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Hand-Arm Vibration Syndrome

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This Medical Discussion Paper will be useful to those seeking general information about the medical issues involved. It is intended to provide a broad and general overview of a medical topic that is frequently considered in Tribunal appeals.

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Introduction

Hand-Arm Vibration Syndrome (HAVS) is a common occupational medicine condition caused by exposure to hand-arm vibration from the use of hand-held vibrating tools or hand contact with vibrating work surfaces. It is comprised of vascular, neurological and musculoskeletal abnormalities.¹ The vascular component of HAVS was first reported by Loriga in Italy in 1911 and since then it has received the most clinical and research attention. It is a form of secondary Raynaud's phenomenon manifested by cold-induced finger blanching and is sometimes referred to as vibration white finger (VWF). The extent of the problem was first brought to public attention in the United States by Hamilton in 1918 in her report of the high prevalence of Raynaud's phenomenon in the limestone quarry workers of Bedford, Indiana. Subsequently there was increased recognition that hand-arm vibration was also associated with neurological and musculoskeletal abnormalities and the term Hand-Arm Vibration Syndrome was developed to capture the three types of abnormalities associated with hand-arm vibration exposure. An international conference on hand-arm vibration in Stockholm led to the development of classifications, referred to as the Stockholm Workshop Scales, for the vascular² and neurological³ components of HAVS in the 1980s. These classifications were based on history and physical examination, and it was mentioned at the time they were created that objective tests needed to be developed to measure the various components of HAVS. Recent studies have indicated that more advanced HAVS cases may be associated with upper extremity disability,⁴ work-related disability⁵ and decreased quality of life.⁶

Workplace Vibration Exposure and Risk of HAVS

The risk of developing HAVS depends on the vibration intensity (measured in acceleration units), vibration frequency, daily exposure time in hours and the duration of vibration exposure in years. According to the International Organization for Standardization (ISO),⁷ the key exposure metric to determine the risk of the vascular component of HAVS is the cumulative exposure to hand-arm vibration over a working lifetime and this is supported by some, but not all, empirical studies.⁸ The prevalence of HAVS in workers regularly exposed to vibration has been reported to vary from 6% to 100% with an average of 50%⁹ and these variations in estimates are thought to be due to differences in the cumulative exposure in the different groups of workers. The reported latencies between first exposure and the development of HAVS range from 6 weeks to 14 years,¹⁰ and latency can be quite short with HAVS developing in less than two years if the exposure levels are high.

Pathophysiology and Histopathology of HAVS

The mechanisms by which vibration leads to tissue damage and the vascular, sensorineural and musculoskeletal outcomes of HAVS are incompletely understood although, as summarized by Stoyneva et al,¹¹ considerable research has been done in this area. Absorption of vibration may be associated with tissue shearing and bending stresses that may increase the risk of tissue damage through increases in oxidative stress and inflammation. Finger biopsies of patients with HAVS¹² have shown thickening of the smooth muscle of digital arteries due to muscle cell hypertrophy. As well vascular endothelial cell damage leads to release of the potent vasoconstrictor endothelin – 1 and an imbalance between endothelin – 1 and calcitonin-gene-related peptide (CGRP), a powerful vasodilator. Vibration damage may also be associated with changes in sensitivity to vasodilating and vasoconstricting factors. Finger biopsies have also shown demyelination of nerve fibres, axonal degeneration and nerve fibre loss.¹² The loss of digital cutaneous perivascular nerve fibres, which secrete CGRP, also leads to an increased tendency to vasoconstriction, showing an inter-relationship between the pathophysiology of vascular and sensorineural effects. Necking et al¹³ have reported that biopsies of the abductor pollicis longus muscle of patients with HAVS have shown evidence of damage to muscle fibres, which correlate with the duration of vibration exposure.

Evidence for Health Effects Attributed to Hand-arm Vibration

1. Vascular

Raynaud's phenomenon is the clinical outcome most clearly associated with hand-arm vibration exposure. Raynaud's phenomenon may be primary or secondary. Primary Raynaud's phenomenon is not due to any identifiable underlying cause or disease. It often becomes manifest by the early 20s and affects about 5% of adults,¹⁴ with the condition being more prevalent in women than men. Secondary Raynaud's phenomenon is due to other factors such as crushing or penetrating hand trauma or some diseases such as connective tissue diseases like scleroderma. The Raynaud's phenomenon of HAVS is a type of secondary Raynaud's phenomenon due to exposure to hand-arm vibration.

