Vibration injuries in Norwegian forest workers

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Hellstrøm, B., and Lange Andersen, K. (1972). *Brit. J. industr. Med.*, 29, 255-263. Vibration injuries in Norwegian forest workers. A free medical examination with compensation for lost earnings was offered to the forest workers in three areas of eastern Norway. Sixty-six per cent attended (413 workers, of whom 296 used chain saws). The prevalence of Raynaud's phenomenon (RP) was 47% in chain saw operators, 14% in forest workers not exposed to vibration, and 9% in 302 indoor workers not exposed to vibration. The high prevalence of RP in chain saw operators was attributed to a traumatic vasospastic disease (TVD). The average time of latency was eight years. The standard symptoms of TVD were attacks of blanching and numbness. Cyanosis and pain occurred rarely. In subsamples, measurements of tactile two-point discrimination and maximal isometric muscle strength (hand grip and finger pressure) as well as x-ray examinations of the wrists and the hands gave no evidence of vibration injury to peripheral nerves, muscles, bones, or joints.

The injury threshold for local vibration is poorly defined (Sterner *et al.*, 1950; Axelsson, 1967), and new, potentially harmful vibratory tools are still being marketed. One relatively recent offender in this field is the piston-engine operated chain saw used in forestry. The prevalence and clinical picture of vibration injuries caused by chain saws have differed considerably in various studies (Grounds, 1964; Treiberg, Utbult, Lund, and Plevin, 1964; Kylin and Lidström, 1968; Takagi, 1968; Barnes, Longley, Smith, and Allen, 1969; Taylor, Pearson, Kell, and Keighley, 1971). The present paper reports the prevalence and symptoms of vibratory injuries in Norwegian chain saw operators.

Methods

Sampling

Our study was part of a general health survey of forest workers carried out by field studies in three areas in eastern Norway (Romedal in 1963; Hurdal in 1968-69; Hernes in 1969-70). The forest workers of seven employers—practically the whole forest worker population

in the areas—were offered a free medical examination plus compensation for lost earnings. Sixty-six per cent attended. A later attempt to study the remnant had to be given up.

To estimate the prevalence of Raynaud's phenomenon (RP) in an indoor working population not exposed to occupational vibration, all male participants of a routine periodic health examination appearing before one of us (B.H.) during a certain period of time in 1967 were studied. This group did not differ significantly from the forest workers as far as age was concerned (mean 43.9 ± 11.8 years (S.D.) v. 45.6 ± 12.3 years in the forest workers, $0.05 < P < 0.1$), but did so differ in other respects (urban v. rural, lower level of daily activity, different nutritional habits). The first 207 subjects studied at Hernes were chosen for studies of non-circulatory vibration injuries. A various number of tests failed, as specified below, and two-point discrimination results obtained in Hurdal (*vide infra*) were added to the material.

Clinical examination

A standard medical examination including detailed case histories on vibration exposure and RP was made in every subject. With increasing experience, changing focus of interest—but also varying capacity of the examining teams—the questionnaire was changed several times in the course of the study.

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Tactile two-point discrimination Blunt plastic rods with fixed distances of 0, 1.5, 3.0, 4.5, and 6.0 mm were pressed firmly and evenly against the midline of the right and left ring finger pads. The subject, eyes closed, was instructed to report whether he could perceive the gap or not. About 10 answers were obtained on each side of the approximate two-point threshold. The two-point limen was finally estimated by linear interpolation. The standard error of a single determination was ± 0.5 mm (estimated by comparing the bilateral measurements in 49 forest workers without occupational vibratory exposure or RP).

Muscle strength The maximal isometric strength of the hand grip and of finger flexion in the metacarpophalangeal joints was measured bilaterally by strain-gauge dynamometry. The position of the arm, hand, and the fingers was strictly standardized.

X-ray study X-rays were taken of the hands and wrists. The total (T) and medullary (M) width were measured at the midpoint of both middle metacarpals and the 'osteoporosis index' (cortical area $(0.785 (T^2 - M^2))$ as per cent of total area $(0.785 \cdot T^2)$) was calculated (Nordin, 1969).

