Thermography in the hand angiopathy from vibrating tools

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SUMMARY. 25 workers with symptoms of vibrating tool angiopathy were examined with both thermography and photoplethismography. The thermal pattern of the normal hand was established. Thermography, even if done only under standard conditions, is capable of objectively demonstrating significant lesions in 84% of the cases. Photoplethismography of the same patients and under the same conditions is positive in only 24% of the cases. Thermography after a cold immersion test does not give substantially better results from those obtained under standard conditions. The usefulness of the method is advocated especially for disability insurance medicine and occupational medicine.

Key words: angiopathy; thermography; vibrating tools; chill test.

A) Introduction

Occupational lesions due to vibrating tools were noted in the first years of this century, a short time after the introduction of pneumatic perforators in the mining tunnel, and construction industries. Nowadays such lesions are more frequent because of the actual increase in the number of workers exposed and because of the increase in the number of cases that come to a physician's attention seeking to take advantage of the new insurance benefits offered them.

I) Vibrating tools

1. Vibrating tools are defined as those tools having high speed, low amplitude oscillating movements.

The *period* is the time necessary for the mobil point to return to its starting position.

Oscillation defines the movement carried out.

The physical variables of the tool, which influence the responce of the human organism to the vibrations, can be referred to:

a) the *frequency:* number of oscillations per second. The most dangerous frequencies are those that induce the phenomena of resonance in the whole human body or in part of it. In the hand-forearm-arm system, this phenomenon is produced in the band of frequencies between 30 and 80 Hz [1]. Hypothetically, depending on the characteristics of the vibrations there will be different pathologic patterns. Thus, low frequencies (10-30 Hz) should be responsible for bone and joint changes [2], and higher frequencies (up to 600 Hz) [3,4], should be more damaging to vessels and nerves. Recently it has been shown that the 125 Hz frequency band is the most suitable for causing vasospasms [5,6].

b) The *amplitude:* the distance travelled through by the mobile point during one oscillation.

When their frequencies are equal, the most dangerous vibrations are those with larger amplitudes [7].

c) The *acceleration:* expressed in meters per square-second. It is the only parameter perceived by the person exposed to vibrations. When the accelerations are equal, the vibratory sensation is better perceived with frequencies between 1 and 10 Hz [1].

2. Vibrating tools are classified according to the type of movement of the working part.

   a) Alternate (simple percussion: hammers, chissels, riveters).

   b) Rotating (simple rotation: drills, screw-drivers, millers).

   c) Mixed (alternate and rotating movement : pneumatic perforators).

3. Vibrating tools are used both in agriculture (power mouvers) and in industry (mining, construction, metallurgical and sheet metal, ship, building, aircraft, forest, textile, and shoe industries).

   Precise data are lacking, but probably more than 750.000 workers are exposed to the dangers of vibrating tools in Italy.

   In the U.S.A. there are more than 3.000.000 such workers [7].

II) EFFECTS OF VIBRATIONS ON THE HUMAN BODY

1. The effects of vibrations depend not only on the characteristics of the vibrations themselves (frequency, amplitude, and acceleration), but also on *other factors:*

   a) the weight of the tool (varying from a few kilograms to more than 30 kg.).

   b) the availability of a support.

   c) the type of handle the tool has'.

   d) the duration of exposure, and the duration of the interval between exposures [9].

   e) the characteristics of environment in which the tool is used (temperature, humidity).

   f) the possible means of protection.

   g) the more difficult to evaluate individual factors such as the variability of the build of the workers, their posture during work, and the amount of muscle contraction [9].

2. There are two groups of lesions produced in the human body by vibrating tools:

   a) The general reactions both physical and psychic, due to stimulation of various receptor organs and of other nerve structures (by the vibrations themselves, by noise, by environmental factors, and by the type of work). This group incluses the functional changes due to the stress reaction of the worker.

   b) The local and regional lesions caused directly by the vibrations. These are the most well known and involve the upper limbs. They include bone and joint, neurological, and vascular lesions.

