic Assessment

  Light touch (cotton wool)
  Pain (pin prick)
  Temperature (cold and heat appreciation)
  Aesthesiometry (two-point and depth-sense discrimination)
  Vibration perception threshold
  Phalen's test (wrist flexion)
  Tinel's test (carpal tunnel percussion)

  Musculoskeletal Assessment

  Grip strength (dynamometer)
  Pinch test (thumb and fingers)
  Manipulative dexterity

- **Laboratory/Hospital Tests**

  Vascular Assessment

  Doppler (peripheral segmental blood flow and pressure in arms)
  Digital plethysmography (at rest and following cold stress)
  Digital systolic pressure (plethysmography with local cooling, and whole body cooling as well if necessary)
  Cold provocation test (immersion of digits and hands with recording of digital temperatures)

  Neurologic Assessment

  EMG (to record median and ulnar sensory and motor nerve conductivity)

  Hematologic Assessment

  Total and differential, sedimentation rate, blood viscosity, uric acid, rheumatoid factor, antinuclear antibodies, cryoglobulins, serum protein electrophoresis

  Urinalysis

  Proteinuria, glycosuria

  X-rays

  Cervical spine and ribs (to exclude costoclavicular syndrome)

Olsen [1988] conducted a comparative study of diagnostic tests for vibration white finger. In the four tests used, various aspects of finger blood flow and finger blood pressure were measured. The study concluded that the finger color test may be as valuable as finger systolic blood pressure for diagnostic purposes. The diagnostic values of some of the tests are discussed below.

1. Cold Provocation Test (CPT)

Two generic variations of the CPT have been used in studying HAVS. The versions vary mainly in the length of exposure to the stimulus, the temperature of the cold stimulus, and the responses measured. The subject must be in thermal balance before the test. This is achieved by having the subject rest for about 30 minutes in a room with air temperatures from 21° to 24°C (70° to 75°F).

a. Short Exposure

In the short exposure version of the CPT, the hand is immersed up to the wrist in ice water for 1 to 3 minutes. Blood flow in the fingers of the opposite hand can be measured by plethysmography before, during, and after immersion. The most important measurements involve the reduction in blood flow during cold exposure and the recovery of blood flow following immersion. Finger rewarming time after a short (3-minute) immersion in water at 10°C (50°F) was 1.4 minutes for the control subjects and 2.9 minutes for workers with HAVS ($p = <0.01$). Excluded from the HAVS group were those whose finger temperature did not rise to 30°C during body heating at a room temperature of 40° to 45°C (104° to 113°F) for 15 minutes [Welsh 1986]. Niioka et al. [1986] found that the finger skin rewarming time after a CPT could distinguish between HAVS patients and controls with a false discrimination of 6%, a sensitivity of 80%, and a specificity of 100%.

b. Long Exposure

In the long exposure CPT, after the subject has achieved thermal equilibrium in a thermal neutral room, the arm up to the elbow or shoulder is immersed in water at 10° to 15°C (50° to 59°F) for a period of 10 to 15 minutes. After the hand and arm have been removed from the cold water and dried, the time is measured for the finger skin to regain its color and/or temperature (indicating vasodilation and resumption of blood flow). Skin temperature below control values, 5 and 10 minutes after a 10-minute cold exposure, gave a correct diagnosis in 80% to 90% of workers with HAVS and workers without HAVS who had more than 5,000 hr of chain saw use [Kurumatani et al. 1986; Welsh 1986; Niioka et al. 1986]. However, finger-skin temperature response did not distinguish between subjects who did not use vibrating tools, those with Raynaud's disease, and those with less than 5,000 hr of saw use [Welsh 1986; Kurumatani et al. 1986; Niioka et al. 1986].

The response of finger-skin temperature to cold exposure in nonsymptomatic, vibration-exposed and unexposed workers was reported by Scheffer and Dupuis [1989] for laboratory and field studies. The test conditions (5°C air temperature, vibration acceleration of 6.3 m/sec^2 [frequency-weighted], grip force of 15 N, and push force on the tool of 40 N) all contributed to the skin temperature response. The authors suggest that improved protection against cold (e.g., heated tool handles) could be an effective preventive technique.

The response of finger systolic blood pressure (FSBP) to finger cooling has been used to measure changes in peripheral vascular response to cooling in vibration-exposed workers. Olsen et al. [1981] and Olsen and Nielsen [1979] reported that FSBP changes predict 60% to 85% of workers with vibration white finger even when the history of HAVS is not known. Their subjects, however, had vibration white finger, Stage 2 to 3 [Taylor and Pelmear classification]. In less severe cases of HAVS (Stage 1), neither FSBP nor peripheral blood flow measurements were very sensitive. During field conditions, however, measuring FSBP is easier than measuring blood flow [Pyykko et al. 1986a]. The fingernail compression test may also be used. The occurrence of spastic vasospasm and pain in the finger is noted.

Hack et al. [1986] compared responses on the cold provocation test and reactive hyperemia with the history of vibration-induced white finger in workers with no symptoms, symptoms of tingling and numbness, and symptoms of HAVS. The tests distinguished between groups, but only about 60% of the subjects fell into the correct staging category.

Bovenzi [1986] reported that the skin temperature recovery time following finger cooling was significantly prolonged in workers with HAVS, indicating that the workers with HAVS had a more severe and prolonged vasoconstrictive response to the cold provocation test.

Gemne et al. [1986] found the finger blood flow at vasodilatation (finger arterial inflow) after occlusion was less in the group with HAVS than in a reference group without HAVS. Peripheral resistance was also higher in the HAVS group. The authors suggested that the increased peripheral resistance in the HAVS group may be due to a local defect in the vessels with a reduction in flow and intramural pressure.

Arneklon-Nobin et al. [1987] reported that the FSBP, the ratio of the finger systolic blood pressure to the arm systolic blood pressure (FSBP/ASBP), and finger skin temperature measured before and after vasodilatation by body warming are altered in vibration-exposed workers. Finger skin temperature and FSBP were lower in the workers with HAVS both before and after vasodilatation. Digital rewarming time was markedly slower in the vibration-exposed individuals. These studies suggest that measuring the finger skin temperature and FSBP before and after finger cooling and after finger rewarming could be useful diagnostic tests.

Bovenzi [1988] suggested that the finger systolic blood pressure response with finger cooling and ischemia may be a useful objective test for vascular hyperactivity in subjects with HAVS. In his study, the test had a sensitivity to increased arterial tone of 100% and a specificity (negative test without HAVS) of 87%.

