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ORIGINAL ARTICLE

Use of color charts for the diagnosis of finger whiteness in vibration-exposed workers

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Abstract
Objectives To assess the usefulness of color charts for the diagnosis of finger whiteness in vibration-exposed workers.
Methods A group of 146 forestry and stone workers exposed to hand-transmitted vibration (HTV) were examined twice over 1 year follow up period. The anamnestic diagnosis of finger whiteness was made on the basis of (a) a medical history alone, and (b) the administration color charts which showed changes in the skin color of fingers and hands. The cold response of digital arteries was assessed by measuring the change in finger systolic blood pressure (FSBP) after local cooling from 30 to 10°C ($FSBP\%_{10°}$).
Results Assuming the administration of color charts as the gold standard, the sensitivity and specificity of the medical history alone to diagnose finger whiteness was 88.2 and 93.8%, respectively, at the initial cross-sectional study and 94.4 and 97.7% at the end of the follow-up. Random-intercept linear regression analysis of follow up data showed that after adjustment for several covariates, $FSBP\%_{10°}$ was significantly associated with finger whiteness assessed by either medical history alone ($P < 0.005$) or the color charts ($P < 0.001$). However, a statistical measure of overall fit of regression models (Bayesian Information Criterion) suggested that the color chart method performed better than medical history alone for the prediction of the cold response of digital arteries.
Conclusion The administration of color charts seems to reduce the proportion of false positive responses for finger whiteness in a population of vibration-exposed workers. The color chart method was a more significant predictor of digital arterial hyperresponsiveness to cold than medical history alone. These findings suggest that the use of color charts in clinical and epidemiological studies may be of help to assist in the diagnosis of finger whiteness in vibration-exposed workers.

Keywords Color charts · Finger whiteness · Medical history · Hand-transmitted vibration

Introduction

Raynaud's phenomenon is characterized by episodes of finger blanching attacks usually triggered by exposure to cold. When finger whiteness symptoms are frequent and severe, disability can occur in the affected patients. Primary Raynaud's phenomenon is diagnosed when an underlying cause for the condition cannot be identified. Occupational exposure to hand-transmitted vibration (HTV) from powered tools or machines may be associated with a secondary form of Raynaud's phenomenon called vibration-induced white finger (VWF) (Bovenzi 1998; Griffin 1990; Griffin et al. 2003).

A diagnosis of Raynaud's phenomenon is basically made on a history of finger whiteness reported by the patient. It has been suggested that the reliability of the medical history depends on the patients ability to proper understand the physician question and to report clearly the symptoms and signs which occur during a finger blanching

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attack (Maricq and Weinrich 1988). In epidemiological studies, some proportions of both false positive and false negative responses may be expected. Several laboratory tests have been proposed to diagnose objectively Raynaud's phenomenon such as finger rewarming time after immersion of hands in cold water or the measurement of finger systolic blood pressures (FSBP) after local cooling, but these diagnostic procedures are time consuming and require specialized laboratory equipment.

To improve the quality of information obtained from patients studied in either clinical or epidemiological investigations, the presentation of color charts has been suggested (Maricq and Weinrich 1988). The use of this additional diagnostic tool, nevertheless, is still controversial since some authors reported that color charts were useful to reduce the proportion of false positive responses (O'Keeffe et al. 1992), while others found that the clinicians' judgement was not replicated when using color charts (Brennan et al. 1993). So, at present, there is no "gold standard" test for the diagnosis of finger witness.

The aim of this study was to assess the usefulness of color charts for the diagnosis of finger whiteness in a group of workers exposed to HTV. In addition, we investigated the relation between the response of digital arteries to cold provocation and the anamnestic outcome of finger whiteness assessed by either medical history alone or the administration of color charts.