III) LOCAL AND REGIONAL EFFECTS OF VIBRATIONS

1. Bone-joint syndrome:

   a) Clinically: pain, limitation of movement, and, in advance phases, snapping, and atrophy of the nearby muscles of the wrists, elbours, and shoulders.

   b) Radiologically: fine decalcification, epipheseal pseudocystic granular decalcification, especially in the semilunar bone and in the scaphoid; in advance phases the articular surfaces become deformed as in arthrosis, with intra-articular loose bodies, and reduction of the joint space [10,11, 12,13]

2. Neurological involvement: it can be either central or peripheral [7, 14].

   The most common pattern is a polyneuritis characterized by:

   a) slowing of the distal minimal conduction velocity,

   b) lowering of the amplitude of the potential measurable at the fingers,

   c) morphologic changes in the Meissner corpuscles biopsied from the skin of the thumb [15, 16].

3. Vascular syndrome:

   a) clinically: Raynaud phenomenon in the fingers. This may appear bilaterally or may begin in one hand, the one that guides the too1 [9, 17, 18]. This syndrome consists of syncopal ischemic crises accompanied by paresthesia and even anesthesia, and limited motion of the fingers involved. The crises occur during chilling or during the use of vibrating tools. The evolution of this angiopathy is highly variable but depends principally on continues exposure to vibrations.

The pathogenesis of this angiopathy is uncertain:

1) inability of the vessels to catabolize substances that cause vasospasm and that perhaps form in workers exposed to vibrations [23],

2) the mechanical action of the 'callus formed during protracted use of such tools,

3) an immunological mechanism [25],

4) vascular spasm brought about by vibratory microtrauma with successive organic lesions of the arteriolar - arteriosclerotic type [19, 26].

b) Hemodynamic and arteriographic investigations have demonstrated a reduction in digital blood flow with frequent lesions of the vessel walls [19, 20].

On the basis of our experience and of the data from the literature, the frequencies of the lesions and their evolution can be outlined as in table I. For the purposes of this work, the vascular lesions are more interesting because of their relatively early appearance, their relative incidence, and the fact that current investigative techniques are directed toward evaluating vascular involvement.

Tab. I. Cronological evolution of the biologic effects of vibrations: the table shows the latency period for each effect., the peak of maximum frequency, and the maximum percentages of patients taken ill.

Effect	*Latency (months)*	*Peak (months)*	*%*
Psychic	0	< 1	100
Reflex physical	<12	12; 120	?
Bone-Joint	<24		?
Nervous	<24		10-30
Vascular	<12		10-90

c) Instrumental tests (oscillographic, rheographic, photoplethysmographic, thermometric) demonstrate alterations sometimes under normal conditions, but more frequently during crises provoked by cold immersion [7, 21, 22].

The percent of persons affected by angiopathies varies in the literature: 10%, 30%, 50%, 90% [7]. Generally these' involvk nonhomogeneous sample groups, with variations in the type of tool and the duration of exposure. The instrumental tests commonly used to study vibrating tool angiopathies only serve to quantitize objectively the subjective symptoms of vascular damage that the patient complains of (paresthesia, limitation of movement, angiospastic crisis). Often the instrumental test results are scarce even with the artificial triggering of angiographic crises.

B) Aim of this research

The purpose of this work is:

a) to establish the diagnostic value of thermography for the identification of vascular lesions from vibrating tools.

b) to compare the validity of thermography to that of other investigative methods routinely used, usually photoplethismography.

I) Materials And methods

The patients were 25 men admitted to the Institute of Occupational Medicine. The median age was 5 1 years, with ± 5 standard deviations. All had worked in the mining industries. The median exposure had been 14 years, with ±3.9 standard deviations. The actual number of daily hours worked varied greatly, from 2 to 6. The tool used was always one of the various models of the pneumatic perforator with a weight of 22 to 28 kg., a teoretical frequency of 30 to 40 Hz, and an amplitude of 200 to 300 microns.

The case history was done with an orien-

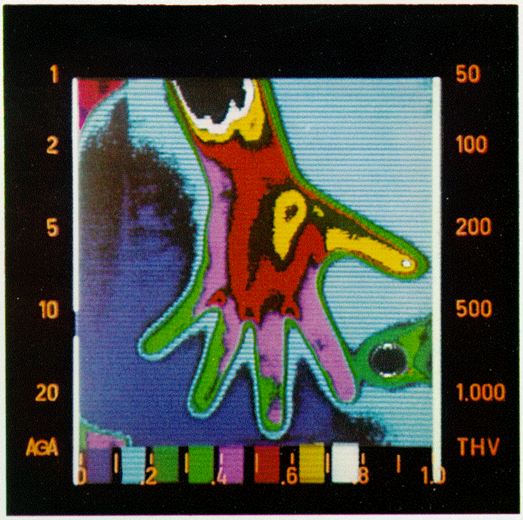


Fig. 1. Normal thermogram, standard conditions.

ted qucstionaire. Paresthesia in both hands was a complaint in 100% of the cases.

