Factors Influencing Finger Systolic Blood Pressure Test for Diagnosis of Vibration-Induced White Finger

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Abstract

Finger systolic blood pressure (FSBP) measurement during finger cooling is a feasible method for the diagnosis of vibration-induced white finger (VWF). The standardization of the FSBP test is required. The final draft of an international standard for the measurement and evaluation of FSBP (ISO/DIS 14835-2) has been proposed in 2004. The aim of this review is to overview factors influencing the FSBP test and discuss some issues in the final draft. The FSBP test is a method of diagnosing VWF with reasonable sensitivity and specificity, although the sensitivity was relatively low in studies of mild VWF. The test results depend on cold provocation procedures including finger cooling, body cooling, room temperature and other factors such as clothing and smoking. There are some versions of procedures for cold provocation and the tested fingers in the final draft. These may cause a low sensitivity of the FSBP test. To determine how the methodological difference influences the results of the FSBP test, further studies are needed. Although there are issues in the draft, the international standard of the FSBP test is extremely useful for the diagnosis, treatment and compensation of VWF.

Key words: cold provocation, finger systolic blood pressure, vibration-induced white finger

Introduction

The effects of exposure to hand arm vibration on health have been recognized as the hand-arm vibration syndrome (HAVS) characterized by complex vascular, neurological and musculoskeletal symptoms (1). The vascular component, known as vibration-induced white finger (VWF), is the predominant symptom of HAVS and is classified as a secondary form of Raynaud's phenomenon. The assessment of the presence of white finger is mainly based on anamnestic information received from VWF patients (2). For the diagnosis, treatment and compensation of patients with VWF, an objective test is needed to confirm a patient's history of its occurrence. It is difficult, however, to evoke VWF under laboratory condition (3, 4). Many different tests have been used, but their efficacy has been shown to be unsatisfactory (3, 4).

In the late 1970's, Nielsen et al. (5, 6) described a method

of routinely investigating Raynaud's phenomenon using finger systolic blood pressure (FSBP) measurements after finger cooling to disclose digital artery vasospasm. The FSBP measurement during finger cooling is a feasible method for diagnosing VWF (7, 8). This method is often called "critical opening pressure". Different versions of the original test described by Nielsen et al. (5, 6) have been used in some countries (9–19). The standardization of the FSBP test is required. The final draft of an international standard (ISO/DIS 14835-2) (20) has been proposed. Various factors influence the FSBP measurement for estimating VWF. The aim of this review is to overview factors influencing the FSBP test and discuss some issues in the final draft of the measurement and evaluation of FSBP (ISO/DIS 14835-2) (20).

Overviews of studies of FSBP test for vascular assessment

Nielsen et al. (6) suggested that the measurement of FSBP during digital cooling is useful in the diagnosis of Raynaud's phenomenon. FSBP was measured after finger cooling by placing a water-perfused double-inlet-plastic cuff on the mid-phalanx of a finger and a mercury-in-rubber strain gauge on the outer phalanx. After finger cooling to 20, 15 and 6°C, eighteen females with primary Raynaud's phenomena had a

Received Mar. 2, 2005/Accepted Jun. 2, 2005

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significantly greater reduction in FSBP than twenty-two normal females. Body cooling for 20 min before finger cooling enhanced the reaction in both groups. The diagnostic value of a combined finger and body cooling test in primary Raynaud's phenomena was high. The reproducibility of the test was acceptable. The FSBP measurement during finger and body cooling was first used in a group of vibration-exposed subjects (stonecutters) by Olsen and Nielsen (7). The objective test appeared to have a high sensitivity and a high specificity for diagnosing VWF.

We summarize the reported cold provocation procedure, and the sensitivity and specificity of the FSBP test for diagnosing VWF (Table 1). The test enables the differentiation of the chain saw operators with VWF from those without VWF and the control (8). In the study, the sensitivity was 92% and the specificity was 81%. Ekenvall and Lindblad (9) reported that the vasospastic reaction is more pronounced with water at 10°C than with water at 15°C in the perfused cuff and a low room temperature increases the diagnostic sensitivity of the FSBP test. Bovenzi (12) performed the FSBP test during finger cooling in 76 operators of pneumatic hand grinders and impact wrenches in Italy and described that the test sensitivity depended on the severity of the clinical symptoms, varying from 31% for VWF stages 1 and 2 to 100% for VWF stage 3. Virokannas and Rintamaki (14) reported a low sensitivity of the FSBP test. They suggested that this is due to mild cold provocation and mild VWF cases. Kurozawa et al. (15) reported the sensitivity of the test to be as high as 90% using general cooling when finger cooling alone does not demonstrate a pathologic reaction. In 1992, they (16) reported an FSBP

measurement sensitivity of 82% during only finger cooling using the laser-Doppler method. There are several types of transducer commonly available for the detection of blood flow in the measurement of FSBP. Mercury-in-elastic strain gauges have been commonly used in detecting volume changes; an increase in finger volume during pressure release indicates the return of arterial blood flow. It was often difficult to detect signals of volume changes of the fingers during finger cooling using a strain-gauge plethysmograph, particularly in severe cases. The application of laser-Doppler flowmetry enables to detect reopening blood flow more delicately (16).

