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Vasospasm in the feet in workers assessed for HAVS

R. House[1,2], D. Jiang[3], A. Thompson[2], T. Eger[4], K. Krajnak[5], J. Sauvé[2] and M. Schweigert[2]

[1]Division of Occupational and Environmental Health, Dalla Lana School of Public Health, University of Toronto, 155 College Street, Toronto, Ontario, M5T 3M7, Canada, [2]Department of Occupational and Environmental Health, St. Michael's Hospital, 30 Bond Street, Toronto, Ontario, M5B 1W8, Canada, [3]Biostatistics Division, Dalla Lana School of Public Health, University of Toronto, 155 College Street, Toronto, Ontario, M5T 3M7, Canada, [4]School of Human Kinetics, Laurentian University, 935 Ramsay Lake Road, Sudbury, Ontario, P3E 2C6, Canada, [5]Engineering and Control Technology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown, WV 26505, USA.

Correspondence to: R. House, Department of Occupational and Environmental Health, St Michael's Hospital, 30 Bond Street, Toronto, Ontario, M5B 1W8, Canada. Tel: +1416 864 5074; fax: +1416 864 5421; e-mail: houser@smh.toronto.on.ca

Background Previous studies have suggested that the presence of the vascular component of hand–arm vibration syndrome (HAVS) in the hands increases the risk of cold-induced vasospasm in the feet.

Aims To determine if objectively measured cold-induced vasospasm in the hands is a risk factor for objectively measured cold-induced vasospasm in the feet in workers being assessed for HAVS.

Methods The subjects were 191 male construction workers who had a standardized assessment for HAVS including cold provocation digital photocell plethysmography of the hands and feet to measure cold-induced vasospasm. Bivariate analysis and multinomial logistic regression were used to examine the association between plethysmographic findings in the feet and predictor variables including years worked in construction, occupation, current smoking, cold intolerance in the feet, the Stockholm vascular stage and plethysmographic findings in the hands.

Results Sixty-one (32%) subjects had non-severe vasospasm and 59 (31%) had severe vasospasm in the right foot with the corresponding values being 57(30%) and 62 (32%) in the left foot. Multinomial logistic regression indicated that the only statistically significant predictor of severe vasospasm in the feet was the presence of severe vasospasm in the hands (OR: 4.11, 95% CI: 1.60–10.6, $P < 0.01$ on the right side and OR: 4.97, 95% CI: 1.82–13.53, $P < 0.01$ on the left side). Multinomial logistic regression analysis did not indicate any statistically significant predictors of non-severe vasospasm in the feet.

Conclusions Workers assessed for HAVS frequently have cold-induced vasospasm of their feet. The main predictor of severe vasospastic foot abnormalities is severe cold-induced vasospasm in the hands.

Key words Feet; hand–arm vibration; occupational; vasospasm.

Introduction

Hand–arm vibration syndrome (HAVS) is a common occupational health problem that consists of vascular, sensorineural and musculoskeletal components [1,2], which may all contribute to upper extremity disability [3]. The main vascular effect is a form of secondary Raynaud's phenomenon.

Hand–arm vibration exposure results in both local and central sympathetic nervous system stimulation [4]. Acute vibration exposure to one hand is associated with decreased blood flow in not just the exposed hand but also the contralateral hand [5–7] and the toes [6,8]. A central sympathetic vasoconstrictor reflex is involved in vibration-induced vasospasm [9] and this reflex appears to be increased in workers with vascular HAVS [10]. There is epidemiologic evidence that chronic vibration exposure resulting in HAVS is associated with chronic vascular abnormalities in the feet [11–15]. In a systematic review of published papers on this topic, Schweigert [16] concluded that hand–arm vibration was associated with cold-induced vasospasm in the feet but that the vascular component of HAVS needed to be present in the hands before cold-induced vasospasm occurred in the feet. Demonstrating if an association exists between the presence and severity of vasospasm in the hands in workers with HAVS and the occurrence and severity of vasospasm in the feet would add to the existing body of knowledge about the nature and etiology of vibration-induced vascular dysfunction.