There is strong evidence of a causal association between exposure to hand-arm vibration and the development of Raynaud's phenomenon.¹⁵ A recent meta-analysis indicated that there is almost a 7-fold increase in the risk of Raynaud's phenomenon due to exposure to hand-arm vibration (meta-odds ratio: 6.85; 95% CI: 4.17-11.25).¹⁶

The Raynaud's phenomenon is manifested by the development of cold-induced blanching of the fingers. The blanching may also sometimes be triggered by using a vibrating tool. The blanching begins in the tips of one or more exposed

fingers and, as the condition worsens, the blanching may extend down the entire finger and all fingers and thumbs may be affected. Cold exposure may also be associated with cyanosis due to reduced local supply of oxygenated hemoglobin and, during re-warming there may be reactive hyperemia due to vasodilatation. In very severe cases there may be trophic changes with ulceration in the fingers due to decreased blood supply and the ulcerated areas may become gangrenous resulting in loss of digits.

Raynaud's phenomenon may also develop in the feet in workers exposed to hand-arm vibration.^{17,18} The risk of Raynaud's phenomenon in the feet appears to be increased in workers who first develop Raynaud's phenomenon in the hands due to vibration.^{17,18}

It is common for workers to have symptoms of Raynaud's phenomenon for several years before a diagnosis of HAVS is made. As described by Bodley et al¹⁹ workers often face barriers to early diagnosis of HAVS including access to a primary healthcare practitioner with knowledge of occupational conditions such as HAVS, and referral to specialized diagnostic centres. In such instances, the date of onset of HAVS could be attributed to the time of symptom development or the time the symptoms were first documented by a healthcare practitioner rather than the date of HAVS diagnosis.

Workers using vibrating tools may also develop thrombi in the arteries in the hands, in particular in the ulnar artery at the wrist, which lies just below the hypothenar eminence.²⁰ The evidence for these thrombotic lesions being due to vibration is mainly from case reports and, based on the small number of reports, it appears to come to clinical attention infrequently. It is at present unclear if these reported cases are due to work practices (e.g. forceful striking with the hypothenar eminence of the hand) or some aspect of the vibration such as the dominant frequency or impulsivity of the vibration.

2. Neurological

Hand-arm vibration can result in the development of damage to the nerve fibres and skin mechanoreceptors in the fingers, producing digital neuropathy. A recent meta-analysis has indicated approximately a 7-fold increased risk of digital neuropathy due to hand-arm vibration exposure (meta-odds ratio: 7.37; 95% CI: 4.28 – 14.15).¹⁶ The digital neuropathy is usually manifested by numbness and tingling in the fingers that is present even when not exposed to the cold. Cold exposure may lead to digital vasospasm and transient reduction in blood supply to peripheral nerves with resultant transient numbness and tingling but these transient abnormalities do not constitute evidence of the sensorineural component of HAVS.

The Stockholm Workshop Scale for the sensorineural component of HAVS described by Brammer et al³ is based on digital neuropathy and it does not include carpal tunnel syndrome (CTS). However, CTS due to median nerve compression at the wrist is common in workers with HAVS. For example, Lander et al,²¹ reported that, in 162 patients assessed for HAVS, 33% had CTS and 11% had ulnar neuropathy. CTS and digital neuropathy due to HAVS present with similar symptoms, therefore creating a diagnostic challenge.²²

The main established risk factor for CTS is exposure to ergonomic stressors, particularly repeated, forceful wrist movements and/or awkward wrist postures, but there is also recent epidemiological evidence that hand-arm vibration exposure is an independent risk factor for CTS. In particular, recent meta-analyses have found a statistically significant risk of CTS due to hand-arm vibration exposure.^{16,23}

3. Musculoskeletal

Decreased grip strength was reported by Farkkila²⁴ in workers with exposure to hand-arm vibration and this was confirmed in subsequent studies.^{25,26} Necking et al,¹³ using biopsies of the abductor pollicis longus muscle in 20 patients with HAVS and four controls, found that vibration exposure was associated with evidence of direct damage to muscle such as muscle necrosis, fibrosis and structural disorganization. Other pathological findings described by Necking et al suggested motor nerve injury with secondary muscle denervation/re-innervation. Therefore, the decreased grip strength may be related to a combination of direct muscle injury and nerve injury due to vibration.