Statistics Only current statistical methods (Snedecor, 1956) were used. Differences in prevalence were tested by chi-square (fourfold table), and differences between means of continuously variable parameters were evaluated by Student's *t*-test. The probabilities for fulfilment of the null hypothesis are given in the text.

Results

Prevalence of Raynaud's phenomenon

Raynaud's phenomenon was markedly more frequent in chain saw operators than in workers not exposed to occupational vibration (Table 1). In 15 chain saw users RP was attributed to a single episode of trauma, 'hereditary cold fingers' (Hunt, 1936), or previous use of pneumatic drills, in the remainder to

TABLE 1
PREVALENCE OF RAYNAUD'S PHENOMENON

Group	N	Prevalence (%)
1 Forest workers using chain saw > 2.5 hr/day	212	55
2 Forest workers using chain saw < 2.5 hr/day	84	21
3 = 1 + 2 Chain saw operators ..	296	47
4 Forest workers not using chain saw ..	117	14
5 Indoor workers	302	9

Significant group differences ($P < 0.001$): 1 v. 2, 3 v. 4, 3 v. 5
Not significant group difference ($P > 0.1$): 4 v. 5

a 'traumatic vasospastic disease' (TVD) (Wright, 1940) caused by chain saw vibrations. The prevalence of RP appeared to increase with increasing average daily use of the chain saw (Table 1).

Neither age (Table 2) nor smoking (Table 3) appeared to influence the prevalence of RP consistently.

Latent interval of TVD

Ninety-five subjects with TVD attributable to chain saw vibration were able to recall when they started to use chain saws and when their Raynaud symptoms first started. Based on this information, the time of latency varied from 1 to 18 years (mean 8, S.D. ± 3.9 years). One hundred and fifty-three fellers who had never experienced RP had used chain saws for from 1 to 22 years (mean and median 9 years). The remaining workers were unable to remember when they started to use chain saws.

TABLE 2
PREVALENCE OF RAYNAUD'S PHENOMENON (RP) IN RELATION TO AGE

Age group (yr)	1. Chain saw operators			2. Forest workers not using chain saw			3. Indoor workers		
	N	With RP		N	With RP		N	With RP	
		no.	%		no.	%		no.	%
20-29 ¹	40	9	23 ³	12	1	8	44	6	14
30-39	62	29	47	11	0	0	71	3	4
40-49	81	47	58 ³	30	3	10	87	4	5
50-59	76	41	54	46	6	13	63	8	13
60-69 ²	37	12	32 ³	18	6	33 ³	37	6	16

¹Includes one younger man in group 3, and two in groups 1 and 2.

²Includes two 70-year-old men in group 3.

³Prevalences which differed significantly ($P < 0.01$) from that of the remainder of each occupational group (^(*) $P < 0.02$). The rest of the age group prevalences did not differ significantly from that of the remainder of each occupational group.

TABLE 3
PREVALENCE OF RAYNAUD'S PHENOMENON (RP) IN SMOKERS v. NON-SMOKERS

Group	N	Smokers (%)	Prevalence of RP (%)		Significance a - b
			Smokers a	Non-smokers b	
Chain saw operators	296	69	49	42	P > 0.1
Forest workers not using chain saws ..	117	64	19	5	0.02 < P < 0.05
Indoor workers	302	32	9	9	P > 0.9

Extent of RP in subjects with TVD possibly due to chain saw vibration

In most subjects the extent of finger blanching reportedly varied somewhat from attack to attack. Emphasis was laid upon the maximum extent of blanching, and a digit was regarded as affected even when only its tip would blanch. Of the 123 workers whose RP was attributable to the use of chain saws, 18 (15%) had all digits affected. Fifty-seven per cent of the right-hand and 42% of the left-hand digits were affected ($P > 0.1$). In 55 subjects, the symptoms occurred symmetrically. The middle and ring fingers were most frequently affected, the thumb most often spared from symptoms (Fig. 1).