The Occupational Health Clinic at St. Michael's Hospital, Toronto, Canada has been assessing workers with HAVS for many years. Initially, the assessment of the vascular component of HAVS considered only vascular abnormalities in the hands. Over time, we noticed that workers often reported increased cold intolerance of their feet as well as their hands. Consequently, we began to do cold provocation digital plethysmography tests for vasospasm on the feet as well as the hands of all workers being assessed for HAVS.

In this paper, we describe the prevalence of vascular abnormalities in the feet of workers assessed for HAVS at our clinic. We also examine various potential predictors of vasospasm in the feet, in particular if the vascular changes due to HAVS in the hands are associated with cold-induced vasospasm in the feet.

Methods

This is a cross-sectional study of workers who were clinically assessed for HAVS, some of whom had objective evidence of cold-induced vasospasm in the hands. The specific question addressed was whether objectively measured cold-induced vasospasm in the hands is a risk factor for objectively measured cold-induced vasospasm in the feet in workers exposed to hand–arm vibration.

The subjects in this study were 191 male construction workers who were assessed consecutively for HAVS at the Occupational Health Clinic during a 2 year period. The patients had all been referred to the clinic from the Workplace Safety and Insurance Board, the provincial workers' compensation board, after they had initiated a compensation claim for possible HAVS due to upper extremity symptoms, such as finger blanching, numbness, tingling, pain or stiffness. The assessment included an occupational and medical history, an examination focusing on the possible effects of HAVS, blood tests to exclude other possible causal factors such as collagen vascular disease and additional tests including cold provocation digital plethysmography to confirm the diagnosis. Their occupational histories indicated that they were exposed to hand–arm vibration from the use of vibrating power tools. Some tools such as jackhammers may also have been associated with vibration exposure to the feet but the principal exposure in all cases was to hand–arm vibration. Medical and occupational histories confirmed that there was no known personal or family history of primary Raynaud's phenomenon and that the onset of cold-induced digital blanching did not occur prior to work involving exposure to hand–arm vibration. None of the workers had a known history of atherosclerotic peripheral vascular disease.

The data used in the study were abstracted from the workers' medical charts. During the initial assessment process, the data had been collected in a standardized fashion using a questionnaire and clinical data recording forms, which facilitated the abstraction process. The data collected included the subjects' age, years worked in construction, type of construction trade, the presence of cold intolerance in the feet (yes/no), current smoking status (yes/no), the Stockholm vascular scale stage in each hand and the cold provocation digital plethysmography results in the hands and feet. Few workers reported a history of diabetes mellitus and none reported associated complications, such as polyneuropathy. Therefore, this information was not included in the abstracted data. The clinical records from which data were abstracted did not contain any questions about blanching of the toes which we have found is rarely reported because workers are wearing boots or shoes when cold exposed or working with vibrating tools. The Stockholm vascular scale is based primarily on the frequency and distribution of cold-induced blanching in the fingers and the scale varies from 0 to 4, with 0 representing no blanching and 4 severe blanching with trophic changes due to finger ischemia [17].

The assessment of digital plethysmography was carried out in a university-affiliated hospital vascular laboratory and the interpretation of the tracings was done by a vascular clinical specialist using a standardized protocol. The technician carrying out the tests and the vascular specialist interpreting the tests were unaware of the etiological question, therefore minimizing the potential for measurement bias. Cold provocation digital photocell plethysmography is well described in the literature and interpretation of the plethysmography tracings uses standardized changes in pulse amplitude and waveform morphology as an indicator of vasospasm [18–20]. A normal pulse contour exhibits a steeply rising upslope, a fairly sharp peak and a dicrotic notch on the downslope. When vasospasm occurs, there is a reduction in amplitude and a loss of normal morphology with prolongation of the upslope, rounding of the peak and a loss of the dicrotic notch on the downslope. Measurement in our study was done at baseline and post-cold-water immersion (10°C for 2 min) using a Nicolet VasGUARD system with photoplethysmography sensors. The scoring was based on the changes in finger waveforms after cold-water immersion in comparison with the baseline results and the results were read qualitatively in comparison to standard plethysmographic tracings. The values in this study were recorded for each hand and foot as follows: Stage 0 (normal), no changes or mild changes; Stage 1 (non-severe vasospasm), vasoconstrictive changes in morphology and at least a 50% reduction in amplitude from baseline but not marked flattening of the waveform and Stage 2 (severe vasospasm), vasoconstrictive changes in morphology and a severe reduction in amplitude with marked flattening of the plethysmogram. This scale was consistent with the scale for cold provocation digital plethysmography described by Laroche and Theriault [18].