2. Plethysmography

Finger plethysmography, a technique used for measuring finger blood flow, is based on the fact that with each heart contraction, the volume of the fingers increases. This change in finger volume can be measured with a photocell or strain gauge. In practice, the photocell plethysmograph is used more frequently than the strain gauge. The instrumentation for a photocell plethysmograph and the test conditions that can be used in field and laboratory studies have recently been published [Samueloff et al. 1984; Samueloff et al. 1981]. Finger plethysmography, after local cooling, has been recommended as an objective test for HAVS [Pelnar 1986]. Vibration instead of cold water may be used as the stimulus. Standardization of the test procedure and strict adherence to the test protocol are of utmost importance if the results from different studies are to be compared.

3. Aesthesiometry

One of the tests of peripheral neural changes is the finger tip two-point and depth discrimination tests. A version of the test instrumentation has been described [Carlson et al. 1979; Carlson et al. 1984]. As with other semiobjective tests, standardization of the instrumentation and strict adherence to the test protocol are very important (e.g., small differences in the pressure applied by the finger tip against the grooves will change the detection point sensitivity). The results of the tests can be used to support a diagnosis of advanced HAVS (Stages 2 or 3), but because of the number of false-positive and false-negative results, the test data should not be used to override other data and the examining physician's judgment [Carlson et al. 1984; Sivayoganathan et al. 1982]. Data obtained using the improved test correlated significantly with the clinical staging of HAVS in workers with Stage 2 and above [Taylor et al. 1986]. For individual diagnostic purposes, however, the test lacked sufficient discriminatory power.

Haines and Chong [1987] reviewed the literature in which peripheral neurological tests were used to assess the acute and chronic effects of exposure to hand-arm vibration. The peripheral neurological tests demonstrated their usefulness in epidemiologic studies.

4. Arteriography

Ashe et al. [1962], Ashe and Williams [1964], and Takeuchi et al. [1986], utilizing finger biopsy material, observed extensive damage to the digital arterial walls with narrowing of the lumen in the fingers of workers with HAVS. These findings led to the concept that hand arteriography might be a useful tool for the diagnosis of HAVS [Wegelius 1972; Zweifler 1977; James and Galloway 1975; James et al. 1975; Takeuchi et al. 1986]. The procedure does, however, require an intraarterial injection of a dye and, therefore, is an invasive procedure.

The data reported by James and Galloway [1975] indicate that almost all of the workers who had symptoms of HAVS showed digital artery occlusion that was partial or nearly complete. Their control data were limited to three nonvibration-exposed individuals (members of the observation team) who showed little evidence of digital artery narrowing or occlusion.

Takeuchi et al. [1986] reported medial muscular hypertrophy and intima fibrosis in the digital arteries of vibrating tool users.

Okada et al. [1987a] observed thickening of the intima of finger arteries in workers who used vibrating tools. Inaba et al. [1988] reported a thickening of the intima in animals subjected to vibration. Intimal thickening appears to be part of the arterial pathological changes.

5. Grip Force

Hand and finger grip force can be easily measured with a strain gauge or a simple spring resistance dynamometer. Several types of measurements can be made. These include (1) maximum grip force, (2) fatigue curve while producing maximum grip force, and (3) fatigue curve during rhythmic contraction-relaxations. These measurements can be made both before and after a work period, or before and after exposure to vibration [Farkkila et al. 1982].

Because maximum grip force appears to be reduced, and strength fatigue is faster in workers who have used vibrating tools for several years (and may or may not have symptoms of HAVS), a simple grip strength measurement (hand dynamometer) can have some diagnostic usefulness. However, as pointed out earlier, normal standard values for grip strength and grip fatigue indicate a wide inter- and intra-individual variability, which make comparisons difficult to interpret.

6. Nerve Conduction

A decrease in motor and sensory peripheral nerve maximum conduction velocity in the median and ulnar nerves has been reported in workers with histories of occupational hand-vibration-exposure [Lukas 1982; Seppalainen 1972; Sakurai and Matoba 1986]. Maximum conduction velocity of the ulnar or median nerves can be determined by electrical stimulation of the nerves at a designated point and by recording the time for a motor response to occur. The time required for the nerve impulse to travel the distance between the two points can also be calculated [Seppalainen 1972]. In a group of vibration-exposed workers who had complaints and symptoms of HAVS, about 50% showed conduction velocity reduction [Lukas 1982]. Sakurai and Matoba [1986] also reported a decreased motor nerve conduction velocity (MCV) and sensory nerve conduction velocity (SCV) in workers who used vibrating tools. Chatterjee et al. (1978) found that in rock drillers, the SCV in the median nerve was reduced but the MCV was not. Latency, duration, and amplitude of the sensory action potential were also significantly changed in the rock drillers.

Brammer and Pyykko [1987] analyzed the electroneurographic data from 23 studies of workers who used hand-held vibrating tools. After control of the data for polyneuropathy and the effects of hard manual work, a neuropathy remained that involved mainly the sensory nerves in the hands. This sensory neuropathy could be distinguished from compression neuropathies (carpal tunnel syndrome) by measuring the nerve conduction velocity.

Araki et al. [1988] reported that the distribution of sensory nerve conduction velocities (median nerve) was altered and the magnitude of the sensory nerve conduction velocities was significantly slowed in chain saw operators.

Farkkila et al. [1988], in a neurological study of 186 forestry chain saw operators (average usage time 16,600 hr) and 31 nonvibration-exposed workers, found that the disturbance of the ulnar and median MCV and distal latency (DL) did not correlate significantly with the history of HAVS or numbness of the hands. However, a significant correlation was reported between vibrotactile detection thresholds and MCV and DL of the median and ulnar nerves.

7. Sensory Acuity

Some of the common tests of finger tip sensory acuity may assist the physician in diagnosing HAVS. These include (1) cotton wool test (light touch), (2) hot and cold probes (temperature), (3) pin prick (pain), and (4) tuning fork (vibrotactile). A decrease in sensitivity may indicate peripheral neural changes. Taylor et al. [1986] reported that stage assessment of HAVS, based on medical examination and history of exposure, did not correlate well with tests of sensory loss, loss of pain, and temperature discrimination. Sensory acuity tests cannot be used as positive indicators of HAVS [Harada and Matsumoto 1982]. Ekenvall et al. [1986] reported that the temperature neutral zone was increased from about 5°C (9°F) in controls to 10°C (18°F) in 17 vibration-exposed workers with neurological symptoms of HAVS. The vibration threshold was also nearly doubled in the vibration-exposed group as compared with controls.

E. TREATMENT

Several recent studies reported on hospitalized patients with different stages of HAVS who received various types of therapeutic treatment. The effectiveness of the various treatments was analyzed and evaluated. Because multiple treatments were used in all the studies, direct evaluation of the effectiveness of any single treatment is not possible.