Subjects and methods

Subjects and medical investigation

In autumn 2003 to winter 2004, the occurrence of finger whiteness and the cold response of digital arteries were investigated in a group of 173 active HTV workers employed in four companies of forestry workers (cases 137) and one company of stone workers (cases 36), all located in the Tuscany Region, Italy. Of these subjects, 113 forestry workers (82.5%) and 33 stone workers (91.6%) participated in a follow up study 1 year later. Of the 27 workers lost at the follow up, 10 had changed their place of residence, 12 were retired, 5 could not be identified. These subjects did not differ significantly from the participants in the follow up study with respect to age, smoking and drinking habits, and measures of vibration exposure.

Both investigation were made in the same seasonal condition, the median follow up period was 12.8 months (12.5–13.2 months, 25–75 percentile). During this period, all 146 subjects in the study continued to work with vibratory tools: the lumberjacks used chain saws and the stone workers used pneumatic grinders and chipping hammers.

All subjects gave signed informed consent to the study, which was approved by the local health authorities.

The HTV workers were interviewed by trained occupational health physicians on their personal, work and health histories using a structured questionnaire developed within the European research project VIBRISKS (http://www.vibrisks.soton.ac.uk/). They were questioned about smoking, alcohol consumption, metabolic, cardiovascular, and neurological disorders, previous musculoskeletal injuries, and use of medicines.

The clinical diagnosis of finger whiteness was made on the basis of (a) a medical history alone using standardized questions included in the VIBRISKS questionnaire (http://www.vibrisks.soton.ac.uk/), and (b) the administration of color charts. These latter consisted of a series of photographs illustrating various degrees of blanching, cyanosis, or redness of the fingers and hands, according to the scheme proposed by Maricq and Weinrich (1988), partially modified. To obtain independent answers by the subjects, the color charts were shown to the workers at the end of the medical interview and individually administered in private by the same trained occupational health physicians.

The subjects were asked three questions: (a) "have you experienced any of these color changes in your fingers/hands?"; (b) "if yes, please show the affected part(s) (finger, hand palm or both)"; (c) "if yes, when do these color changes occur?". A diagnosis of finger whiteness based on color charts was considered positive when the subject indicated the photographs displaying well-demarcated blanching of the fingers. White patching of hand palm, cyanosis of fingers, or acrocyanosis alone were not considered to be sufficient for a diagnosis of Raynaud's phenomenon. The diagnosis was considered positive when the third question confirmed the appearance of finger whiteness in relation to exposure to cold in the last 2 years.

The VIBRISKS clinically administered questionnaire (http://www.vibrisks.soton.ac.uk/) was used during a private interview of the subjects by trained occupational health physicians. The questionnaire provides several items about hand symptoms and color changes in the fingers (blue, white, red) due to cold exposure. If symptoms were indicated, they were asked if the whiteness were clearly demarcated. They were also asked when finger whiteness first appeared, when the last episode occurred, the frequencies of attacks and their variation with season.

The anamnestic diagnosis of VWF at the medical history was based on the criteria established at the Stockholm Workshop '94 (Olsen et al. 1995): (a) positive history of cold-provoked episodes of well-demarcated blanching in one or more fingers after excluding primary Raynaud's phenomenon or other probable causes of secondary Raynaud's phenomenon; (b) first appearance of finger blanching after the start of occupational exposure to HTV and experience of VWF attacks during the last 2 years.

Vibration-induced white finger symptoms were staged according to the Stockholm Workshop scale (Gemne et al. 1987) separately according to both the medical histories and the color charts.

Cold test

A cold test was performed with subjects in a supine position after a rest period of 20–30 min in a laboratory room with an ambient temperature of 20–22°C. The cold test consisted of strain-gauge plethysmographic measurement of FSBP during local cooling according to the technique proposed by Nielsen and Lassen (1977).

The change of systolic blood pressure in a test finger at 10°C ($FSBP_{t,10^\circ}$) as a percentage of the pressure at 30°C ($FSBP_{t,30^\circ}$), corrected for the change of pressure in a reference finger during the examination ($FSBP_{ref,30^\circ}$ – $FSBP_{ref,10^\circ}$) was calculated according to the following formula:

$$\mathrm{FSBP\%}_{10^\circ} = \left(\mathrm{FSBP}_{t,10^\circ} \times 100\right) / \left[\mathrm{FSBP}_{t,30^\circ} - \left(\mathrm{FSBP}_{ref,30^\circ} - \mathrm{FSBP}_{ref,10^\circ}\right)\right]\ \%$$

To avoid nicotine-induced vasoconstrictive effects on the digital vessels, tobacco users refrained from smoking for at least 2 h before testing.