Liss and Stock²⁷ investigated the association between Dupuytren's contracture and hand-arm vibration. Dupuytren's contracture is an abnormality of the palmar fascia that results in thickening and band formation of the palmar surface with secondary finger contractures. In a literature review they found only three published studies of good quality addressing this topic. All three reported statistically significant odds ratios ranging from 2.1 (95% CI: 1.1-3.9) to 2.6 (95% CI: 1.2-5.5) for this association and two of the studies indicated evidence of a dose-response relationship. A meta-analysis by Descatha et al²⁸ in 2011 reported an increased risk of Dupuytren's contracture due to exposure to hand-arm vibration (meta-odds ratio: 2.14; 95% CI: 1.59 – 2.88); they also reported an independent increased risk of this outcome due to manual work (meta-odds ratio: 2.01; 95% CI: 1.51 – 2.66). Since the study by Descatha et al, additional epidemiological studies have also found an association between hand-arm vibration exposure and Dupuytren's contracture,²⁹⁻³² including two meta-analyses.^{30,32}

A number of other musculoskeletal outcomes have been associated with hand-arm vibration including bone cysts and osteoporosis in the hands

and wrists, osteoarthritis of the wrist, elbow and shoulder, epicondylitis and non-specific muscle and joint pain and stiffness. Hagberg³³ carried out a comprehensive review of these musculoskeletal outcomes and concluded that the evidence that vibration per se is a risk factor was weak although there was strong evidence that work with vibrating tools was associated with these musculoskeletal disorders. Ergonomic factors and/or work practices were potential confounders of an effect specifically due to hand-arm vibration for all of these musculoskeletal outcomes.

HAVS Case Definition Based on Review of Evidence

HAVS refers to the vascular, neurological and musculoskeletal health effects that occur due to hand-arm vibration exposure. These health effects, which are summarized in Table 1, may occur separately or in combination. The vascular effect is secondary Raynaud's phenomenon due to hand-arm vibration and the sensorineural effect is digital neuropathy. There is more controversy about the specific musculoskeletal effect due to hand-arm vibration, but often grip strength is used for the musculoskeletal component of HAVS.

Measurement of HAVS

1. Vascular Component

The diagnosis of Raynaud's phenomenon requires a history of cold-induced finger blanching, which sounds quite straightforward. However, workers may sometimes have difficulty describing the presence and distribution of finger blanching. Other measures may be used to augment the medical history of cold-induced finger blanching. Standard colour photographs of the hands have been developed, which include photos of the vascular component of HAVS as well as other hand photos.³⁴ Workers can be asked to identify which of these photos resembles the appearance of their hands when exposed to the cold. As well workers may be asked to take a photo of their own hands when they are experiencing finger blanching.³⁵

Various objective tests have been used to attempt to measure the cold-induced abnormalities associated with HAVS. The main tests have involved measuring (a) blood flow to the fingers or digital blood pressure and the change in blood flow or digital blood pressure due to the induction of digital vasospasm from a cold stimulus (usually cold water immersion) or (b) the recovery in finger temperature (as an index of recovery of digital vasospasm) after cold water immersion. The main tests that measure induction of vasospasm utilize plethysmography (strain gauge or photocell). The tests that measure recovery of finger temperature include thermometry (using finger thermocouples) or thermography (using an IR camera). There is some variation in test technique in various clinical centres assessing HAVS patients, including the temperature and duration of cold water

immersion and the timing of measurements following cold stimulation. We recently analyzed the performance of thermography to diagnose the vascular component of HAVS using the ISO recommended temperature and duration of cold water immersion and we found insufficient sensitivity and specificity to recommend use of this test.³⁶ Consequently, we now use plethysmography in our clinic as the principal vascular test to confirm cold-induced vasospasm.

2. Neurological Component

The definitive test for measurement of peripheral nerve abnormalities is a nerve conduction test. This test allows measurement of nerve conduction velocity, latency and amplitude in large myelinated nerve fibres. The nerve conduction test is especially useful for measurement of neuropathy proximal to the hand such as median or ulnar neuropathy at the wrist. However conventional electrode placement in the nerve conduction test does not permit measurement of the distal parts of the fingers that are initially affected by hand-arm vibration. Segmental or fractionated nerve conduction may be carried out with ring electrode placement in the distal parts of the finger allowing the potential for improved measurement of digital neuropathy.^{37,38} However, this is technically challenging, and it is not done in most nerve conduction laboratories. In particular, it may be affected by the cold temperature of the digits in HAVS subjects and local re-warming may not be sufficient to control this factor.³⁹ We were not able to produce reliable results in the electromyography laboratory of our hospital when we attempted to use the segmental nerve conduction measurement method described in Japan.