Matoba and Sakurai [1986] described their experiences in treating 500 male workers with HAVS over a 10-year period. The workers had used vibrating tools for an average of 10.5 years, and all exhibited mild to severe symptoms and signs of HAVS. All treatments were given in a hospital, with an average hospital stay of 105 days. Treatment consisted of physiobalneotherapy (water bath), alone or with one or more drugs, nerve blocking, and/or surgical therapy, along with education and training.

Recognizing that an evaluation of the relative effectiveness of all the various combinations of treatment is not possible, the researchers nevertheless selected a group of 60 inpatients matched for age and vibration exposure. Some of the patients received only physiobalneotherapy (group P), whereas the others received physiobalneotherapy plus vasodilating drugs (group D) over a 6-week period. Subjective and laboratory signs improved about 30% to 40% in group P and 60% to 80% in group D [Matoba and Sakurai 1986]. The authors concluded that physiobalneotherapy is the key treatment but that drug therapy, vasodilators, and calcium channel blockers can accelerate improvement in the circulatory, neural, and motor problems present in HAVS. Improvement was not as good in patients with severe HAVS as in those with lesser stages of involvement.

Bielski [1988] reported the benefits derived from balneological treatment of 824 chain saw operators who had peripheral vascular symptoms of HAVS (Stage not specified). Thermography and plethysmography tests indicated statistically relevant improvement in 91% of the patients treated with a brine bath at 34°C (93.2°F) for 20 minutes a day for 24 days. The improvement persisted for at least 6 months after treatment even though the workers were again using chain saws. The author suggested that workers who use chain saws should undergo a 2 to 3 week annual treatment with balneotherapy to reverse and prevent the progression of HAVS. The vibration level produced by the chain saws used was not reported.

Nasu [1986] reported that the use of defibrinogenating drugs in the treatment of HAVS patients provided both subjective and objective improvement. With treatment, statistically significant improvement was observed in the finger-skin temperature, the amplitude of the finger plethysmogram, and the nail compression test before and after cold provocation. The subjective feeling of warmth after treatment was reported by all but 5 of the 118 patients studied. The beneficial effects of the treatment did not appear to be permanent but "reaggravation ranged usually from several months to more than a year" after treatment was stopped. The author also reported (without substantiating data) that the addition of alpha1 blocker (bunazosin hydrochloride) had a better effect than the defibrinogenating drug alone.

The results obtained from treatment trials must be interpreted with caution because (1) with the present state of knowledge, the extent of spontaneous (without treatment) reversal of HAVS when vibration stimulus is withdrawn is unknown, (2) in many studies control populations given hospital treatment and therapy are not included, and (3) there is doubt about the accuracy of assessment of subjects in the absence of proven objective tests. Subjective improvement without objective tests is not acceptable.

F. REVERSIBILITY

The British and Canadian groups have emphasized prevention over treatment as the better approach to the control of HAVS [Brammer 1984; Taylor and Brammer 1982; Taylor 1982a, 1982b]. If HAVS has not progressed beyond the Taylor-Pelmear Stage 2, the signs and symptoms tend to disappear with time if no further exposure to vibration is permitted or if the exposure level (acceleration and time) is sufficiently reduced. For workers with Stages 3 and 4 vibration syndrome, no tested regimen of treatment has resulted in a significant reversal of HAVS signs and symptoms. Therapy is essentially palliative [Brammer 1984; Taylor and Brammer 1982].

Olsen and Nielsen [1988] reported data from a 5-year study of three groups of forestry workers examined in 1978 and again in 1983. Group A (n=13) had no subjective symptoms in 1978 and continued sawing until 1983; group B (n=12) had no symptoms in

1978 and stopped sawing; group C (n=12) had symptoms of HAVS in 1978 but did not stop using chain saws. FSBP was measured with a CPT in 1978 and again in 1983. In 1978, all groups had increased response to the cold provocation when compared to 20 nonvibration-exposed controls. From 1978 to 1983, the vasoconstriction response to the CPT increased in group A ($p<0.05$), was unchanged in group B ($p>0.10$), and improved in group C ($p<0.05$). Antivibration saws were used between 1978 and 1983. In group A, the use of antivibration saws did not prevent further increase in hyperactivity; the improvement of workers in group C (who had HAVS) may have been due to a shift from regular to antivibration saws in 1978. The data suggest that while the use of antivibration saws will not entirely prevent the development of HAVS, it may reduce the occurrence and progress of the disorder.

A 3-year followup study of 55 forestry workers with HAVS was conducted by Ekenvall and Carlsson [1987] to determine the effect of cessation of working with vibrating tools on subjective symptoms and FSBP during finger cooling. The group on first examination included 14 with Stage 1 Taylor-Pelmear symptoms, 25 with Stage 2, and 16 with Stages 3 and 4. Of the 15 workers who continued outdoor work with vibrating tools during the 3-year followup period, none showed any improvement of symptoms (8 showed no change and 7 showed increased subjective impairment). Of the 32 who did not use vibrating tools during the 3-year followup study, 8 showed improvement, 19 showed no change, and 5 showed increased impairment. The subjective improvement reported in this study could not be confirmed by CPT. On the other hand, this study showed an increased reactivity to cold in the impaired group. Thus the CPT appears to provide objective confirmation of the deterioration.

Other studies have indicated that the signs and symptoms of HAVS may be reduced or reversed in some chain saw operators, chippers, and grinders when the worker is no longer exposed to vibration [Riddle and Taylor 1982; Hursh 1982].

V. BASIS FOR THE RECOMMENDED STANDARD

The NIOSH recommendations for control of hand-arm vibration are based on review and analysis of (1) epidemiologic data derived from field investigations, (2) data from clinical examinations of workers who have used vibrating tools, and (3) data derived from laboratory studies. Chapters III and IV contain reviews of the published data on which this recommended standard is based. HAVS is a chronic, progressive disorder that normally requires months or years of vibration exposure to manifest itself. The quantitative relationship between the magnitude of the vibration exposure and the latency and severity of the disorder is not precisely known.

A. PREVALENCE OF HAVS

Several hundred published epidemiologic and clinical studies have reported the development of HAVS in workers who used vibrating tools. In the epidemiologic studies summarized in Table IV-8, the prevalence of the vascular symptoms of HAVS ranged from 6% to 100%, with more than half of the studies showing a prevalence rate greater than 40%.