Allen et al. (17) described that a modified FSBP test may be helpful in the assessment of patients presenting for examination in connection with claims for VWF. Bovenzi (18) obtained a sensitivity of 84% and a specificity of 98% when a discriminating FSBP% threshold <60% during finger cooling to 10°C was applied. In his study, finger cooling to 15°C was not a sufficient cold stimulus to provoke digital vasospasm. Bovenzi's study (18), as well as Ekenvall and Lindblad's study (21), indicated that cold-induced vasoconstriction is stronger in smokers than in nonsmokers. Bovenzi (18, 22) also found that age does not influence the digital arterial response to cold in healthy subjects.

In 2002, Bovenzi (19) reported the results of FSBP measurement during finger cooling to 10°C for 455 controls and 874 workers exposed to vibration. His study confirms the findings of previous investigations that suggest that FSBP measurement during finger cooling is a useful laboratory method for diagnosing VWF.

The FSBP test appears to be a diagnostic method with

Table 1 Reported cold provocation procedures, sensitivities and specificities of FSBP measurement for diagnosis of VWF

Author	Year	Reference	Subject	Finger cooling (reference temperature)	Body cooling	Room temperature	Cutoff FSBP%	Sensitivity	Specificity
Olsen and Nielsen	1979	(7)	20 controls 5 exposed controls 13 VWF patients	(30°C) 10°C 6°C	8–12°C 10 min	15–19°C	FSBP=0	100	87
Olsen et al.	1982	(8)	20 controls 26 exposed controls 13 VWF patients	(30°C) 10°C 6°C	8–12°C 10 min	16–19°C 9–16°C	FSBP=0	91	81
Ekenval and Lindblad	1982	(9)	10 controls 10 exposed controls 10 VWF patients	(30°C) 15°C 10°C		23°C 17°C	FSBP%<60%	100	100
Pyykkö et al.	1986	(10)	21 exposed controls 27 inactive VWF 12 active VWF	(30°C) 20°C 15°C 10°C 15°C		18–22°C		25	95
Ekenval and Lindblad	1986	(11)	14 controls 15 exposed controls 111 VWF patients	(30°C) 15°C 10°C		16°C	FSBP%<60%	74	97
Bovenzi	1988	(12)	30 controls 56 exposed controls 20 VWF patients	(30°C) 10°C		22°C	FSBP%<60%	100	87
Olsen	1988	(13)	15 controls 56 exposed controls 23 VWF patients	(30°C) 15°C 6°C	8–12°C 10 min	20–22°C	FSBP=0	87	100
Virokannas and Rintamaki	1991	(14)	37 unexposed controls 37 VWF patients	(30°C) 15°C 10°C		20–23°C	FSBP%<76%	50	84
Kurozawa et al.	1991	(15)	22 controls 40 exposed controls 60 VWF patients (mild 36 severe 24)	(35°C) 10°C	10°C 10 min	26°C	FSBP%<90%	82	90
Kurozawa et al.	1992	(16)	13 controls 40 exposed controls 59 VWF patients	(35°C) 10°C		26°C	FSBP%<80%	88	77
Allen et al.	1992	(17)	22 controls 8 exposed controls 26 VWF patients	15°C 10°C		16°C 20°C 24°C	FSBP=0	81	100
Bovenzi	1993	(18)	31 controls 46 exposed controls 19 VWF patients	(30°C) 15°C 10°C		22–23°C	FSBP%<60%	84	98
Bovenzi	2002	(19)	455 controls 723 exposed controls 151 VWF patients	(30°C) 10°C		20–23°C	FSBP%<60%	87	94

reasonable sensitivity and specificity. Results of this test depend on cold provocation procedures including finger cooling, body cooling, room temperature and other factors such as smoking.

Final draft of measurement and evaluation of FSBP (ISO/DIS 14835-2) (20)

In 2004, the final draft of the measurement and evaluation of FSBP (ISO/DIS 14835-2) (20) has been proposed. The summary of the ISO draft is shown in Table 2.