An alternative is to use quantitative sensory tests (QSTs) such as current perception threshold (CPT) or a combination of vibration perception threshold (VPT) and temperature perception threshold (TPT), in conjunction with conventional nerve conduction studies. The CPT or combination of VPT and TPT allows measurement of all of the important nerve fibres in the fingers that may be damaged by vibration. For example, CPT measurements are usually carried out in the index finger (median nerve innervation) and baby finger (ulnar nerve innervation) at three frequencies – 2000 Hz, 250 Hz, and 5 Hz, which correspond to large myelinated (A β), small myelinated (A δ) and unmyelinated (C) fibres respectively.

The QSTs have been found to be better predictors than the nerve conduction tests of the Stockholm Workshop Scale for the sensorineural component of HAVS. This has been shown in studies examining CPT⁴⁰ and VPT.⁴¹ Therefore, the quantitative sensory tests appear to be more sensitive tests than conventional nerve conduction tests for the measurement of the sensorineural abnormalities in the distal fingers associated with HAVS. Similarly, when segmental nerve conduction is done, the nerve conduction findings in the distal portions of the fingers have been reported to be better predictors of the Stockholm sensorineural scale stages than are the findings across the wrists.³⁸

Hence the QSTs and the segmental nerve conduction in the distal segments of the fingers appear to be measuring a similar phenomenon.

However, QSTs are less objective than the nerve conduction tests and therefore should be used in conjunction with nerve conduction tests, especially if the assessment is occurring in a compensation setting.

3. Musculoskeletal Component

A thorough clinical examination of the upper extremities is the best method to determine the presence of musculoskeletal problems that might be associated with hand-arm vibration exposure and/or ergonomic factors. Grip strength can be measured using a grip dynamometer; usually three measurements are done in each hand and the average is obtained. Other tests such as X-rays of the hands and wrists to demonstrate bone abnormalities, CT scan, MRI or bone density measurement could be done depending on the clinical context but are usually not part of a routine assessment for HAVS.

Clinical Assessment of a Worker to Diagnose HAVS

The assessment protocol has not been fully standardized and there is some variation in the assessment components in different centres. A recommended assessment might include the components described in Table 2.

The occupational history is essential and should include documentation of the type of work in which hand-arm vibration exposure occurred, the vibrating tools used, and the duration of exposure to vibrating tools. Any associated workplace measurements of hand-arm vibration would be helpful in estimating the exposure. The medical history is also essential to enquire about symptoms of finger blanching, numbness and tingling in the fingers and musculoskeletal symptoms, as well as a history of other medical problems that might be associated with conditions similar to HAVS. The physical examination should focus on the vascular, neurological and musculoskeletal systems and is an essential component for diagnosis. The blood tests should include tests to identify other causes of Raynaud's phenomenon such as connective tissue disease, common causes of neuropathy like diabetes mellitus, and musculoskeletal co-morbidity such as rheumatoid arthritis or osteoarthritis. The blood tests that we do include the following: antinuclear antibody, rheumatoid factor, CBC, ESR, thyroid function (TSH), Vitamin B12, RBC folate, and random blood glucose. We previously included serum cryoglobulins and cold agglutinins but these tests were found to have very low positive rates and low utility in the routine clinical assessment of possible HAVS;⁴² consequently they have been discontinued as part of our routine assessment. However, these tests still might be used occasionally if a specific case suggested a condition associated with abnormalities in serum cryoglobulins and/or cold agglutinins.

Objective assessment of the components of HAVS is usually needed for compensation purposes and it is in this area where differences are likely to be present in different centres. The Doppler assessment is used to determine the presence of other lesions in the larger blood vessels in the upper and lower extremities. The digital plethysmography (baseline and after cold water immersion) measures induction of vasospasm in the fingers from cold stimulation. This combination of tests provides an assessment of the vascular component of HAVS. The nerve conduction study mainly measures neurological co-morbidity such as median or ulnar neuropathy at the wrist. The QSTs can be used to determine the presence of digital neuropathy but should be evaluated in conjunction with nerve conduction studies. A grip dynamometer can be used to objectively measure grip strength and the results can be compared to population normal values based on age and sex.⁴³ The results must be interpreted in conjunction with the results of the overall assessment because grip strength can be affected by musculoskeletal co-morbidity (such as epicondylitis) and/or neurological co-morbidity (such as CTS with motor nerve involvement). The Purdue pegboard is a test of finger/hand dexterity, which helps to assess overall impairment in hand function.