Vascular symptoms were reported in 0% to 14% of control workers who did not use vibration-producing tools, with a median prevalence of 4%. In all studies that compared workers who did with those who did not use vibrating tools, the prevalence of vascular symptoms was always higher in the vibration-exposed group.

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. Protection can be provided by medical monitoring of the workers, engineering controls to reduce the vibration levels produced by the tools, work practices such as limited daily use time of vibrating tools and ergonomic design of tools and work methods, protective clothing and equipment, and worker training programs in the proper handling and maintenance of vibrating tools and in recognition of the early symptoms of HAVS.

B. RATIONALE FOR FREQUENCY-UNWEIGHTED ACCELERATION MEASUREMENTS

The 1/3-octave-band center-frequency weighting of the acceleration has been used previously to express the magnitude of the vibration exposure. However, on the basis of recently published data cited in this section, NIOSH proposes the use of the frequency-unweighted acceleration. The frequency-weighted acceleration concept assumes that the harmful effects of 1/3-octave-band center-frequency accelerations are independent of frequency between 6.3 and 16 Hz but progressively decrease with higher frequencies between 16 and 1,500 Hz. The frequency-unweighted concept assumes that the magnitude of pathophysiologic effects from exposure to vibration are proportional to the acceleration and are frequency independent at all frequencies.

The rationale for frequency weighting is based primarily on the data reported by Miwa [1967, 1968a, 1968b]. From these studies, data were obtained on the levels of acceleration that subjects identified as "tolerance limit" or "unpleasant" sensations when they pressed a hand on a plate that was vibrating at a frequency of 10, 20, 30, 60, 100, or 300 Hz. The acceleration level required for the subjective sensation of "tolerance" and "unpleasant" limits increased progressively with vibration frequency above 16 Hz. These psychophysically derived test data were not analyzed to determine the correlation between frequency and acceleration and the development of clinical or pathophysiologic signs and symptoms of HAVS. The investigators assumed that the subjective degree of "intolerance" would be related to injury.

Data from some epidemiologic and laboratory studies support the concept that the pathophysiologic effects of vibration are mainly frequency independent. Engstrom and Dandanell [1986] and Dandanell and Engstrom [1986] reported vibration acceleration levels and frequencies produced by riveting hammers, bucking bars, rivet shavers, and drills used in the aircraft industry. Most of the acceleration occurred at frequencies above 400 Hz (up to 10,000 Hz). If the ISO [1986] frequency-weighting criteria were applied, most of the higher frequency acceleration would be excluded from the exposure assessment. At frequencies below 400 Hz, the frequency-weighted acceleration was only about 10 m/sec^2 for the riveting hammer and bucking bar. At frequencies between 400 and 10,000 Hz, the frequency-weighted acceleration was 2 m/sec^2 for drills, 5 m/sec^2 for rivet shavers, and 6 to 10 m/sec^2 for riveting hammers and bucking bars. In the absence of frequency weighting, the acceleration was about 100 m/sec^2 at frequencies between 100 and 10,000 Hz.

Riveting hammers and bucking bars were used not more than 15 minutes per working day, with a total daily exposure to vibrating tools of not more than 30 minutes. Of the 288 workers studied, the authors reported that 59 showed finger blanching; of those with more than 10 years of exposure, 50% had HAVS. This prevalence of HAVS far exceeded that expected from exposures at 10 m/sec^2 (frequency weighted) for similar years of exposure and 30 minutes of daily use time. The authors suggested that frequency weighting would have grossly underestimated the health impact of the high-frequency vibration acceleration produced by these vibrating tools.

The data from experimental studies of Nohara et al. [1986] also call into question the assumption that pathophysiologic effects of vibration acceleration are frequency-independent at 16 Hz or below and frequency-dependent above 16 Hz. The test group consisted of five healthy, 25- to 31-year-old males who were nonsmokers and had never used vibrating tools. For the 1-hr test periods at 1- to 4-day intervals, subjects grasped with the left hand a 40-mm- (1.6-in.-) diameter handle that was fixed to a vibrating plate. A constant acceleration of 50 m/sec^2 at randomized frequencies of 30, 60, 120, 240, and 960 Hz was applied to the plate during the test period. For control values, the subjects grasped the handle for 1 hr without vibration.

Physiologic parameters measured were finger blood flow, finger skin temperature, and peripheral motor nerve conduction velocity of the ulnar and median nerves. The data were analyzed by NIOSH and are summarized in Table V-1.

Table V-1.—Changes in physiologic functions after 1-hr exposures to hand-arm vibration at 50 m/sec^2 and frequencies of 30 to 960 Hz*

	Average change in physiologic function				
Frequency (Hz)	Skin temperature °C	Skin temperature °F	Blood flow (ml/100 per min)	MCV† ulnar nerve (m/sec)	MCV median nerve (m/sec)
0§	0.8	1.4	2.0	4.0	3.0
30	0.0	0.0	14.0	3.0**	2.5
60	0.50	0.9	5.0	4.5	1.5**
120	0.60	1.1	5.5	5.5	5.5
240	1.0	1.8	5.0	2.0	1.0
480	1.0	1.8	6.5	1.0	2.5
960	0.20	0.4	2.5**	.0**	1.0

*Based on data from Nohara et al. [1986].
†Motor nerve conduction velocity.
§Without vibration (control).
**After-vibration exposure value is higher than before-vibration value.

The following generalizations can be made based on the data summarized in Table V-1 at a fixed vibration acceleration of 50 m/sec^2:

- None of the physiologic functions measured showed a consistent change in function with vibration frequency.

- Each physiologic function had one or more vibration frequencies at which the physiologic effects were greatest.

- The frequencies at which the maximum effects occurred were different for the various physiologic functions.

- The maximum effects occurred at the lowest exposure frequency (30 Hz) for only one function (peripheral blood flow).

- Maximum change occurred in skin temperature at 240 and 480 Hz, in blood flow at 30 Hz, and in MCV at 120 Hz.

- Grasping the handle for 1 hr without vibration (control) also resulted in changes in the physiologic functions measured.

Nohara et al. [1986] concluded that the peripheral nervous system was affected most at the lower frequencies and the circulatory system was affected significantly at both the lower and the higher frequencies. The data from the study do not support the assumption that frequencies above 16 Hz have progressively less harmful effects than the lower frequencies.

The Nohara study has the following obvious shortcomings: only a small number of subjects were tested, exposures were not repeated at any of the frequencies, and each exposure was limited to 1 hr per test session.