The analyses were carried out using SAS 9.2 (SAS Institute, Cary, NC). All P values were two tailed and a *P* value <0.05 was regarded as being statistically significant. Age and years worked in construction were not normally distributed and therefore were summarized in the descriptive analyses using the median and range. Categorical variables and ordinal variables were summarized using the number (percent) in various categories. In the bivariate analysis, the association between the ordinal digital plethysmography scores in each foot and various predictor variables, including cold intolerance in the feet, current smoking, occupation (pipefitter versus non-pipefitter) and the Stockholm Vascular scale stage in each hand were examined using Spearman rank correlations. Spearman rank correlations were also used to examine the correlations between exposure duration and age as well the correlations between the plethysmography variables for the hands and feet with each other and with exposure duration. The multivariable analysis was carried out using multinomial logistic regression with the dependent variable being the digital plethysmography scores in the feet. Multinomial logistic regression estimates a separate set of coefficients for the different levels of the dependent variable in comparison to the same baseline level. In our study, the levels of the dependent variable compared were (i) Stage 1 versus 0 and (ii) Stage 2 versus 0. This type of regression allowed us to assess separately the predictors of non-severe and severe vasospasm in the feet. The predictor variables examined included current smoking status, duration of vibration exposure, the Stockholm vascular scale score, the digital plethysmography score in the hands and any other variables found to be statistically significant in the bivariate analysis. Both the Stockholm vascular scale score and the digital plethysmography scores in the hands were analyzed as categorical variables. Separate analyses were done for each foot using the Stockholm vascular scale score and the digital plethysmography score from the hand on the same side. Interaction terms were also examined. In all the models, an initial saturated model was fitted followed by backwards stepwise elimination to produce the final model. Age was not included in the models because it was highly correlated with years worked in construction (Spearman $r = 0.80$). However, if age replaced years worked in construction in the models, the final results of the backwards stepwise elimination were the same.

The study was approved by the Research Ethics Board of St. Michael's Hospital, a teaching hospital affiliated with the University of Toronto.

Results

All of the workers were men. They had a median age of 57 years (range: 28–75 years) and a median number of years worked in construction of 36 (range: 4–52 years). One hundred and fifty-six workers (82%) were pipefitters and the rest worked in various trades including 14 (7%) electricians, 6 (3%) welders, 10 (5%) carpenters and 5 (3%) other trades. One hundred and sixty-nine workers (88%) reported cold intolerance in their feet. A total of 59 workers (31%) were current smokers. The numbers (%) in the Stockholm scale stages were as follows: Stage 0: 53 (28%), Stage 1: 17 (9%), Stage 2: 60 (31%), Stage 3: 61(32%) and Stage 4: 0 (0%) in the right hand and 54 (28%), 19 (10%), 56 (29%), 62 (32%) and 0 (0%) in the corresponding stages in the left hand.

The results of the digital plethysmography in the hands and feet are shown in Table 1. The overall percentage of workers with vasospasm (Stage 1 or 2) in the feet was 63% in the right foot and 62% in the left foot. Severe (Stage 2) vasospasm was found in the right foot in 31% of workers and in the left foot in 32% of workers.

In the bivariate correlational analysis, there were no statistically significant correlations between the digital plethysmography results in either foot and cold intolerance in the feet, occupation (pipefitter versus non-pipefitter) or the Stockholm vascular scale stage in either hand. There was a statistically significant correlation ($r = 0.17$, $P < 0.05$) between current smoking and the plethysmography score in the left foot but not the right foot. The results of the correlational analysis of the digital plethysmography scores in the hands and feet and exposure duration are shown in Table 2. The digital plethysmography results in the two feet were highly correlated ($r = 0.70$, $P < 0.001$), as were the digital plethysmography results in the two hands ($r = 0.76$, $P < 0.001$). There were also statistically significant, although lower, correlations between the digital plethysmography results in the hands and feet for both the same side and the opposite side. Exposure duration was not statistically significantly correlated with the digital plethysmography results in the hands or feet.