Angiospastic crises in both hands during cold exposure was a complaint in 88%.

The controls were 2.5 men with a median age of 45 years (ranging from 30 to 52). None had ever worked with vibrating tools nor ever had Raynaud's disease or Raynaud's phenomenon. Patients with previous traumatic lesions to the arms or shoulders were excluded from both groups.

There were 15 smokers in the cxperimental groups (60%), and 12 in the control group (48%). All these men were studied with both photoplethismography and thermography under standard conditions. Photoplethismography was done also after cold immersion (hands for 5 minutes in water at 5°C) in all patients; and thermography after cold immersion in 16 patients.

The thermographic standard conditions were: 20 minutes in a constant 18°C environment with thermograms of the dorsal surfaces of the hands.

II) THE THERMOGRAM OF THE NORMAL HAND

For an objective appraisal of thermographic patterns in vibration angiopathies the comparison with the normal hand thermogram is indispensable. The thcrmographic pattern of the hand (Fig. 1) in the control subjects was rather variable but nevertheless sufficiently classifiable (Table 11) considering three temperature gradients (hot, warm, and cool).

1 Carpal Region: three zones arc recognizable:

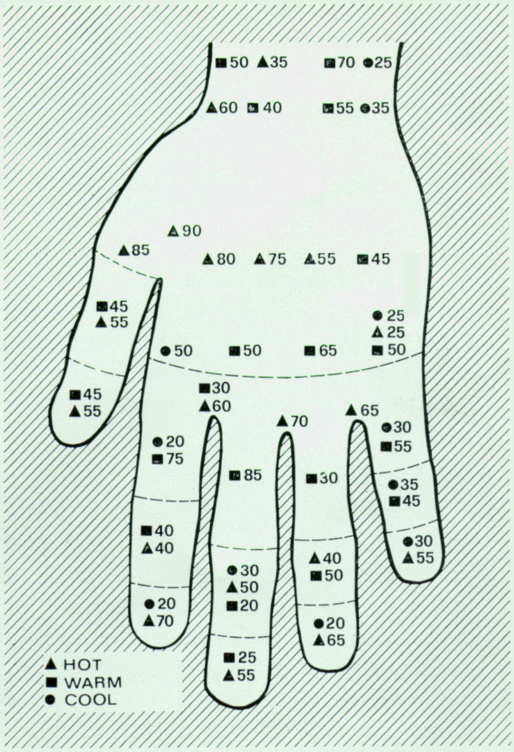
a) the ulnar side, where there arc mostly warm temperature areas (70%), sometimes cool area5 *(25%)*, and only once did there appear a hot area.

b) the *radial side usually* has hot or warm temperatures (85%).

c) the anatomic snuff box is the warmest region of the wrist, never being cool.

2 *Metacarpal Region:* always had hot or warm temperatures. t-lot areas decrease

Tab. I I. Normal thermal pattern. The number next to each symbol indicates the frequency in percent.



Tab. III. Data of the patients examined.

