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DIGITAL PHOTOPLETHYSMOGRAPHY IN THE DIAGNOSIS OF TRAUMATIC VASOSPASTIC DISEASE

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By means of the photoplethysmographic method including the cold test, skin blood flow was recorded in the fingers of 42 chain-saw operators and 36 control subjects. The essential difference between the groups pertained to the height of the pulse wave amplitude after the cold test and to the fall in amplitude expressed as a percentage of its initial value. A limit of a 90% fall in amplitude after the cold test is proposed as a criterion for differentiating a normal from a pathological vasospastic reaction. A fall in amplitude is correlated with the intensity of subjective disorders, i.e. the attack of vibration-induced white fingers. The obstructive form and loss of amplitude of the pulse wave form are accepted as pathological.

Key terms: chain-saw operators, cold test, low-frequency vibration, skin blood flow, vibration disease, white fingers.

The long-term use of vibrating tools and the transfer of vibration to the arm, leads to the occurrence of traumatic vasospastic disease, known also as hand-arm vibration syndrome, Raynaud's phenomenon of occupational origin or vibration-induced white fingers (1–3). The resulting damage to the peripheral circulation, nervous system, muscles, bones and joints may occur separately or together (4). Vascular symptoms appear as white fingers, Raynaud's phenomenon, i.e. the attack of well defined blanching or cyanosis of the fingers caused by cold, noise, vibration or stress (5). Although the pathogenesis of this event has not been fully explained, it has been confirmed that during an attack of vibration–induced white fingers skin capillary blood flow is interrupted (6). Verification of this functional impairment is important, not only for establishing a correct diagnosis but also for the resulting financial and other compensations at work (7). Consequently, attempts are made to record this hyperreactivity of the blood vessels by various means, always including thermal stimulation. The following methods are used: measurement of digital blood flow and pressure by plethysmography (2, 8–10), skin temperature recording by digital thermometry (11, 12), or infrared telethermography (13) and determination of skin blood flow by the photoplethysmographic method (14–16).

Outside factors such as temperature changes and air humidity, food and liquid intake, drugs, smoking, pain and stress, can cause significant changes in blood flow (14). For this reason the method of registering pulse volume must be non-invasive, standardized and capable of differentiating normal from spastic conditions in peripheral blood vessels. Reflection photoplethysmography is a simple, easily applicable, non-invasive technique for examining the pulse volume of the peripheral circulation. It is based on monitoring the intensity of infrared light emitted in, and reflected back from, the vascular tissue, so that blood volume changes in the tissue correlate with variations in the photoplethysmographic curve (17). On the basis of these data conclusions can be made on the condition of skin microcirculation, and indirectly of haemodynamic conditions in the digital arteries (18–20). During an attack of vibration-induced white fingers a significant spasm or complete occlusion of the digital arteries does not usually occur (12). Decreased skin circulation is therefore considered to be a major occurrence. For this reason photoplethysmography, whose curve represents the condition of skin circulation, can give valuable data for the determination and monitoring of digital skin blood vessel changes in traumatic vasospastic disease. The purpose of the present study is to evaluate its applicability and establish the criteria for differentiating pathological vasospastic reactions from normal reactions to cold.

SUBJECTS AND METHODS

The examination included 42 male forestry workers, aged 22–58 years (44.63±9.21) who had worked with a chain-saw from 5 to 37 years (28.58±14.40). All subjects complained of white-finger attacks during cold weather or during work with a chain-saw. According to the Taylor-Pelmear scale of subjective disorders, their subjects were classified from grade 1 to 3 (21). A group of 37 healthy males, aged 22–56 years (42.58±8.54), were included in the investigation as controls having no history of vascular or metabolic disease. During their working life they had not worked with any vibrating tool or in a low temperature environment, nor had they performed hard physical work. The groups did not differ statistically with regard to age, sex, smoking habit and the number of right-handers. The majority were moderate smokers (22) and nearly all were right-handed (90%).

A Gutman photoplethysmograph was used, type ULP 40, with a single channel photoreceptor. Recording was performed by attaching a photoreceptor by adhesive tape to the finger pulps of each finger of both hands. During that time the subject sat calmly, arms kept at the heart level (20). Air temperature in the room ranged from 20 to 24 °C, and noise and air currents were reduced to a minimum. The apparatus was automatically calibrated, and the speed of the recording paper was 25 mm/sec.