FIG. 1. Localization of Raynaud's phenomenon in 123 chain saw operators with traumatic vasospastic disease.

Symptoms of TVD

The attacks were produced by cold, particularly 'wet cold', and hardly ever by vibration alone. The combined effect of a sustained hand grip, vibration, and cold produced by driving a motorcycle or a car in cold damp weather was the surest trigger in many cases. Attacks were most frequent in the morning and in the afternoon, and rarely occurred when the subjects had worked themselves warm. No subject had ever experienced nocturnal attacks or emotional triggering.

During the attack, blanching and numbness were the usual symptoms. During rewarming, 'pins and needles' were the regular complaints (Table 4). Between attacks, 84 out of 94 (89%) subjects with TVD had no symptoms, and the remainder were rather vague on the following local disturbances: weakness of hand grip, stiffness of the fingers, and clumsiness. Neither pain nor impaired sensation between attacks was reported by any subject.

TABLE 4
SYMPTOMS OF OCCUPATIONAL RAYNAUD'S PHENOMENON IN CHAIN SAW OPERATORS
(Per cent of subjects in each group reporting symptoms as stated)

Attacks per year (N = 123)		Symptoms during attacks (N = 123)	
> 100	22	Numbness	100
10-100	54	Blanching	96
< 10	24	Stiffness	41
Recovery time (min) (N = 78)		Clumsiness	11
		'Pins and needles' ..	11
		Pain	9
		Cyanosis	4
		Symptoms during rewarming (N = 78)	
		'Pins and needles' ..	90
		Pain	22
		Cyanosis	4
		None	10

Physical signs in subjects with Raynaud's phenomenon

Neither trophic lesions nor cyanosis were observed during the clinical examination which took place at ordinary room temperature.

Tactile discrimination

Two-point thresholds were not obtained in two subjects who did not cooperate properly, and were also impossible to determine in four fingers due to local lesions. The data from an earlier study by a comparable method (the V-test of Mackworth, 1953) in 26 of the Hurdal chain saw operators with RP (Hellström, Stensvold, Halvorsrud, and Vik, 1970) were included.

The two-point threshold did not differ significantly between users and non-users of chain saws (Table 5). The threshold was slightly but significantly ($P < 0.01$) higher in subjects with than without RP. However, in 37 workers with unilateral ring finger affection, the two-point threshold was on the average only 0.1 mm larger on the affected side ($P > 0.5$).

Among the subjects with the highest two-point threshold, no worker was found with exceptionally high values attributable to vibratory peripheral nerve injury.

Muscle strength

Results were not obtained in seven workers because of technical trouble.

Operators of chain saws tended to have a weaker hand grip than workers not exposed to occupational vibration, as did subjects with RP when compared

TABLE 5

TACTILE TWO-POINT THRESHOLD ON PADS OF RING FINGERS IN 231 FOREST WORKERS

Group	N ¹	Threshold (mm) (mean $\pm$ SEM)
Using chain saws	352	3.5 $\pm$ 0.04
Not using chain saws	106	3.6 $\pm$ 0.07
Raynaud phenomenon	197	3.6 $\pm$ 0.06
No Raynaud phenomenon ..	261	3.4 $\pm$ 0.05

¹Number of 4th fingers tested. Data obtained in only one finger in four subjects.

with those free from such symptoms (Fig. 2). A similar trend was present in finger pressures (data not shown), but for all parameters the group differences fell short of statistical significance.

Lesions of bones and joints

From slight to marked periosteal appositions, as described by Humperdinck (1940) and probably a consequence of heavy manual labour (McLaren, 1937), were found in the fingers of most subjects whether they used chain saws or not. Minor cyst-like areas of decalcification and osteoarthritic changes were also fairly common but apparently unrelated to the use of chain saws or the presence of RP (Table 6).

In the x-ray pictures of the hands of 23 workers, slight blurring of one or both metacarpals made exact measurements of the osteoporosis index im-

FIG. 2. Hand grip strength related to body height and age. Age group 2: subjects 20-29 years old; age group 3: subjects 30-39 years old, and so on. Vertical bars mark $\pm$ SEM.