Prognosis of HAVS

If vibration exposure continues, the various components of HAVS would be expected to worsen in severity. If exposure ends, there may be some improvement in the vascular component of HAVS, especially in milder cases. There is evidence that smoking may delay improvement in plethysmography response to cold challenge after exposure to vibration ends.⁴⁴

Management of HAVS

The medical management of workers with existing HAVS is mainly directed towards control of symptoms. Workers with HAVS should avoid cold exposure as much as possible and wear thermal protective clothing when exposed to cold ambient conditions. The warm clothing helps to maintain core body temperature; if the core temperature drops, there is reflex vasoconstriction in the extremities, which might precipitate attacks of Raynaud's phenomenon. Calcium channel blocking agents may be used for control of cold-induced vasospastic symptoms, although results are mixed and many workers are initially reluctant to take medication. Smoking should be avoided.

Workers with HAVS can usually remain at work, especially if there is some reduction in their hand-arm vibration exposure and/or cold exposure. However, in more severe cases, such as those with severe, painful and frequent finger blanching and/or trophic changes in the fingers, a change in work with complete discontinuation of vibration exposure and/or cold exposure may be needed.

Workers could wear ISO approved anti-vibration gloves, if possible, even though AV gloves are, in general, more effective in attenuating transmission of higher vibration frequencies.⁴⁵ It is recommended that tools be gripped with the minimum grip force consistent with safe operation of the tools to minimize vibration transmission to the hands and regular work breaks should be provided to workers when exposed to vibration. The use and regular maintenance of anti-vibration, ergonomically designed tools would be the best method to reduce hand-arm vibration exposure.

Controversial Issues Related to HAVS

1. HAVS of the Feet Related to Vibration Exposure

Acute vibration exposure to one hand is associated with a decrease in blood flow in not only the exposed hand but also the other hand⁴⁶ and the toes.⁴⁷ This is thought to be due mainly to generalized stimulation of the sympathetic nervous system. The concentration of noradrenaline, which is secreted by sympathetic nerve endings, has been shown to be higher in the plasma of workers with the vascular component of HAVS than in controls following cold stimulation⁴⁸ and workers with HAVS have greater urinary excretion of noradrenaline in comparison to controls.⁴⁹ Other mechanisms may also be involved such as the systemic release of endothelin-1 from vascular endothelial cells damaged by vibration.⁵⁰ A systematic literature review by Schweigert¹⁷ concluded that cold-induced vasospasm in the feet may also be present in workers with the vascular component of HAVS in their hands. Analysis of our own data in patients with HAVS has indicated that the presence of cold provocation plethysmography abnormalities in the hands is associated with an approximately 5 fold increased risk of similar abnormalities in the feet.¹⁸ As well our recent analysis of thermography data indicated that, following cold water immersion, there is delayed rewarming of not only the fingers, but also, to a lesser extent, the toes in HAVS subjects in comparison to controls.³⁶

There is also some evidence that the vascular component of HAVS in the hands may be associated with neurological effects in the lower extremities. However significant neurological symptoms appear to be reported much less frequently than vascular symptoms in the lower extremities of workers with HAVS. Schweigert,¹⁷ in his review of lower extremity health effects in workers with HAVS, identified only two papers that considered neurological outcomes.^{51,52} These two studies found that workers with hand-arm vibration syndrome in comparison to controls had decreased nerve conduction velocity in the medial plantar nerves of the feet.^{51,52} Possibly recurrent cold-induced ischemia of the nerves in the lower extremities is the underlying mechanism, although additional research is needed to clarify this.

2. HAVS Complicated by Carpal Tunnel Syndrome (CTS)

CTS frequently occurs in workers using vibrating tools. This is presumed to be mainly due to the ergonomic stressors associated with tool use, in particular repeated forceful flexion and extension of the wrists and awkward wrist postures. However, there is evidence that vibration exposure is an independent risk factor for CTS. A systematic literature review by Palmer et al⁵³ found that there was reasonable evidence that regular and prolonged use of hand-held vibratory tools increased the risk of CTS by more than two-fold. Recent meta-analyses have also found that hand-arm vibration is a risk factor for CTS; Barcenilla et al²³ and Nilsson et al¹⁶ reported meta-odds ratios of 5.40 (95% CI: 3.14-9.31) and 2.93 (95% CI: 1.74-4.95) respectively for the association between hand-arm vibration exposure and CTS.