Registration of the pulsatile waves was carried out in basal conditions and after a cold provocation test, performed by immersing the hand in a cold bath at 10 °C for a period of 10 minutes (11). The height of the amplitude (A) and the slope of the wave form (St=A/B) were analysed (Figure 1) (14–23). The appearance of certain forms of the pulse wave (Figure 2) was also observed (24–26).

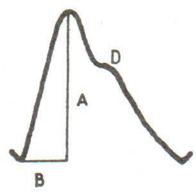

Figure 1 *Digital pulse wave.*
A=amplitude height, B=distance from the beginning of the pulse wave to the vertical, D=dicrotic notch

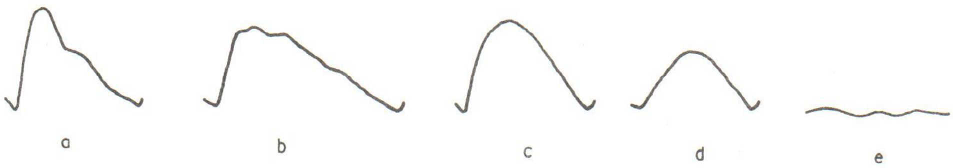

Figure 2 *Forms of the digital pulse wave.*
a = normal, b = peaked, c = without dicrotic notch, d = obstructive, e = without amplitude.

A normal pulse wave (Figure 2-a) was asymmetric, with a rapidly ascending limb and a sharp peak with a clearly defined dicrotic notch in a downslope. Multiple peak pulse wave with or without dicrotic waves (Figure 2-b) was taken to indicate functional vasospastic changes (known as the »peaked« form), and the absence of dicrotic notch (Figure 2-c) indicated reduced elasticity of the blood vessel walls. The obstructive wave form (Figure 2-d) was symmetric and of lower amplitude, and was a reflection of permanent changes in the blood vessel walls. A flat wave form without recognisable features could be registered (Figure 2-e) which indicated maximally reduced blood flow through the skin blood vessels, usually resulting in a clinical picture of Raynaud's phenomenon.

For statistical analysis the Mann-Whitney test, t-test of proportion, χ^2 test and sign test were used.

RESULTS

The pulse amplitude was reduced in the 3rd and 4th fingers ($P<0.05$) of the right hand and in the 3rd, 4th ($P<0.05$) and 5th fingers ($P<0.01$) of the left hand in chain-saw operators in relation to the control group. The significance of the difference in the amplitude height increased ($P<0.01$) after the cold test for all fingers (Table 1). The reduction of amplitude after the cold test did not show statistically significant differences between the two groups when expressed in millimetres. However, when this reduction was expressed as a percentage of the initial amplitude values a significant difference appeared ($P<0.01$) (Table 2).

The decrease in amplitude after the cold test was not uniform on the fingers of one and the same subject. When only the greatest decrease in amplitude was taken into account for each subject, the limit of a 90% drop in amplitude in relation to its initial value represented a 90th percentile of these values in both groups (Figure 3).

The mean reduction in pulse amplitude for each chain-saw operator was correlated with the intensity of subjective disorders, i.e. the appearance of white fingers classified according to the Taylor-Pelmear scale (Figure 4). Thus, it was relatively easy to define the 1st from the 2nd grade, but in chain-saw operators classified in grades 2 and 3 the mean reduction in amplitude was the same.

The slope of the curve varied between the groups for the 3rd finger on the right ($P<0.05$) and the 4th and 5th fingers on the left hand ($P<0.01$), before the cold test. The difference became significant ($P<0.01$) on all fingers after the cold test.

Table 1

Pulse amplitude (mm) before and after the cold test in chain-saw operators and the control group

Finger	Before test		After test	
	Chain-saw operators	Control group	Chain-saw operators	Control group
Right hand				
I	14.83 ± 9.35	14.06 ± 8.47	3.14 ± 3.04	8.22 ± 4.30**
II	18.66 ± 12.81	20.86 ± 9.80	2.76 ± 2.32	9.19 ± 4.08**
III	15.09 ± 8.90	19.94 ± 10.55*	3.45 ± 3.26	11.30 ± 6.09**
IV	12.78 ± 8.11	16.16 ± 7.62*	2.92 ± 2.54	9.11 ± 4.90**
V	16.16 ± 12.15	17.97 ± 11,00	3.30 ± 3.74	8.55 ± 5.17**
Left hand				
I	16.81 ± 10.26	14.36 ± 10.93	4.02 ± 4.10	10.05 ± 5.84**
II	18.09 ± 13.39	21.75 ± 11.21	3.54 ± 4.50	11.61 ± 8.86**
III	16.19 ± 10.66	20.55 ± 11.13*	4.23 ± 5.13	11.25 ± 6.52**
IV	14.47 ± 10.09	20.11 ± 11.48*	4.07 ± 3.75	9.69 ± 6.45**
V	14.09 ± 9.92	20.16 ± 10.28**	4.38 ± 5.68	13.48 ± 12.76**