The cold test at the cross-sectional and follow up investigation was performed by the same health personnel who used the same method and apparatus (Digitmatic 2000, Medimatic A/S, Copenhagen, Denmark). The FSBPs were measured in the same test and reference fingers at both examinations.

Measurement and assessment of vibration exposure

Current and past exposures to HTV were investigated by means of the VIBRISKS questionnaire which includes a section dedicated to the types of vibrating tools used over a working life, and the daily and cumulative exposure duration for each tool.

Vibration was measured on the tools used by the forestry and stone workers according to the ISO 5349-1 procedure (International Organization for Standardization ISO) (2001), and the root-sum-of-squares of the frequency-weighted rms acceleration values for the *x*-, *y*- and *z*-axes (a_v) was calculated for each tool.

Questionnaire data, information obtained by interviewing employees and employers, and company records were used to estimate daily exposure duration and total years of tool use.

Using the vibration magnitudes and exposure durations, a cumulative vibration dose was calculated for each worker, according to the following formula:

$$dose = \sum_i \left[a_i^2 t_i\right]$$

where a_i and t_i are the acceleration magnitude (a_v in m s^{-2} rms) and the total exposure duration (hours) respectively, for tool *i*.

Statistical methods

Data analysis was performed with the statistical software Stata 9.0 SE (Stata Corporation 2005, College Station, TX, USA) with the level of significance set at $P = 0.05$ (two-tailed). Continuous variables were summarized using the mean as a measure of central tendency and the standard deviation (SD) as a measure of dispersion.

Sensitivity, specificity, and positive and negative predictive values for the anamnestic diagnosis of finger whiteness by means of a medical history alone assuming the color charts as the gold standard, were calculated by conventional techniques.

Random-intercept linear regression analysis was used to assess the relation between $\mathrm{FSBP\%}_{10^\circ}$ and finger whiteness (assessed by either medical history alone or the administration of color charts) over the follow up period. Age, body mass index, smoking, drinking, leisure time with vibratory tools, and cumulative vibration dose were included in the regression models as covariates. The contribution of covariates to the fit of regression models was assessed by the likelihood ratio statistic. The Bayesan Information Criterion (BIC) was used as a measure of overall fit and a means to compare regression models including finger whiteness diagnosed by means of a medical history alone or the color charts (Raftery 1996).

Results

At cross sectional study, the age of the HTV workers averaged 41.8 (SD 8.1) years. Duration of exposure to HTV averaged 16.2 (SD 8.1) years.

At the cross-sectional survey, 23 HTV workers (15.8%) reported VWF at the medical interview alone. Of these, 15 (10.3%) were positive and 8 (5.5%) were negative at the presentation of the color charts. Two workers (1.4%), who did not report VWF at the medical interview, recognized the sign of finger blanching when the color charts were administered.

The change in the occurrence of finger whiteness symptoms over the follow up period are reported in

Table 1 Change in vascular disorders in the vibration-exposed workers who participated in both cross-sectional and follow up investigations (n = 146)

Symptoms	Never symptoms	Stationary VWF symptoms	Change in vascular symptoms	
			Improved	Deteriorated
Finger whiteness (medical history)	122 (83.6)	19 (13.0)	4 (2.7)*	1 (0.7)
Stages of finger whiteness (medical history)	122 (83.6)	15 (10.3)	4 (2.7)*	5 (3.4)*
Finger whiteness (color charts)	128 (87.7)	17 (11.6)	0 (–)	1 (0.7)
Stages of finger whiteness (color charts)	128 (87.7)	14 (9.6)	0 (–)	4 (2.7)*

Stages of finger whiteness are according to the Stockholm scale. Values are given as numbers (%)

* Proportion of change $P < 0.05$

Table 1. At the medical history alone, 19 workers (13%) reported stationary VWF symptoms, 4 (2.7%) recovered from VWF and 1 (0.7%) developed VWF during the follow up period. When the color charts were presented at the end of the medical interview, 17 workers (11.6%) reported stationary VWF symptoms, none recovered from VWF and 1 (0.7%) developed VWF during the follow up period.