The presence of CTS complicates the diagnosis of the sensorineural component of HAVS (digital neuropathy) because both conditions may present with symptoms of numbness and tingling in the fingers. This may lead to misdiagnosis, especially when workers are first assessed by a primary care practitioner. CTS is well known in the general medical community, but HAVS less so, which suggests that any misclassification is likely to be in the direction of HAVS cases being initially misdiagnosed as CTS.

In HAVS, the numbness and tingling usually involve the digital nerve fibres of both the median and ulnar nerves and it is not uncommon to have all of the fingers affected. In CTS, the symptoms are usually restricted to the median nerve although sometimes patients report symptoms in all of the fingers. Increased symptoms of numbness and tingling while trying to sleep are typical of CTS, due to postural effects influencing median nerve compression at the wrist and are usually not present in digital neuropathy. CTS can be both sensory and motor with thenar muscle wasting due to motor neuropathy, whereas digital neuropathy is principally sensory. HAVS may be associated with musculoskeletal effects, but thenar atrophy has not been reported due to vibration exposure.

Nerve conduction studies with conventional electrode placement are useful for the diagnosis of CTS and other neuropathies proximal to the hand such as ulnar neuropathy at the wrist or elbow. However, such nerve conduction studies are not sensitive measures of digital neuropathy as discussed previously. Quantitative sensory tests (QSTs) may be used in the diagnosis of digital neuropathy, but QSTs measurement may also be affected by median and ulnar neuropathy proximal to the hand,⁵⁴ and therefore the QSTs should be interpreted in conjunction with nerve conduction studies. Previous research has indicated an increased risk of Raynaud's phenomenon in individuals with CTS,^{55,56} and this conclusion was supported in recent reviews of the topic.^{57,58} The Raynaud's phenomenon is presumably secondary to compression and irritation of autonomic nerve fibres in the median nerve in the carpal tunnel.

The first occurrence of Raynaud's phenomenon shortly after the development of CTS and/or improvement in the Raynaud's phenomenon symptoms after carpal tunnel release surgery would suggest that the Raynaud's phenomenon might be secondary to the CTS. Hartmann et al⁵⁷ carried out a meta-analysis to estimate the prevalence of Raynaud's phenomenon in 675 patients with CTS from eight previous studies. Despite some heterogeneity in previous study results, the estimated pooled prevalence from the meta-analysis was only 15.5%. Therefore, most individuals with CTS do not develop Raynaud's phenomenon. Verghese et al⁵⁶ found that autonomic disturbances consistent with Raynaud's phenomenon were associated with the severity of electrophysiological findings on nerve conduction studies. This suggests that the occurrence of clinically significant Raynaud's phenomenon due to CTS is more likely to be present in severe cases of CTS.

3. HAVS Complicated by Smoking

Garner et al recently carried out a systematic review of the literature and meta-analysis of risk factors for primary Raynaud's phenomenon.⁵⁹ They found that risk factors for primary Raynaud's phenomenon included smoking (meta-odds ratio: 1.27; 95% CI: 1.06-1.53), female gender (meta-odds ratio: 1.65; 95% CI: 1.42-1.91), family history (meta-odds ratio: 16.6; 95% CI: 7.44-36.8), manual occupation (meta-odds ratio: 2.66; 95% CI: 1.73-4.08), migraine headaches (meta-odds ratio: 4.02; 95% CI: 2.62-6.17), cardiovascular disease (meta-odds ratio: 1.69; 95% CI: 1.22-2.34) and unmarried marital status (meta-odds ratio: 1.67; 95% CI: 1.20-2.33).

Therefore, smoking is a risk factor for the development of primary Raynaud's phenomenon. However, the literature is unclear about whether smoking modifies the risk of development of secondary Raynaud's phenomenon due to hand-arm vibration exposure. After development of the vascular component of HAVS, plethysmographic improvement in cold-induced vasospasm following removal from vibration exposure appears to be delayed in smokers compared to non-smokers.⁴⁴

4. HAVS with Pre-existing Raynaud's Phenomenon

The underlying pathophysiology of the vascular component of HAVS and pre-existing Raynaud's phenomenon is likely somewhat different, but there is no test that can be used to determine definitively the cause of the finger blanching. A family history of Raynaud's phenomenon and the presence of Raynaud's phenomenon prior to vibration exposure are consistent with the presence of primary Raynaud's phenomenon. However, workers often begin to work with vibrating tools in their late teens and early 20s before the symptoms of primary Raynaud's phenomenon might become manifest. Therefore, it

may be difficult to differentiate the vascular component of HAVS from primary Raynaud's phenomenon, especially if the symptoms begin within a few years of starting work.