Starck and Pekkarinen [1988] compared the observed and predicted prevalence and latency periods of HAVS among workers using different types of vibrating tools. For operators of chain saws that produce relatively low-frequency and low-impulse vibrations, the predicted and observed values were in good agreement when acceleration was calculated according to the ISO 5349 frequency weighting [ISO 1986]. However, for pedestal grinders, stone workers, shipyard workers, and platers whose tools produced higher impulses and frequencies, the comparisons were less consistent. Frequency weighting of the acceleration in accordance with ISO 5349 did not appear to adequately reflect the harmful effects of tools that produced higher-frequency and higher-impulse vibrations.

The data reported by Hyvarinen et al. [1973] suggest no constant frequency relationships on the threshold acceleration levels required for the production of finger vasospasms in lumberjacks who had a "history of traumatic vasospastic disease." The frequency of 125 Hz was more effective in producing finger vasospasms than higher or lower frequencies. These data suggest that acceleration frequency weightings throughout the entire vibration-frequency spectrum produced by vibrating tools may underestimate the potential risk to workers exposed at higher vibration frequencies. The degree of intimal thickening observed

Table V-2.—Minimum acceleration levels required to produce vibration sensation and vasospasm at various frequencies (rms m/sec^2)*

Frequency (Hz)	Minimum acceleration levels (rms m/sec^2)	
	Sensation	Vasospasms
16.0	0.4	—
31.5	0.8	35
63	0.7	65
125	0.6	70
250	0.9	70
500	1.8	71
2,000	25	80

*Adapted from Brammer [1982a].

in experimental animals subjected to either 30 or 480 Hz at 50 m/sec^2 was comparable [Inaba et al. 1988].

Literature surveys by Brammer [1982a, 1982b] suggest that the minimal vibration acceleration level required to produce a sensation of vibration and a pulseless vasospasm does not consistently increase as the vibration frequency is increased. For the production of vasospasm, the minimum vibration acceleration required did not vary with vibration frequencies between 31.5 and 2,000 Hz, and the minimum vibration acceleration required to produce vibration sensation was independent of frequency between 31.5 and 500 Hz. The minimum vibration acceleration levels required to produce vasospasm and sensation at frequencies of 31.5 to 2,000 Hz are given in Table V-2.

Because of the lack of objective, experimentally derived data, it is not possible to quantitatively convert the health impact of frequency-weighted accelerations to frequency-unweighted accelerations. However, some semiquantitative conversions are possible. Frequency weighting that is done by reducing the input of the higher frequencies (especially above 400 Hz) decreases the total acceleration energy calculated for the vibrating tool. The frequency-weighted acceleration will therefore underestimate the total energy produced by the vibrating system. Frequency-unweighted acceleration calculated over the entire frequency range of the tool will be higher than the frequency-weighted acceleration, but it is a more complete representation of the energy actually produced.

The rationale for recommending the use of frequency-unweighted acceleration is supported by the following information:

1. Data from epidemiologic, clinical, and laboratory studies suggest that the hazardous effects of vibration exposure are frequency independent.

2. Exposure measurements based on frequency-unweighted acceleration have the advantage of simplifying the measurement of vibration acceleration levels of vibrating tools used in industry.

3. The prevalence of HAVS among users of high-frequency (up to 10,000 Hz) vibrating tools was 50% with 10 years of exposure at a frequency-weighted acceleration of about 10 m/sec^2 for about 30 minutes per day of actual tool use [Dandanell and Engstrom 1986]. The frequency-weighted acceleration level grossly underestimated the HAVS-producing effect of the high-frequency vibration exposure.

C. 4-HR-PER-DAY USE TIME

All of the guidelines, standards, and published studies of the harmful effects of vibration exposure accept a time-dose relationship between total vibration exposure and the development of HAVS. The exposure dose can be expressed as m/sec^2 normalized for 4 hr, 8 hr, or any other amount of tool use time per day. If the acceleration level is expressed by all researchers as a time-corrected, 4-hr/day equivalent, comparisons of data from different studies would be easier. The ISO [1986] and ANSI [1986] guidelines recommend using a 4-hr energy equivalent acceleration expressed in m/sec^2. The time (hr/day) and dose (acceleration in m/sec^2) energy equivalents are plotted as a log-log function. In these relationships it is assumed that the daily exposure time required to produce symptoms is inversely proportional to the square of the acceleration and is independent of the vibration characteristics of the tool. Thus if the vibration level is reduced by one-half, the exposure time may be doubled. The total daily time of actual tool use has not usually been reported, but in most industries it does not exceed 4/hr day.

D. DOSE-RESPONSE RELATIONSHIP

HAVS is a chronic disorder with a latency period between the first exposures and the appearance of the first signs and symptoms. The latency period may vary from a few months to several years, depending on many interacting factors. Among the more important factors that determine the clinical profile of HAVS are

1. Vibration acceleration level of the tool

2. Total hours of tool use
3. Pattern of daily tool use
4. Type of tool
5. Vibration profile produced by the tool
6. Ergonomics of tool use
7. Vibration tolerance of the individual
8. Antivibration devices used
9. Tobacco and drug use

As a result of the complexity of the confounding interactions between these factors and the lack of experimentally derived objective data, dose-response relationships cannot be established with precision. Establishing a reliable, valid, minimal dose-risk level would require quantitative data not presently available.

In 1982, Brammer [1982a, 1982b] analyzed the epidemiologic data derived from several reports that contained data on the vibration level produced by the tool used (frequency-weighted m/sec^2), daily tool use (hr/day), and the latency period (years of tool use) preceding the first appearance of vascular symptoms. The analysis was presented as percentiles of population that would be expected to have Stage 1 HAVS as a function of acceleration (frequency-weighted) and years of tool use. Based on extrapolations of these analyses, predictions are that 5% of the workers who use vibrating tools will develop early Stage 1 HAVS in <2 years at 10 m/sec^2, in 5 years at 4 m/sec^2, in 10 years at 2 m/sec^2, and in >20 years at 1 m/sec^2 [Brammer 1982a]. The predicted minimum (frequency-weighted) acceleration (m/sec^2) required to produce Stage 1 HAVS (finger blanching) has been reported to be 1 to 2.9 by Brammer [1982a], 1 to 2.1 by Miura et al. [1959], and <4.7 by Taylor et al. [1977].

The data on the pathogenesis of HAVS are not sufficient to establish an REL that would ensure that healthy workers who use vibrating tools would not develop signs and symptoms of HAVS. Because such an REL cannot be justified on the basis of present dose-response data, the prevention and control of HAVS as an occupationally-induced disorder must be based on other considerations. The approach to controlling HAVS must be through (1) medical monitoring to recognize the first signs and symptoms of developing HAVS, (2) medical removal of workers who exhibit signs and symptoms of Stage 2 HAVS, (3) engineering controls to minimize the level of vibration produced by tools, (4) establishment of a work regimen to reduce exposure to a feasible minimum, (5) ergonomic design of tools and workplaces, (6) training of workers to recognize and report early signs of HAVS, and (7) supervision to ensure optimal tool maintenance and use.