Patient	Age	Years of exposition	Clinical symptoms		Pkotoaletkismograpky		Thermography		
			Pare-stkesia	Raynaud's pheno menon	Standard conditions	After chill test	Standard conditions	LTG °C	Recovery time (minutes)
1) L.P.	55	10	+	+	normal	altered	altered	5	45
2) G.S.	43	8	+	+	normal	normal	altered	2	35
3) P.A.	56	10	+	+	altered	altered	altered	6	60
4) P.N.	55	9	+	-	normal	altered	altered	4	30
5) C.R.	39	8	+	-	altered	altered	altered	9	70
6) T.M.	47	12	+	+	normal	normal	altered	4	35
7) S.T.	50	10	+	+	normal	altered	altered	4	25
8) L.U.	50	12	+	+	altered	altered	normal	1	15
9) R.O.	48	10	+	+	normal	normal	altered	6	40
10) E.C.	52	20	+	+	normal	altered	altered	3	30
11) B.E.	54	19	+	-	normal	altered	altered	3	30
12) L.I.	55	19	+	+	normal	altered	altered	9	45
13) M.O.	59	19	+	+	altered	altered	normal	0,5	10
14) L.A.	45	13	+	+	altered	altered	altered	3	35
15) P.I.	52	15	+	+	normal	normal	normal	1	35
16) P.A:	58	17	+	+	normal	altered	altered	4	50
17) Z.U.	50	13	+	+	normal	altered	altered	3	-
18) R.I.	58	15	+	+	normal	altered	normal	1	-
19) B.E.	57	15	+	+	normal	normal	altered	3	-
20) E.F.	50	18	+	+	normal	altered	altered	5	-
21) F.C.	49	16	+	+	normal	altered	altered	6	-
22) E.G.	47	16	+	+	normal	altered	altered	5	-
23) G.G.	52	17	+	+	altered	altered	altered	4	-
24) L.P.	48	16	+	+	normal	altered	altered	3	-
25) G.L.	46	20	+	+	normal	altered	altered	4	-

from the first metacarpal (90% of the observations) to the fifth metacarpal (55%). Here there are linear cool areas along extensions of the axes of the fingers and corresponding to the extensor tendons.

3. *Metacarpal-phalangeal joints*

Except for the first, they have warm or cool temperature. In fact there is a prevalence of hot areas at the level of the first (85%), then a prevalence of cool areas at the level of the second joint (50%), and then a prevalence of warm temperature areas at the last three joints (50-65% of the observations).

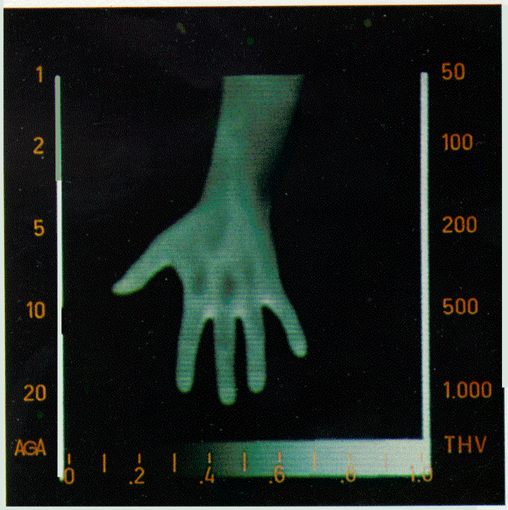
4. *Fingers*

Even in this sector the temperature diminishes from the radial side to the ulnar side. The thumb, in fact, is generally uniformly hot (55%) or warm (45%), while the fifth finger is cool (35%) or warm (45%).

The terminal phalanges are mostly hot. Cool areas were found in percentages varying between 20%, for the 2nd, 3rd, and 4th fingers, and 30% for the 5th finger.