TABLE 6

LESIONS OF BONES AND JOINTS

(Per cent of 207 forest workers with lesions as specified in right v. (left) wrist and hand)

	Using chain saw (N = 150)	Not using chain saw (N = 57)	Having RP (N = 73)	Not having RP (N = 134)
'Cysts'	39 (38)	53 (54)	40 (36)	44 (46)
Osteoarthritis . .	26 (28)	32 (35)	32 (21)	25 (35)
Other lesions . .	20 (18)	30 (21)	14 (15)	28 (21)

FIG. 3. Nordin's (1969) index of osteoporosis (see text) related to age. Age groups as in Fig. 2. Vertical bars mark $\pm$ SEM.

possible. The results obtained in the remaining 184 subjects indicated that osteoporosis of the metacarpals was not influenced by chain saw vibration, as no statistically significant group difference was found (Fig. 3).

Discussion

Prevalence of Raynaud's phenomenon in chain saw operators

The regrettably low attendance renders our estimate of prevalence inaccurate but does not invalidate the

conclusion that RP was more frequent among chain saw operators than in forest workers who did not use vibratory tools. (Even if every man who did not attend had been a chain saw operator without RP, which was not the case, the 27% prevalence of RP among chain saw operators would still be significantly higher than the 14% among the forest workers who did not use chain saws; cf. Rose and Blackburn (1968)). We were unable to clarify why so many subjects failed to appear, but the information we got indicated that sheer inconvenience plus a certain general suspicion rather than the presence or absence of Raynaud phenomenon played the major role in this respect. We have no reason to doubt the credibility of the subjects we studied. The low prevalence of symptoms reported between attacks does not indicate any tendency to exaggeration. Also, in 44 of the present subjects with TVD who were re-examined after several weeks, the two histories corresponded closely. Ultimately, in 11 out of 11 workers with alleged TVD, RP was provoked experimentally by a combined general and local cold exposure, whereas no such symptoms appeared in seven controls who denied having RP (Hellström and Myhre, 1971).

Our results confirm that the use of chain saws can produce TVD, as was first reported by Grounds (1964), and run contrary to the statement of Pecora, Udel, and Christman (1960) that RP of occupational origin is disappearing. The present prevalence of RP agrees closely with the 49% found by Kylin and Lidström (1968) but is markedly lower than the prevalences reported by Grounds (1964) and by Takagi (1968) and the more than 80% found in several groups exposed to various other types of occupational vibration (Riesenfeld-Hirschberg, 1928; Grotjahn, 1931; Hamilton, 1930; Seyring, 1930; Bruusgaard, 1941; Ponhold, 1943; Hunter, McLaughlin, and Perry, 1945; Agate, Druett, and Tomblason, 1946; Anda, 1960). The reason for this discrepancy may lie in the vibration characteristics of the various tools, in the conditions under which they are used, or in the subjects who use them. Each set of factors offers still unresolved problems.

The chain saw vibrations analysed by Kaminsky (1963) and by Axelsson (1967) were within the zone of hazard proposed by Agate and Druett (1947), as were the vibrations estimated by Grounds (1964). However, the vibrations vary between different models of chain saws, with the type of work done, and with the conditions of the saw (Axelsson, 1967). The present workers had used more than 40 chain saw models in all, and many wore out one saw every year. To obtain even a rough estimate of the vibrations received by the hands of one worker up to the point when he shows TVD is a formidable task, beyond our capabilities. Such information is sorely needed, however, both to evaluate the part played by the factors presumed to be of importance for the

pathogenesis of TVD and to obtain well-founded safety limits for local vibration.