More subjects reported symptoms in the medical interview than recognized finger whiteness in the color charts. There was little difference between the two methods for workers who reported stationary symptoms at the follow-up. When subjects at the follow-up reported a change in symptoms they were classified: (a) "improved" when finger whiteness was not present for 2 years or the stage of VWF was lower than at baseline, or (b) "deteriorated" when symptoms appeared or the stage of VWF was increased. The proportion of change over the follow-up period in the stages of VWF according to the Stockholm Workshop scale (Gemne et al. 1987) was significant for finger whiteness assessed by both medical history alone and the color chart method.

Assuming the color charts as the gold standard, the sensitivity and specificity of medical history alone to diagnose finger whiteness was 88.2 and 93.8%, respectively, at the initial cross sectional study, and 94.4 and 97.7% at the end of the follow-up. The positive and negative predictive values (PPV, NPV) for the medical history was 65.2 (PPV) and 98.4% (NPV) at the cross-sectional survey, and 85.0 (PPV) and 99.2% (NPV) at the follow up (Table 2).

Random-intercept linear regression analysis of longitudinal data showed that the reduction of $FSBP\%_{10°}$ over time was significantly associated with the presence of finger whiteness assessed by either medical history alone ($P < 0.005$) or the color charts ($P < 0.001$). However, when the two regression models were compared by means of the difference (Δ) in the Bayesan Information Criterion (BIC), there was very strong evidence that the model including finger whiteness assessed by color charts performed substantially better, at least from a statistical viewpoint, for the prediction of the vasoconstrictor response to cold at the follow-up than finger whiteness assessed by the medical history alone (ΔBIC = 15.1), (Raftery 1996). The model included the personal characteristics and the exposure parameters that represent factors known to influence FSBP. Table 3 reports the likelihood ratio test of the variables included in the models when the association was significant. The $FSBP\%_{10°}$ was inversely related to the cumulative vibration dose ($0.001 < P < 0.05$), while no

Table 2 Point estimates (95% confidence intervals) of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for the anamnestic diagnosis of finger whiteness by means of a medical history alone, assuming color charts as the gold standard

History of finger whiteness	Color charts for finger whiteness		Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
	Positive	Negative				
Cross-sectional study (n = 146)						
Positive	15	8	88.2 (63.6–98.5)	93.8 (88.1–97.3)	65.2 (42.7–83.6)	98.4 (94.2–99.8)
Negative	2	121				
Follow up study (n = 146)						
Positive	17	3	94.4 (72.7–99.9)	97.7 (93.3–99.5)	85.0 (62.1–96.8)	99.2 (95.7–100)
Negative	1	125				

Data from workers who participated in both cross-sectional and follow up investigations (n = 146) are reported

Table 3 Random-intercept linear regression of FSBP%$_{10°}$ on continuous and dichotomous predictors in the HTV workers (n = 146) who underwent cross-sectional and follow up investigations