5. *Longitudinal Thermal gradient*

It should be noted that, in each subject, A



B

C

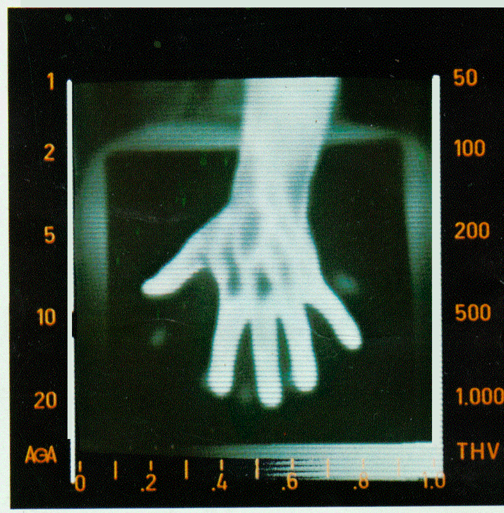
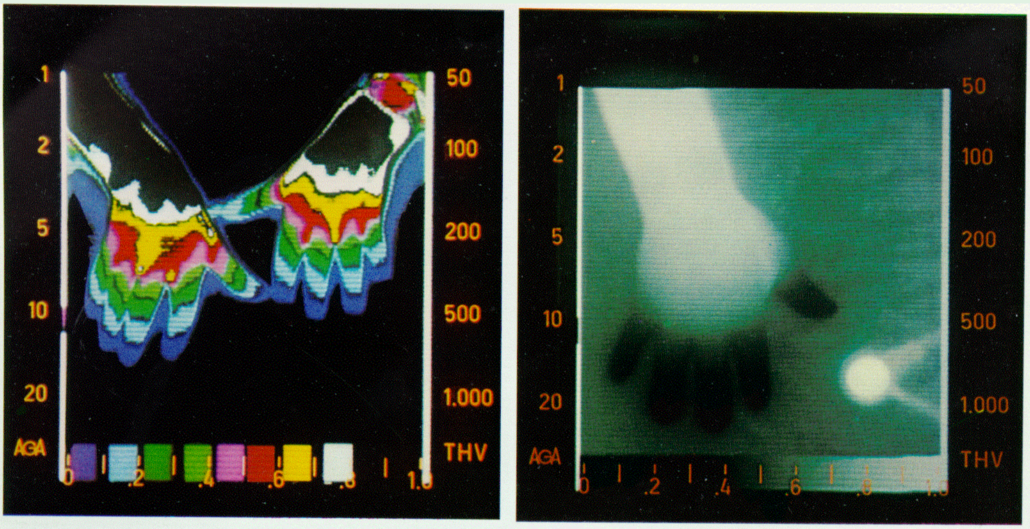


Fig. 2. A) Normal thermogram, standard conditions. B) Marked hypothermia 1 min. after chill test. C) Ten minutes after chill test, return to normal values.

the heat of the fingers does not correspond to that of the carpal and metacarpal. Therefore it is essential to refer to the Longitudinal Thermal Gradient (LTG), that is, to the difference in temperature between the carpo-metacarpal region and the fingers. In the normal hand the LTG values are always positive. That is, there is always reduction of the temperature from the carpo-metacarpal to the fingers. The LTG is highest for the first and second finger (1.2” and 1.9°C respectively), intermediate for the third and fourth (1° and 0.9°C), and least for the fifth (0.2°C). The law value of the LTG for the fifth finger is explained on the basis of the thermal situation of the ulnar side of the carpo-metacarpal region which, as been said above, is almost always cool.

6. Cold immersion test

After immersion of the hands for 5 minutes in cold water (5” C) the normal subject shows immediate marked hypothermia. This is more evident at the



A B

Fig. 3. Thermograms under standard conditions, in vibration syndrome: thermal amputation of all fingers bilateraly in two patients with Raynaud phenomenon.

level of the fingers, with an increase in the LTG to as much as 10-11°C (Fig. 2).

Thermograms done 15 minutes after the test show a constant return to the base-line thermal pattern.

III) Thermographic Pathg Patterns in Vibrating toolTOOI. Angiopathies of the hand

The thermograms in vibrating tool angiopathy show more or less marked distal hypothermia with notable increase in the LTG. This is a pattern similar to that found in Raynaud's disease, either of the occupational disability type (workers exposed to vinyl chloride), or of the nonoccupational type [28]. Of the 25 patients studied thermographically under standard conditions (Table III) 21 cases (84%) had positive thermograms. In only 4 cases (16%) were the thermograms normal and none of these coincided with the 3 patients that had not complained of angiospastic crises in their case histories.

In 10 of the 21 positive cases (47.6%) the involvement was bilateral, with « thermal amputation » of all the fingers (Fig. 3). In the remaining 11 cases (52.4%) the lesion revealed thermographically was unilateral (7 righ-sided, and 4 left-sides). In 4 of these cases all the fingers of the involved hand were hypothermal. In the remaining 7 cases only one or two lingers were involved (Fig. 4), and these showed no predisposition for any of the five fingers. In the last group the first finger was never involved. The hypothermia is always more marked at the finger level rather than at the carpometacarpal level. This leads to a constant increase of the LTG's of the fingers involved, with median values reaching 4.5°C (with ±1.6 standard deviations), but always clearly above the normal values.

The photoplcthismographic exams done on the same patients, under standard conditions, gave clearly less satisfactory results (abnormal tracings 24%, normal tracings 76%) (Fig. 5). In only one case was the photoplethismogram abnormal when the thermogram was normal.