Values expressed as arithmetical mean ± standard deviation
* $P<0.05$; ** $P<0.01$ (Mann-Whitney test)

Table 2

Reduction in pulse amplitude after the cold test in chain-saw operators and the control group expressed in millimetres and as a percentage of the initial amplitude height

Finger	Chain-saw operators	Control group	Chain-saw operators	Control group
	$\bar{X}$ ± SD (mm)		%	
Right hand				
I	11.64 ± 7.76	8.27 ± 7,43	64**	24
II	15.90 ± 12.68	11.38 ± 10.29	66**	14
III	11.64 ± 8.26	9.68 ± 16.38	52**	11
IV	9.85 ± 7.90	7.00 ± 8.73	51**	7
V	12.85 ± 12.10	9.41 ± 10.69	49**	9
Left hand				
I	12.76 ± 8.34	9.25 ± 10.04	57**	13
II	14.54 ± 11.08	10.13 ± 12.26	74**	17
III	11.95 ± 9.40	12.41 ± 8.38	50**	16
IV	10.40 ± 8.18	10.19 ± 11.62	54**	14
V	9.95 ± 8.27	8.55 ± 10.49	46**	13

$\bar{X}$±SD = arithmetical mean ± standard deviation
% = expressed as geometrical mean
* $P<0.05$; ** $P<0.01$ (Mann-Whitney test)

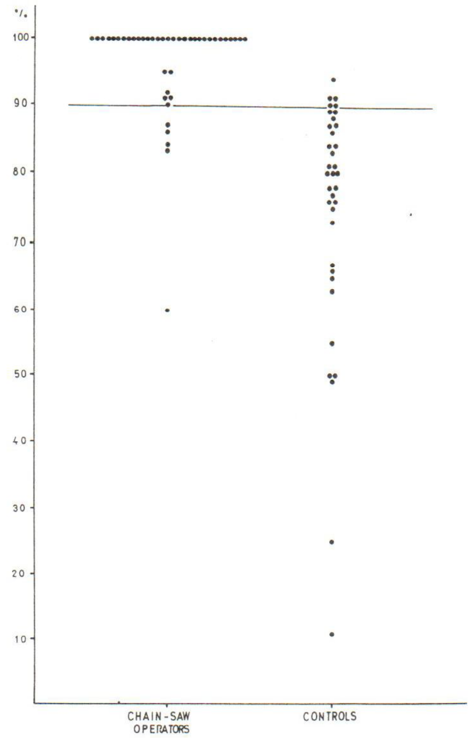

Figure 3 *Maximal fall in pulse amplitude after the cold test expressed as a percentage of the initial amplitude height in chain-saw operators and the control group.*

Figure 4 *Mean relative fall in pulse amplitude in relation to the attack of white fingers in chain-saw operators classified according to the Taylor-Pelmear scale.*

The pulse amplitude in chain-saw operators before the cold test was highest on the forefinger. The other fingers did not show the same order on both hands. After the cold test no rules could be set up regarding the height of the amplitude on certain fingers and there were no statistically significant differences. The same conclusion is valid for the analyses of the relative reduction in amplitude on certain fingers. There was likewise no statistically significant difference in the relative drop in amplitude between the corresponding fingers of the right and left hands.

The frequency of certain pulse wave forms in subjects exposed to vibration varied in relation to the control group. Before the cold test this difference was not statistically significant, and after the test a significant number of normal and »peaked« wave forms was found in chain-saw operators.

The obstructive form and absence of pulse amplitude were significant in chain-saw operators after the cold test, while in the control group only one obstructive form was registered. Although the difference between the groups with regard to these two wave forms was evident, it was not statistically evaluated because of their exceptionally small number in the control group. This difference can be seen from the percentages in Fig. 5.