E. CONCLUSIONS

1. Setting a Standard

HAVS is a chronic disorder with a latency period varying from a few months to several years. The latency is believed to depend on many interacting factors, including vibration level produced by the tool, hours of tool use per day, environmental conditions, type and design of the tool, manner in which the tool is held, vibration spectrum produced by the tool, vibration "tolerance" of the worker, and tobacco and drug use by the worker. Because of the complex interactions among these and other factors and the general lack of objective data, it is not currently possible to establish meaningful dose-response relationships. Thus it is not possible to establish a specific REL that will protect all workers against the development of HAVS in all occupational situations. However, the problem of HAVS is too serious and pervasive to delay measures for correcting it. NIOSH has therefore recommended a standard for exposure to hand-arm vibration that includes no specific exposure limit but does include medical monitoring and surveillance, engineering controls, good work practices, use of protective clothing and equipment, worker training programs, and administrative controls such as limited daily use time. If this standard is implemented, it will protect workers who use vibrating tools from the debilitating effects of HAVS. NIOSH also anticipates that this criteria document will stimulate research and development in all areas relating to hand-arm vibration.

2. Use of Frequency-Unweighted Acceleration Measurements

The 1/3-octave-band, center-frequency-weighted acceleration historically has been used to express the magnitude of vibration acceleration levels. The frequency-weighted acceleration concept assumes that the harmful effects of vibration are independent of frequencies between 6.3 and 16 Hz but that the effects progressively decrease with higher frequencies between 16 and 1,500 Hz. On the basis of data published in recent studies, however, NIOSH has concluded that the use of the frequency-unweighted acceleration is a more appropriate means of assessing the health risk to exposed workers. Although the major consensus standards-setting organizations currently recommend the frequency-weighted acceleration levels, NIOSH believes that this measurement grossly underestimates the HAVS-producing effects from tools that vibrate at high frequencies. Exposure measurements based on frequency-unweighted acceleration provide the additional benefit of simplifying the measurements because the acceleration data produced by the accelerometer is frequency unweighted.

3. Medical Monitoring

Medical monitoring of workers who use vibrating hand tools is a vital component of any standard for preventing or controlling HAVS. The medical monitoring program must include (1) a preplacement medical examination with special emphasis on peripheral vascular and neural factors, (2) yearly or more frequent exams designed to detect HAVS in its early and reversible stages, and (3) an open channel of communication with the workers to ensure that the early symptoms are promptly reported.

4. Medical Removal

NIOSH recommends that workers who develop Stage 2 HAVS be removed from further exposure to vibration until they are free of signs and symptoms of HAVS. If HAVS is permitted to progress beyond Stage 2 by the continued use of vibrating tools, the effects can become irreversible. A provision for medical removal could be controversial, but it would provide a powerful incentive for the employer to implement the engineering and administrative controls necessary to reduce the worker's risk of developing HAVS.

VI. OTHER STANDARDS AND RECOMMENDATIONS

Recommendations and guidelines for permissible worker exposure to hand-arm vibration have been formulated or are in the process of being formulated in several countries, including the USSR, Czechoslovakia, Finland, Sweden, Australia, United Kingdom, Japan, Poland, and the United States. Even though the problems of objectively diagnosing HAVS, measuring the input parameters of vibration energy transmitted to the hand and arm, and establishing reliable dose-response relations are formidable, some agreement has been reached in establishing vibration exposure criteria [Griffin 1980]. The major national and international guidelines, standards, and recommendations reviewed in this chapter suggest that vibration exposure be expressed as acceleration in m/sec^2 over the vibration spectrum of 1/3-octave-band center frequencies of 6.3 to 1,250 Hz. The acceleration limit is standardized to 4 hr of actual tool use time per day.

A. DOMESTIC

1. American Conference of Governmental Industrial Hygienists (ACGIH)

The American Conference of Governmental Industrial Hygienists (ACGIH) has established threshold limit values (TLVs®) for physical agents in the work environment, including a TLV for hand-arm (segmental) vibration [ACGIH 1988]. The TLVs "refer to component acceleration levels and duration of exposure . . . that most workers may be exposed [to] repeatedly without progressing to Stage 3 of the Taylor-Pelmear classification for Vibration-induced White Finger (VWF)." Because of the relative lack of controlled, experimentally derived dose-response data, the values are designed to be used as guides in the control of hand-arm vibration exposure and not as absolute tolerance levels. The measurement and calculation of the vibration levels produced by vibrating tools conform to the procedures and instrumentation set forth in the ISO Guideline 5349 [ISO 1986].

The TLV presents, in tabular form, acceleration values that should not be exceeded for various total daily exposure times. The accelerations are frequency-weighted and are expressed in m/sec^2 or g (acceleration due to gravity; 1 g = 9.81 m/sec^2) based on the weighting factors given in the ISO Guideline 5349. The use of the table is relatively straightforward.

Suggestions are provided on how to prevent and control excessive vibration exposure through engineering controls, work practices, administrative procedures, and medical supervision. However, the TLV does not provide guidance for estimating the risk that any group of workers has for developing HAVS within a given period when exposed to various frequency-weighted, component acceleration levels. The only reference to risk estimates is the statement that acute exposure to a frequency-weighted component acceleration three times the TLV will produce an equal level of biologic health effects in 5 to 6 years of exposure (presumably equivalent to Stage 2 on the Taylor-Pelmear classification). The TLV states the following:

> *"It should be recognized that the application of the TLV alone for hand-arm vibration will not protect all workers from the adverse effects of hand-arm vibration exposure. The use of: (1) antivibration tools, (2) antivibration gloves, (3) proper work practices which keep the worker's hands and remaining body warm and also minimize the vibration coupling between the worker and the vibration tool . . . , and (4) a conscientiously applied medical surveillance program are ALL necessary to rid VWF from the workplace." [ACGIH 1988]*

However, objective and subjective tests that are required for the diagnosis of HAVS, its stage of progression, and medical removal of affected workers are not stressed.