In 16 of the 25 angiopathy patients (13 with positive thermograms and 3 with negative thermograms under standard conditions) the *cold immersion* test was performed. The thermograms were taken every five minutes, from one minute after the chilling

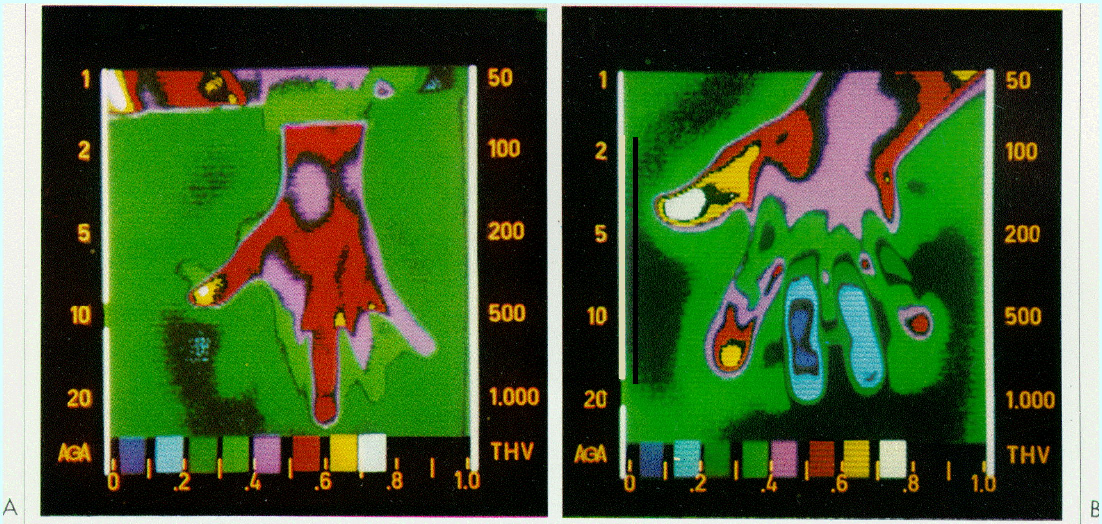
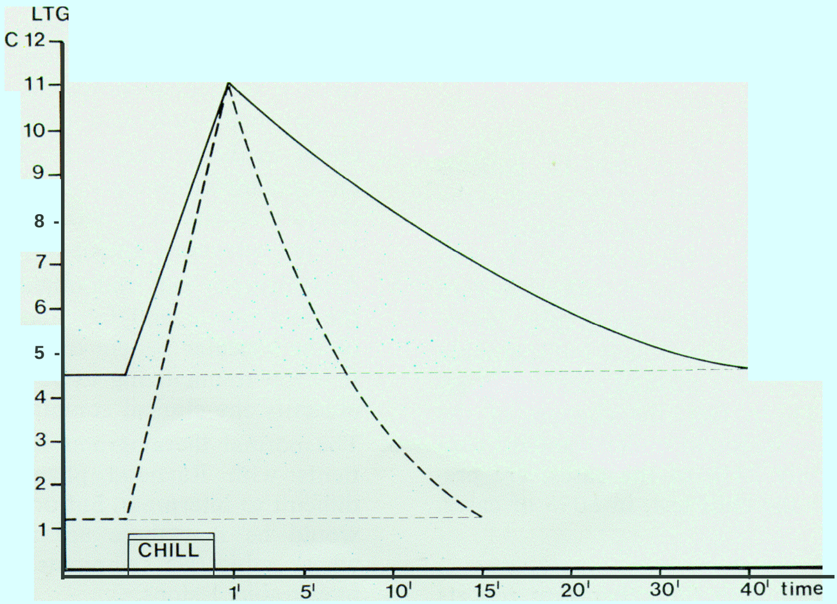
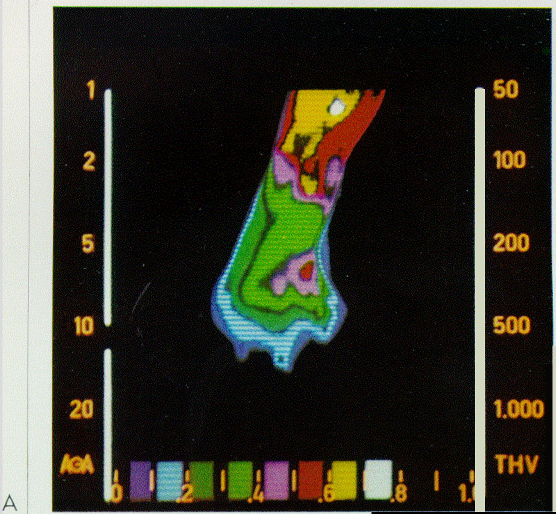