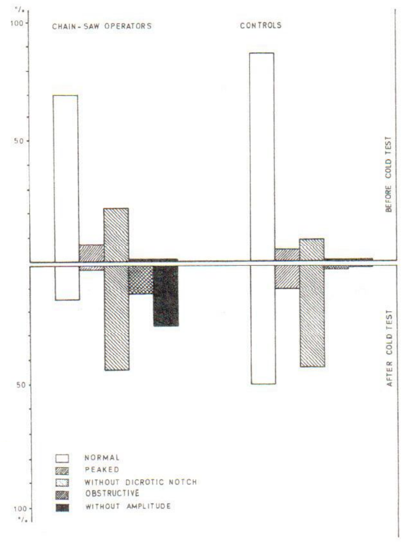

Figure 5 *The relative frequency of certain forms of the pulse wave before and after the cold test in chain-saw operators and controls.*

DISCUSSION

Several authors have written about the photoplethysmographic method of registering skin blood flow (4, 7, 14, 25, 27). They expounded its usefulness in diagnosing and monitoring vasospastic diseases caused by low-frequency vibrations. Thus, they found a wave height and slope of the pulse wave form (14) or wave height and form (7) in basal conditions sufficient for distinguishing patients with vasospastic disorders from healthy persons. The reduced amplitude and the degree of reduction after the cold test are not considered to be acceptable criteria. The present investigation shows that the pulse amplitude in basal conditions cannot be considered an adequate indicator for differentiation of vasospastic from normal reactions to cold. A significant difference exists in the height of the amplitude between the control group and subjects exposed to vibrations only after the cold test. The results of this study indicate that the reduction in amplitude after the cold test, expressed in percentages in relation to its initial value is the best indicator of pathological vasospastic reaction. According to medical history, plethysmography results and skin temperature recovery time, *Laroche* (7) suggested a classification for the severity of vibration disease. One third of the normal amplitude served as a criterion for defining the moderate form, and the absence of amplitude as a criterion of the serious form of vibration syndrome. In this study, with a tolerance of 10% false positive and negative results, a limit of a 90% reduction in amplitude after the cold test can be taken as a criterion for differentiation of the normal from the pathological vasospastic reaction. A relative drop in amplitude was more marked in patients who, according to the Taylor-Pelmear scale (21), were classified in higher grades, which also indicated a relative reduction in amplitude as adequate criterion for objectivization of vasospastic disease. Although *Cooke and co-workers* (14) found significant differences in the curve slope in patients with Raynaud's disease in relation to healthy persons, in this investigation its advantages in relation to a relative drop in amplitude were not found. The same authors did not find a difference in pulse wave between the fingers of the right and left hands, while the difference noticed in this investigation pertained only to the height of the amplitude in basal conditions. However, differences were not found in the height of the amplitude after the cold test and in the relative decrease in amplitude. This investigation demonstrated that there was no predilected finger or hand for the development of vasospastic changes as a result of work with a chain-saw. *Laroche* (7) and *Sumner and Strandness* (24)have shown a »peaked« and obstructive curve forms as pathological, and according to the results of this investigation the obstructive form and absence of amplitude after the cold test are signs of vasospastic incident.

The following conclusions are suggested for practical application in evaluation of the results of blood flow measurement by the photoplethysmographic method:

Digital photoplethysmography is an effective and useful method in the diagnosis of traumatic vasospastic disease.

A 90% reduction in the pulse wave amplitude after the cold test indicates a pathological vasospastic reaction in chain-saw operators.

A relative decrease in the pulse wave amplitude is in correlation with the appearance of white fingers according to the classification by the Taylor-Pelmear scale.

There is no significant difference in the vasospastic reaction between the fingers on either hand and between the fingers of the right and left hands.

Obstructive pulse wave form and the absence of amplitude may be considered as signs of a pathological reaction.

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Sažetak

DIGITALNA FOTOPLETIZMOGRAFIJA U DIJAGNOZI TRAUMATSKE VAZOSPASTIČNE BOLESTI

Mjerenje krvnog protoka u koži prstiju fotopletizmografskom metodom uz primjenu termalnog testa provedeno je kod 42 sjekača motornom pilom i 36 muškaraca kontrolne skupine. Bitna razlika između skupina nađena je u visini amplitude krivulje pulsnog vala poslije testa hladnoćom te u padu amplitude izražene kao postotak njezine početne vrijednosti. Predložena je granica od 90% pada amplitude nakon testa hladnoćom kao kriterij za razlikovanje normalne od patološke vazospastičke reakcije. Pad amplitude je povezan s intenzitetom subjektivnih smetnji, tj. pojavom »bijelih prstiju«. Kao patološki prihvaćeni su opstruktivni oblik i gubitak amplitude krivulje pulsnog vala.

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Ključne riječi: bijeli prsti, krvni protok u koži, niskofrekventne vibracije, sjekači motornom pilom, termalni test, vibracijska bolest.