The occurrence of the other components of HAVS - the digital neuropathy and musculoskeletal symptoms – in a worker with a history of hand-arm vibration exposure supports a diagnosis of HAVS. Blood tests such as RF and ANA can be used to screen for connective tissue disease, which may cause secondary Raynaud's phenomenon. The occupational history is also important to identify a history of other problems that may be associated with secondary Raynaud's phenomenon such as significant hand trauma and frostbite.

5. Raynaud's Phenomenon Resulting from Exposure to Cold Temperatures

Attacks of Raynaud's phenomenon are precipitated by exposure to cold ambient conditions in individuals with Raynaud's phenomenon (primary or secondary, including HAVS). Frostbite is an established cause of secondary Raynaud's phenomenon. There is also recent evidence that suggests that repeated exposure to cold conditions, in the absence of frostbite, may be associated with the development of Raynaud's phenomenon.

Piedrathita et al⁶⁰ carried out a descriptive study of 24 workers who worked in cold storage rooms with temperatures between -43 °C and -62 °C in a freeze-drying coffee company in Sweden. The most prevalent cold-related health problem reported was episodic finger symptoms (50% prevalence). Twenty percent reported peripheral circulation problems and two subjects had been given a previous diagnosis of Raynaud's phenomenon.

Carlsson et al⁶¹ evaluated the effects of 14 months of military training in cold winter conditions in 54 military conscripts. Assessments were carried out at baseline and after completion of 14 months of training. In comparison to baseline, cold-induced digital symptoms including pain/discomfort and white fingers were found to be increased in both prevalence and severity at follow-up.

Thetkathuek et al⁶² carried out a cross-sectional study of health effects in 497 frozen food workers (52.7% men, 47.3% women) exposed to repeated cold temperatures at work and office worker controls in Thailand. In the cold-exposed group the temperatures in the work environment ranged from 17.2 °C to 19.2 °C in most sections and -18.0 °C in the warehouse. Episodic digital symptoms (darkening of fingers, reddening of fingers, finger pain, toe pain, hands and legs sensitive to cold, fingers and toes sensitive to cold) were reported more frequently in warehouse workers than controls (OR=13.51; 95% CI 5.17-35.33). As well cardiovascular symptoms (described by the authors as pallor of fingers,

chest pain, arrhythmia) were significantly higher in employees working in cold conditions in sizing (OR=2.52, 95% CI: 1.14-5.54) and in the warehouse (OR=2.83, 95% CI: 1.28-6.26) in comparison to controls.

Kaminski et al⁶³ carried out a cross-sectional study in France of 1,374 employees exposed to cold but not vibration in 17 poultry slaughterhouses and 6 canning factories to investigate individual and occupational risk factors for Raynaud's phenomenon. In general, the slaughterhouses were colder than the canning factories; it was mentioned by the authors that sometimes the temperatures could be as low as 0 to 6 °C in slaughterhouses and meat processing factories. Working in poultry slaughter and processing was significantly associated with an increased risk of Raynaud's phenomenon (OR=3.6; 95% CI: 1.6-7.8). Some of this increased risk was due to different working conditions, such as frequency of breaks and taking breaks in an unheated room, but after controlling for these work conditions, the increased risk associated with the industry type persisted.

Roquelaure et al⁶⁴ carried out a large cross-sectional study of 3,710 workers (2,161 men and 1,549 women) in France to evaluate risk factors for Raynaud's phenomenon. Raynaud's phenomenon was defined as the occurrence of at least occasional attacks of finger blanching triggered by exposure to environmental cold in the previous 12 months and a total of 87 cases of Raynaud's phenomenon (56 women and 31 men were diagnosed). Logistic regression modelling indicated that, among the work-related factors studied, Raynaud's phenomenon was associated with exposure to a cold work environment or cold work objects (OR=2.2; 95% CI 1.0-4.6).