Fig. 4. Thermograms under standard conditions in vibration syndrome. Two cases with localized lesions. A) Marked hypothermia of second and fourth finger left hand. B) Hypothermia of third and fourth finger left hand.

Tab. IV. The graph shows the LTG recovery times after chill test. Dotted line: normal subjects. Continuous line: patients with Raynaud phenomenon (vibration syndrome).





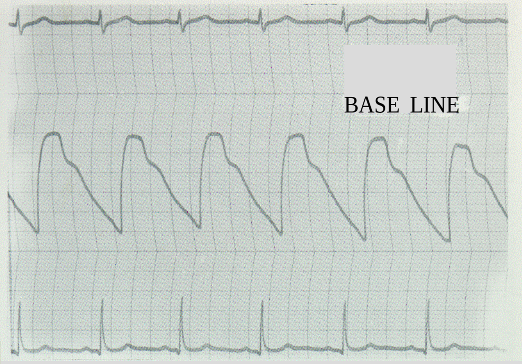


Fig. 5. Patient with Raynaud phenomenon, vibration syndrome. A) Thermogram, standard conditions. thermal amputation of all fingers. B) Photoplethismogram is normal under standard conditions.

until the values returned to their base-lines.

The chill test induces marked hypothermia in both the angiopathic patients and the normal subjects, with an increase in the LTG of about 6 or 7” C from the base-line values. (The one minute post-chill test thermograms had LTG’s as great a 11” C). In contrast with normal subjects, whose return to base-line values takes 15 minutes, the angiopathic patients have a very much slower return of their LTG’s to base-line values (Fig. 6). Their median time was 40 minutes (Table IV) with a range from 25 to 70 minutes. The lengthening of the recovery time was observed in 14 of the 16 patients (87.5%). Thus the chill test does not significantly increase the number of positive results, even though it better reveals the patterns of slight lesions found under standard conditions. In photoplethysmography, however, the cold immersion test is indispensable because it leads to a marked increase in results (Fig. 7). In fact, the changes of the sphygmic waves, found under standard conditions in only 24% of the cases, are presented, after the chill test, in 8O% of cases.

Conclusions

1. In contrast with the other rare reports in the literature ([29,30]), this study shows that thermography is extremely useful in objectifying the subjective symptoms of vibrating tool angiopathy.
2. Thermography is very demonstrative even under standard conditions.
3. The scarce improvement in thermographic results after chill tests, in comparison to those under standard conditions (87.5% vs 84%), does not justify the use of cold immersion, especially since it induces angiospastic crises, and is very badly tolerated by the patients.
4. Other methods, cutaneous thermometry and photoplethismography, obtain satisfactory results only with a chill test or in very advanced angiopathy cases.
5. Arteriography can undoubtedly establish the anatomical and functional situation of the vascular system of the hand, but it is too traumatizing to be used just to objectify the clinical complaints.
6. The normal thermograms in certain patients with Raynaud phenomenon are difficult to interprete, but one hypothesis would be that these are initial stages where subjective symptoms precede demonstrable lesions.