The results of the multinomial logistic regression for the saturated models in each foot were similar with the only statistically significant variable being the digital plethysmography results in the corresponding hand. No interaction terms were found to be statistically significant. The results of the final models from the backwards

Table 1. Number (%) of digital plethysmography results in study participants

Extremity	Side	Plethysmography stage[a]		
		Stage 0	Stage 1	Stage 2
Hand	Right	89 (47)	66 (35)	36 (19)
	Left	94 (49)	64 (34)	33 (17)
Foot	Right	71 (37)	61 (32)	59 (31)
	Left	72 (38)	57 (30)	62 (32)

[a]Stage 0: normal; Stage 1: non-severe vasospasm; Stage 2: severe vasospasm.

stepwise regression from the saturated models are given in Table 3. As this table indicates, there were no statistically significant predictors when comparing Stage 1 versus 0 vasospasm in the feet. However, when comparing Stage 2 versus 0 vasospasm in the feet, Stage 2 (severe) vasospasm in the hands was a statistically significant predictor with odds ratio of 4.11 (95% CI: 1.60–10.6) for the right side and 4.97 (95% CI: 1.82–13.53) for the left side.

Discussion

This study has shown a high prevalence of vascular abnormalities in the feet of workers being assessed for HAVS. A total of 88% of workers reported cold intolerance in their feet in response to a specific question about this. Digital plethysmography indicated that the percentage of workers with objective evidence of vasospasm (Stage 1 or 2) was 63% in the right foot and 62% in the left foot. Severe vasospasm was seen in 31% of subjects in the right foot and 32% of subjects in the left foot. The multinomial logistic regression analysis indicated that the main predictor of severe vasospasm in the feet was severe vasospasm in the hands. There were no statistically significant predictors of non-severe vasospasm in the feet.

Table 2. Spearman rank correlations between plethysmography variables and exposure duration

	Plethysmography			
	Right hand	Left hand	Right foot	Left foot
Plethysmography				
Right hand				
Left hand	0.76***			
Right foot	0.19**	0.18*		
Left foot	0.17*	0.20**	0.70***	
Exposure duration	0.06	0.02	−0.06	−0.05

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

This study had a large sample of consecutive patients who had been assessed with cold provocation digital plethysmography of the hands and feet. The subjects were not recruited from patients who had been tested because they had complained of foot symptoms. The aim of this cross-sectional study was to determine if workers with objective evidence of vascular HAVS have an increased risk of cold-induced vasospasm in the feet. It was not designed to investigate whether hand–arm vibration exposure *per se* is a risk factor for vascular effects in the feet; this is a different question that would require a non-vibration-exposed control group and has already been the subject of several studies [11–16].

Previous studies have reported a higher prevalence of 'coldness' in the lower extremities in workers with HAVS compared with non-vibration-exposed controls [11–13]. The prevalence of coldness in the feet has also been found to increase as the frequency of attacks of HAVS increase [13]. A pathological basis for the reported symptoms in the feet was suggested by Hashiguchi *et al.* [15], who reported that vascular medial muscle hypertrophy and increased collagen in perivascular connective tissue were present in both the fingers and toes of 21 workers with HAVS. Skin temperature in both the fingers and the toes has been shown to be lower in workers with HAVS compared with non-exposed controls [11,12,14]. However, no statistically significant skin temperature differences in the toes have been found in vibration-exposed subjects without HAVS in comparison to controls, either at baseline or post-cold-water immersion [11]. This suggests that the presence of the vascular component of HAVS in the hands in vibration-exposed workers is required before measurable circulatory effects are found in the lower extremities [16]. Our results are somewhat supportive of this. In particular, we found that severe vasospasm in the feet is much more likely in workers with severe vascular

Table 3. Multinomial logistic regression predictors of plethysmography stages[a] in the feet