Various working conditions have been suggested as having an effect on the development of TVD: tight grip (Hamilton, 1930; Marshall, Poole, and Reynard, 1954), overhead drilling (Hunter *et al.* 1945; Ashe and Williams, 1964), and a cold environment (Hamilton, 1930; Davies, Glaser, and Collins, 1957; Williams and Riegert, 1961). Their effect is possibly twofold: (1) determining the amount of vibratory energy absorbed by the hands, and (2) modifying the condition of the hands (particularly their blood flow) during vibratory exposure. The most obvious reason for the relatively low prevalence of TVD in our subjects is the fact that until recently the chain saws were used for only a few hours a day and usually with long vibration-free pauses between exposures. Intermittent exposure may lower the incidence of TVD (Riesenfeld-Hirschberg, 1928; Pecora *et al.*, 1960; Magos and Okos, 1963). Another factor of possible relevance is the strenuousness of forest work (total daily caloric intake often more than 6 000 kcal), which must provide a strong drive for peripheral vasodilatation even in very cold environments (e.g., Hellström, Berg, and Vogt Lorentzen, 1970).

Our results indicate a wide variation in the individual susceptibility to occupational vibration. Although generally accepted (e.g., Agate, 1949), the basis for this variation in resistance to vibration is poorly known. It may be anatomical (pattern of arm/hand vasculature (Seyring, 1930) or resonance frequency of the hand/arm system (Sroka, 1951; Coermann and Lange, 1967)), physiological (Wright, 1940; de Takats, 1945), or a benefit from particularly skilful use of the tool (Hamilton, 1930). Grotjahn's (1931) observation that young workers were especially vulnerable to local vibration was not confirmed by Agate (1949) nor by the present findings where the prevalence of RP in the youngest group was significantly lower than in the rest of the chain saw operators (Table 2). As in the studies of Telford, McCann, and MacCormack (1945) and Barnes *et al.* (1969), smoking was of no importance (Table 3).

Forest work in Norway can acclimatize the worker to cold with a consequent improvement of finger blood flow in the cold (Strømme, Lange Andersen, and Elsner, 1963) and reduced cold pain and cold pressor responses (Hellström, 1965). Telford *et al.* (1945) found that previous outdoor work delayed the onset of TVD. A similar effect of acclimatization to cold in the present subjects is conceivable, but an improved cold tolerance may as well enhance the development of TVD as it leads to abandoning local protection (against vibration as well as cold) even in very cold weather.

We have, at present, neither the means to improve individual resistance against TVD nor the methods

to reveal (and exclude from vibration) those subjects with a particularly low resistance against TVD.

Prevalence of Raynaud's phenomenon not caused by vibration

The 14% prevalence of RP in forest workers not exposed to vibration did not differ significantly from the 9% in indoor workers (Table 1). These results are in agreement with the 12% found by Kylin and Lidström (1968) and the 8% reported by Renard (1963) in comparable groups in Sweden. Raynaud's phenomenon can be caused by a wide variety of diseases (Jepson, 1951), most of which are rare. About 90% of the present cases with RP of non-occupational origin had 'hereditary cold fingers' (Hunt, 1936). Lewis and Pickering (1934) estimated the prevalence of this harmless condition at 25% in young men. The factors determining the prevalence of 'hereditary cold fingers' are unknown.

Latent time of TVD

The free interval of TVD varies from one week (Marshall *et al.*, 1954) to more than 20 years (Jepson, 1954). The present eight years are an exceptionally long average free interval, however, previously found only in Finnish stone masons using pneumatic drills (Vainio, 1950). Japanese chain saw operators had a mean latent interval of 4.7 years (Takagi, 1968) and Australian forest workers 3.15 years (Grounds, 1964), which are in better keeping with the two to three years most commonly reported (Jones, 1960) than our results. The factors determining the relatively low prevalence of TVD in the present investigation may have contributed to the long time of latency as well.