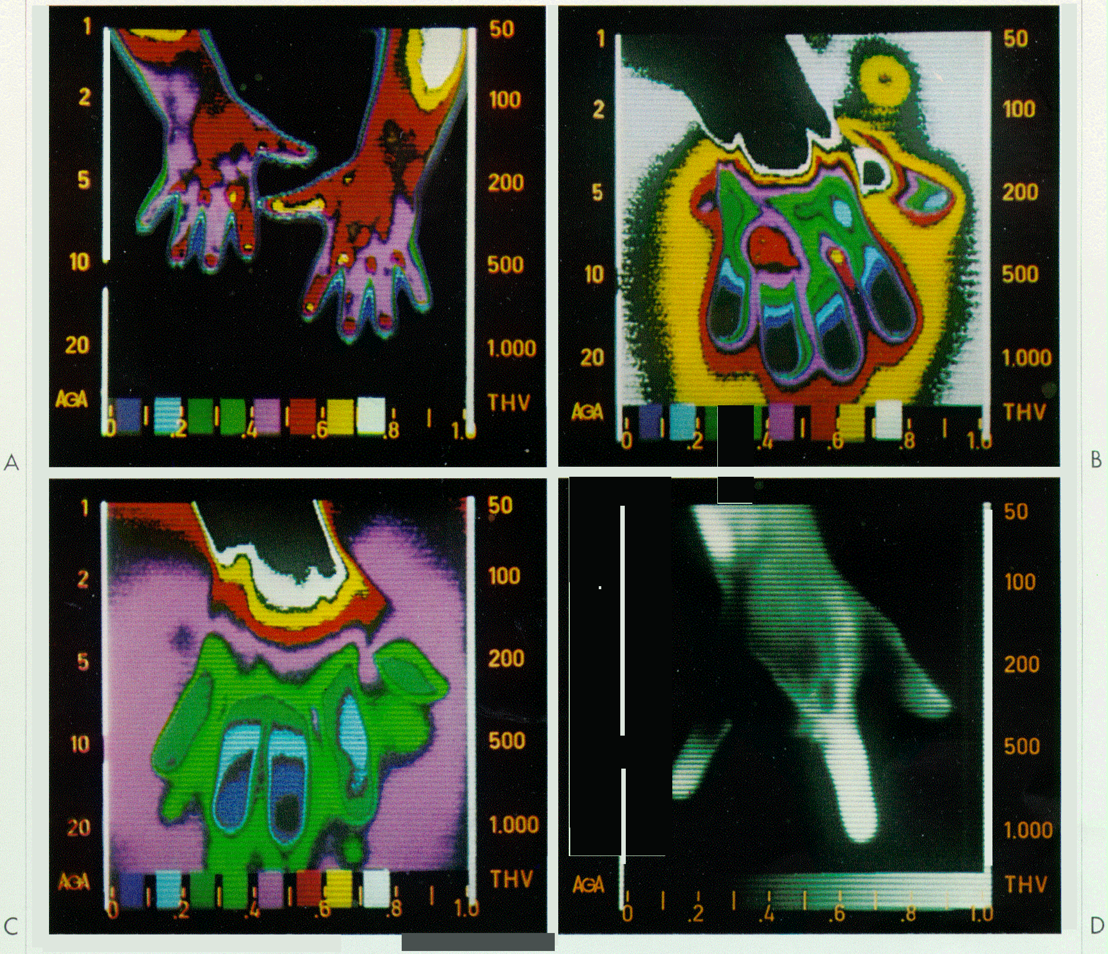


Fig. 6. Patient with Raynaud phenomenon, vibration syndrome. A) Thermogram under standard conditions, slight hypothermia of 3rd finger right hand. B) Marked hypothermia of entire hand one minute after chill test. C) Extensive hypothermia persists after 20 minutes. D) Hypothermia persists in 3rd and 4th fingers, after 40 minutes.

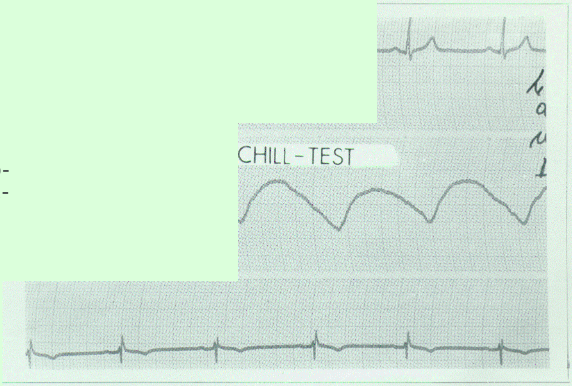


Fig. 7. Same case as Fig. 6: alteration of photoplethismogram after chill test. Under standard conditions the tracing was normal.

7. The suitability of thermography to inocuously reveals most of the vibrating tool angiopathies, makes it the diagnostic method of choice in lability insurance, occupational, and forensic medicine.

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