It is desirable to perform measurement in the cold season because the season might affect the measurement. Examination between 9:00 to 18:00 is recommended to avoid the effect of circadian biorhythm. Adaptation and subject preparation in terms of meals, smoking, alcohol intake, use of caffeine and vasoactive medical drugs, which potentially affect peripheral circulation, are described. Light indoor clothing was used by the subjects in the studies. The clothing should be more strictly indicated by the clo value. Approximate clo values of 0.7 to 0.8 are recommended.

Room temperature varied from 9°C to 26°C in the previous studies (7–19). Low room temperature and body cooling seem to make the FSBP test more reliable. Too low a temperature may cause a freezing feeling. Nasu et al. (23) investigated the effect of room temperature on FSBP measurements during finger cooling. FSBP measurement during finger cooling to 10°C was repeated at room temperatures of 24°C, 22°C and 20°C at 30 min intervals, in 20 healthy controls and 22 vibration exposed men. There was a tendency that the difference in FSBP% between the two groups increases with decreasing room temperature. Subjects felt cold at a room temperature of 20°C. Nasu et al. (23) recommended a room temperature of 22°C. The room temperature of 21±1°C is suggested in the final draft. Finger cooling to 5–6°C may be considered an unsuitable stimulus because it causes pain in the tested finger (23). In most studies, finger cooling was conducted at 15°C or 10°C. It is recommended that FSBP measurement can be made at both 15°C and 10°C in the final draft.

In the original test (5–8), body cooling was performed by

the cooling of the frontal part of the body with a cooling blanket perfused with water at 8–12°C. Body cooling was not performed in several studies (9–12, 14, 16–19) because the cold procedure was uncomfortable to subjects. In the final draft, finger cooling without body cooling is preferred but body cooling may be used.

Limitation of FSBP test and some issues in the final draft of measurement and evaluation of FSBP (ISO/DIS 14835-2) (20)

The lowest sensitivity of the FSBP test was reported by Pyykkö et al. (10). It probably resulted from the low severity of VWF among the forest workers examined. Ekenvall and Lindblad (11) reported that the sensitivity is 57% in mild diseases even at a room temperature of 16°C. Sensitivity has

Fig. 1 Finger cooling with and without occluding cuff. (Panel a) During the cooling, blood flow is stopped through the inflation of the occluding cuff placed more proximally on the cooled finger. The double-inlet cooling cuff produces the same pressure as the occluding cuff. (Panel b) Finger cooling without occluding cuff.

Table 2 Summary of final draft of measurement and evaluation of FSBP (ISO/DIS 14835-2)

Time of year	Cold season
Time of day	9:00–18:00
Subjects preparation	More than 1 h after a meal and less than 4 h of fasting More than 3 h after smoking and other stimulants such as caffeine More than 12 h after intake of alcohol and vasoactive medical drugs
Clothing	Light indoor clothing (0.7–0.8 clo)
Adaptation of subjects	At least 30 min in the environment of examination room
Room temperature	21±1°C
Posture	Seated or spine relaxed posture
Test hands and fingers	All possible fingers or the most affected finger or the middle or ring finger
Finger cooling	15°C and 10°C (with or without occluding cuff) Reference temperature 30°C (35°C)
Duration of finger cooling	5 min
Sensors	Strain-gauge plethysmography or photoplethysmography or laser-doppler flowmetry
Body cooling	Finger cooling without body cooling is preferred but body cooling may be used

been relatively low in studies with mild VWF. A negative cold test does not exclude the diagnosis of VWF.

The measurement of FSBP during both finger and body coolings was originally claimed to have both a high sensitivity and a high specificity. Body cooling may be used to detect mild VWF. However, the procedure (duration, extent of body surface area cooled, and temperature of cooling) of body cooling is not standardized in the final draft.

A strain-gauge plethysmograph with a digit cooling system (Medimatic Denmark) was used in most studies. The digit cooling system was specialized for the assessment of Raynaud's phenomenon. For example, a double-inlet cooling cuff has the same pressure as an occluding cuff (Fig. 1). During the cooling, blood flow is stopped by inflating the occluding cuff placed more proximally on the cooled finger. The occluding cuff heightens the effect of finger cooling caused by a water-perfused double-inlet cuff. Finger cooling without an occluding cuff has also been described in the final draft. We suppose that finger cooling without an occluding cuff results in a low sensitivity.