The overall evidence from these studies appears to be consistent with repeated exposure to cold working environments causing the development of Raynaud's phenomenon. However, the evidence is mainly from cross-sectional studies and it is possible that, at least to some extent, the symptoms of pre-existing Raynaud's phenomenon are simply becoming more evident in the cold, rather than the de novo development of Raynaud's phenomenon due to the cold.

Appendix

Vibration Measurement

The contact of the hand with a vibrating tool or surface can result in exposure to vibration over a broad frequency range. The resonant frequency of the fingers of the human hand is in the range of 150 to 300 Hz and frequencies above 100 Hz are better absorbed than lower frequencies by the fingers and hands.^{65,66} In contrast, lower frequency vibration can be transmitted to the arms and shoulders.^{67,68}

Vibration is a vector quantity and therefore its measurement involves a description of both intensity, which is measured in acceleration units and direction. Vibration acceleration is usually measured in three orthogonal axes using a triaxial accelerometer that is mounted on the tool handle. The measurements are frequency weighted to attempt to account for differences in the response of the hand-arm system to different frequencies. The values from the three axes can be combined and, in conjunction with the daily exposure duration in hours, used to calculate an A(8) in meters/sec² (an eight hour energy equivalent vibration total value). According to the European Directive 2002/44/EC⁶⁹ the daily exposure limit value is an A(8) of 5 meters/sec² and the daily exposure action value, which requires employers to implement measures to protect workers from hand-arm vibration, is 2.5 meters/sec².

Relation between Vibration Magnitude and the Time for Development of HAVS

There is an inverse relationship between the vibration exposure time for the onset of finger blanching (i.e. latency) and the daily vibration magnitude (A(8)). Based on epidemiological studies of exposure/response, the relation between latency and vibration magnitude has been estimated by Griffin⁷⁰ to be as follows:

$$Y_{10\%} \approx 30/A(8)$$

(Where Y_{10%} is the number of years that produces finger blanching in 10% of workers exposed to a particular vibration daily magnitude A(8)).

Using this equation, the relation between the latency (expressed as Y_{10%}) and the daily vibration magnitude (expressed as A(8)) could be illustrated as follows:

Vibration exposure in meters/sec ² (A(8))	Latency in years (Y10%)
15	2
10	3
7.5	4
5	6
2.5	12
1	30

These estimates pertain to groups of workers. However, there is a large variation in individual susceptibility to hand-arm vibration exposure, which makes estimation for individuals difficult. For example, while one worker may develop HAVS symptoms in only a few years, others with similar exposure may be unaffected after 25 years.⁷¹

Table 1. Hand Arm Vibration Syndrome (HAVS) Components

HAVS Components	Description of Components
Vascular	Raynaud’s phenomenon: This refers to secondary Raynaud’s phenomenon due to hand-arm vibration exposure. Other causes of Raynaud’s phenomenon should be excluded by medical history, examination, and additional tests. Epidemiological evidence indicates that after the fingers are affected, the toes may be secondarily affected.
Neurological	Digital neuropathy: This refers to a neuropathy in the fingers due to hand-arm vibration exposure. Other causes of neuropathy should be excluded by medical history, examination, and additional tests. Epidemiological evidence indicates that hand-arm vibration exposure is an independent risk factor for carpal tunnel syndrome (CTS). However, CTS is not included in the neurological component of HAVS.
Musculoskeletal	Decreased grip strength: This refers to decreased grip strength due to hand-arm vibration exposure. Other causes of decreased grip strength should be excluded by medical history, examination, and additional tests.

Table 2. Recommended Assessment Protocol for HAVS

Recommended Assessment Protocol for HAVS
1. Medical History
2. Occupational History
3. Physical Examination
4. Additional tests <ul style="list-style-type: none"> a) Blood tests to rule out other similar conditions <ul style="list-style-type: none"> • Antinuclear antibody, Rheumatoid factor, TSH, CBC, ESR, Vitamin B12, RBC folate, and random blood sugar b) Tests of Vascular Function <ul style="list-style-type: none"> • Doppler examination of the upper and lower extremities • Cold provocation digital plethysmography c) Tests of Neurological Function <ul style="list-style-type: none"> • Nerve conduction test • Quantitative sensory tests (CPT or a combination of VPT and TPT) d) Musculoskeletal Tests <ul style="list-style-type: none"> • Grip strength e) Test of Finger/Hand dexterity <ul style="list-style-type: none"> • Purdue pegboard

Figure 1. Photo of Finger Blanching in a HAVS Patient



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