2. American National Standards Institute (ANSI)

The American National Standards Institute's *Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand* (S3.34-1986) was prepared by a working group of the Acoustical Society of America [ANSI 1986]. This guide is more comprehensive than either the ISO Guideline 5349 or the ACGIH TLV. The major features of the ANSI guide include (1) methods for the measurement of vibration and analysis of the data, and (2) procedures for reporting worker exposure. The goal of this document is to reduce worker exposure to hand-arm vibration and thereby reduce the probability of incurring HAVS. Special features include (1) a discussion of the factors that may influence the probability of occurrence or the severity of the pathophysiologic effects of vibration, (2) a figure (Figure A-1 of Appendix A) that presents daily vibration "exposure zones" (0.5-1 hr/day to 4-8 hr/day) for frequency-weighted rms acceleration (m/sec^2) of 1/3-octave-band center frequencies (6.3 to 1,250 Hz), and (3) a figure (Figure B-1 of Appendix B) that presents total exposure time in years before the first appearance of Taylor-Pelmear Stage 1 symptoms in the 30th, 40th, and 50th percentiles of vibration-exposed worker groups for frequency-weighted acceleration (m/sec^2) and actual exposures of 4 hr/day. The latent periods (Figure B-1 of Appendix B) of the ANSI standard and Figure 2 of ISO Guideline 5349 are identical except for the percentiles of worker groups included (10th to 50th percentile and 30th to 50th percentile, respectively). Both figures base exposure time on number of years until the first appearance of finger blanching (Stage 1 in the Taylor-Pelmear classification). Appendices A and B are stated not to be part of the official standard. Thus the ANSI guide does not include a recommended numerical limit for vibration exposure.

B. INTERNATIONAL

1. International Organization for Standardization (ISO)

The ISO *Guidelines for the Measurement and the Assessment of Human Exposure to Hand-Transmitted Vibration* [ISO 1986] emphasizes standardized procedures for measuring and assessing the levels of hand-arm vibration to which the worker may be exposed when using various vibrating tools. It does not specify the limits for safe exposure in terms of acceleration and daily exposure, nor does it specify the risk of health impairment for different operations and tools. The document presents guidance "to protect the majority of workers against serious health impairment and to assist in the development of hand-operated tools the use of which will reduce the risk of disorders in workers caused by vibration."

The ISO guidelines lack a description of (1) the clinical features of hand-arm vibration syndrome and (2) objective tests and procedures for diagnosing HAVS. Appendix A of the ISO guidelines presents exposure time in years for different percentiles of population groups exposed to various levels of frequency-weighted acceleration (m/sec^2) before finger blanching occurs. However, finger blanching is only one aspect of HAVS and usually is not the first to occur.

The ISO document points out its shortcomings and gives precautions about the use of their guidelines. The procedures and techniques for measurement, assessment, and expression of the vibration intensity are similar to the approaches used in other vibration guidelines. Of special interest is Appendix B, which contains recommendations for medical preventive measures, engineering control methods, administrative approaches, and worker training. Appendices A and B are not part of the official standard; thus the ISO guide does not include a recommended numerical exposure limit.

2. Australian Council of Trade Unions—Victorian Trades Hall Council (ACTU-VTHC)

In 1982, the Australian Council of Trade Unions--Victorian Trades Hall Council (ACTU-VTHC) published the *Health and Safety Bulletin Guidelines on Hazards of Vibration* [ACTU-VTHC 1982]. This publication presents guidelines for whole-body, hand-arm, and low-frequency vibration exposures and is not an official standard. These guidelines take into consideration vibration characteristics, health effects, sources, control methods, medical monitoring, measurements, and prevention. The presentation reviews the state of the art and does not introduce new data or new concepts. Specific details are not given for measuring the vibration of hand-held tools. The acceptable weighted acceleration levels cited (in m/sec^2) are based on the draft version of ISO Guideline 5349 [ISO 1986]. A frequency-weighted, 4-hr exposure limit of 1 m/sec^2 is suggested.

The document provides an informative summary of the measurement of vibration, the effects of vibration on the body, and useful procedures for controlling or preventing the effects. However, the guidelines are directed more to trade union personnel than to those responsible for the measurement, assessment, and control of HAVS.

3. USSR

The 1972 USSR State Standard (Gost Standard 17770-72) is a revision of earlier state standards and sanitary standards [Griffin 1980]. Some of the pertinent features of the standard are as follows:

- Limits are for octave bands of 8 to 2,000 Hz.
- Procedures are given for measuring the vibration levels of tools.
- Hand-held vibrating tools should not weigh more than 22 pounds (10 kg).
- Force exerted on the tool should not exceed 44 pounds (20 kg).
- Preemployment and yearly medical examinations should be given for those working at vibration levels exceeding 20% of the limit.
- Actual maximum daily use time for vibrating tools should be 5 to 6 hr.
- Working environment temperatures should be above 16°C (60°F); rewarming facilities should be required when they are below 16°C.
- Gloves are required to prevent hand cooling.
- If HAVS symptoms occur, the worker should be transferred to work that does not involve vibration exposure.
- Prophylactic measures are suggested (e.g., massage, exercise, vitamins, and ultraviolet radiation).

The limits for vibration exposure for vibrating tools were 2 m/sec^2 at 10 Hz to 50 m/sec^2 at 2,000 Hz. Vibration disease from the use of vibrating tools covered by this standard includes whole-body complaints, as well as peripheral neural, vascular, and muscular symptoms.

4. United Kingdom

The 1987 *British Standard Guide to the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand* [BSI 1987] "provides guidance on measuring and evaluation of hand-transmitted vibration exposure . . . [and] a uniform method for measuring and reporting hand-transmitted vibration." The sections on characterization of hand-transmitted vibration, measurement of hand-transmitted vibration, and characterization of vibration exposure cover the same areas as ANSI 53.34 [ANSI 1986] and ISO Guideline 5349 [ISO 1986] (frequency-weighted acceleration and frequency cutoff at 1,250 Hz 1/3-octave-band center frequencies). Of special interest and value are Appendices A and B, which contain discussions of the dose-effect relationship for hand-transmitted vibration and the guideline for preventive procedures. However, those discussions are included as appendices and are not considered to be part of the standard. No numerical recommended exposure limits are given. A particularly important guideline presented in Appendix A indicates that with "a tool having a frequency weighted vibration magnitude of about 4 m/sec^2 rms, used regularly for 4 hours a day, there may be an occurrence of symptoms of (finger) blanching in about 10% of the vibration-exposed population after about 8 years."