References

- (1) Pelmear PL, Taylor W, Wasserman DE. *Hand-Arm Vibration: A Comprehensive Guide for Occupational Health Profession*. New York: Von Nostrand Reinhold; 1992.
- (2) Gemne G. Diagnostics of hand-arm system disorders in workers who use vibration tools. *Occup Environ Med*. 1997; 54:90–95.
- (3) Taylor W, Pelmear PL. *Vibration White Finger in Industry*. London: Academic Press; 1975.
- (4) Juul C, Nielsen SL. Locally induced digital vasospasm detected by delayed rewarming in Raynaud's phenomenon of occupational origin. *Br J Ind Med*. 1981;38:87–90.
- (5) Nielsen SL, Lassen NA. Measurements of digital blood pressure after local cooling. *J Appl Physiol*. 1977;43:907–910.
- (6) Nielsen SL. Raynaud phenomena and finger systolic pressure during cooling. *Scand J Clin Lab Invest*. 1978;38:765–770.
- (7) Olsen N, Nielsen SL. Diagnosis of Raynaud's phenomenon in quarrymen's traumatic vasospastic disease. *Scand J Work Environ Health*. 1979;5:249–256.
- (8) Olsen N, Nielsen SL, Voss P. Cold response of digital arteries in chain saw operators. *Br J Ind Med*. 1982;38:82–88.
- (9) Ekenvall L, Lindblad LE. Digital blood pressure after local cooling as a diagnostic tool in traumatic vasospastic disease. *Br J Ind Med*. 1982;39:388–391.
- (10) Pyykkö I, Färkkilä M, Korhonen O, Starck J, Jäntti V. Cold provocation tests in the evaluation of vibration-induced white finger. *Scand J Work Environ Health*. 1986;12:254–258.
- (11) Ekenvall L, Lindblad LE. Vibration white finger and digital systolic pressure during cooling. *Br J Ind Med*. 1986;43:280–283.
- (12) Bovenzi M. Vibration white finger, digital systolic blood pressure, and some biochemical findings on workers operating vibrating tools in the engine manufacturing industry. *Am J Ind Health*. 1988;14:575–584.
- (13) Olsen N. Diagnostic test in Raynaud's phenomena in workers exposed to vibration: a comparative study. *Br J Ind Med*. 1988;45:426–430.
- (14) Virokannas H, Rintamäki H. Finger blood pressure and rewarming rate for screening and diagnosis of Raynaud's phenomenon in workers exposed to vibration. *Br J Ind Med*. 1991;48:480–484.
- (15) Kurozawa Y, Nasu Y, Nose T. Diagnostic value of finger systolic blood pressure in the assessment of vasospastic reactions in the finger skin of vibration-exposed subjects after finger and body cooling. *Scand J Work Environ Health*. 1991;17:184–189.
- (16) Kurozawa Y, Nasu Y, Oshiro H. Finger systolic blood pressure measurement after finger cooling. Using the Laser-Doppler method for assessing vibration-induced white finger. *J Occup Med*. 1992;34:683–686.
- (17) Allen JA, Doherty CC, McGrann S. Objective testing for vasospasm in the hand-arm vibration syndrome. *Br J Ind Med*. 1992;49:688–693.
- (18) Bovenzi M. Digital arterial responsiveness to cold in healthy men, vibration white finger and primary Raynaud's phenomenon. *Scand J Work Environ Health*. 1993;19:271–276.
- (19) Bovenzi M. Finger systolic blood pressure indices for the diagnosis of vibration-induced white finger. *Int Arch Occup Environ Health*. 2002;75:20–28.
- (20) International Organization for Standardization. *Mechanical vibration and shock—Cold provocation tests for the assessment of peripheral vascular function—Part 2: Measurement and evaluation of finger systolic blood pressure*. International Draft, ISO/DIS 14835-2, 2004.
- (21) Ekenvall L, Lindblad LE. Effect of tobacco use on vibration white finger disease. *J Occup Med*. 1989;31:13–16.
- (22) Bovenzi M. Finger systolic blood pressure during local cooling in normal subjects aged 20 to 60 years: reference values for assessment of digital vasospasm in Raynaud's phenomenon of occupational medicine. *Int Arch Occup*

Environ Health. 1988;61:179–181.

- (23) Nasu Y, Kurozawa Y, Ishigaki, H, Shinohara T. Interrelationship between room temperature and local cooling temperature on FSBP%. *Jpn J Occup Med Traumatol*. 1998;46:435–441. (Article in Japanese)
- (24) Poole K, Elms J, Mason HJ. The diagnostic value of finger systolic blood pressure and cold-provocation testing for the vascular component of hand-arm vibration syndrome in health surveillance. *Occup Med*. 2004;54:520–527.