Predictors	FSBP%$_{10°}$ (%) medical history	FSBP%$_{10°}$ (%) Color Chart
Intercept	111 (70.3 to 152)	98.1 (59.1 to 137)
Age (year × 10^{-1})	4.3 (0.2 to 8.4)	3.7 (–0.1 to 7.5)
BMI (kg/m^2 × 1/5)	2.3 (–2.2 to 6.8)	1.9 (–2.4 to 6.2)
Smoking	–1.1 (–7.6 to 5.5)	–1.8 (–8.0 to 4.3)
Drinking	4.2 (–3.1 to 11.6)	3.5 (–3.4 to 10.4)
Leisure time with vibrating tools (hours × 10^{-2})	–0.02 (–0.5 to 0.5)	–0.03 (–0.5 to 0.4)
Vibration dose [ln(m^2 s^{-4} h)]	–4.6 (–7.1 to –2.1)**	–3.1 (–5.6 to –0.7)*
Finger whiteness (medical history)	–17.8 (–26.9 to –8.6)†	–
Finger whiteness (color charts)	–	–29.2 (–39.5 to –19.0)‡
Follow up	1.3 (–2.3 to 4.9)	1.8 (–1.8 to 5.5)
BIC$^\#$	2656.0	2641.9

Age, body mass index (BMI), leisure time with vibrating tools, and log-transformed vibration dose are included in the regression models as continuous covariates. Finger whiteness was assessed by either medical history alone or color charts. Maximum likelihood estimates of regression coefficients (95% confidence intervals), and the Bayesian Information Criterion (BIC) for the two regression models are reported. See text for definition of FSBP%$_{10°}$

Likelihood ratio test (χ^2, 1df): * 6.1 (P = 0.015); ** 12.9 ($P < 0.0005$); † 14.1 ($P < 0.0005$); ‡ 28.2 ($P < 0.0001$)

$^\#$ Difference in BIC = 15.1 (i.e., very strong support for the model including finger whiteness assessed by color charts)

association was found for age or other individual personal characteristics.

Discussion

Patients affected with a severe form of Raynaud's phenomenon are usually able to report their symptoms very accurately. In the field of occupational exposure to HTV, the exposed workers may be confused in reporting symptoms particularly when they begin. Proper questions by the physician and an accurate description of the symptoms by the patient are essential for an anamnestic diagnosis of Raynaud's phenomenon. According to the report of a working group at the Stockholm Workshop '94 (Olsen et al. 1995), a medical interview is still the best available method of diagnosing Raynaud's phenomenon in vibration-exposed workers.

In clinical work, some authors have reported that the presentation of color charts, in addition to a medical interview, is a useful tool for the diagnosis of Raynaud's phenomenon (Maricq and Weinrich 1988). It has been suggested that the administration of color charts can lessen the proportion of false positive cases and this may be of help for standardizing the diagnosis of Raynaud's phenomenon in epidemiological studies (O'Keeffe et al. 1992). To the contrary, comparing three different assessment methods for the classification of Raynaud's phenomenon, Brennan et al. (1993) concluded that color chart assessment was too insensitive to detect Raynaud's phenomenon, while individual clinician assessment based on consensus opinion of a group of clinicians was more reliable for diagnosing Raynaud's phenomenon.

The findings of this longitudinal study of VWF in vibration-exposed workers seem to suggest that the administration of color charts, in addition to a medical history, may reduce the frequency of false positive responses for finger whiteness. It is our opinion that color charts may be used in the field for the health surveillance of workers exposed to HTV for several reasons: (a) they are simple to use and understand, (b) they are quick, requiring only 2–3 min, (c) they are cheap, (d) they can be standardized, and (e) they are relatively independent of culture.

It should be noted, however, that when compared with the color chart method, the performance of the medical history alone to detect finger whiteness (in terms of sensitivity, specificity, and predictive values) was greater at the follow up than at the initial cross-sectional survey. Therefore, a learning effect over time for the recognition of finger whiteness symptoms cannot be ruled out.

In this study, an objective measure of digital vasoconstrictor response to cold (FSBP%$_{10°}$) was found to be related to finger whiteness assessed by the color chart method more significantly than when the same symptom was investigated by a medical history alone. This finding seems to suggest that the use of color charts in clinical and epidemiological studies may be of additional help to assist in the diagnosis of Raynaud's phenomenon in HTV workers.

In conclusion, our experience with the color chart method in the context of the European epidemiological project VIBRISKS suggests that the use of color charts may improve the quality of information obtained by workers who report finger blanching attacks at the medical interview. The method is easy to implement and to use by workers and occupational health personnel.

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