Symptoms of TVD

Except for the particular syndrome caused by high-speed vibratory tools (Dart, 1946; Peters, 1946; Agate and Druett, 1947) the clinical picture of TVD has been described as 'almost stereotyped' (Drenckhahn, 1936; Gurdjian and Walker, 1945; Hoerner, 1952) and indeed was so in our subjects. The occurrence of cyanosis and pain varies considerably in various studies (compare, e.g., Hunt (1936), Hunter *et al.* (1945), Telford *et al.* (1945), Agate (1949), and Takagi (1968)) and was remarkably low in the present study. Cyanosis is apparently a late feature of TVD (Ashe, Cook, and Old, 1962), related to the severity of the disease (Agate, 1949). Pain was but reluctantly admitted by the present subjects and may have been underestimated. The extent of the lesion (Fig. 1) reflects the fact that both hands are exposed to chain saw vibration. An asymmetrical distribution of RP (Jones, 1960) is of little diagnostic value in these subjects.

Tactile discrimination

Although several authors have reported intact peripheral sensation in subjects with TVD (Hardgrove and Barker, 1933; Telford *et al.*, 1945; Agate, 1949; Ashe *et al.*, 1962), there is ample evidence that occupational vibration, including that from chain saws (Takagi, 1968), can damage peripheral nerves and impair sensation (Hamilton, 1930; Seyring, 1930; Grotjahn, 1931; Fløysturp, 1948; Jepson, 1954; Ejrup and Sjöström, 1955). TVD has been hypothetically linked to peripheral nerve damage (Cummins, 1940; de Takats, 1945; Marshall *et al.*, 1954), and Anda (1960) even regards sensory impairment a *sine qua non* for the diagnosis of TVD. Our results do not support this view. The method is crude, but the results agree closely with earlier findings by a more precise approach in forest workers (Hellström, 1965). The threshold is higher than that found in, for example, students (Hellström, 1965), most probably a result of the toughened finger skin in forest workers rather than because of nerve injury. As the chain saw operators had about the same two-point threshold as those not exposed to vibration, our findings fail to substantiate the recent hypothesis (Stewart and Goda, 1970) that occupational vibration causes TVD by toughening the skin.

Muscle strength

A direct vibratory injury of muscles may occur (Beintker, 1930; Teleky, 1938) but most cases of muscle atrophy attributed to occupational vibration have apparently been secondary to lesions of peripheral nerves (Seyring, 1930; Silberkuhl, 1943; Hunter *et al.*, 1945; Marshall *et al.*, 1954) and a few cases to lesions of the spinal cord (Maassen and Büttner, 1940; Novotný and Uher, 1959). In keeping with their intact peripheral sensation, the present subjects presented no visible atrophy of the hand muscles nor any significant impairment of muscle strength. These negative findings, which agree with those of Hamilton (1930), Grotjahn (1931), Hunt (1936), Agate (1949), and Ashe *et al.* (1962), contrast sharply with the results of Takagi (1968), possibly because of different vibratory exposures in the two groups.

Lesions of bones and joints

With the possible exception of small cyst-like areas of decalcification (Brailsford, 1936; McLaren, 1937; Davies *et al.*, 1957) lesions of the bones and joints attributed to occupational vibration are relatively infrequent (Rostock, 1936; Vossenaar, 1936; Teleky, 1938; Siebs, 1941) and hardly pathognomonic of vibratory injury. These cyst-like areas of decalcification have also been attributed to constant jarring of the joints (Hunter *et al.*, 1945). The present x-ray findings provide no evidence that the occupational vibration to which our subjects had been exposed

had exerted any marked influence on the osteoporotic processes or been the causative agent of the various, quite frequent, but mostly minor pathological lesions in the hands.

Disability

A high rate of heat production is possibly an excellent prophylactic against attacks of RP during work. Attacks before work started and extra local protection (gloves and mittens) hampered work but not to the extent of jeopardizing wage earning. The relatively benign picture of TVD outlined above is possibly due mainly to a short daily exposure time. In the course of the last few years lopping by chain saw has become common, increasing the average daily exposure time to five to six hours, or more in the most arduous workers. On the other hand, manufacturers now try to reduce chain saw vibrations and have also introduced warmed handles. What impact these opposite trends will have on the prevalence and the clinical picture of vibratory lesions in forest workers is hard to predict, but there is little hope that the widespread, although not very grave, damage already inflicted will disappear (Hunt, 1936; Agate, 1949; Marshall *et al.*, 1954).

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