Extremity	Predictor variable	Plethysmography stage comparison in feet	
		Stage 1 versus 0 Odds ratio (95% CI)	Stage 2 versus 0 Odds ratio (95% CI)
Right foot	Plethysmography in right hand		
	(reference = Stage 0)		
	Stage 1	1.15 (0.55–2.39)	1.20 (0.53–2.71)
	Stage 2	0.80 (0.26–2.48)	4.11 (1.60–10.6)**
Left foot	Plethysmography in left hand		
	(reference = Stage 0)		
	Stage 1	1.03 (0.49–2.19)	1.32 (0.60–2.90)
	Stage 2	1.11 (0.34–3.63)	4.97 (1.82–13.53)**

[a]Stage 0: normal; Stage 1: non-severe vasospasm; Stage 2: severe vasospasm.

**$P < 0.01$.

HAVS in the hands. However, the number (%) of workers with severe vasospasm in the feet was greater than the number (%) with severe vasospasm in the hands and therefore severe vasospasm in the hands was not a necessary condition for the presence of severe vasospasm in the feet.

Unrecognized peripheral vascular disease may have been present in some participants, especially when considering that their median age was 57, and this may have contributed to the increased prevalence of abnormal plethysmographic findings in the feet. Atherosclerotic disease usually develops more quickly and severely in the legs than the arms and post-occlusion reactive hyperemic indices have been shown to be reduced in the legs but not the arms of individuals with increased cardiovascular risk factor burden [21].

Localized increase in sympathetic activity has been implicated for many years in the development of HAVS [4]. Hand–arm vibration exposure also appears to cause central sympathetic stimulation as indicated by the association of acute exposure with an increase in heart rate [6] and changes in heart rate variability [22]. Noradrenaline, which is secreted from sympathetic nerve endings, has been shown to be higher in the plasma of HAVS subjects than in controls following cold exposure [23] and workers with HAVS have increased urinary excretion of noradrenaline in comparison to controls [24]. Central sympathetic stimulation may in turn loop back to affect acral vasospasm via a central sympathetic vasoconstrictor reflex [9], which appears to be exaggerated in workers with HAVS [10]. Other mechanisms may also be involved. Bovenzi *et al.* [25] found that salivary endothelin ET (1-21) concentrations were significantly greater in forestry workers with HAVS than in controls. Endothelin-1 is a family of potent vasoconstrictors produced by endothelial cells, which may play a role in the pathophysiology of HAVS [4]. Systemic elevation of endothelin ET (1-21) concentrations could contribute to an increased likelihood of generalized vasospasm.

These mechanisms may also help to explain other systemic health effects that have been associated with HAVS. In particular, Pyykko *et al.* [26] first reported that workers with vascular HAVS have increased hearing loss compared with vibration-exposed workers without vascular HAVS and Palmer *et al.* [27] have shown that this effect persists after careful control of noise exposure and other factors. The hypothesized mechanism is cochlear vasospasm [27] due to central nervous system stimulation associated with the development of HAVS. As well, it has been suggested that vibration-induced damage to the central nervous system may result in a number of systemic symptoms, such as headaches, sleep disturbance, increased irritability and impotence [28].

There have also been reports of workers exposed principally to vibration transmitted through their feet developing 'vibration white toes' [29,30]. This would likely involve local vascular changes due to direct vibration exposure to the feet [30] and hence would be mechanistically different from cold-induced vasospasm in the feet secondary to HAVS.

In summary, our study has shown that there is a high prevalence of cold-induced vasospasm in the feet in workers being assessed for HAVS and that severe cold-induced vasospasm in the hands is a risk factor for severe cold-induced vasospasm in the feet. This health effect in the feet should be evaluated in workers being assessed for HAVS. Future research might focus on the pathophysiology and functional significance of this lower extremity vascular effect and possibly other systemic problems associated with hand–arm vibration.

Key points

- Many workers with hand–arm vibration syndrome have cold-induced vasospasm in their feet.
- The occurrence of severe cold-induced vasospasm in the hands is a risk factor for cold-induced vasospasm in the feet.
- Workers being assessed for hand–arm vibration syndrome should be assessed for cold-induced vasospasm in their feet as well as their hands.

Disclaimer

The findings and conclusions of this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Conflicts of interest

None declared.

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