5. Japan

Early Japanese guidelines for permissible vibration exposure levels are derived from both field and laboratory data and are based on the concept of "no complaint" and "complaints by 50%" of the subjects [Miwa 1967, 1968a, 1968b]. The Miwa curves for "tolerance limits" and "unpleasant limits" were frequency dependent with acceleration levels of 17.8 m/sec^2 for "tolerance limit" and 3.2 m/sec^2 for "unpleasant limit" at 20 Hz. In 1970, the Japanese Association of Industrial Health (JAIH) proposed limits for exposure to hand-held vibrating tools. The limits were for "intolerable levels" of vibration for 10 to 400 minutes daily at octave bands of 8 to 250 Hz. Permissible acceleration levels for 400 minutes of exposure ranged from about 1.5 m/sec^2 below 16 Hz to 35 m/sec^2 at 250 Hz; and for 30 minutes of daily exposure, permissible acceleration levels were about 6.5 m/sec^2 below 16 Hz and 100 m/sec^2 at 250 Hz. The limits based on "intolerable levels," although not strictly comparable with ISO guidelines, appear to be higher than the levels recommended in ISO Guideline 5349, which are based on the development of HAVS in vibrating tool users.

6. Czechoslovakia

The official 1977 *Czechoslovakian Guide* evolved through a series of revisions, including the 1967 Hygiene Regulation #33 of the Czechoslovakian Ministry of Health [Griffin 1980]. The 1967 regulation is for vibration octave bands ranging from 8 to 500 Hz, and it is based on 2-hr daily exposures. If daily exposures are less than 2 hr for either uninterrupted or regularly interrupted exposure patterns, correction factors in permissible acceleration levels are provided. The guide states that when exposures exceed these limits, protective measures are required. At frequencies below 20 Hz, permissible acceleration levels are constant but are exposure-time dependent.

The exposure limits in the 1977 Guide are similar to but not exactly the same as those in ISO Guideline 5349. The frequency range and the frequency weighting are similar; however, for exposure time above 1 hr, the vibration limits are lower than those in ISO Guideline 5349.

7. Sweden

Efforts in Sweden to establish guidelines for vibration exposure control have been directed mainly to chain saws and their use [Griffin 1980]. The earlier studies led to the conclusion that vibrations in the frequency range of 50 to 500 Hz were important in producing hand-arm injuries. Two vibration exposure limits were suggested—the "injury risk limit" and the "occupational injury limit." Below the injury risk limit, there was no danger of vibration-induced injury, whereas above the occupational injury limit, there was a definite risk of injury. Between the two limits, the risk of injury depended on exposure duration. Short exposures above the occupational injury limit were considered to have minimal risk [Axelsson 1977]. The SFS 1977: 1166 Labor Safety Board Ordinance concerning the use of vibrating tools has revised directions that became valid January 1, 1987, as Ordinance AFS1986:7, "Vibration from Hand-Held Tools" [Danielson 1986]. The manufacturers, suppliers, and purchasers of Swedish equipment are all held responsible for ensuring that the equipment is constructed to produce the least possible amount of vibration. The worker must be infonned of the risks of using vibrating tools, and medical examinations must be furnished at no cost to the workers.

In 1973, the Swedish Board of Occupational Safety and Health set a limit of 50 N as the maximum permissible vibration force. Studies by Axelsson [1977] indicated that a 50-N force measured in a laboratory would correspond to 90 to 100 m/sec^2 rms measured on chain saws held by an operator (this equivalent may change with the grip force applied by the operator); 90 m/sec^2 is the 1- to 2-hr exposure at 500 Hz given in ISO Guideline 5349.

8. Poland

In 1986, Poland published proposed maximum permissible intensity values for hand-arm vibration exposures [Biuletyn Zeszyt 1986]. In general, the document followed the draft version of ISO Guideline 5349 [ISO 1986]. The measurement of vibration and the analysis procedure follow the ISO guidelines. The Polish guidelines are based on 8 hr of daily use of the vibrating tools.

The maximum permissible acceleration levels at various vibration frequencies for an 8-hr day of tool use are presented. For 1/3-octave-band center frequencies, the permissible acceleration levels in m/sec^2 are listed as 1 m/sec^2 at 20 Hz, 2 m/sec^2 at 40 Hz, 4 m/sec^2 at 80 Hz, 8 m/sec^2 at 160 Hz, 16 m/sec^2 at 320 Hz, 32 m/sec^2 at 640 Hz, and 50 m/sec^2 at 1,000 Hz. This represents another method of vibration frequency weighting of acceleration level. For the frequency range of 5.6 to 1,400 Hz, the frequency-weighted maximum permissible acceleration level for an 8-hr daily tool use is 1.4 m/sec^2. For a 4-hr tool use, it would be 2.8 m/sec^2. In Table 2 of the Polish document, correction factors are listed for the actual use time in each hr that is less than 60 minutes.

The document does not include a discussion of health effects, diagnosis, treatment, or control procedures.

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.

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APPENDIX A. CALCULATION OF VIBRATION ACCELERATION LEVELS FOR EPIDEMIOLOGIC STUDIES

A. All individual values for acceleration data (e.g., tables, spectra, etc.) for any and all vibration coordinate axes were first converted into m/sec^2. Decibel (dB) levels were also converted into m/sec^2 using the formula

$$L_{dB} = 20\,Log\,\frac{a}{a_o}$$

where

a_o is the reference acceleration value, and
a is the measurement value.

In the cases where only mechanical displacement was given, the following formula was used,

$$g_{peak} = (.02)\,(D.A.)\,\mathrm{f}^2$$

where

$D.A.$ is the double amplitude displacement (cm), and
f is the frequency (Hz).

The peak values were then converted into m/sec^2.

B. Where applicable, each vibration direction (axis) was tabulated forming a m/sec^2 rms sum for each direction. The total vector sum equivalent vibration was next obtained using the following formula for each tool:

$$a_t = \left[(a_x)^2 + (a_y)^2 + (a_z)^2\right]^{1/2}$$

C. Once vector sums for each of the tools were obtained, then a daily average in m/sec^2 rms across each of the tool types or family of tool types was obtained for each study. Where applicable, when the worker's incremental vibration exposure time for each tool type in a given study was *stated therein and known,* then a "time weighted average" (TWA) was obtained using the following formula:

$$TWA = \left[(a_1)^2 \frac{T_1}{T} + (a_2)^2 \frac{T_2}{T} + ... (a_n)^2 \frac{Th}{T} \right]^{½}$$

where

a_1 is the acceleration with tool Type 1,
a_2 is the acceleration with tool Type 2,
a_n is the acceleration with tool Type n,
T_1 is the time of using tool Type 1,
T_2 is the time of using tool Type 2,
T_n is the time of using tool Type n, and
T is the total daily exposure time in hr.

APPENDIX B. DECIBEL (dB) EQUIVALENTS

Table B-1.—Decibel (dB) equivalents in m/sec^2 (acceleration)

dB*	m/sec^2
100	0.1
120	1.0
140	10
160	100
180	1,000

*10^{-6} m/sec^2.

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